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1. Introduction

Reduction of CO_2 emissions resulting from mode shift (to rail from air and road) has for many years been presented as a major justification for high speed railway development, with savings measured in millions of tonnes of CO_2 adduced for a variety of schemes. The recent HS2 report to Government predicts that implementation of the proposed UK high speed rail system could deliver net savings of up to 27MT of CO_2 over a 60 year period[1].

Although such figures might sound impressive in isolation, they must be viewed in the context of UK transport emissions as a whole – 140MT per annum, 26% of total emissions – and the requirements of the 2008 Climate Change Act – a reduction to 20% of contemporary levels by 2050. With high speed rail likely to comprise the principal intervention in UK transport in the next half century, it seems clear that it must deliver far more, in line with growing environmental and sustainability concerns.

Much of the problem lies with the fact that, whatever the capability of high speed rail to deliver emissions reductions might be, the promoters of such schemes remain focussed upon their primary aim of delivering economic benefits. These have traditionally been presumed to accrue principally from shorter journey times and greater numbers of people travelling, and are underpinned by the core assumption of 'business as usual' ie that economic life, energy supply, freedom to travel and freedom to emit, etc, remain broadly similar to present conditions. Such a 'business as usual' philosophy leads naturally towards increased speed and increased travel volumes, and inevitably renders the more contemporary aim of reduced emissions much harder to achieve. In this context, aspirations for reduced CO_2 – and hence consequent achievements of such reductions – are inevitably low.

This study explores a radically different philosophy, in which the environmental imperative of mitigating climate change, rather than conventional economics, becomes the key driver for high speed rail development. It assumes that in the coming decades, the fight against climate change will steer the world towards a more 'carbon-driven' economy, in which infrastructure development is prioritised upon its ability to deliver the necessary emissions reductions, rather than conventional economic benefits. It assumes also that a quasi-wartime agenda will apply, whereby the attainment of the strategic goal of mitigating climate change will have at least equal priority to more conventional economic considerations, and that all projects, large or small, must play their full part in achieving final victory.

It naturally follows that travel choices must focus upon lower-energy, lower-emitting modes of travel, and that pricing and regulatory mechanisms (eg road pricing, aviation fuel tax, subsidised rail fares, all underpinned by appropriate 'monetising' of CO_2) will fall into line. This all implies huge modal shift to the railways, but it can only happen with a step-change increase in network capacity.

In such a world – already envisioned by the Climate Change Act and likely fuel supply scenarios (ie 'Peak Oil') – it is entirely logical to assume that a process of

[1] Item 4.2.28 / Figure 4.2c sets out possible emissions savings over a 60 year period, resulting from implementation of HS2, ranging from 26.6MT reduction (most optimistic) to 4.6MT reduction (median) to 25.0MT increase (most pessimistic). This is noted as amounting to "a range of -0.3% to +0.3% of UK transport emissions", with the conclusion drawn that "HS2 would not be a major factor in managing carbon in the transport sector". No vision is offered of what other surface transport intervention (in the absence of HS2) might deliver the legally-committed 80% CO_2 reduction target of the 2008 Climate Change Act.

optimisation will exist, whereby high speed rail proposals are selected as much on environmental as on economic criteria. It is also reasonable to assume that achievement of increased network capacity, rather than pure point-to-point speed, will become the key driver for high speed rail development.

This study aims to establish a more rigorous 'carbon accountancy' for railway projects, focusing upon the following:

- The environmental benefits arising from mode shift to rail.
- The ability to facilitate this mode shift through increased network capacity.
- The carbon footprint of railway construction.

Two high speed rail schemes will be considered as exemplar projects:

- The Government's HS2 proposals, published in March 2010.
- The High Speed North proposals, promoted by the 2M Group of London and SE councils, and published in July 2008.

The central methodology of the study is to consider published data for transport CO_2 emissions and for the environmental performance of rail and other vehicles, and to make reasonable extrapolations in the context of a) commonly accepted climate change and fuel supply projections, and b) legal commitments arising from the 2008 Climate Change Act.

It is readily acknowledged that much of the data included in this study comprises generic figures based on statistical analysis, and as such, approximations rather than hard scientific facts. Such approximations are inevitable, given the macroscopic nature of this study, and the relative infancy of the disciplines both of carbon accountancy, and of railway network design. Although they would certainly detract from a definitive detailed analysis of a specific, localised proposal, it must be stressed that this is not the primary purpose of this study. This can be summarised as follows:

- to gain an understanding of the various factors that drive the 'carbon footprint' of high speed rail, and of their relative magnitudes;
- to realise the true potential of high speed rail (or simply 'new rail') to deliver step-change reductions in CO_2 emissions, in line with growing environmental concerns, and the growing priority that such concerns will attract in future years;
- to develop a methodology for comparative assessment of potential mode shift, and consequent emissions reductions;
- to allow better-informed and more relevant choices to be made in the development of a UK high speed rail network.

It is hoped that this study can be regarded as a 'work in progress', to be developed and refined as more data becomes available. But any deficiencies in this regard should not obscure the basic message, that current high speed rail strategy is fundamentally misaligned with contemporary environmental/sustainability imperatives, and that far more is achievable with comprehensive networks designed to optimise capacity and efficiency. If the UK is to achieve radical reductions in transport CO_2 emissions, in compliance with national and international targets, it is vital that alternative strategies are adopted in the development of a UK high speed rail network.

2. Carbon Accountancy for High Speed Rail

2.1 The Environmental and Sustainability Imperative

The need to develop the UK transport system in accordance with contemporary standards of environmental and sustainability best practice should be self-evident. However, it is worthwhile to list the key drivers that compel a radical transformation of contemporary high-CO_2 travelling attitudes and habits, with new railways offering the clear low-CO_2 alternative.

- ***Avoidance (or mitigation) of Climate Change***
  CO_2 emissions, primarily arising from the burning of fossil fuels, are commonly acknowledged as the chief vector in human-driven climate change. Transport accounts for 26% of total UK CO_2 emissions (550MT total, 140MT in transport), and two thirds of total oil consumption. These figures require to be radically cut, as part of a wider CO_2 reduction strategy.
- ***Compliance with the Law***
  The 2008 Climate Change Act has legally committed the UK to achieving an 80% reduction in CO_2 emissions across all sectors, including transport. It is vital that the ability to travel is retained, whilst achieving this radical target, and this would seem to demand fundamental structural changes in all aspects of contemporary living. Such changes (at least in transport) will only happen with major Government-led initiatives, and a 'wartime' philosophy under which all projects, large or small, are required to demonstrate their performance in reducing emissions Against this background, it would seem reasonable to expect high speed rail to play its part.
- ***International Pressure***
  It should not be forgotten that many countries (for instance, Pacific atolls overwhelmed by rising sea levels) will feel the adverse effects of climate change long before the UK does. Densely populated coastal regions in the Indian Subcontinent and China are also highly vulnerable, amongst many other areas primarily in the developing world. There is a high chance that if UK Governments were to ignore their own self-imposed targets, and fail to achieve the required reductions on an incremental and planned timescale, then other countries might apply pressure to force this country to comply, with immediate effect. Such unplanned cuts could result in a cessation of all non-essential travel (another parallel with wartime!) and have a calamitous effect on the UK economy. This creates a practical as well as a moral imperative to take radical action to reduce CO_2.
- ***Reduced Dependency upon Fossil Fuels***
  99% of all travel is reliant upon oil (ie petrol or diesel fuel), and while world demand is rising, reserves are finite, and dwindling. The concept of 'Peak Oil' has been advanced, whereby the world economy is catastrophically destabilised, as rising global demand outstrips the capacity to supply, or to migrate to alternative sources of energy. Any action to reduce transport's consumption of oil, as part of a drive to reduce CO_2, will also defer the onset of a 'Peak Oil' crisis.

All of the above considerations establish a pressing need for any national transport infrastructure project to optimise its performance in respect of CO_2 emissions and unsustainable use of raw materials, in addition to more conventional economic criteria.

2.2 Understanding the Carbon Footprint of High Speed Rail

It is clearly vital that UK high speed rail development is optimised to achieve the greatest environmental gains, and to do this, it is essential to understand the various factors that contribute to the ‘carbon footprint' of high speed rail.

The carbon footprint of high speed rail, and indeed of any new railway proposal, can be determined from the following:

- Operational emissions arising from frictional losses ie air resistance and rolling resistance, plus acceleration/deceleration etc.
- Emissions savings arising from modal shift from higher-emitting modes such as air and road.
- ‘Grey' emissions arising from construction of fixed infrastructure (and rolling stock).

The ‘green' credentials of high speed rail are underpinned by the central assumption that the emissions savings arising from the modal shift will outweigh the emissions associated with construction and the increased operational emissions due to the higher speed. This is the basic environmental theory behind high speed rail, and its validity is generally accepted, albeit with some outstanding concerns as to the magnitude of the ‘high speed' and the emissions associated with creating the necessary infrastructure.

Most if not all high speed rail schemes so far put forward have offered a degree of environmental justification, loosely based around the balance between the above 3 factors. But, as previously noted, these schemes have been developed with unrealistically low ambitions for net emissions savings, entirely misaligned with national environmental targets. Moreover, there appears to be no consistent and rigorous means by which such savings are calculated.

A principal aim of this study is to set out the basis of an improved methodology. However, even before such a methodology is advanced, it is important to identify the basic drivers, that should deliver optimum emissions reductions:

- Modal shift maximised, for maximum passengers and goods transferred to rail.
- Train operation optimised to maximise CO_2 gain through transferring from higher-emitting mode.
- Minimised new infrastructure for minimum ‘embodied' CO_2.

There is a clear potential for interdependencies between these 3 factors, that could cloud the issue. For instance, a high speed network of minimised length might be highly efficient to operate, with low ‘embodied' CO_2. However, it might not serve the areas that generate a high proportion of the transport emissions, hence the desired savings will not be achieved. In the main, however, (notwithstanding such interdependencies, which must be identified) it is clear that appropriate effort must be made to optimise all 3 factors.

3. High Speed Rail Design Considerations

3.1 Alignment of strategy with climate change objectives

This study has reviewed potential strategies for achieving the 80% (or fivefold) emissions reduction target of the 2008 Climate Change Act (see Appendix A1, and Figure 3.1 below), and has determined that:

a) modal shift will comprise the primary strategy by which the target will be met,

b) with roads emissions comprising over 90% of total transport emissions, this is the sector that must be targeted as a priority,

c) these targets will only be met through major Government-led interventions.

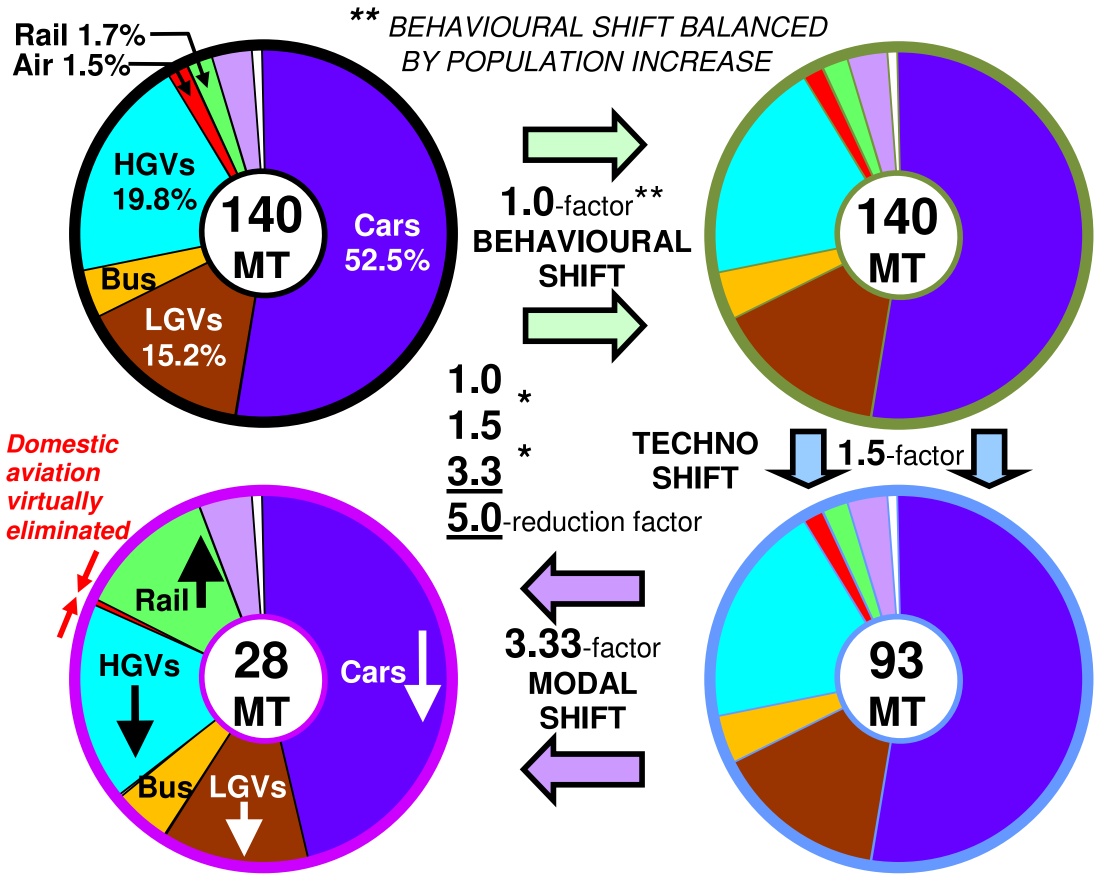

Fig 3.1: Quantified 'Shift' methodologies to achieve fivefold cut in CO_2 emissions

Although the HS2 proposals have a modal shift strategy, it is aimed largely at aviation, rather than the much higher-emitting roads sector. As such, it fails, in its scale and ambition, to meet contemporary climate change requirements. This is due, at least in part, to the 'business as usual' assumptions under which the HS2 proposals have been developed, and the predicted emissions reductions (a median 4.6MT of CO_2 over 60 years, within a +25.0MT to -26.6MT range) may not represent the scheme's true potential to generate reductions in CO_2 emissions. It is an aim of this study to establish this potential.

If high speed rail is to constitute a transport solution appropriate to a modern world in which CO_2 emissions and fuel sustainability have become critical issues, it seems vital that whatever solution is adopted aligns fully with the CO_2 reduction agenda, and is optimised appropriately. It should not be forgotten that high speed rail will comprise the principal intervention in UK long distance surface transport over the next half century (ie the currency of the Climate Change Act). If high speed rail does not make a meaningful contribution to achieving the required reductions in CO_2 emissions for intercity/interconurbation journeys, nothing else seems likely to do so.

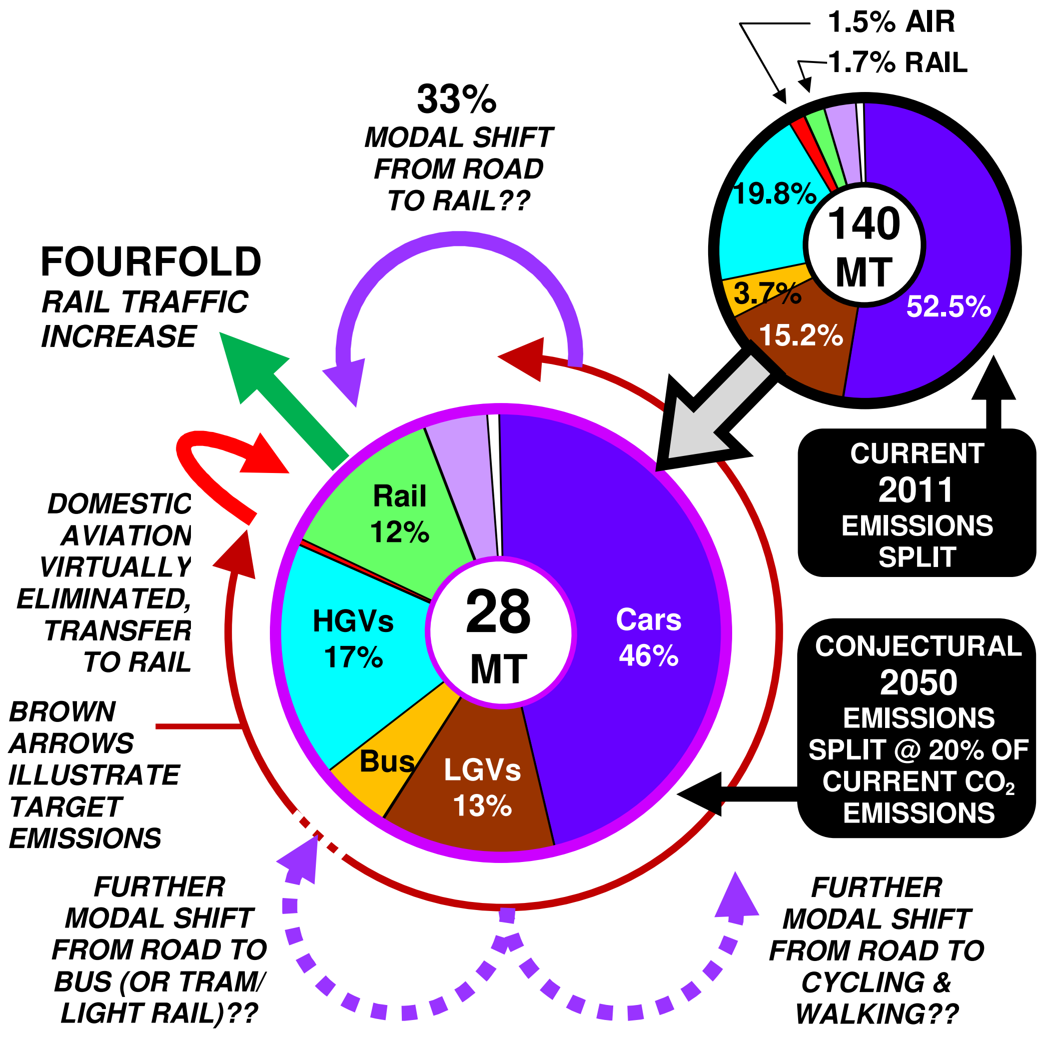

Fig 3.2: Step-Change Increase in Rail Traffic arising from 33% Modal Shift: Other CO_2 Emissions Reductions Strategies also illustrated

Aside from high speed rail, there are many other more localised strategies, involving light rail, bus and walking/cycling, which must also play their part. But these primarily address short-distance journeys, possibly up to a 50km horizon. Beyond this point, an enhanced railway network seems the best prospect of delivering the required transformation in travel patterns.

The issue then centres around how high speed rail might align with a general requirement for an enhanced railway appropriate to intercity journeys greater than 50km in length. This tends to go against 'received wisdom' amongst certain 'experts', who have suggested that high speed rail is only appropriate to intercity journeys typically of at least 200km in length. But this is simply restating the guiding principles of the French model which, naturally enough, reflects French demography, geography and railway operating patterns.

It would seem far more logical to develop a 'UK-appropriate' model of high speed rail, one that will integrate and harmonise with the existing intercity network, rather than detract from it (as 'exclusive' models of development, favoured by certain experts, tend to do). This will comprise one of the principal criteria against which candidate high speed rail schemes will be assessed.

3.2 Requirement for Capacity

Assuming that such a model of integrated high speed rail can be created, addressing all major intercity/interconurbation flows greater than 50km, it would appear to be capable of converting of the order of one third of contemporary transport emissions (and in doing so offer a significantly lower-energy, lower-CO_2 transport solution). But if the equivalent volume of journeys were to transfer from the dominant road sector to rail, an approximate fourfold[2] increase in rail travel (both passenger and goods) would result.

With the rail network already under severe capacity pressure on most main line axes, the construction of new railways would appear to be the only practicable solution by which a traffic increase of this magnitude could be accommodated. The addition of 2 new tracks parallel to 2 existing in itself doubles capacity, but there is a further approximate doubling through the segregation of higher speed express passenger traffic from slower freight and local passenger traffic, and the operation of longer trains, operating at higher load factors. Together, these effects will combine, to deliver the required fourfold increase in capacity.

It must be stressed that if this extra capacity is not provided, the railway system will be unable to accommodate the increased passenger and goods traffic, and the desired step-change reductions in CO_2 emissions (proportionate to the requirements of the 2008 Climate Change Act) will not be achieved.

[2] Anecdotal evidence states that a modal shift of 1% away from passenger road transport results in a 13% increase in rail traffic. A simplistic scaling up, to a 30% modal shift from road (amounting to a 33% reduction on road transport's current 90% share), would indicate a 390% increase in rail traffic. The mathematical inaccuracies inherent in such large percentage changes are acknowledged, but this would still indicate that the notional requirement for a fourfold increase in capacity is of the correct order of magnitude.

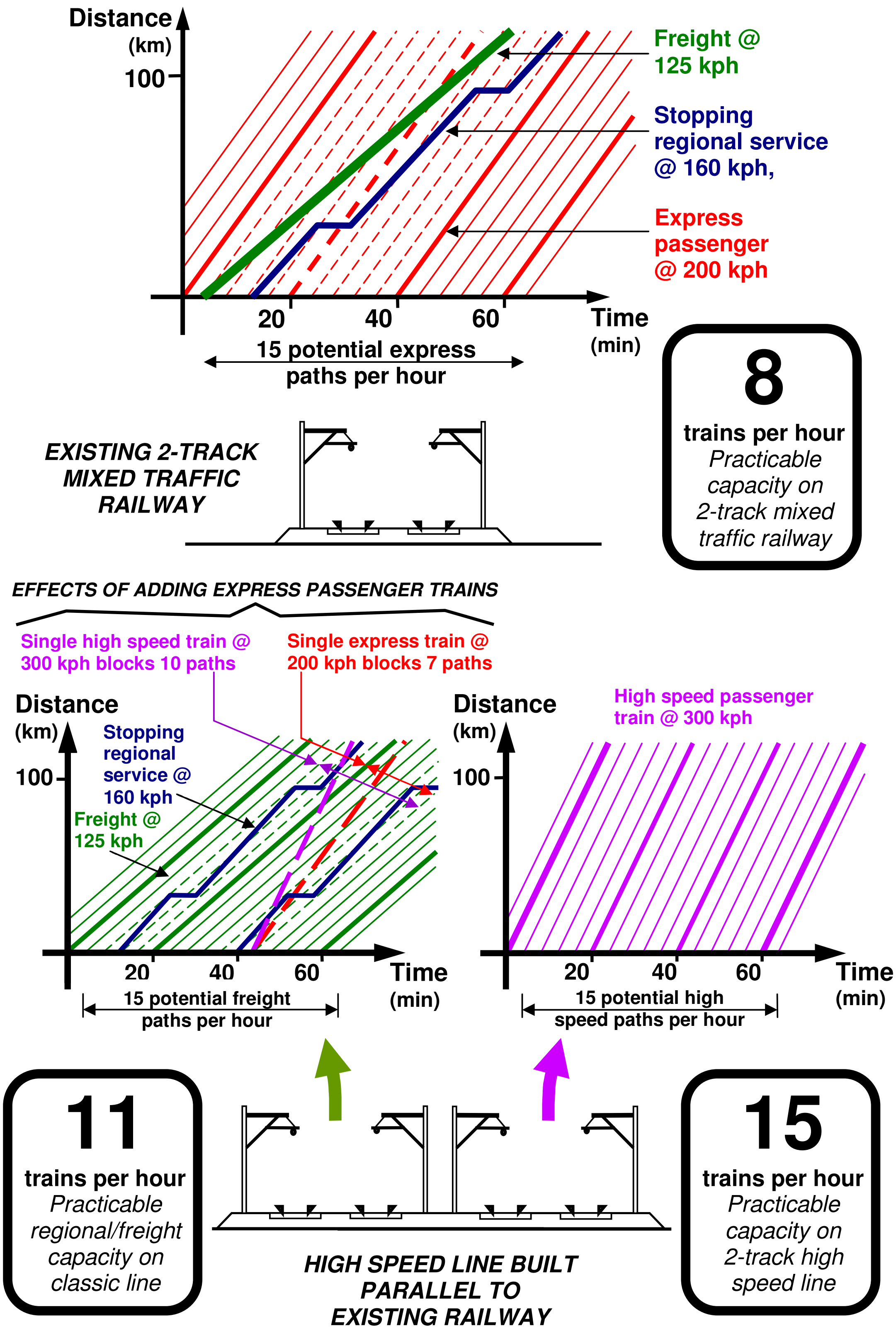

Fig 3.3: Capacity Gains through Addition of Parallel High Speed Line

3.3 Requirement for Connectivity

Even with the necessary capacity provided, it is still necessary to configure the high speed network in such a way as to enable the desired modal shift to happen. Notwithstanding the exigencies of environmental or fuel supply crises, which might compel travellers to abandon the car and the plane, and take the train instead, the new high speed rail system should still offer an attractive alternative for as many as possible, a journey of at least equivalent quality.

Overall timings should be comparable, and the inevitable interchange between modes (eg cycle from home to local station, local train to regional hub, high speed service to another conurbation, local train/metro/taxi to final destination) should be as seamless as possible. The whole issue can be summed up in the single word 'connectivity'.

The following points set out what might be considered an ideal of connectivity:

- ***Location of Hubs***
  All hubs of high speed system should be located at centroid of local rail and public transport system in each conurbation/region served.
- ***Optimised Interchange***
  Through co-location of new high speed and existing city centre hubs, optimised interchange between high speed and local/regional/residual intercity network should be provided.
- ***Integration with Existing Intercity Network***
  Noting the fact that high speed rail will take over the primary role of the existing intercity railway in connecting major centres of population (and also the fact that high volume of interchange could overwhelm some city centre hubs) the new network should integrate with the existing, to offer through running to as many destinations as practicable.
- ***Comprehensive Network***
  All conurbation hubs should be interlinked by direct services, ideally of at least hourly frequency.
- ***Second Tier Cities connected to High Speed Network***
  Where possible, high speed services should continue beyond the conurbation hubs to 'second tier' cities, that might otherwise be blighted through disconnection. At the very least, these communities, often located on uniaxial main lines with no 360º connectivity, should have viable links at either end of their main line to the high speed network. See idealised network shown in Figure 3.4.
- ***Enhanced Network***
  The existing railway network, developed during the Victorian era in a largely ad-hoc manner and without the benefit of a guiding masterplan, fails in many ways to offer the ideal connectivity. Several key centres eg Merseyside, East Midlands and Scotland, are poorly interlinked, and more recent developments (new towns such as Milton Keynes, and major airports, in particular Heathrow) lack the 360º connections that such centres require. Wherever possible, high speed rail should be configured to address these deficiencies.

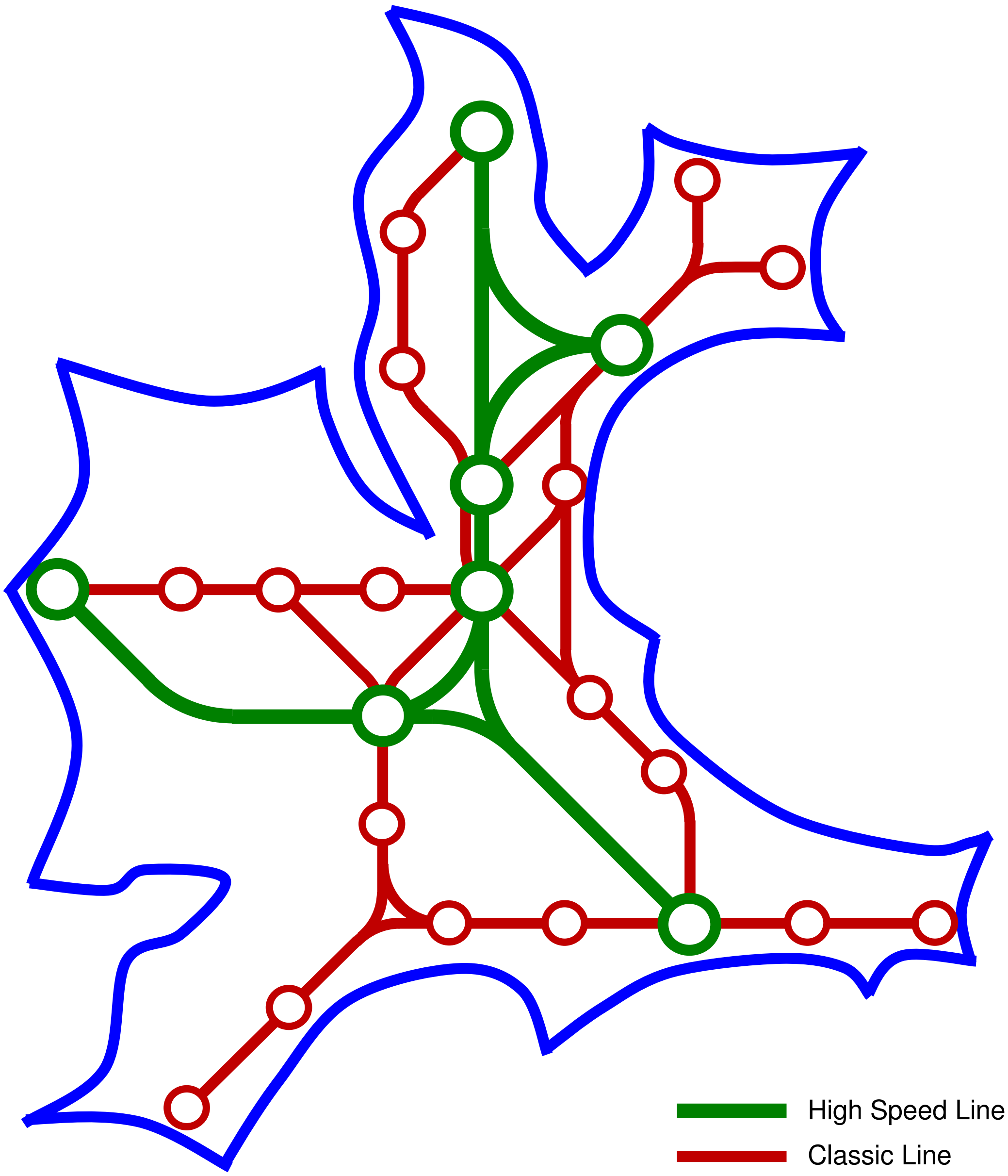

Fig 3.4: Idealised Configuration of Integrated High Speed & Classic Networks

3.4 The 'need for speed'?

Capacity and connectivity appear to be the principal considerations in the development of a lower-CO_2 future transport system. However, the 'need for speed' must also be taken into account. There is a commonly-accepted objective for a London-Glasgow journey time of less than 3 hours; this has historically (on the basis of London-Paris Eurostar operation) been considered the key criterion for displacing the short haul aviation currently dominant on Anglo-Scottish routes. A sub-3-hour London-Glasgow journey time is only achievable with speeds considerably in excess of the 200kph maximum speed that applies across the existing network. Thus a degree of high speed would seem essential for both the business case and environmental rationale underpinning the development of high speed rail in the UK.

However, it is important to note that Anglo-Scottish journeys represent only a relatively small proportion (16% by volume, 29% by emissions) of the total quantum of UK inter-conurbation journeys within the 'Zone of Influence' of a northern high speed line. While high speed rail is being advanced as the low-CO_2 alternative to domestic aviation, there is an obvious danger that the requirement to achieve competitive shorter journey times to Scotland (for which the high energy consumption, and CO_2 emissions, of speeds in the region of 300kph can be justified against the much higher-emitting aviation alternative) will dictate the speed that is adopted for the entire high speed network.

The majority of journeys on this network would be within England, typically no greater than 300km in length, and for these journeys, rail already comprises the fastest option; here, the competing transport mode is the private car, and the effect of greater operating speeds, to achieve shorter journey times, would seem only to reduce the environmental advantages that might be achieved.

Given that most rail journeys involve at least one change of trains, it must be appreciated that journey time is dependent as much on the quality of the connection as it is on speed. A clear danger with high speed rail is that the time gained through faster point-to-point journeys could be lost through difficult connections between the high speed and local rail hubs in the originating and destination cities. It seems clear that equal attention must be paid to connectivity as to speed; this highlights the need for efficient interchange and general integration between high speed and classic networks.

Concentrating pro-tem on the issue of speed, differential operating speeds – ie higher speeds to time-sensitive destinations in Scotland and the North-East of England, and lesser speeds to closer Midlands and Northern destinations – might give the optimum solution, in terms of energy consumption and consequent CO_2 emissions. However, differential speeds also have the effect of massively compromising line capacity, and thus reducing its overall capacity and hence ability to deliver the necessary step-change modal shift.

This conflict does not appear to be capable of resolution, if the high speed line were only to be constructed as a 2-track railway. But the classic railway expedient, of constructing main lines in 4-track format, would appear to offer a way forward, albeit at higher initial infrastructure cost and associated CO_2 emissions.

Issues concerning operational and design speed are discussed in greater detail in Appendix B7. Of particular importance are the increased technological and safety risks associated with extreme speed in the 350 – 400kph region.

3.5 Scope of UK High Speed Rail Project

It is important to define the scope of the UK high speed rail project. This has loosely been termed 'HS2', a high speed rail system extending northwards from London to the Midlands, the North and ultimately Scotland. The approximate 'Zone of Influence' of a northerly oriented high speed rail system is indicated in green in Figure 3.5 below. From this the 'Green Zone' and 'Red Zone' are defined.

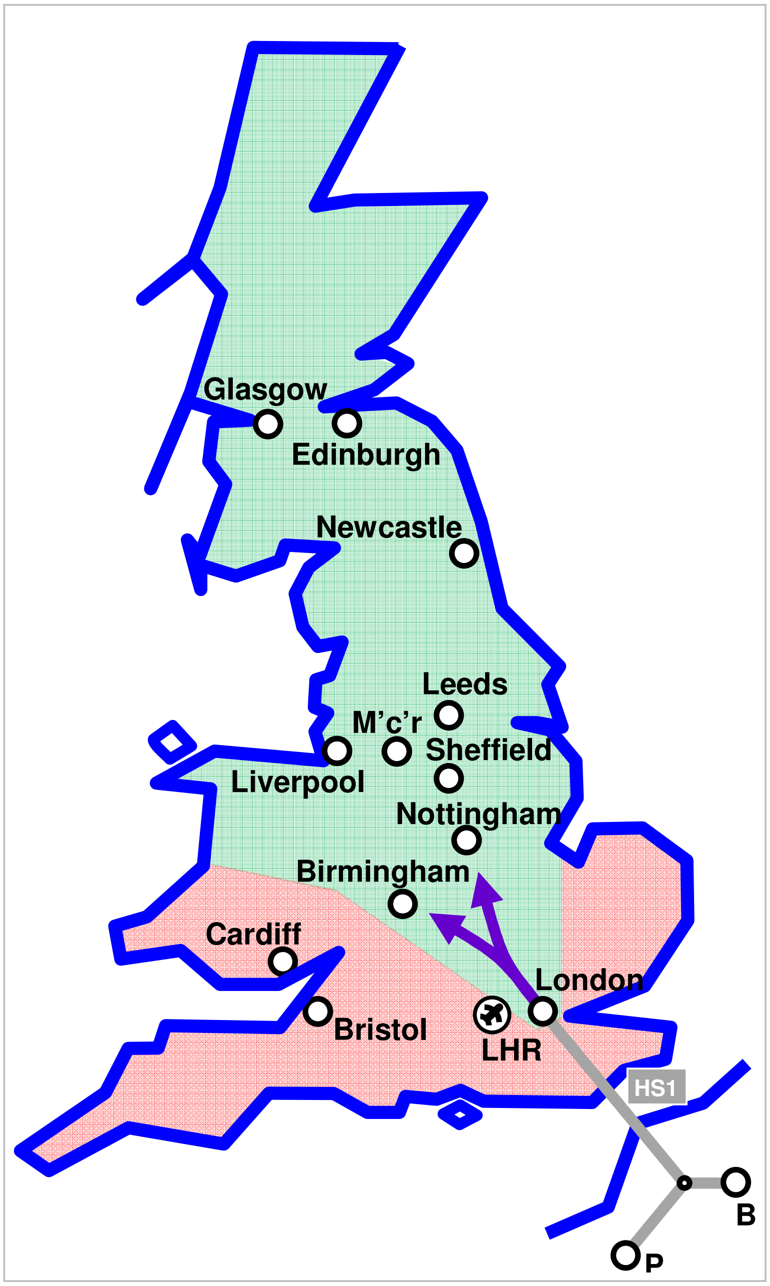

Fig 3.5: Idealised Scope for High Speed Line to the north of London, showing primary conurbations

A reasonably uniform geographical spread of benefits arising from the establishment of high speed rail in the UK is a key political consideration, especially in view of the large sums of public money likely to be expended. Given the major differences between the various high speed rail schemes that have been put forward, there is in fact remarkable convergence as to the primary conurbations that should be served. These are as follows (approximate population in brackets):

- West Midlands / Birmingham (2.6 million)
- East Midlands / Nottingham (0.7 million)
- South Yorkshire / Sheffield (1.3 million)
- Greater Manchester (2.5 million)
- Merseyside / Liverpool (1.3 million)
- West Yorkshire / Leeds (2.2 million)
- North-East / Newcastle (1.6 million)
- Lothian / Edinburgh (0.8 million)
- Strathclyde / Glasgow (2.3 million)

All the above conurbations (or wider metropolitan regions, with local rail network focussed on the nominated city) represent high concentrations of population for which a new system of high speed, high capacity railways would comprise a viable transport system. All would be served by the core high speed networks (or short extensions therefrom) of both the HS2 and High Speed North proposals. It is of course necessary for the populations noted above to be able to access the new network, and this would seem to demand that the high speed network also focuses upon the same hubs as do the local networks.

Together with the London conurbation (circa 8 million), the primary conurbations listed above represent 23 million of the 40 million population within the zone of influence of a northern high speed line. This leaves a 17 million 'non-conurbation' population, of whom a significant proportion inhabit the next tier of secondary cities. Considering the entire zone of influence of a northern high speed line, the 'non-conurbation' population, living in 'second tier' communities greater than 100,000, and served by the existing intercity network, amounts to around 5 million. Thus the Green Zone population breaks down: conurbations / **other cities** / towns & rural: 23M / **5M** / 12M.

Within the potential scope of a high speed line from London to the Midlands lie the following major communities, all greater than 200,000 population:

- Luton (240,000)
- Milton Keynes (200,000)
- Northampton (200,000)
- Coventry (350,000)
- Leicester (400,000)

The above 5 cities, which might be characterised as a loose 'South-East Midlands' grouping, collectively amount to a 1.4 million population, over half that of the West Midlands, and considerably more than the East Midlands (centred upon Nottingham). These cities are all key components of the existing intercity rail network; and although they lack the size and concentration of population to demand dedicated new lines or hub stations on the core high speed network, they are still stakeholders whose needs must be addressed. As will be clarified in later sections of this study (Section 4.9), high speed rail has equal potential to either benefit or blight intermediate communities.

3.6 Network Design Considerations

It is important to note the 'clustering' of the 9 primary conurbations into a fairly linear 'band', extending approximately north-north-west from London to the central belt of Scotland. Considered in terms of compass bearing, there is no more than a 35 degree variance between Birmingham (310º) and Newcastle (345º). Although it is clearly not feasible to cover all these primary conurbations with a single line, it is still possible to exploit this unique feature of UK geography[3] and encompass these communities within a single axis of development. This philosophy is to an extent reflected in all major high speed rail proposals, in which a single stem, or spine, extends north from London, before splitting either in the Midlands or the North.

The existence of a multiplicity of major conurbations and communities along the axis of the proposed high speed line creates a demand for a routeing strategy that will optimise connectivity. This would ideally be achieved by means of direct connections between all communities (ie not simply a 'fan' of high speed links to London).

Even if this ideal of total interconnectivity is achievable, there is still a limit upon the number of stations that a dedicated high speed rail network can practicably serve. Such stations can only be at specific locations, while population (of the conurbation itself) is of necessity distributed over a wide suburban spread. It is clearly desirable that the high speed station should be co-located with the existing hub station, at the heart of the conurbation's local rail (and wider public transport) network.

The proximity of the Midlands and Northern conurbations is another significant feature. These are typically at 50-60km intervals, and under certain theoretical 'models' (as exemplified by the French practice in developing *Lignes à Grande Vitesse*, with stations typically at 200km spacing) might be deemed to be too closely spaced for high speed rail to provide an appropriate solution. There has even been the suggestion that the East Midlands, South Yorkshire and West Yorkshire might have to share a single high speed hub station!!

But all this fails to recognise the fact that the French high speed model has been developed to suit French geography and demography. As already noted, the shape of the UK, and the distribution of its population, is completely different from that of France, and would seem to demand a different 'UK-appropriate' solution, bespoke to local needs and capable of harmonising and integrating with the existing rail network.

With considerable urban population in the second tier cities, which are destined to remain on the classic intercity network, this bespoke high speed solution must also be geared to maximise the benefits that will accrue to these communities (and avoid the risk of blight, arising from bypassing and lack of integration between high speed and classic networks).

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[3] The essentially linear nature of UK population distribution, with most major conurbations located within a fairly narrow band, and no especially impenetrable intervening mountain barrier, is a feature unique (among major industrialised nations) to the island of Great Britain. Excepting what might be classified as the London commuter zone extending to the South Coast, the only major conurbations outside the 'zone of influence' of a high speed line to the North comprise Avon Valley/Bristol and South Wales/Cardiff. Other countries which might be considered exemplars of high speed rail either have a central mountainous spine hindering regional interconnection (eg Italy and Japan) or are much more 2-dimensional, with a centrally-located capital city, and viable high speed corridors extending in all directions (eg France and Spain).

3.7 Optimisation of High Speed Proposals

The potential of high speed rail to deliver the greatest possible CO_2 emissions reductions will only be realised if it can be optimised against a wide range of criteria:

- ***Coverage of Network***
  Modal shift can only happen on the corridors along which the new rail capacity and/or connectivity is provided.
- ***Timescale for Development***
  Modal shift will be maximised with the earliest feasible implementation of the new high speed network. This facet of optimisation is closely associated with the selection of practicable routes causing least controversy, avoiding unnecessary intrusion into sensitive areas. It is also closely related to issues of cost and of limited resource, both of which will restrict the pace at which the high speed solution can be rolled out.
- ***Interchange and Integration***
  The 'conversion level' (ie the proportion of total transport emissions convertible to rail through the specific intervention of a northern high speed line/system) will be optimised through the greatest practicable interchange and integration between high speed and classic networks, to spread the benefits to greater populations.
- ***Operational Efficiency***
  The 'exchange rate' of conversion from higher-emitting road and air transport to lower-emitting rail will be maximised through the minimisation of rail's grams of CO_2 per passenger kilometre figure. This will be achieved through configuration of network to achieve highest practicable load factor, and avoidance of excessive speed (ie that which does not deliver proportionate environmental or commercial benefits).
- ***Carbon Footprint of New Infrastructure***
  This represents a one-off CO_2 cost, of emissions resulting from the manufacturing and construction activities associated with the creation of the new infrastructure. There is an additional consideration of maintenance, in that such activities might disrupt the efficient functioning of the infrastructure.

The following Section 4 of this study details the methodologies by which comparisons are made against the above criteria. Although the specific purpose of these comparisons is to establish 'environmental performance' in respect of CO_2 emissions, it should be emphasised that throughout, there is a general correspondence between good environmental performance and good business performance. These themes are developed in greater detail in Appendix A4.

It cannot be stressed too highly, that optimisation of the criteria listed is possible only with the correct engineering, operational and environmental philosophies, and a 'model' of high speed rail that is appropriate to the specific needs and circumstances of the UK. It is especially important that schemes are developed against a balanced specification, without any single criterion being accorded undue priority over others.

Particular concern centres around an imperative to establish high speed rail access to Heathrow proposals that, for many proposals, appears to lead to massively increased infrastructure costs and environmental intrusion (in the Chilterns and elsewhere), and greatly reduced operational efficiency and effectiveness in cutting CO_2 emissions, all for the benefit of relatively few passengers. Accordingly, this study also investigates the CO_2 cost of bringing high speed rail to Heathrow.

4. Proposed Methodology of Study

4.1 Aims of Study

As noted previously, the basic aim of this study is to gain a greater understanding of the carbon footprint of high speed rail. From this, the true potential to deliver emissions reductions can be assessed, and objective comparisons can be drawn between alternative schemes. It is a high level study, that draws together data from a variety of information sources (generally in the public domain and none that constitutes 'privileged' information), to establish the following key strands:

1. the total quantum of contemporary UK transport emissions capable of conversion to rail, through the implementation of a high speed line to the north.
2. a quantification of the relative magnitude of flows between principal conurbations.
3. a quantification of the reduction in CO_2 emissions arising from conversion of aviation and road transport flows to rail, paying due heed to issues of speed and load factor.
4. an assessment of the quality of the interchange with existing transport networks at primary interchanges, and accessibility to second tier centres.
5. the geographical scope and timescale over which these emissions reductions might be achieved.
6. a quantification of the mitigation of environmental intrusion that can be achieved through routeing along existing transportation corridors.
7. the CO_2 emissions arising from construction activities.
8. the hugely disproportionate influence of Heathrow Airport (in the political requirement for 'high speed' airport access) upon development of the high speed rail network, and the consequent cost in terms of expenditure and CO_2.
9. an assessment of potential savings in CO_2 emissions through optimised rail access to Heathrow.

The uncertainties inherent in many of the statistics used in this study, in particular those relating to CO_2 emissions, and to the environmental performance of rail and other vehicles, are acknowledged. The methodologies employed in the determination of relative traffic flows, and consequent CO_2 emissions, are also somewhat 'broad-brush'.

These imply similar uncertainties in the outcomes of the study, at least in an absolute sense, and would not be appropriate in a detailed transport planning study focussed on local issues, such as have already been carried out to support various high speed rail proposals.

However, it must be stressed that this is not the primary purpose of this study. Indeed, it must be questioned whether an excessively detailed and localised approach is appropriate at an early stage in formulating proposals for what can only be a national network. This would seem to demand a more 'macro' approach.

As noted above, this study's purpose is to determine:

- high speed rail's potential for emissions reductions,
- the relative magnitude of factors influencing its carbon footprint,
- a rigorous basis on which rival schemes can be compared.

The methodologies employed are considered to be appropriate for both the 'high level' objectives of this study, and for the comparisons that will be undertaken. Whatever the issues of absolute precision, the accuracy of the comparisons will be of an order of magnitude greater, so long as 'like' is compared with 'like', and the same methodologies are fairly and consistently applied to the schemes under consideration.

Two 'candidate schemes' will be considered:

- The Government's HS2 proposals for a Y-shaped system, focussed upon Birmingham and extending northwards either side of the Pennines, initially to the North-West and to Yorkshire, with the potential for further development to Scotland and to the (English) North-East. These proposals were initially published in March 2010 and (with further development) are now put forward for official consultation.
- The High Speed North proposals for a 'Spine and Spur' system based upon an east-sided spine route from London to Glasgow, broadly aligned with the M1 and ECML. These proposals were published in July 2008 by the 2M Group of London and South-East councils.

The two schemes exhibit radically different approaches in all aspects of network development such as:

- degree of predication upon Heathrow,
- configuration of the network, and
- operational philosophy.

It is self-evident that fundamental issues such as these must be rigorously examined, and their relative influences (on CO_2 emissions, economic performance, total network operation, etc etc) thoroughly understood, before the Government commits to any particular high speed rail proposal. It is hoped that this study will shed more light on all of these issues.

4.2 Candidate Proposal : HS2

HS2 envisages an extended 'Y', comprising a trunk route from London through the Chilterns to the West Midlands, forking either side of the Pennines. It will proceed west-sided to Manchester and (ultimately) Scotland and Merseyside (with a Liverpool -Manchester link assumed), and east-sided to the East Midlands, Yorkshire and (ultimately) the North-East. Total length of the Extended Y is 1092km.

The HS2 proposals are primarily London- and Birmingham-centric, and will offer few other connections between regional cities, all of which will be located on separate spurs off the trunk route. It is conceived primarily as an 'exclusive' system, operating European size rolling stock (too large in cross-section and too long to fit onto the classic UK network), and linking to the existing intercity network only at a limited number of key hubs. To accommodate anticipated advances in high speed rail technology, sections of HS2 so far designed allow for speeds up to 400kph (250MPH), with an initial operating speed of 360kph envisaged.

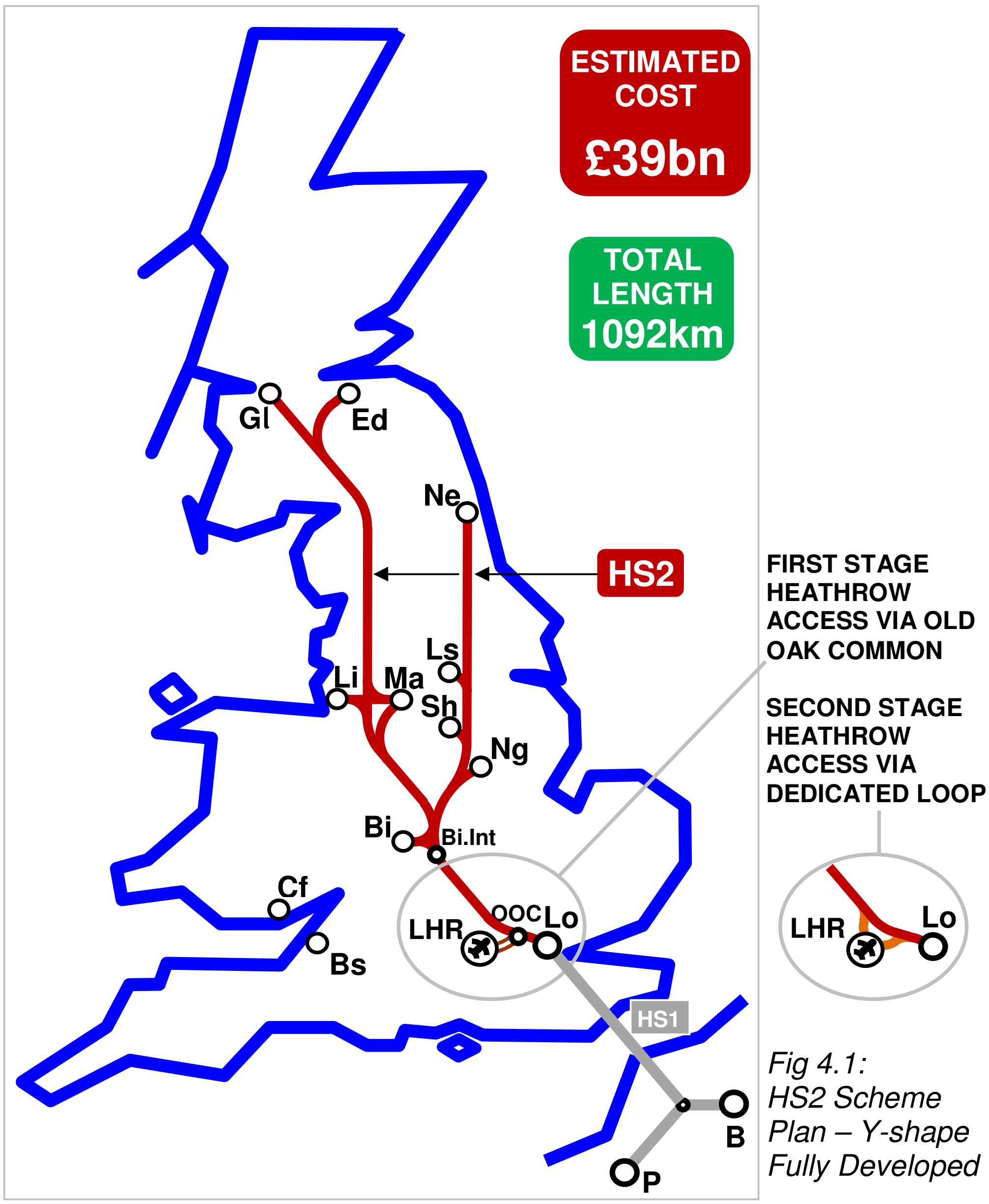


Fig 4.1: HS2 Scheme Plan – Y-shape Fully Developed

4.3 Candidate Proposal : High Speed North

High Speed North envisages a single M1-aligned spine running to the east of the Pennines, via the East Midlands, South and West Yorkshire and the North-East to Scotland, and with westward spurs to the West Midlands, and across the Pennines to Greater Manchester and Merseyside. Total length of the High Speed North 'Spine and Spur' network is 935km. A Heathrow connection is provided by means of associated development of a regional 'Compass Point' network.

High Speed North is conceived as a new interconurbation network, offering much-improved connectivity and enhanced capacity between all principal regional conurbations. It has been developed with the aim of maximum integration with the existing intercity rail network, with through services operating to second tier destinations. No definitive design speed has been established for High Speed North, but a notional figure of 320kph (200MPH) – which would deliver London-Glasgow journeys comfortably under 3 hours – might be assumed.

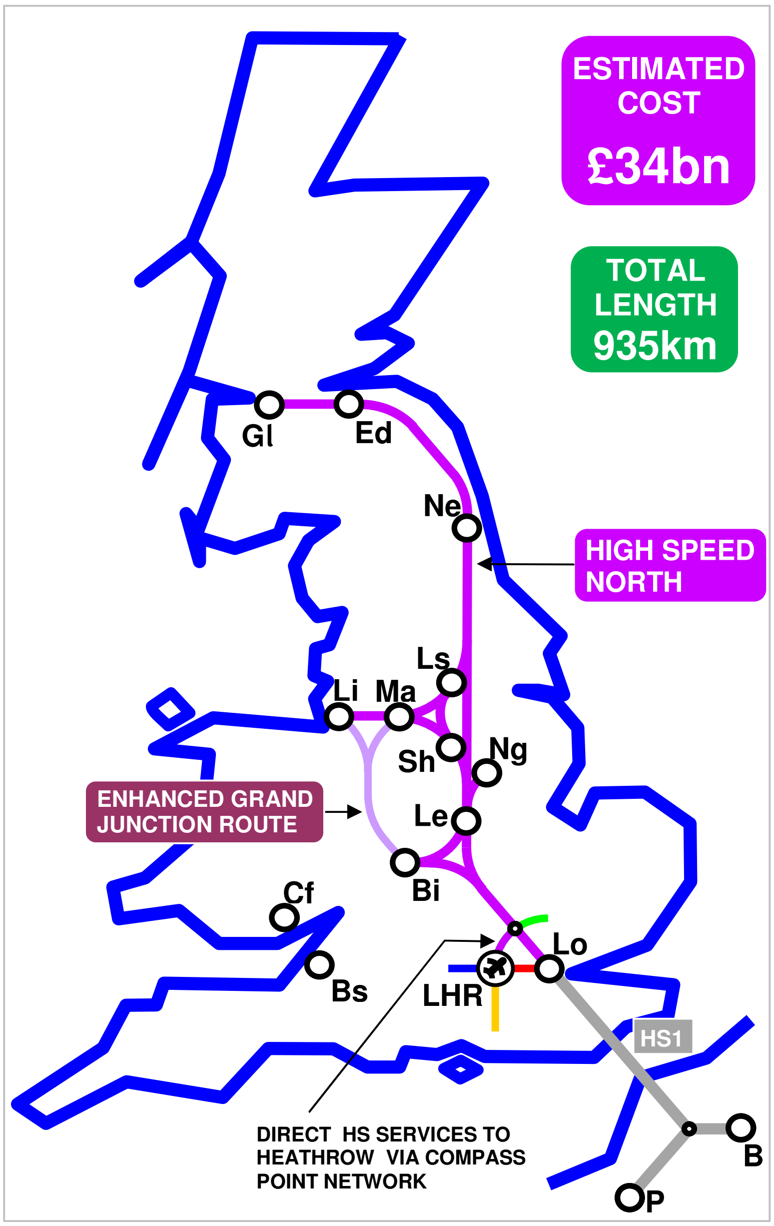


Fig 4.2: High Speed North Scheme Plan: 'Spine & Spur' fully developed

4.4 Calculation of CO_2 Reductions – Step by Step

On the basis of both HS2 and High Speed North covering the same key destinations to the north of London, and offering significantly increased speeds fulfilling the remit for London-Glasgow journey times below the critical 3 hours, the two candidate schemes appear to have sufficient coincidence of core objectives to validate the comparisons drawn in this and subsequent sections of this study.

There are four strands to the calculation of potential reductions in CO_2 emissions:

- ***Quantum of existing traffic flows capable of conversion to rail***
  This is determined by both geographical scope and capability of candidate high speed rail scheme to achieve optimum connectivity and capacity between all primary conurbations. *(refer Sections 4.6 & Q6)*.
- ***Timescale by which emissions reductions are achieved***
  Timescale is determined by simple practicability and public acceptability of high speed rail proposals, and by potential economic and environmental gains. *(refer Sections 4.7 & Q7)*.
- ***Integration of high speed network with existing railway system***
  Integration is necessary to extend the effectiveness of high speed rail as an intervention capable of generating modal shift from road transport. This is determined by assessment of connectivity to existing network, and enhancements offered to 'off-network' second tier cities. *(refer Sections 4.8 & Q8)*.
- ***Relative reduction in CO_2 emissions through conversion to rail***
  This is determined by the differential Environmental Performance Indicator between road (or air) transport and rail, appropriately adjusted to reflect load factor and operating speed, inter alia. *(refer Sections 4.9 & Q9)*.

The same methodologies will be applied to both HS2 and High Speed North, to ensure consistent outcomes.

The following sections 4.5 to 4.9 summarise each aspect of the calculations, and consistently crossrefer to Appendix Q, Sections Q5 to Q9.

4.5 Target CO_2 Emissions
(Ref Appendix Q5)

The initial step is to identify the quantum of UK transport emissions that might be converted through the intervention of a northward-oriented high speed railway.

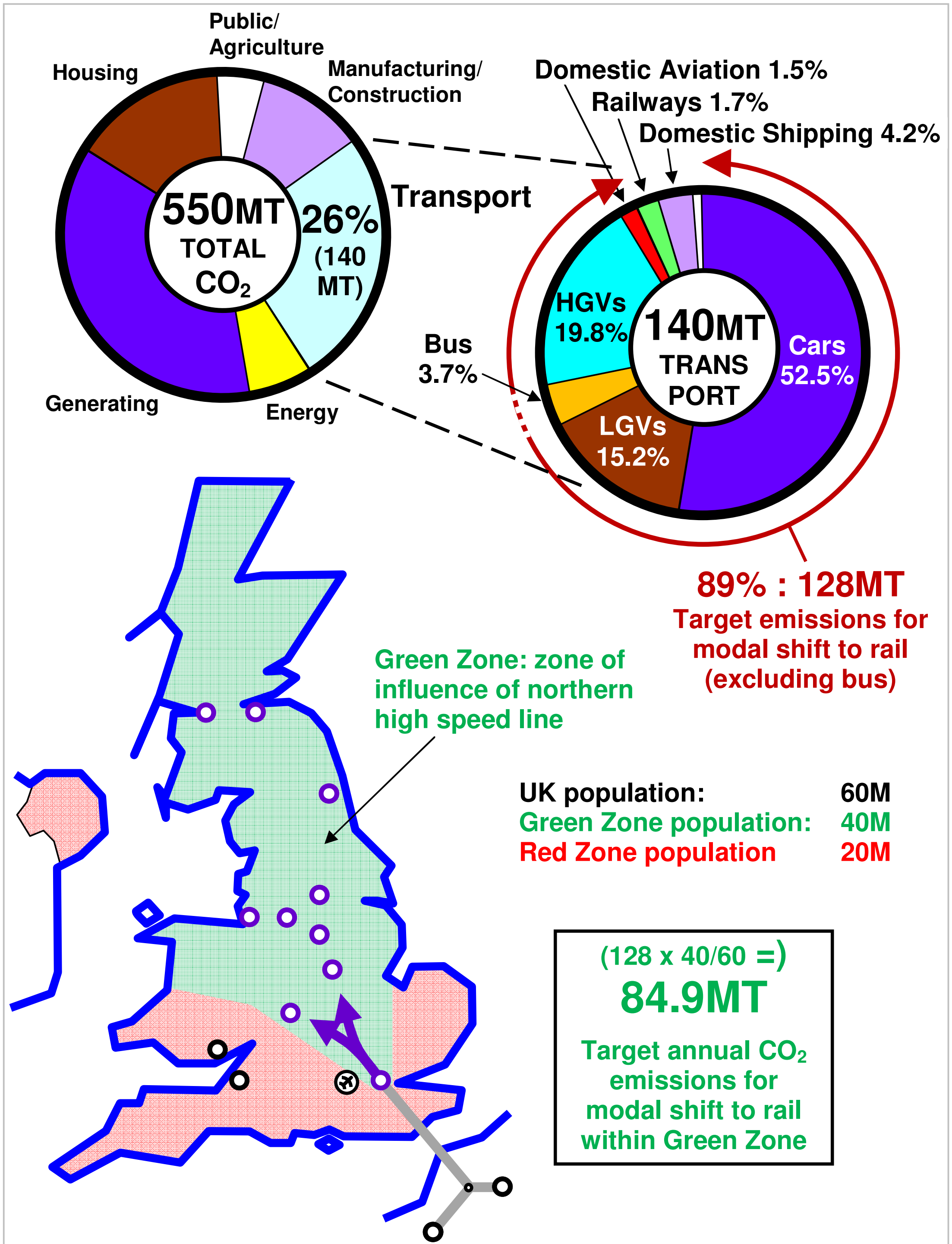


Fig 4.3: 'Target' CO_2 emissions for high speed line to North

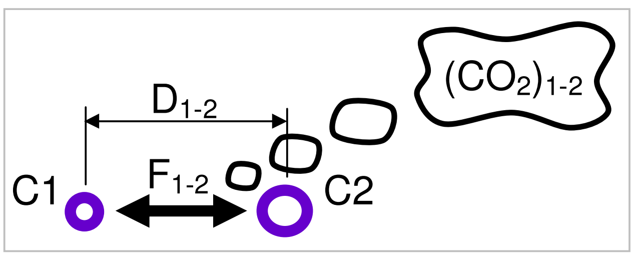
Transport emissions amount to 26% of total UK CO2 emissions, or 140MT per annum. Over 90% of this 140MT ie domestic aviation and all roads emissions except for buses, is potentially convertible to rail. This amounts to 128MT per annum.

The ‘zone of influence’ of a high speed line to the North (aka the ‘Green Zone’) is also considered. With the Green Zone covering a population of 40 million, two thirds of the UK total, it can simplistically be deduced that convertible emissions also comprise two thirds of the 128MT. Hence a figure of 85MT of CO_2 per annum is calculated as the ‘target emissions’, the baseline from which reduced emissions will be calculated, with the progressive introduction of new sections of high speed line.

4.5.1 Calculation of Connectivity, Flow and Capacity Required

To make comparative calculations between the two candidate schemes, it is necessary to be able to assess relative traffic flows between the primary conurbations, that will be at the heart of the proposed high speed rail network. This will inform requirements for connectivity and capacity, on a nationwide basis.

Interconurbation flow – and therefore required capacity – is calculated for all flows between primary conurbations, by means of a gravitational model. Flow (F_{1-2}) is taken to be proportional to the product of the populations linked (P_{C1} x P_{C2}), and inversely proportional to the intervening distance (D_{1-2}). So traffic flow and also (in the case of a capacity-critical system) capacity requirement between population centres can be expressed as follows:



$$F_{1-2} \propto \frac{P_{C1} \times P_{C2}}{D_{1-2}}$$

4.5.2 Translation of Flow into CO_2 Emissions

The volume of traffic as calculated above is not directly indicative of CO_2 emissions, or energy use. Energy use (and hence CO_2) corresponds to the quantum of journeys, the product of flow and distance. So transport CO_2 emissions between population centres C1 and C2 can be expressed as follows:

$$(CO_2)_{1-2} \propto F_{1-2} \times D_{1-2}$$

Hence: $$(CO_2)_{1-2} \propto \frac{P_{C1} \times P_{C2}}{D_{1-2}} \times D_{1-2}$$

Simplifying: $$(CO_2)_{1-2} \propto P_{C1} \times P_{C2}$$

Thus it can be inferred that CO_2 emissions between two centres are independent of distance, and proportional only to the connected populations.

4.6 National Connectivity, Capacity, and Consequent CO_2 Emissions *(Ref Appendix Q6)*

The relationships established in the previous section make it possible to define potential flows and consequent CO_2 emissions between all of the principal conurbations listed in Item 3.5. These results are presented in the form of an 'Interconurbation Connectivity Matrix' and an 'Interconurbation Emissions Matrix'. These matrices give numerical scores for each of the 45 'conurbation pairs' that pertain to the 10 conurbations under consideration. The magnitudes of the various scores have no significance, in an absolute sense; the significance lies in their relative magnitude.

4.6.1 Review of InterConurbation Connectivity

The flow data allows aggregated flows to be calculated along each individual element of the proposed network; thus areas of 'strong' and 'weak' flows can be identified. In the case of HS2's 'Y', certain flows at the extremities of the networks are so weak as to cast doubt on the viability of constructing the full length of new route; this is due to the primary London-centricity of the system, with few other interregional journey opportunities created. Whereas the 'spine and spur' of High Speed North enables a far greater range of interregional journeys, thus stimulating much larger flows at the extremities. See Figures Q4 and Q5.

It is also possible to quantify the total improvement in capacity/connectivity achieved by each candidate scheme. This might simplistically be inferred as the achieved benefit, in the calculation of a Benefit-Cost Ratio. In this assessment, the performance of HS2 is greatly hampered by its essential London-centricity, with few interregional links created (19 out of 45 possible conurbation pairs); this limits its total score to 76. By contrast, High Speed North scores far higher, addressing all possible interconurbation links, and achieving a total score of 127.

4.6.2 Consideration of Capacity of 2-track High Speed Line

For both candidate schemes the strongest flows exist on the initial London-Midlands section, and this establishes a strong case for 4-track construction in this area. It seems clear that this aspiration will be far more difficult to achieve along HS2's Chiltern route, than along the less sensitive M1 corridor.

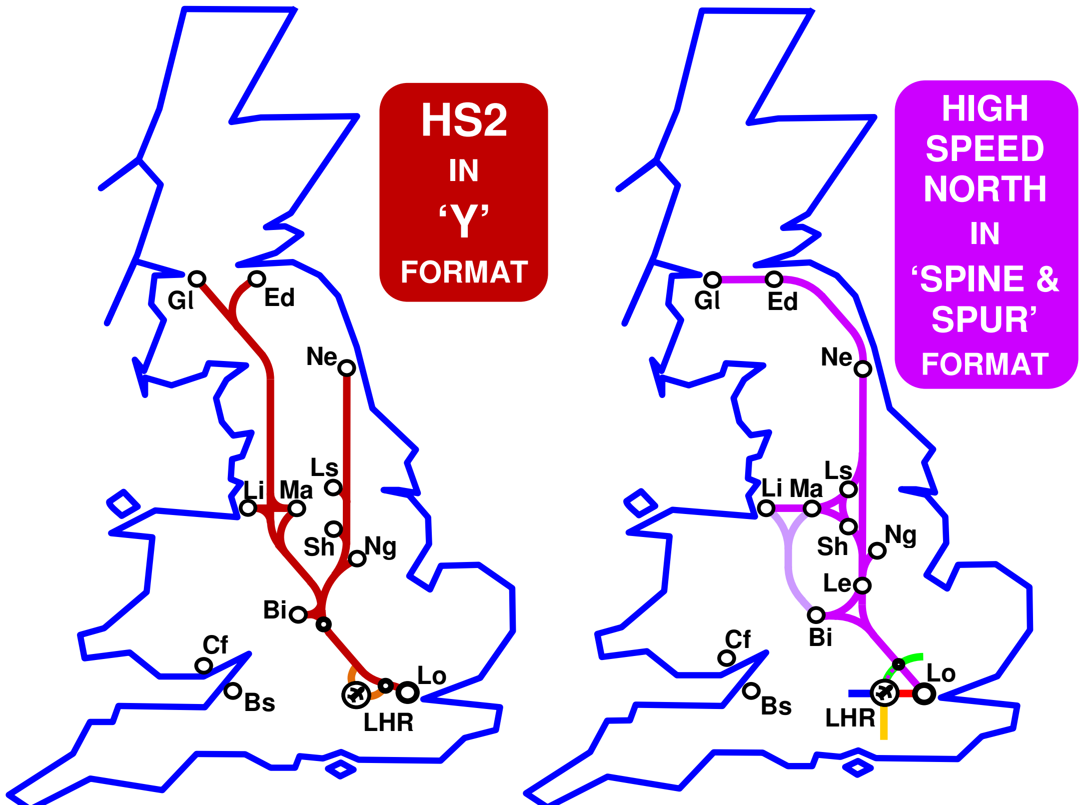
4.6.3 Translation of Connectivity into CO_2 Emissions

As with flow, the matrices also allow the relative magnitude of potential reductions in CO2 emissions (enabled by the new capacity created and consequent step-change modal shift) to be calculated. The important point to appreciate is that modal shift (and consequent emissions reductions) can only be achieved where new capacity is created; and with HS2 neglecting so many interregional corridors, its potential is inevitably limited.

HS2 achieves an Interconurbation Emissions Score of 163, while High Speed North achieves the maximum 224. On tis measure alone, HS2's potential to reduce CO_2 emissions is only 73% of that of High Speed North.

The comparisons are summarised in Figure 4.4.

HS2	Category	HSN
76	Interconurbation Connectivity Score	127
60	Percentage of Feasible Total	100
163	Interconurbation Emissions Score	224
73	Percentage of Feasible Total	100



InterConurbation Linkage Matrix (HS2)

City	Gl	Ed	Ne	Li	Ma	Ls	Sh	Ng	Bi	Lo
Gl										
Ed	N									
Ne	N	N								
Li	N	N	N							
Ma	Y	Y	N	Y						
Ls	N	N	N	N	N					
Sh	N	N	N	N	N	N				
Ng	N	N	N	N	N	N	N			
Bi	Y	Y	Y	N	Y	Y	Y	Y		
Lo	Y	Y	Y	Y	Y	Y	Y	Y	Y	

InterConurbation Linkage Matrix (HSN)

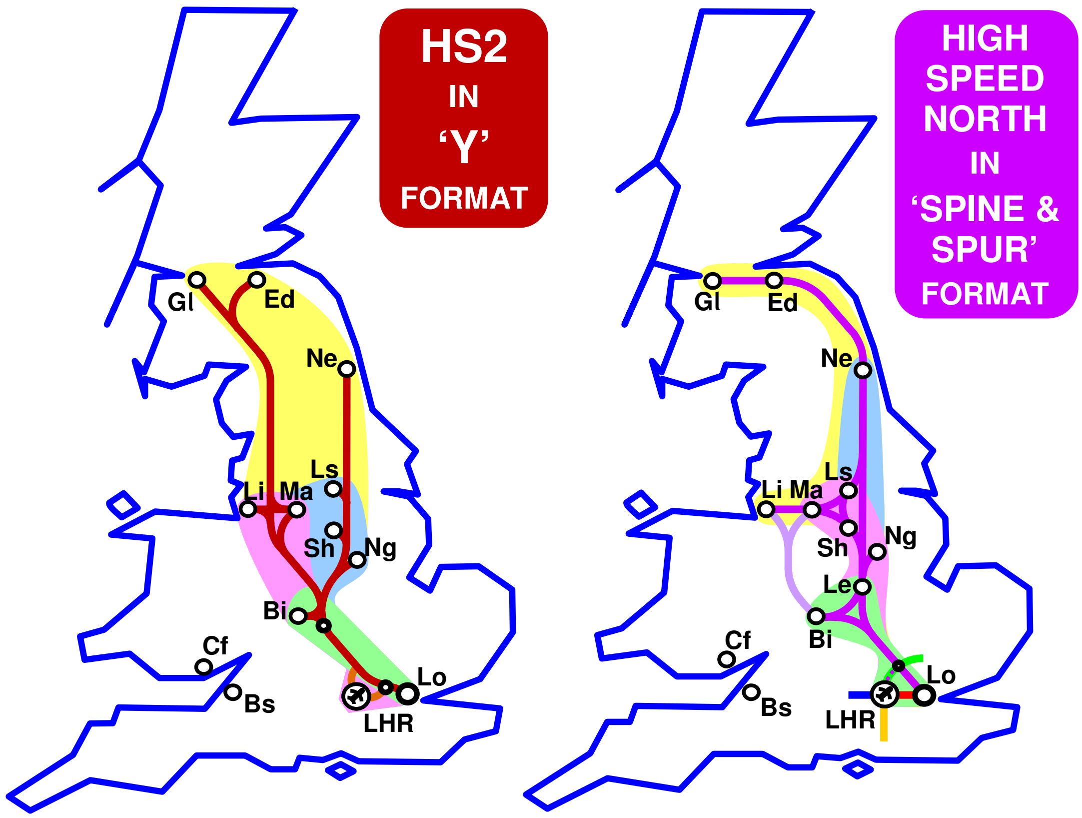
City	Gl	Ed	Ne	Li	Ma	Ls	Sh	Ng	Bi	Lo
Gl										
Ed	Y									
Ne	Y	Y								
Li	Y	Y	Y							
Ma	Y	Y	Y	Y						
Ls	Y	Y	Y	Y	Y					
Sh	Y	Y	Y	Y	Y	Y				
Ng	Y	Y	Y	Y	Y	Y	Y			
Bi	Y	Y	Y	Y	Y	Y	Y	Y		
Lo	Y	Y	Y	Y	Y	Y	Y	Y	Y	

Fig 4.4: Comparison of Connectivity and Emissions Reduction Potential

4.7 Timescale for Completion of National System
(Ref Appendix Q7)

The emissions reduction potential of any new high speed rail system will be maximised through earliest practicable completion. This would appear to demand that routes are chosen that avoid sensitive areas (such as the Chilterns) and instead follow established transportation corridors (such as the M1) along which much reduced environmental impact, and hence public opposition and delay.

The projected timescale for HS2 in Figure 4.5 below is based upon the Government's own projections for initial phases, and some reasonable extrapolations to completion.



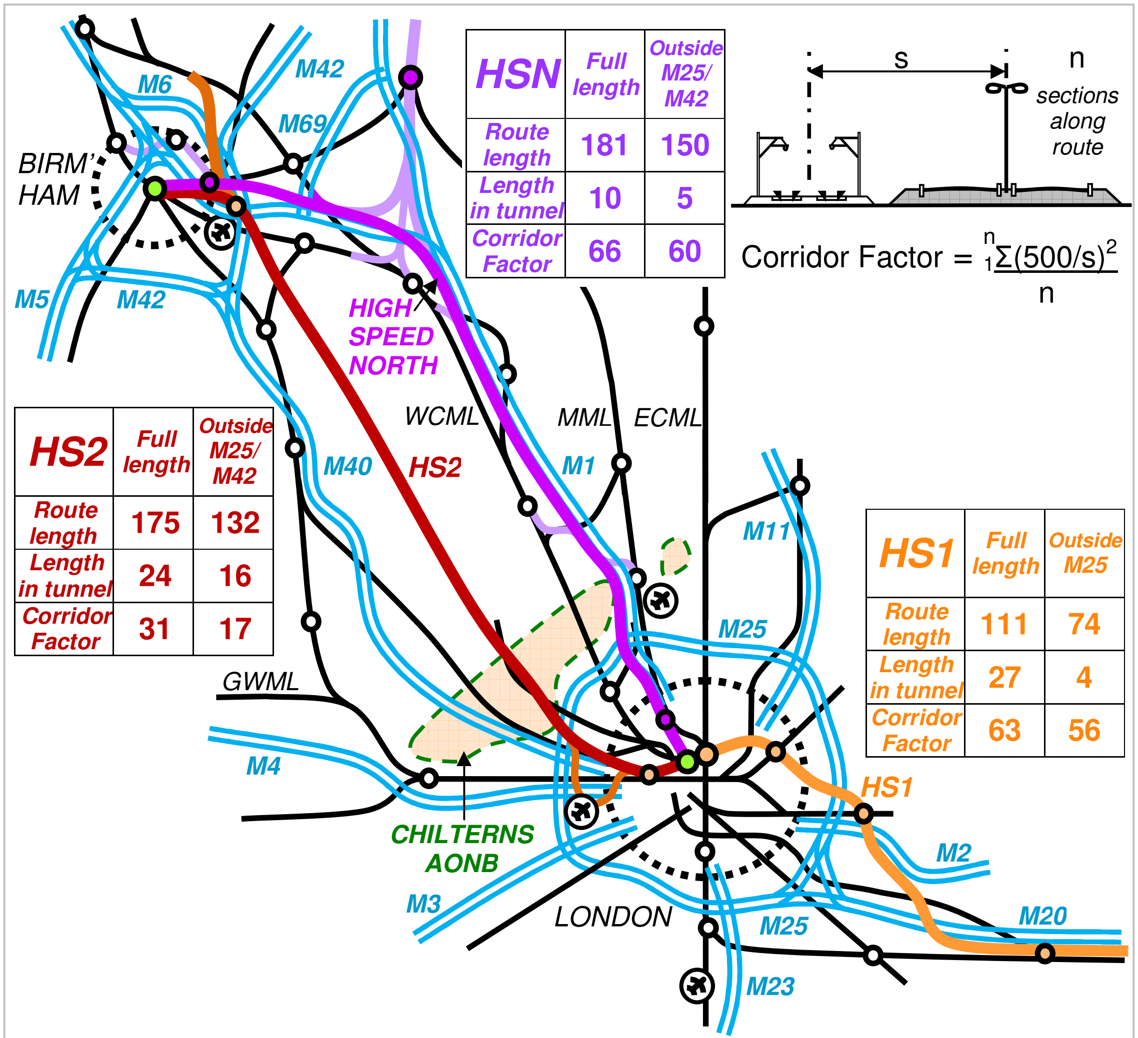
HS2			Stage	High Speed North		
Date	Emissions score	%age total		%age total	Emissions score	Date
2025	49	0.22	1	0.27	60	2017
2028	69	0.31	2	0.63	141	2021
2031	129	0.57	3	0.79	177	2025
2041	163	0.73	4	1.00	224	2031

Fig 4.5: Projected Staged Timescales to Completion

Although some of HS2's slow timescale (the 19th Century London & Birmingham Railway was completed far faster, using picks and shovels) might be attributed to 'business as usual' financial pressures, it is plain that much of the delay is due to an expectation of planning delays due to protracted public inquiries and other legal processes.   Most of these issues will be avoided along the much less controversial M1 corridor, and a much faster 'Alaska Highway' implementation (ie rapid construction to attain vital strategic goal) is feasible for High Speed North.

It is useful to quantify the mitigation that adherence to existing transportation corridors might offer.   The concept of 'Corridor Factor' is set out in Figure 4.6 below (and is explained in greater detail in Appendix D5).   Under this methodology, the entire route lengths of the London to West Midlands sections of both HS2 and High Speed North are examined, and offset dimensions to adjacent motorways (or dual carriageways or railways) are measured; the greater the proximity, the greater the benefit adduced.   As a control, HS1 is also assessed.

The comparisons below show that HS2 will generate very little mitigation, while High Speed North is approximately on a par with the best practice established by HS1.



HSN	Full length	Outside M25/ M42
Route length	181	150
Length in tunnel	10	5
Corridor Factor	66	60

HS2	Full length	Outside M25/ M42
Route length	175	132
Length in tunnel	24	16
Corridor Factor	31	17

HS1	Full length	Outside M25
Route length	111	74
Length in tunnel	27	4
Corridor Factor	63	56

$$\text{Corridor Factor} = \frac{\sum_{1}^{n}(500/s)^2}{n}$$

Fig 4.6: High Speed Rail proposals : Calculation of Corridor Factor

4.8 Wider Integration Issues
(Ref Appendix Q8)

All calculations of CO_2 emissions so far undertaken focus only upon those which occur due to traffic flows between conurbations; these have not yet been related to the total quantum of UK transport CO_2 emissions.

Such a correlation can be established without great difficulty, owing to the distance-independent relationship (set out in Item 4.5.2) between CO_2 and connected populations. On this basis, it is possible to identify the emissions attributable to:

- journeys between conurbations (23.3M of total 40M Green Zone population),
- journeys involving 'second tier' communities (a further 5M),
- journeys across the entire Green Zone.

The relative magnitudes of the above categories are set out in Figure 4.7.

It can be appreciated that the emissions reduction potential of a high speed rail system, linking only the principal conurbations within the Green Zone, is limited. These communities only represent around 58% of the total population, and their travel interaction (from which the CO_2 emissions arise) comprises only 28% of the total. This is the proportion of total emissions (within the Green Zone) that could be converted to lower-emitting rail.

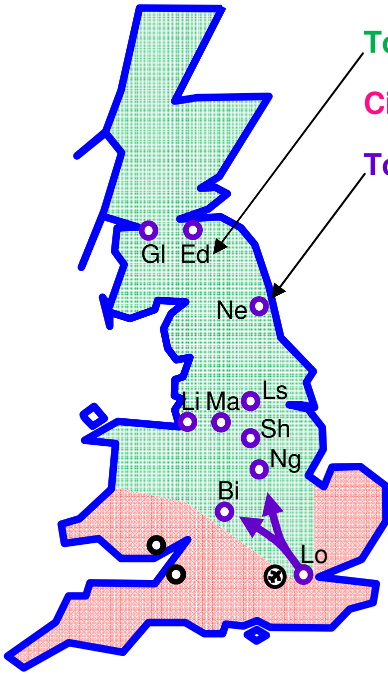
With due allowance for the localising effect of commuting, it is assumed that a high speed rail system providing complete interconnection between conurbations would allow conversion of 23% of current emissions.

But if the reach of high speed rail can be extended to the second tier communities – for instance Luton, Milton Keynes, Leicester and Coventry along the M1/M6 corridor, all easily accessible from an M1-aligned route – then the potential for CO_2 reductions greatly increases. With over 70% of the Green Zone population now encompassed within the scope of the high speed rail solution, journeys between these centres now account for 44% of the total emissions.

With due allowance made for the incomplete connectivity that even the ideal high speed route might bring to the secondary communities (additional to the effect of commuting), it is assumed that an optimally integrated high speed line proposal might allow conversion of up to 33% of total CO_2. This is the judgement that has been applied to High Speed North.

For HS2, the reverse effect applies. Not only does it fail to integrate with the second tier centres (which it tends instead to blight through its segregation from the classic railway), it also shows poor integration within the conurbations that it is intended to serve. A prime example of this is the HS2 proposed Fazeley Street terminal in Birmingham, separated from the principal hub of the West Midlands network at New Street Station. There are also major concerns in this respect with HS2's hybrid London terminal strategy, with Old Oak Common and an unimproved Euston Station offering far fewer connections than might be achieved with Euston Station alone, well connected to the surrounding local Tube and local rail (ie CrossRail and Thameslink) networks.

For this reason, the conversion level of HS2 has been downgraded from 23% to 18%.



Calculation of convertible CO_2 via HSL to North			
Green Zone population product	$(P_{GZ})^2$	a	1600
Conurbation population product	$(\Sigma P_c)^2$	b	543
Internal conurbation population product	$\Sigma(P_c)^2$	c	94
Inter-conurbation population product	(b–c)	d	449
Percentage convertible emissions *through total conurbation connectivity*	d/a		28%
Conurbation & city population product	$(\Sigma P_{cc})^2$	e	784
Internal conurbation population product	$\Sigma(P_c)^2$	c	94
Inter-conurb & city population product	(e–c)	f	690
Percentage convertible emissions *through total conurbation/city connectivity*	f/a		43%

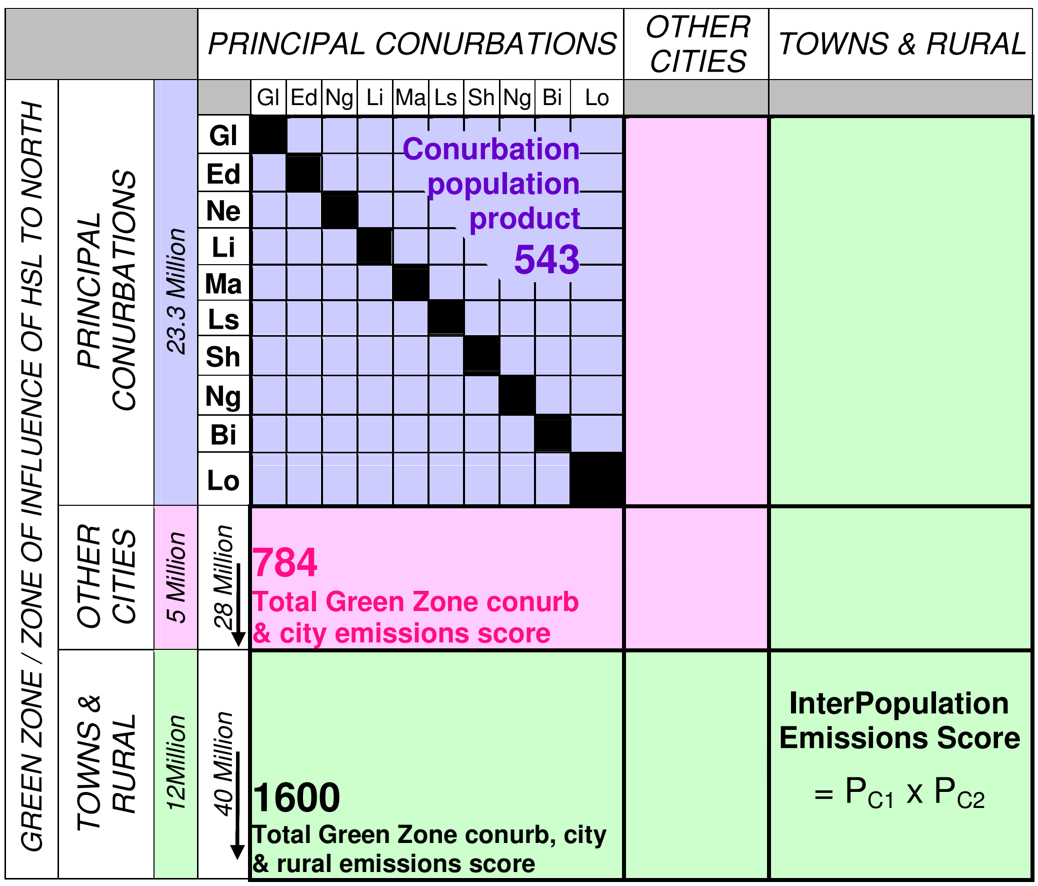


Fig 4.7: InterPopulation Emissions Matrix

4.9 CO_2 Value of Modal Shift
(Ref Appendix Q9)

The foregoing sections (4.6 – 4.8) have identified the quantum of Green Zone CO_2 emissions that might be convertible to lower-emitting rail transport. But to maximise achieved emissions reductions, it is vital that when a journey is converted from road or air, the equivalent rail journey is accomplished at minimised CO_2 emissions.

There are two principal drivers in the optimisation of rail emissions:

- ***Speed*** – energy use, and hence rises proportional to the square of speed.
- ***Load factor*** – high speed rail will deliver best environmental performance with maximised seat occupancy.

The environmental performance indicator (EPI) for high speed rail – derived from RSSB data, and baselined upon a specified speed and load factor – can be modified to reflect different speeds, and higher load factors more appropriate to contemporary environmental concerns. See Figure 4.8 below.

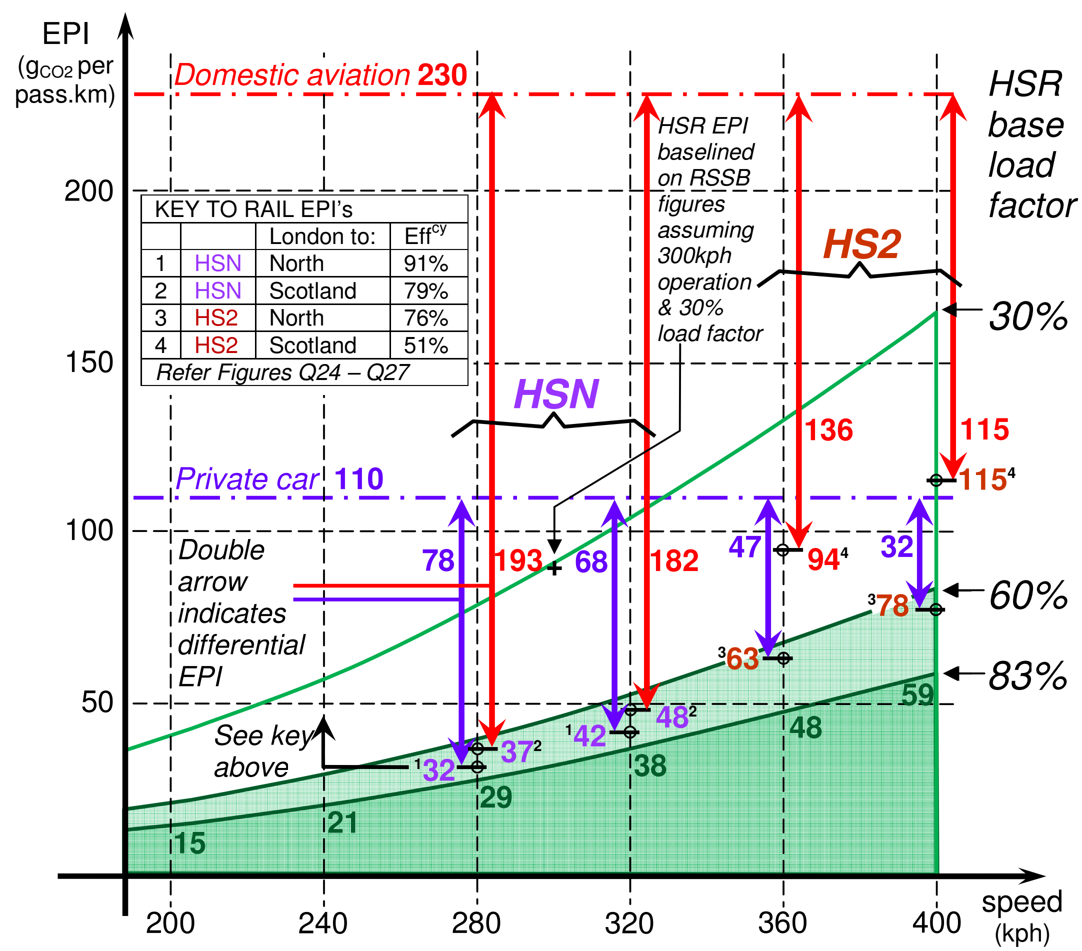


Fig 4.8: Differential EPIs between private car, domestic aviation and HSR, for varying rail speeds

Load factors for various specific route combinations:

- London to Scotland
- London to North of England
- ‘CrossCountry’ northward from Birmingham

are assessed for the different network configurations of HS2 and High Speed North.

It can be seen from Figure 4.9 that concentration of services upon a core route – as is possible with a ‘spine and spur’ network – can deliver significantly higher load factors, as well as interregional links, greater frequencies and lesser line occupancy of critical sections of route. See Figures Q24 – Q29. These higher load factors – expressed as Relative Operational Efficiency – result in improved environmental performance of High Speed North relative to HS2.

Notional consideration is also given to the conversion of freight flows through the provision of enhanced capacity through high speed rail.

Overall, it is assessed that HS2 might enable a typical converted journey to be accomplished at 50% of current CO_2 emissions; but that High Speed North, through its greater route efficiency and lesser ambition for operating at extreme speeds, would enable the same journey at 29% of current CO_2 levels.

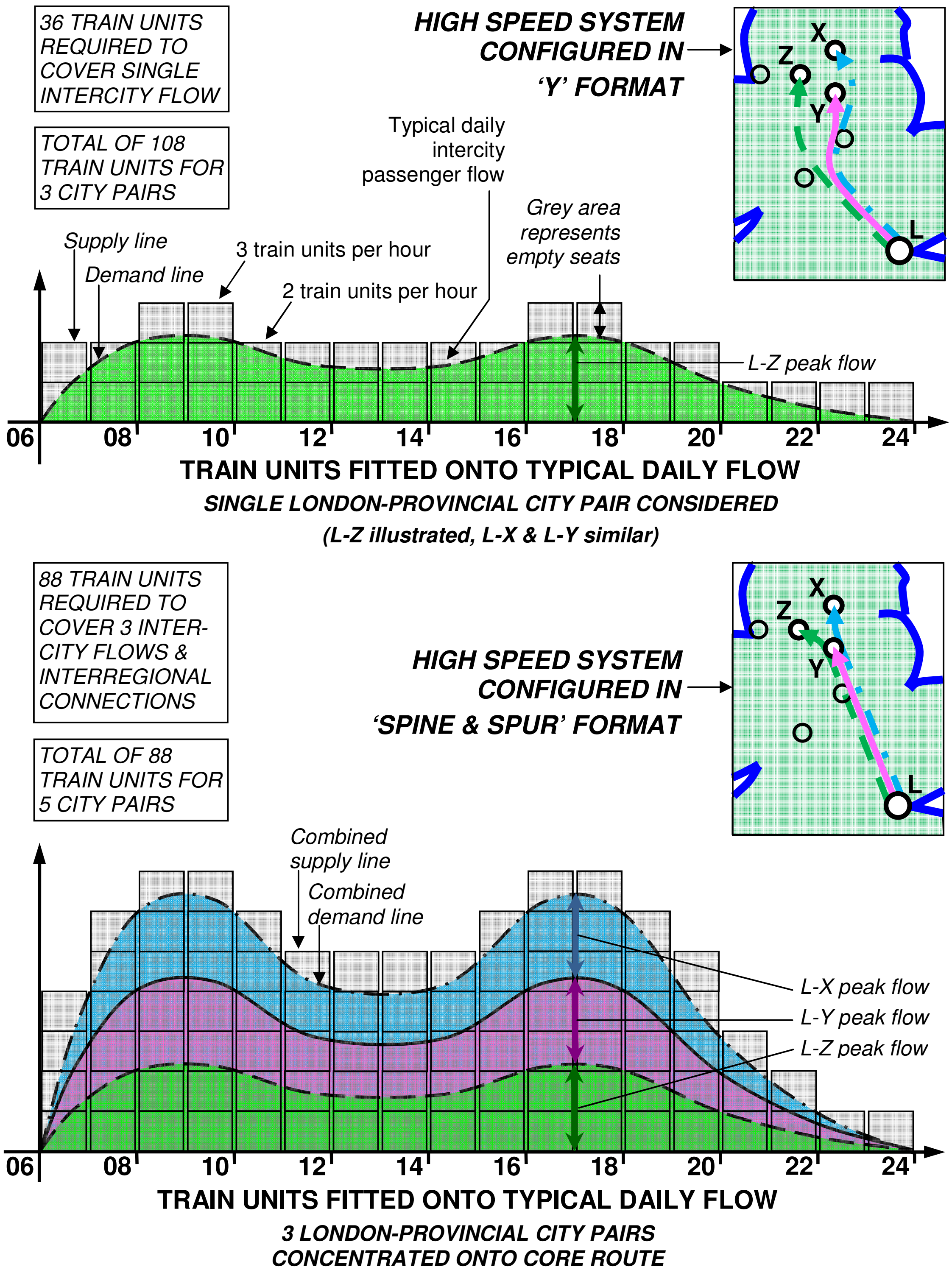


Fig 4.9: Greater Operational Efficiency from Concentration of Services onto Core Route

4.10 Summated Comparisons of Environmental Performance

With issues of network coverage, pace of implementation, integration with existing network and operational efficiency all considered, the final step is to calculate the total reduction in operational CO_2 emissions, accruing over a 40 year period, that will be brought about by the implementation of the candidate schemes. This is presented as a tabular calculation, with transport emissions within the targeted sector ie those deemed convertible for rail within the geographical scope of a northern high speed line calculated for each year until 2050. By aggregating these reduced emissions, and comparing with an aggregated baseline figure, the quantum of reductions can be deduced.

The mechanisms of the calculation are presented in Table 4.10, and are quantified in Table 4.11, with the reduced emissions aggregated over the 40 year period to 2050.

HS2 shows overall CO_2 emissions reductions of 107MT, and an annualised reduction of 5.5MT per annum. High Speed North shows overall CO_2 emissions reductions of 593MT, and an annualised reduction of 23.8MT per annum. The HS2 figure is certainly better than the most optimistic predictions of the Government, but it is overshadowed by the hugely superior performance of High Speed North.

The comparisons are depicted in Figure 5.1, with savings in CO_2 emissions itemised for the various contributory factors ie

- Network coverage optimised for maximum modal shift,
- Quickest Timescale to Completion,
- Greater Operational Efficiency : Speed,
- Greater Operational Efficiency : Load Factor,
- Maximised integration between classic & high speed network,
- Superior Heathrow access,
- Carbon Footprint of Infrastructure.

It will be noted that the calculation of 'operational' emissions savings (ie due to Coverage, Timescale, Speed, Load Factor and Integration) is cumulative and co-dependent. The contribution of each factor can only be defined by 'normalising' all others; this leaves the sum of each factor's contribution greater than the total calculated saving. A logarithmic regression is then applied, to reproportion the individual savings to give an accurate summation.

The figures for carbon footprint of infrastructure and Heathrow access are as set out in Table 4.12 (Section 4.11), and in Figures 4.13 and 4.14 (Section 4.12).

It is useful to contextualise High Speed North's potential for CO_2 emissions reductions against the requirements of the 2008 Climate Change Act. To reduce the UK's overall CO_2 emissions (of 550MT per annum) to 20% of contemporary levels requires a cut of 440MT. It would be idle to pretend that high speed rail is the answer to all the UK's CO_2 emission problems, even within the field of transport. But if executed properly, it would make a worthwhile contribution, and with another 18 projects of similar magnitude across the whole of range of the economic and social life of UK plc, the challenge would be met.

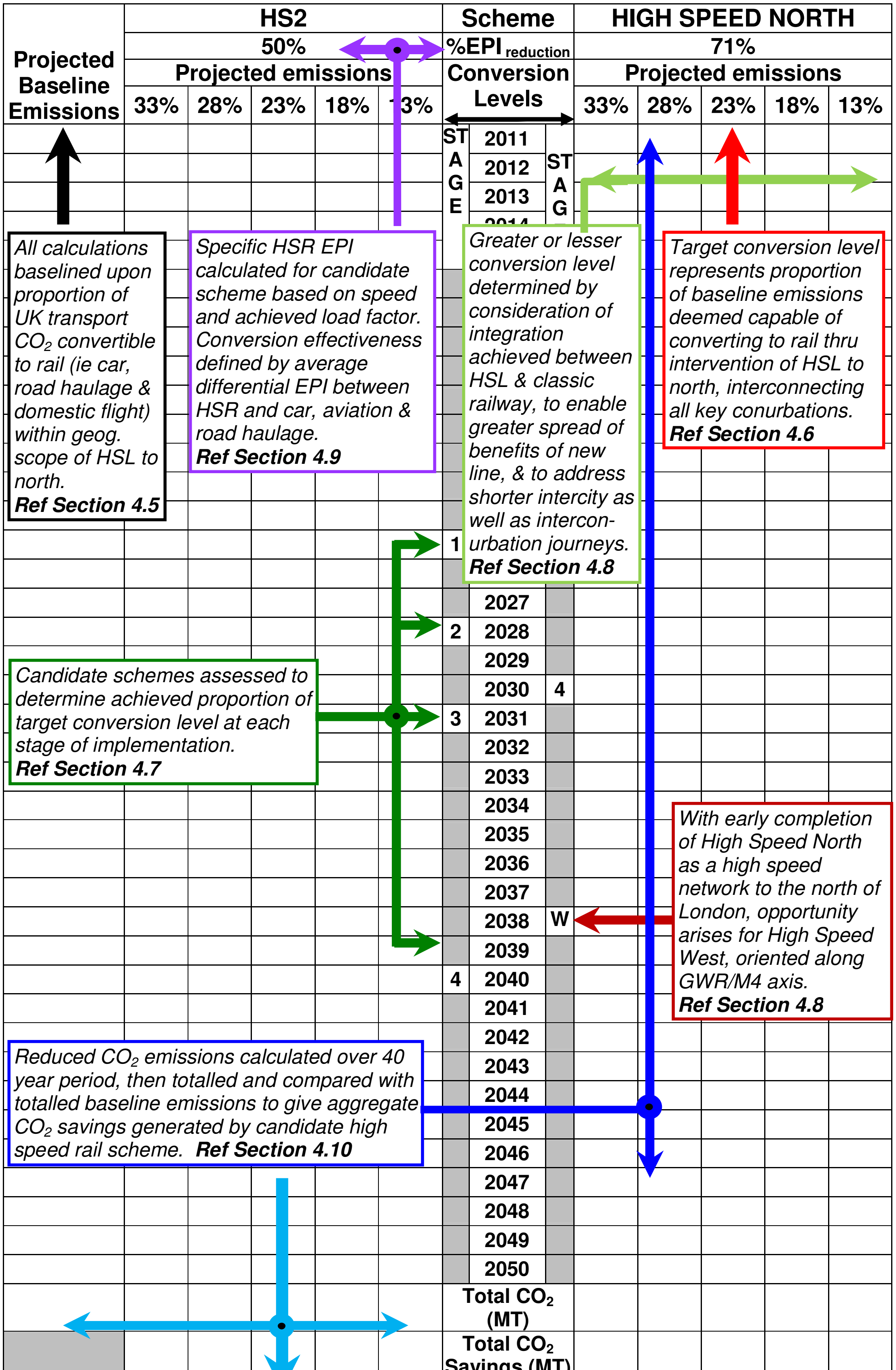


Table 4.10 Key Diagram illustrating Methodology for calculating CO_2 reductions

Projected Baseline Emissions (MT pa)	HIGH SPEED TWO					Scheme			HIGH SPEED NORTH				
	0.50					Proportionate EPI_{diff}			0.71				
	Projected emissions					Conversion Levels			Projected emissions				
	33%	28%	23%	18%	13%				33%	28%	23%	18%	13%
84.9	84.9	84.9	84.9	84.9	84.9	S	2011	S	84.9	84.9	84.9	84.9	84.9
84.9	84.9	84.9	84.9	84.9	84.9	T	2012	T	84.9	84.9	84.9	84.9	84.9
84.9	84.9	84.9	84.9	84.9	84.9	A	2013	A	84.9	84.9	84.9	84.9	84.9
84.9	84.9	84.9	84.9	84.9	84.9	G	2014	G	84.9	84.9	84.9	84.9	84.9
84.9	84.9	84.9	84.9	84.9	84.9	E	2015	E	84.9	84.9	84.9	84.9	84.9
84.9	84.9	84.9	84.9	84.9	84.9		2016		84.9	84.9	84.9	84.9	84.9
84.9	84.9	84.9	84.9	84.9	84.9		2017	1	84.9	84.9	84.9	84.9	84.9
84.9	84.9	84.9	84.9	84.9	84.9		2018		79.6	80.4	81.2	82.0	82.8
84.9	84.9	84.9	84.9	84.9	84.9		2019		79.6	80.4	81.2	82.0	82.8
84.9	84.9	84.9	84.9	84.9	84.9		2020		79.6	80.4	81.2	82.0	82.8
84.9	84.9	84.9	84.9	84.9	84.9		2021	2	79.6	80.4	81.2	82.0	82.8
84.9	84.9	84.9	84.9	84.9	84.9		2022		72.4	74.3	76.2	78.1	80.0
84.9	84.9	84.9	84.9	84.9	84.9		2023		72.4	74.3	76.2	78.1	80.0
84.9	84.9	84.9	84.9	84.9	84.9		2024		72.4	74.3	76.2	78.1	80.0
84.9	84.9	84.9	84.9	84.9	84.9	1	2025	3	72.4	74.3	76.2	78.1	80.0
84.9	81.8	82.3	82.8	83.2	83.7		2026		69.3	71.7	74.0	76.4	78.8
84.9	81.8	82.3	82.8	83.2	83.7		2027		69.3	71.7	74.0	76.4	78.8
84.9	81.8	82.3	82.8	83.2	83.7	2	2028		69.3	71.7	74.0	76.4	78.8
84.9	80.6	81.3	81.9	82.6	83.2		2029		69.3	71.7	74.0	76.4	78.8
84.9	80.6	81.3	81.9	82.6	83.2		2030	4	69.3	71.7	74.0	76.4	78.8
84.9	80.6	81.3	81.9	82.6	83.2	3	2031		65.1	68.1	71.1	74.1	77.1
84.9	76.9	78.1	79.3	80.5	81.8		2032		65.1	68.1	71.1	74.1	77.1
84.9	76.9	78.1	79.3	80.5	81.8		2033		65.1	68.1	71.1	74.1	77.1
84.9	76.9	78.1	79.3	80.5	81.8		2034		65.1	68.1	71.1	74.1	77.1
84.9	76.9	78.1	79.3	80.5	81.8		2035		65.1	68.1	71.1	74.1	77.1
84.9	76.9	78.1	79.3	80.5	81.8		2036		65.1	68.1	71.1	74.1	77.1
84.9	76.9	78.1	79.3	80.5	81.8		2037		65.1	68.1	71.1	74.1	77.1
84.9	76.9	78.1	79.3	80.5	81.8		2038	W	65.1	68.1	71.1	74.1	77.1
84.9	76.9	78.1	79.3	80.5	81.8		2039		61.1	64.7	68.3	71.9	75.5
84.9	76.9	78.1	79.3	80.5	81.8	4	2040		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2041		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2042		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2043		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2044		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2045		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2046		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2047		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2048		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2049		61.1	64.7	68.3	71.9	75.5
84.9	74.8	76.3	77.9	79.4	80.9		2050		61.1	64.7	68.3	71.9	75.5
3397	3201	3231	3260	3290	3320		Total CO_2 Emissions		2803	2893	2983	3073	3163
	195	166	136	107	77		Total CO_2 Savings (MT)		593	504	414	324	234

Table 4.11: Tabulation of CO_2 Savings over 40 Year Period of Climate Change Act

4.11 'Grey' Infrastructure CO_2 Emissions

Table 4.12 sets out a calculation to determine 'Infrastructure CO_2' for both HS2 and High Speed North. The following issues are taken into account:

- London-Leicester section of High Speed North assumed to comprise quadruple track; all length of HS2 is double track (notwithstanding capacity concerns).
- HS2 route length assessed for proportion of tunnel and viaduct; proportion of tunnel and viaduct applicable to High Speed North factored down by 1.40 (ie ratio of speed raised to 1.5 power).
- High Speed North assessed for lesser speed, with both topography equivalent to HS2, and with easier topography (as assessed from a provisional vertical alignment).

From the assessments in Appendix E, the following findings relate to likely CO_2 emissions resulting from the building of the new railway infrastructure. Given the uncertainties that are inherent in all the source data, and the assumptions that have had to be made particularly with regard to the construction process, the findings can only be regarded as highly approximate, in an absolute sense. But in a comparative sense, they are far more reliable, and would seem to indicate that High Speed North would incur considerably less 'grey' CO_2 emissions, than HS2 would.

Scheme	HS2	HSN (lesser speed)	HSN (easier topography)
Total length of new build (km)	1092	935	935
Length of quadruple track (km)	0	130	130
Design speed (kph)	400	320	320
Exponential on 400/320 speed	1.50		
Factor on tunnel/viaduct length	1.40 (= $(400/320)^{1.50}$)		
Proportion viaduct/tunnel	0.189	0.135	0.135
CO_2 per kilometre (T/km)	16900	16900	16900
Proportion earthworks	0.811	0.865	0.865
CO_2 per kilometre (T/km)	13100	9550	7700
Total Infrastructure CO_2	15.0MT	11.3MT	9.6MT

Table 4.12: Total Infrastructure CO_2 Emissions for UK High Speed Networks

This arises from 3 principal drivers: the shorter route length, the lower speed specification and the easier topography in which the line is constructed.

However, the most important conclusion concerns the relationship between infrastructure and operational CO_2 emissions. The former is measured in the tens of millions of tonnes (over a 40 year period); the latter is measured in hundreds of millions of tonnes. But most crucially, it must be recognised that operational emissions relate to issues of network coverage and operational efficiency, both of which are fundamentally linked (Sections 4.6 and 4.9) to the physical layout of the infrastructure. From this it might be concluded that the true priority in the issue of 'grey' CO_2 is not in fine-tuning the infrastructure to ensure that the least CO_2 is emitted in its construction – but instead, to ensure that the infrastructure is put in the best place, and in the correct configuration, to ensure the greatest coverage and operational efficiency, and the speediest practicable implementation.

4.12 CO_2 Emissions arising from High Speed Rail Access to Heathrow

Figures 4.13 and 4.14 present key statistics relating to the capabilities of HS2 and High Speed North, in improving Heathrow Airport's accessibility to the national rail network. These summarise the findings of Appendix F, to which reference should be made for greater detail. The diagrams illustrate four key comparators:

- Connectivity between the airport and regional destinations, considered in terms of both direct trains, and also a single change of trains.
- Numbers of travellers using 'high speed' services, or associated links to the national rail network, to access Heathrow.
- Marginal additional costs arising from meeting the aim of achieving high speed rail access to Heathrow, additional to the fundamental objective of an enhanced intercity/interconurbation railway.
- Potential CO_2 emissions reductions, arising from establishment of rail 'spokes' as the primary means of regional/national access to Heathrow, with conversion of existing air and road flows.

The above comparisons all demonstrate that High Speed North, with associated Compass Point network, comprises a vastly more effective means of distributing Heathrow's surface flows. This can be attributed to the fact that the primary means of distribution (ie the Compass Point network focussed upon Heathrow) is far better matched to the essentially 360-degree and disaggregated nature of an airport's surface access flow, than a uniaxial high speed railway (ie HS2) could possibly be. The Compass Point solution connects to far more communities, and demands the construction of far less dedicated infrastructure.

As can be appreciated from the comparisons in Figures 4.13 and 4.14, the more effective Heathrow access solution offered by the High Speed North proposals gives major environmental benefits, with a relative saving of 24MT of CO_2 over a 40 year period. Its far greater connectivity should also deliver corresponding economic benefits.

However, the greatest environmental influence of Heathrow lies in its capability to distract development of UK high speed rail from its primary purpose of providing new capacity for enhanced (and faster) interconurbation links. A somewhat politicised parallel agenda has been established, to achieve high speed rail access to Heathrow as an alternative to domestic flights. This will achieve finite environmental gains, of the order of 5MT of CO_2 over a 40 year period. But these gains are dwarfed by the many negative impacts of predicating the high speed line upon Heathrow:

- Delayed implementation through controversial Chiltern alignment.
- Poor coverage of resulting London-centric 'Y' network, offering no capacity enhancements along Transpennine and other interregional axes.
- Inefficient operation arising from adoption of 'Y', rather than 'spine and spur'.

Collectively, these drawbacks result in HS2's vastly suboptimal environmental performance, with attributable CO_2 emissions of the order of 330MT (or one third of a billion tonnes) higher than that of High Speed North, over the 40 year period of the 2008 Climate Change Act. It should also be noted that routeing the high speed line close to Heathrow adds in the region of £3 billion to local infrastructure costs, in addition to the £5 billion attributable to the extra route length of the 'Y'.

This would appear to indicate that the current predication of high speed rail development upon Heathrow is a somewhat ill-advised strategy.

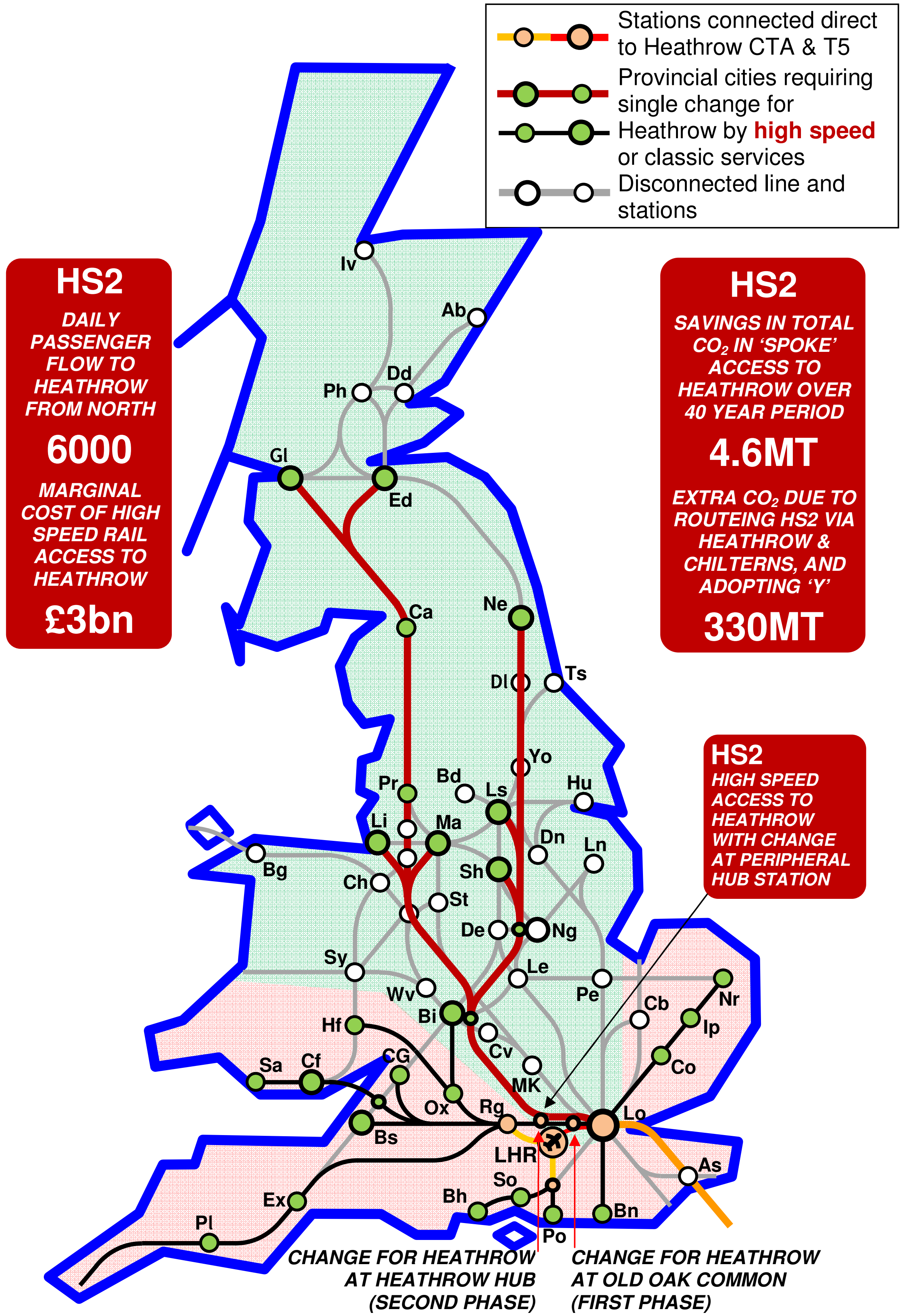


Fig 4.13: HS2 : Rail Connections to Heathrow & Spoke Access CO_2 Emissions

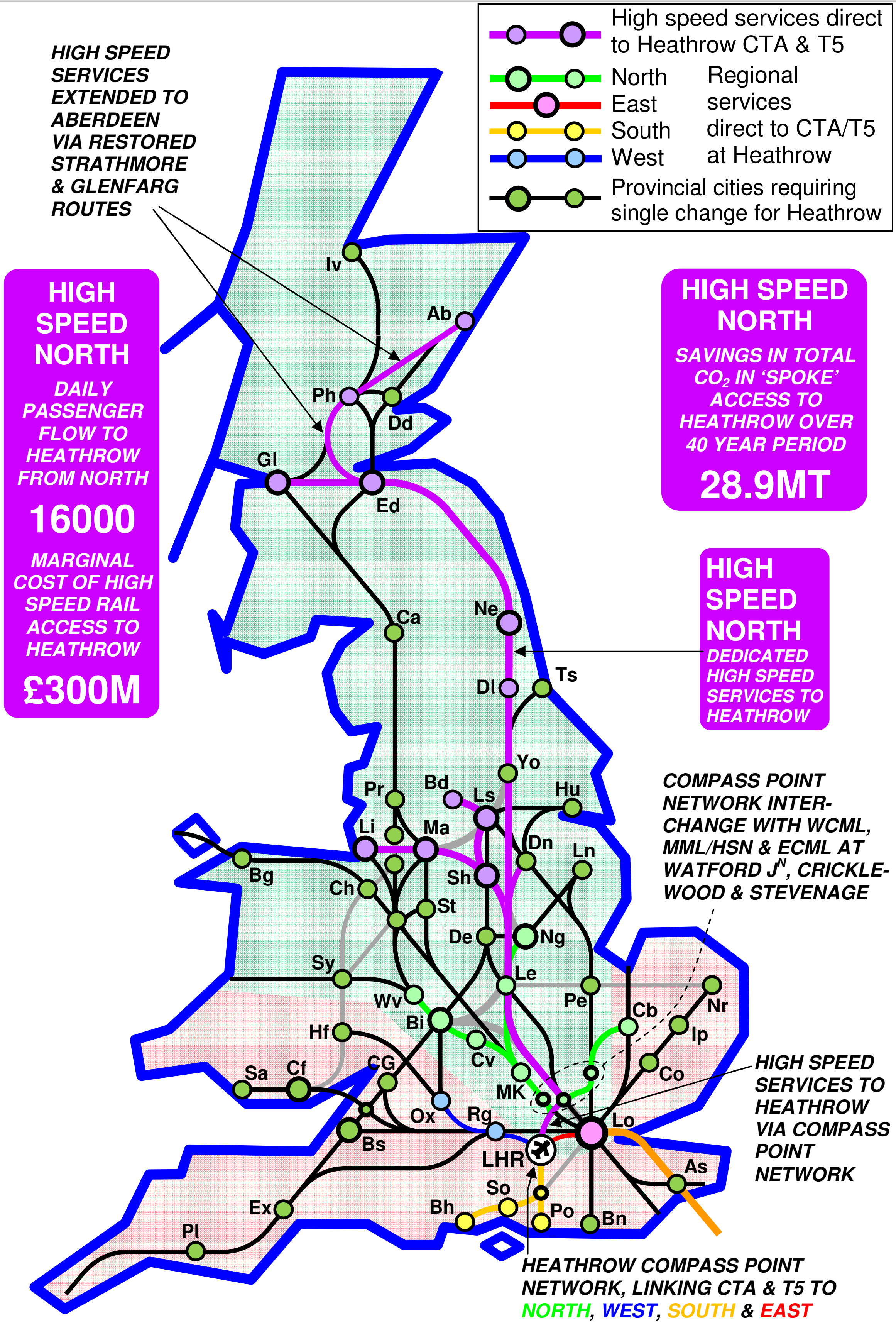


Fig 4.14: High Speed North : Rail Connections from Heathrow & Spoke Access CO_2

5. Conclusions

The primary purpose of this study is to establish the full potential of high speed rail as a vector to drive reductions in UK transport CO_2 emissions, at a scale compatible with the requirements of the 2008 Climate Change Act. This establishes four key strands, four central aims that must be addressed:

- to gain an understanding of the various factors that drive the 'carbon footprint' of high speed rail, and of their relative magnitudes;
- to realise the true potential of high speed rail (or simply 'new rail') to deliver step-change reductions in CO_2 emissions, in the context of current and growing environmental concerns;
- to develop a methodology for comparative assessment of potential modal shift, and consequent emissions reductions;
- to allow better-informed and more relevant choices to be made in the development of a UK high speed rail network.

5.1 Factors driving Carbon Footprint of High Speed Rail

The carbon footprint of high speed rail cannot be examined in isolation; instead, it is necessary to consider the overall effect that it will have in generating modal shift, and thus radically reducing the CO_2 emissions of the national transport system. This transformational capability is governed by four driving factors against which any proposal must be optimised:

- Optimised network coverage with comprehensive interconnection – *it is only possible to generate major modal shift along any particular intercity corridor if new capacity is provided along that corridor.*
- Pace of implementation – *environmental controversy through HS2's unnecessary Chiltern route will delay achievement of CO_2 reductions and damage the 'green' credentials of high speed rail.*
- Integration with the existing railway network and other transport systems – *to maximise CO_2 reductions, a single integrated and enhanced network is essential, accessible to as much of the UK population as practicable.*
- Maximised operational efficiency in respect of both speed and network configuration – *modal shift gives maximum CO_2 savings when rail's own carbon footprint is minimised*.

As can be seen from the comparisons in Figure 5.1, High Speed North's greater network coverage, adherence to existing transport corridors, superior integration and enhanced operational efficiency (through both avoidance of excessive speed and adoption of correct network configuration) enable it to vastly outperform HS2 on all of the listed criteria.

The 'grey' infrastructure CO_2 emissions attributable to the construction process have also been assessed. Notwithstanding the considerable uncertainties in the data for 'embodied' and 'construction' CO_2, it is still clear that these 'grey' emissions are of an order of magnitude lower than those arising from the operation of the network. But most of these 'operational' emissions are a direct consequence of network coverage, configuration, and routeing through sensitive areas – all infrastructure issues. Hence it can be concluded that true 'carbon-criticality' of railway infrastructure lies not just with economy of design, and use of recycled materials, but more importantly in ensuring that the infrastructure is put in the correct place. Optimisation of the entire system, to deliver maximum environmental (and economic) performance, is essential.

5.2 Potential of High Speed Rail to Deliver Cuts in CO_2 Emissions

This study has envisaged a quasi-wartime scenario, entirely consistent with the gravity of the anticipated climate change and energy supply crises, and with the requirements of the 2008 Climate Change Act, in which the attainment of step-change modal shift becomes a crucial element in the fight to reduce CO_2 emissions/ oil consumption. Under such conditions, the roads sector (accounting for over 90% of UK transport CO_2 emissions) would become the primary target, rather than domestic aviation. HS2 could then perform far better than the broadly 'carbon-neutral' (and aviation-targeted) outcome so far predicted, with around 100MT of CO_2 savings over 40 years. But the High Speed North proposals, optimised against the criteria set out in the previous paragraphs, would deliver savings of around 600MT.

Of all the criteria, efficient integration – as opposed to the HS2 philosophy of segregated operation – is the single factor that delivers the greatest potential emissions reductions. This raises issues of operational philosophy, in developing a model of 'high speed rail' between primary conurbations, that optimises environmental performance, and allows the benefits of the new railway to spread out to 'second tier' communities such as Milton Keynes, Coventry and Leicester.

For this, full integration between the existing intensively operated 'classic' network and the new high speed network seems essential, with stations spaced far closer than 'foreign' models of high speed rail might dictate. What is required is a bespoke and integrated model, tailored to the unique requirements of UK geography, demography and topography, and capable of delivering modal shift on journeys as short as 50km.

How much this constitutes high speed rail *per se* is debatable. Also debatable is the absolute value of speed. The findings of this study indicate consistently that capacity and connectivity, rather than speed, are the key drivers in optimising environmental performance. They would appear also to deliver good business performance.

5.3 Development of Assessment Methodology

This study has developed methodologies and metrics appropriate to the holistic assessment of the comparative environmental performance of major transport schemes. Its 'macro' approach, and use of generic data (for characteristic emissions data for various modes of travel, etc) mean that its results cannot be regarded as especially accurate, in absolute terms. But in a comparative sense, consistent application of the methodologies to the candidate schemes implies a far greater level of accuracy which for the first time allows rigorous evaluation of rival candidate proposals.

This study should be regarded as a 'work in progress', rather than definitive and finalised outcomes. As better data becomes available, the spreadsheet calculations that underpin this study should be updated to ensure even greater accuracy.

5.4 Choices to be Made

The massive disparities in emissions reduction potential between HS2 and High Speed North raise serious questions as to the methodologies by which major transport infrastructure schemes are developed. It seems vital that the 'business as usual' thinking that underpins the HS2 proposals must be swept aside, and more contemporary and appropriate methodologies adopted to address heightened environmental concerns, backed up by the legal requirements of the 2008 Climate Change Act.

5.5 Environmental vs Economic Considerations??

It must be emphasised that the superior environmental performance of High Speed North, consistently demonstrated throughout this study, does not exist in isolation. To calculate CO_2 emissions arising from the establishment and operation of railway infrastructure, it is necessary to make more conventional assessments of operational efficiency, of length of route to be constructed (from which cost might be inferred) and of traffic flow and communities connected (from which benefit might be inferred). On all these considerations, High Speed North appears vastly superior.

In terms of Benefit-Cost Ratio (the traditional metric by which infrastructure schemes stand or fall) High Speed North's lower cost (£34bn vs £39bn) and greater benefit (interconurbation connectivity score of 127 vs 76) indicates a BCR almost twice that of HS2. None of this should be surprising. Good environmental performance (in terms of either reduced CO_2 emissions or avoidance of negative landscape impacts) is generally synonymous with good engineering, and good economic performance.

5.6 Methodology Issues

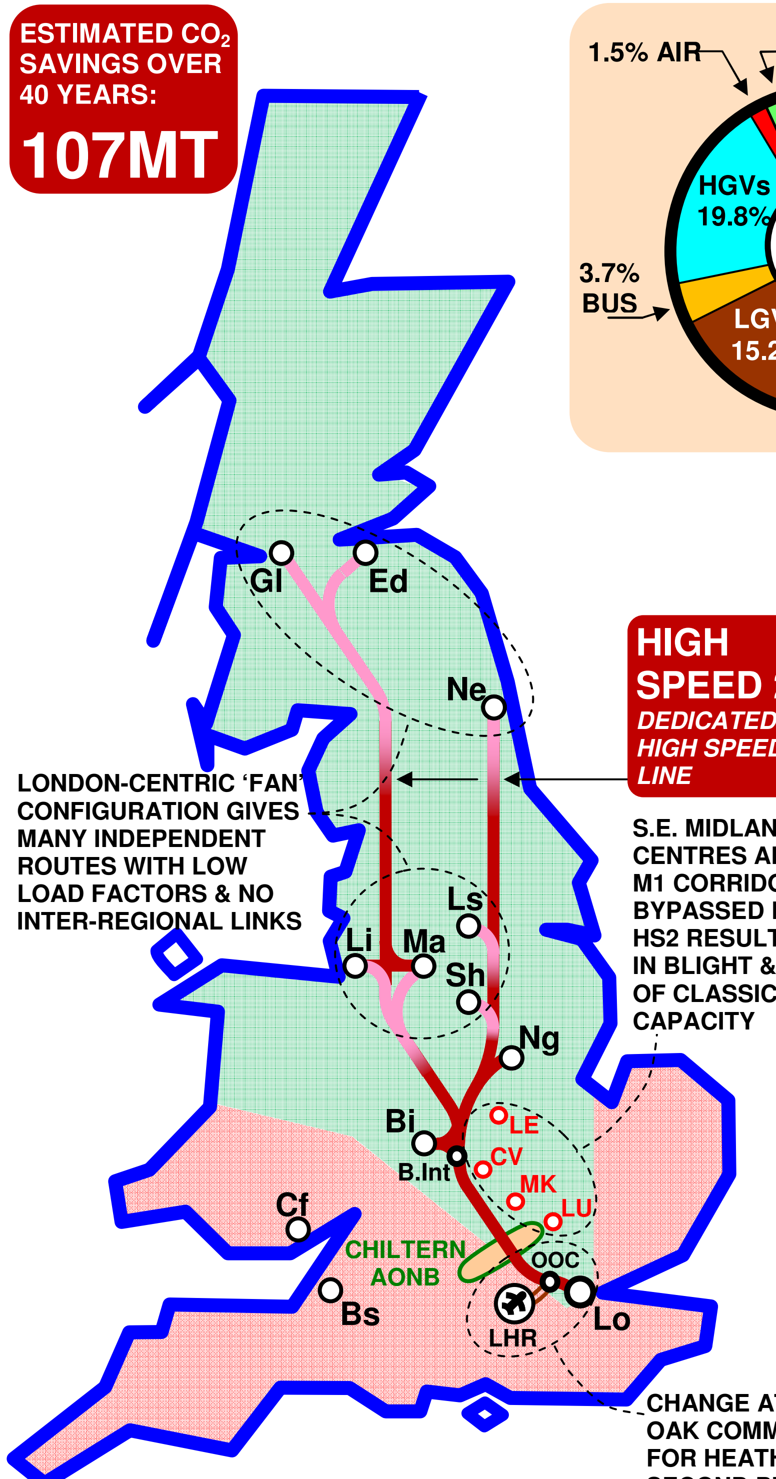
It is necessary to reflect upon how and why the High Speed North proposals appear to so comprehensively outperform those of HS2.

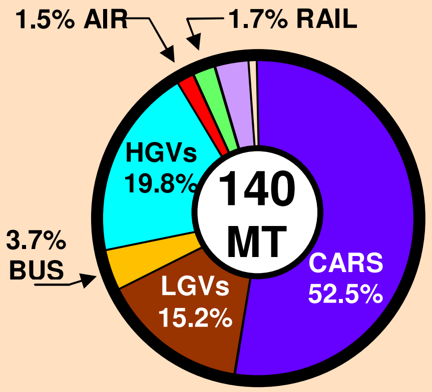
Part of the cause seems to lie with the restrictive remits to which railway schemes are traditionally developed. These tend to examine only the specific scheme under consideration, within the remitted corridor, and to treat all parallel proposals and existing operations as constants. This might be appropriate for a major bridge or station scheme; but for a new high speed line, comprising the most fundamental railway development for over a century, with ramifications spreading across the entire intensively operated UK rail network, the scope of the consideration must be similarly broad, and existing concepts challenged, to ensure an optimised outcome.

Another concern is that of professional discipline. So far, the development of high speed rail in the UK has been led by the transport planning profession, working to primarily economic criteria, and with engineering largely a support function. Under such an approach, national targets for CO_2 emissions reductions have been broadly neglected, journey time savings have become the key objective rather than capacity or connectivity, and the politicised requirement of achieving high speed rail access to Heathrow has been allowed to assume undue priority. HS2's focus upon Heathrow carries a massive – and so far unrecognised – additional cost, both financial (around £8 billion extra) and environmental (330MT of 500MT CO_2 differential between HS2 and High Speed North is attributable to the effects of routeing via Heathrow).

Such drawbacks have been avoided in the development of the High Speed North proposals. These take a more fundamental and holistic 'railway engineering' approach, considering the primary requirement for comprehensive connectivity and capacity enhancement on a UK-wide basis, to achieve the twin goals of reduced transport CO_2 emissions and superior economic performance. With regard to Heathrow, a more appropriate 'regional' solution is adopted, delivering more comprehensive access to the UK's national airport and allowing the high speed line to follow existing motorway corridors.

All the evidence indicates that the alternative 'railway engineering' approach of High Speed North delivers outcomes that are of an order of magnitude superior to those of HS2, and address contemporary environmental concerns. This raises a clear imperative in the development of high speed rail schemes, to adopt new and more appropriate methodologies.





89% of current UK transport CO_2 emissions (ie all roads except buses) and domestic aviation) are potentially convertible to rail. Green areas define Zone of Influence of northern high speed line, with 40M of 60M total UK population.

Target CO_2 emissions = 140MT x 89% x 40/60 = 85MTpa

UK HSR development should be configured to achieve greatest possible reduction below 85MT, through modal shift to lower emitting rail.

Major modal shift – compatible with radical requirements of 2008 Climate Change Act – will result in approximate fourfold increase in rail traffic. With all inter-conurbation rail corridors – along which HSR might be provided – already under significant capacity pressure, 2 new high speed tracks parallel to existing comprise best means of achieving required step-change in network capacity.

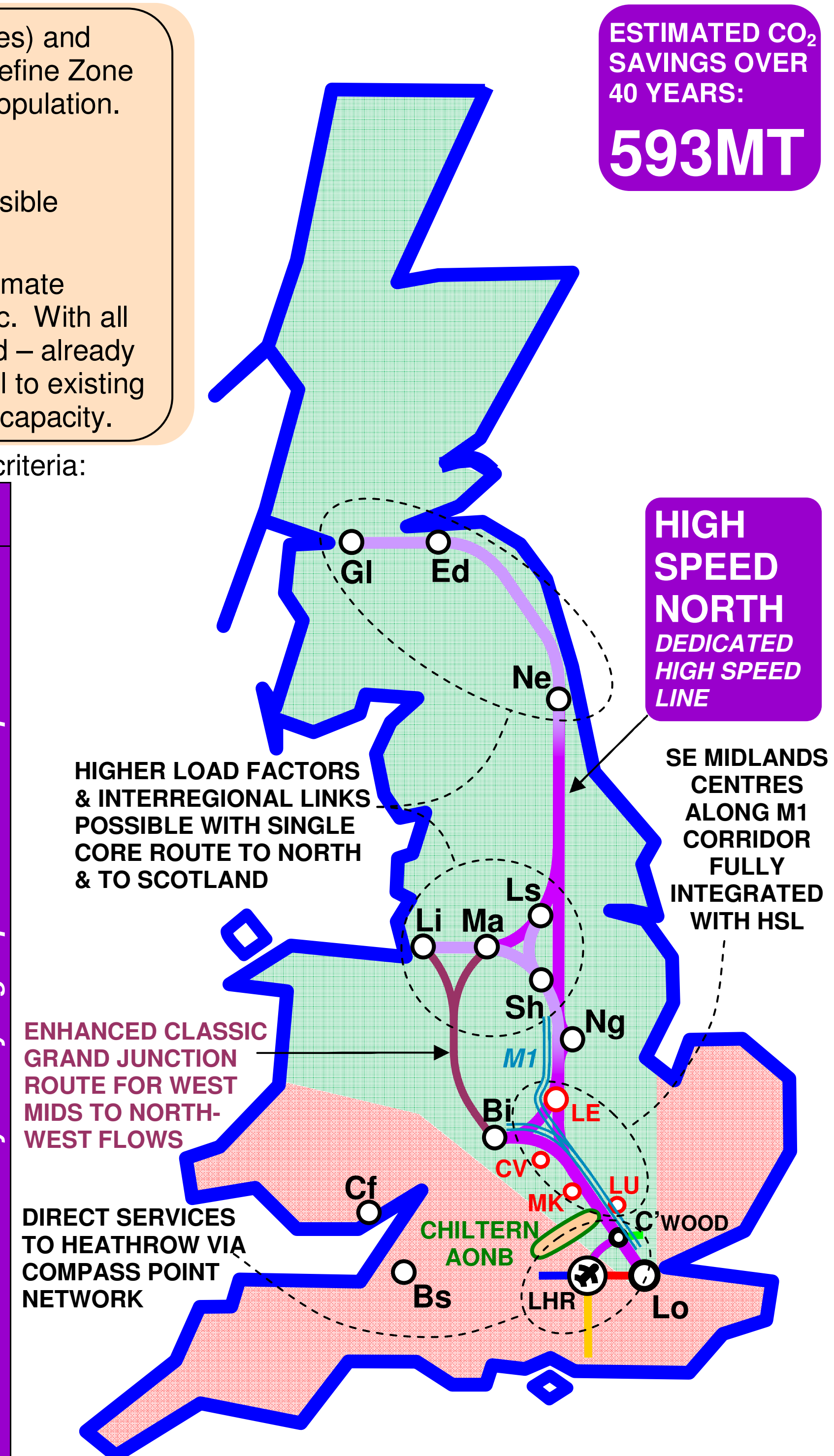
Maximised emissions reductions can be achieved through optimising the following criteria:

No / Ref	Criterion	High Speed 2	High Speed North	HSN CO_2 saving
1A / 4.6	Maximised modal shift between conurbations	Potential modal shift limited by London- & Birmingham-centric 'funnel' configuration with no connectivity on Transpennine axis and little overall between Northern and Scottish centres	Spine & spur configuration of HSN covers all existing main line axes incl. Transpennine and CrossCountry to enable full inter-connection between all Midlands, Northern & Scottish conurbations.	92 MT
2B / 4.7	Quickest Timescale to Completion	Network completion delayed by controversy of route via Chiltern AONB and through rural areas to north. Greater route length also takes longer to build.	Much lower environmental intrusion along M1 corridor & shorter total route length allows quicker completion at lesser cost	117 MT
3C / 4.9	Greater Operational Efficiency : Speed	360kph operating speed applied as standard across new-build sections of network, with no flexibility due to restricted 2-track route through Chilterns.	4-track London-Leicester section allows differential speeds: 240kph London to Midlands 280kph London to Scotland 320kph North to Scotland	47 MT
4D / 4.9	Greater Operational Efficiency : Load Factor	Configuration as London-centric fan limits load factor with relatively weak flows to individual destinations	Concentration of services onto strong core routes allows higher load factors & more viable services	52 MT
5E / 4.8	Maximised integration between classic & high speed network	Operation as 'exclusive' railway limits integration of HSR with both conurbations & secondary centres. Major risk of blight to bypassed communities eg Coventry, Leicester, MK & Luton.	Network fully integrated with existing intercity network to serve secondary centres. National connectivity much greater. Potential for modal shift & emissions reductions greatly increased	172 MT
6F / 4.11	Superior Heathrow access	No direct airport access so interlining flows still need domestic flights for long-haul connections	Efficient spine & spur configuration & allied Compass Point network allows direct services from all regions	24 MT
7G / 4.12	Carbon Footprint of Infrastructure	400kph design speed needs straighter alignments with higher embankments, longer tunnels and increased CO_2	Emissions reduced through: Shorter route length Lower 320kph design speed Lighter engineering	6 MT

Extra million tonnes of CO2 saved over 40 years by High Speed North compared with

HIGH SPEED 2	
Length of new build	1092km
Estimated cost	£39bn
Emissions saved (40 yrs)	$106MT_{CO2}$
InterConurb Emissions score	163 (73%)
InterConurb Connectivity	76 (60%)
Conurbation Pairs connected	19 (42%)

PERCENTAGES RELATE TO MAX POSSIBLE INTERCONURB CONNECTIVITY



HIGH SPEED NORTH	
Length of new build	935km
Estimated cost	£34bn
Emissions saved (40 yrs)	$593MT_{CO2}$
InterConurb Emissions score	224 (max)
InterConurb Connectivity	127 (max)
Conurbation Pairs connected	45 (max)

Fig 5.1: Summary of Comparisons between HS2 and High Speed North

Appendix Q : Quantified Comparisons

The following sections Q5 – Q9 enlarge upon the calculations set out in Sections 4.5 – 4.9.

Q5 Target CO_2 Emissions

The initial step is to identify the quantum of UK transport emissions that might be converted through the intervention of a northward-oriented high speed railway.

- *Figure Q1: Target CO_2 Emissions for high speed line to the North*

This defines transport emissions as a proportion of total UK emissions, and identifies the particular transport emissions ie domestic aviation and all roads emissions except for buses, which are capable of beneficial conversion to rail. This amounts to 128MT per annum.

The 'zone of influence' of a high speed line to the North is also considered. It seems reasonable to assume that high speed rail as an intervention will only achieve meaningful emissions reductions in the geographic area in which it is provided. The 128MT is accordingly scaled down, taking due account of the proportion of the population potentially served by the proposed high speed line[4].

A figure of 84.9MT of CO_2 per annum is calculated as the 'target emissions', the baseline from which reduced emissions will be calculated, with the progressive introduction of new sections of high speed line. This figure will also be used to project future emissions which would occur in the absence of high speed rail as a transport intervention.

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[4] It is acknowledged that the geographic 'split' of emissions into 'Green Zone' and 'Red Zone', proportioned according to population (as indicated in Figure Q1), is somewhat simplistic. There will be major 'crossover' between the two zones, and it is essential that (northern-oriented) high speed rail is developed so as to integrate these flows. See Item 4.5.3.

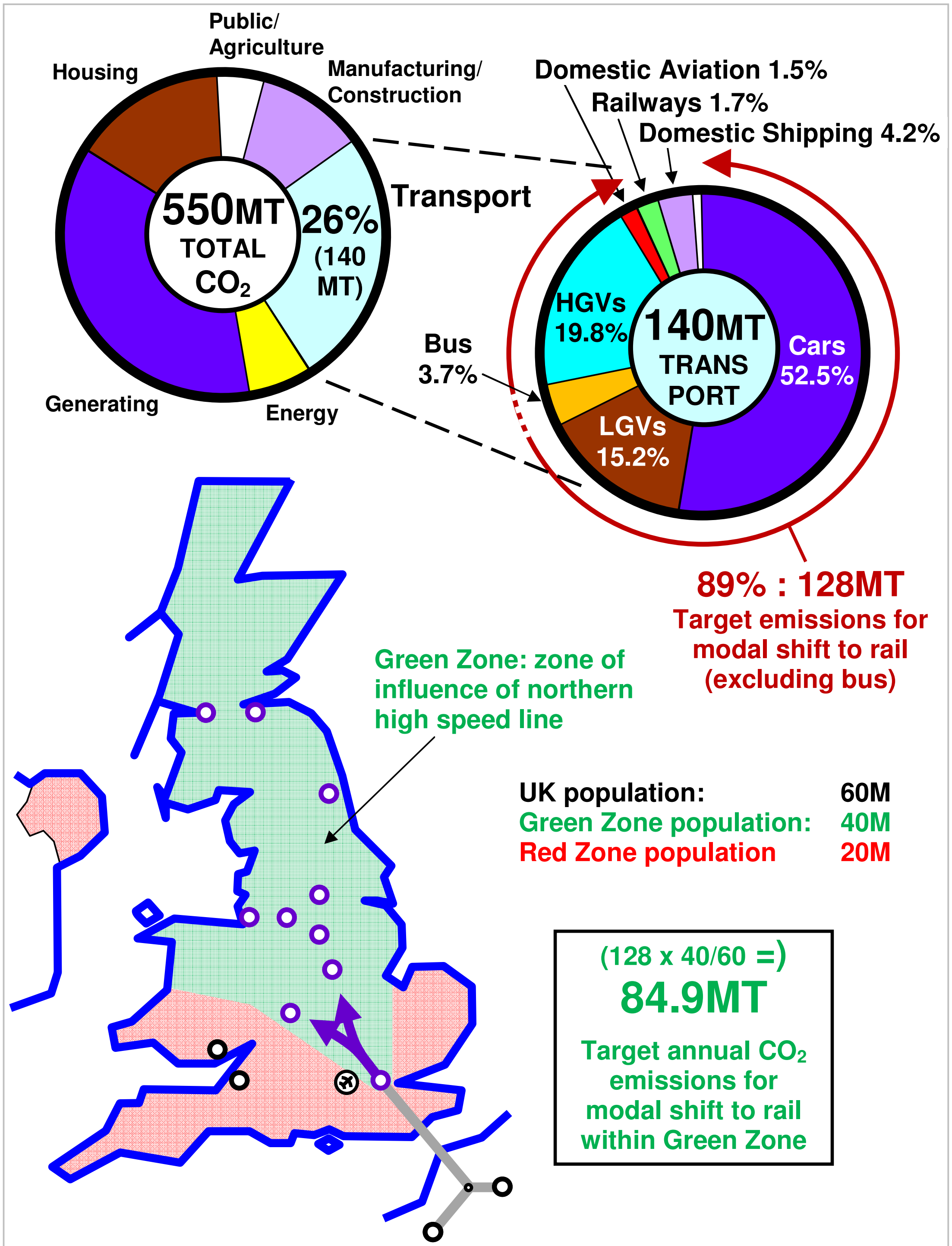


Fig Q1: 'Target' CO_2 emissions for high speed line to North

Q5.1 Calculation of Connectivity, Flow and Capacity Required

To make comparative calculations between the two candidate schemes, it is necessary to be able to assess relative traffic flows between the primary conurbations, that will be at the heart of the proposed high speed rail network. This will illustrate requirements for connectivity and capacity, on a nationwide basis.

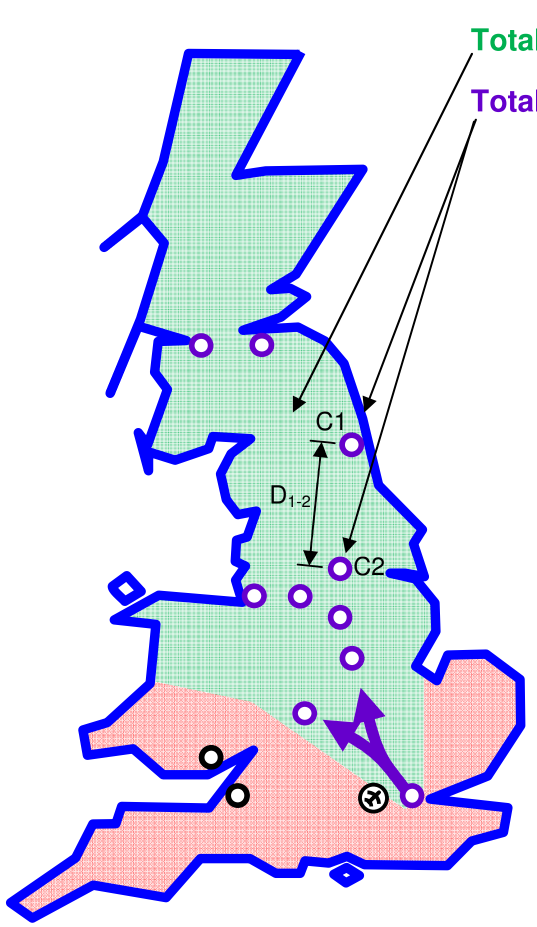
- *Fig Q2: InterConurbation Connectivity & Resulting Emissions*

A gravitational model has been adopted, whereby the traffic flow $F_{1\text{-}2}$ between two population centres C1 and C2 is defined as the product of the two populations P_{C1} and P_{C2}, divided by the intervening distance $D_{1\text{-}2}$.

$$F_{1\text{-}2} \propto \frac{P_{C1} \times P_{C1}}{D_{1\text{-}2}}$$

Total Green Zone population P_{GZ}: 40M

Total conurbation population ΣP_C: 23M



InterConurbation Connectivity

$$\propto \frac{P_{C1} \times P_{C2}}{(D_{1\text{-}2})^1}$$

Calculation of convertible CO_2 by means of northern HSL			
Green Zone population product	$(P_{GZ})^2$	a	1600
Conurbation population product	$(\Sigma P_c)^2$	b	543
Intraconurbation population product	$\Sigma(P_c)^2$	c	94
Interconurbation population product	(b – c)	d	449
Percentage convertible emissions	d/a		28%

InterConurbation Emissions

$$\propto P_{C1} \times P_{C2}$$

Fig Q2: InterConurbation Connectivity & Resulting Emissions

This is analogous to Newtonian gravity between two masses, but while gravitational force is proportional to the 'inverse square' of intervening distance (between the centroids of the masses) the distance relationship for traffic flow is taken to be 'inverse linear'. This stems from the principal deterrents to travel – cost and time – both being broadly proportional to distance. This appears to be a reasonable assumption across the principal population centres of mainland UK, where 'there and back in a day' journeys are possible, with the appropriate transport mode (car, train or plane) chosen.

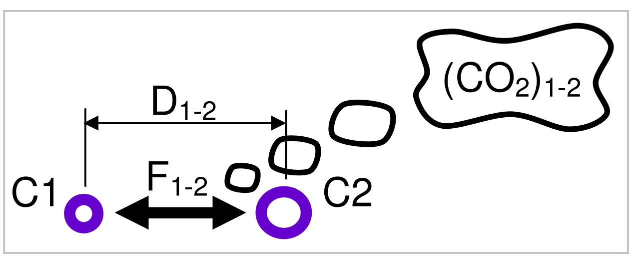
How much this is reflected in fact is debatable. The long-standing London-centric nature of the UK economy has tended to focus transport demand upon London and the South-East, and interregional flows will, in proportionate terms, be smaller. This is reflected both in the historic provision of connectivity (with the primary intercity rail network focussing upon London, and slower and lesser-quality links between the regions) and the difficulty in providing further capacity (a general problem in the 'hothouse' economy of the metropolitan area, which would seem to indicate a need to redress the balance with greater development in the regions).

These issues of connectivity and capacity are possibly the biggest factors that frustrate the agenda for equitable regional development, and a London-centric high speed rail network (as currently proposed) would seem to make matters worse. But if high speed rail can be configured to provide an equivalent standard of connectivity and capacity across all primary conurbations, it would appear to offer a massive opportunity to reinvigorate the regions.

Assuming a 'level playing field' in respect of fundamental connectivity, then the linear model of traffic flow would seem to be appropriate to describe interconurbation flows.

Q5.2 Translation of Flow into CO_2 Emissions

The foregoing commentary relates to the potential flows between conurbations, enabled by improved capacity and connectivity. The figures developed are not directly indicative of CO_2 emissions, or energy use. Energy use corresponds to the quantum of journeys, the product of flow and distance. So while flow F_{1-2}
between population centres C1 and C2 can be expressed as follows:



$$F_{1-2} \propto \frac{P_{C1} \times P_{C1}}{D_{1-2}}$$

an extra dimension of distance has to be factored into the calculation of CO_2 emissions, as follows:

$$(CO_2)_{1-2} \propto \frac{P_{C1} \times P_{C1}}{D_{1-2}} \times D_{1-2}$$

Simplifying $(CO_2)_{1-2} \propto P_{C1} \times P_{C1}$

The idea, that emissions are related to the populations connected, but independent of distance, at first appears highly counter-intuitive. But it is a logical consequence of the tendency for travel volumes to decrease with distance, while energy use increases with distance. An alternative way of looking at this possibly surprising proposition is offered by the 'Best Friends Forever' or 'BFF' analogy.

> Suppose you have a circle of friends, distributed near and far across the country. These are all your Best Friends Forever (BFFs) whom you love equally, and you wish to visit them as often as you can. But inevitably, with the cost and time taken in travelling, you end up visiting the BFFs who live closer more often than the ones who live further away.
>
> Looking back at your diaries over the space of several years, you discover that the number of visits that you paid to each BFF was in inverse proportion to the distance at which that BFF lived; but that with carbon footprint naturally increasing with increasing distance, your frequent trips, each with low CO_2 emissions to your (geographically) closer BFFs, had the same total carbon footprint as your less frequent trips, each with higher CO_2 emissions to your more distant BFFs.

The above example (with due apologies for possible trivialisation of the fundamental human need to travel) illustrates how distance appears to be largely immaterial in the production of CO_2. In the case cited, with the same individual bond of friendship (equating to the 'gravitational' constant) between BFFs, travel CO_2 between pairs of friends is constant. Scaling up to the case in point, that of transport emissions between UK conurbations, friendship is replaced by the more macroscopic attraction that exists between communities, for trade, for work and for leisure. Here again, the flow between individuals is a constant, at least on a statistical level, and irrespective of distance; the only variables are the magnitudes of the two populations linked.

The independence of emissions from distance allows the CO_2 emissions attributable to travel between conurbations – essentially, the 'core business' of a high speed line – to be deduced as a proportion of the transport CO_2 of the entire geographical region which the high speed line is intended to serve.

Population of the Zone of Influence of a northern high speed line (aka the Green Zone) is 40 million, and its transport emissions are the result of the sum of each individual's interaction with the other 39,999,999[5] inhabitants of the Midlands, North Wales, the North and Scotland. Discounting the extra noughts of the millions, the total emissions attributable to the Green Zone can be calculated as follows:

$$(CO_2)_{GZ} \propto (P_{GZ})^2 = 40^2 = 1600$$

Considering flows between the total 23.3 million population of the 9 Green Zone conurbations plus London, 'conurbation' emissions can be calculated as follows:

$$(CO_2)_{CONURB} \propto (\Sigma P_C)^2 = 23.3^2 = 543$$

[5] Spurious accuracy acknowledged. But hopefully, the point is made.

This figure includes emissions arising from travel within individual conurbations, as well as between them. 'Intraconurbation' emissions equate to the sum of the squares of all individual conurbation populations.

$$(CO_2)_{C\text{-}INTRA} \propto \Sigma (P_C)^2 = 94$$

This then allows the level of interconurbation emissions to be calculated as follows:

$$(CO_2)_{C\text{-}INTER} \propto (\Sigma P_C)^2 - \Sigma (P_C)^2 = 543 - 94 = 449$$

From this, it could be deduced that interconurbation emissions represent a 28% (=449/1600) proportion of total Green Zone emissions.

But it is necessary at this stage to re-examine the central proposition underpinning the 'inverse linear' model of traffic flow/connectivity. This has assumed interconurbation trips within the UK all to fall within the 'there and back in a day' mindset of the traveller, with journeys up to 5 or 6 hours tolerated. This is reasonable for interconurbation flows, but not necessarily all trips across the Zone of Influence of a northern high speed line (aka the Green Zone). Much of personal travel comprises commuting, to schools and workplaces, for which a much lower 'tolerance limit' – perhaps 2 hours – will apply. Although these trips will be very large in number, they are predominantly short distance, and will have a relatively smaller impact upon CO_2 emissions.

Accordingly, the calculated 28% proportion has been nominally reduced by 5%, to 23%. This is taken to be the proportion of Green Zone transport CO_2 that is attributable to flow between conurbations, and represents the maximum 'conversion level' of a high speed system linking conurbations.

Put another way, if a high speed line system can be configured to provide the UK railway network with sufficient capacity to enable full conversion of interconurbation flows to rail, 23% of total transport CO_2 emissions appear to be capable of conversion to rail. However, 23% does not represent the final conversion level attributed to each candidate scheme. Further qualitative consideration is necessary, to determine whether:

- the intervention of high speed rail can extend beyond the conurbations, to the next tier of secondary cities (in which case the conversion level would increase to a higher percentage),

or:

- the configuration of high speed rail, in particular its distribution system from dedicated 'high speed' terminal to local public transport system, will fail to effectively 'mobilise' the full population of the conurbation (in which case the conversion level would decrease to a lower percentage).

These issues are considered in Section Q8.

Q6 National Connectivity and Capacity, translated to CO_2 Emissions

The second step is to quantify the increase in connectivity and capacity that would come about through the new inter-conurbation links created by the high speed line. The more corridors covered by the candidate scheme, and the more conurbations linked, the greater the benefits.

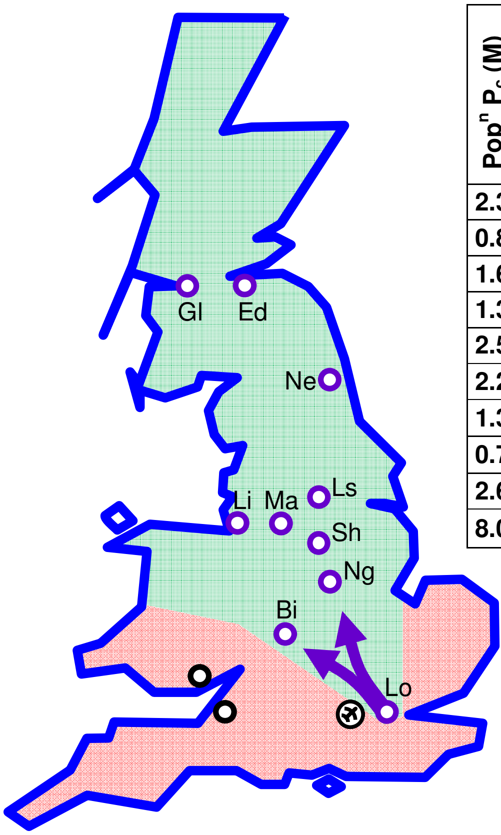
- *Figure Q3: InterConurbation Connectivity Matrix*

If high speed rail is assumed (pro tem) to comprise a means of improving connectivity, and enhancing capacity between conurbations, it is necessary to be able to quantify the relative benefits that will accrue from connecting any particular pair of conurbations. As noted in Item Q5.1, a quasi-gravitational model has been developed, whereby inter-conurbation flow is taken to be directly proportional to the product of the connected populations, and inversely proportional to the direct distance between the city centres (Birmingham, Leeds, Manchester etc) at the core of each conurbation. This defines individual InterConurbation Connectivity (ICC) scores as part of a broader InterConurbation Connectivity Matrix.

The interconurbation rail corridors, along which each ICC score has been calculated, are already under considerable pressure, with limited spare capacity to accommodate further traffic. Although there is a clear order of precedence, as to which will become critical first (it is commonly accepted that the West Coast Main Line is under greatest pressure, and will be first to run out of capacity) this consideration is rendered to a certain extent irrelevant with the anticipated modal shift that is necessary to meet climate change objectives.

With the fourfold increase in rail traffic likely to come about if rail is to supersede most longer distance road journeys, all existing principal rail corridors would be overwhelmed; as noted previously, the only practicable solution is to provide the required extra capacity through the construction of new railway lines (high speed or otherwise). But the higher the ICC score along a particular corridor, the more compelling is the case for new railway construction.

Under the methodology outlined in Figure Q5 (with a unity exponential applied to distance between conurbations), the maximum practicable ICC score for a comprehensive network interlinking all conurbations is 126.8. If a candidate scheme can achieve this ideal of interconnectivity, it is deemed capable of achieving the full ‘conversion level’ (see Section A4), the percentage of transport emissions that are attributable to interconurbation flow and might be converted to rail through the intervention of a comprehensive high speed rail system.



Pop^n P_c (M)	City	Glasgow	Edinburgh	Newcastle	Liverpool	Manchester	Leeds	Sheffield	Nottingham	Birmingham	London
2.3	Gl										
0.8	Ed	68									
1.6	Ne	194	148								
1.3	Li	285	283	195							
2.5	Ma	295	282	171	50						
2.2	Ls	288	262	131	104	57					
1.3	Sh	335	310	177	113	64	48				
0.7	Ng	382	360	227	133	93	98	50			
2.6	Bi	406	396	278	127	113	148	110	73		
8.0	Lo	553	532	395	285	259	270	221	172	160	

Distances between Primary Conurbations

InterConurbation Connectivity Score

$$= \frac{P_{C1} \times P_{C2}}{D_{1-2}}$$

City	P_c	Gl	Ed	Ne	Li	Ma	Ls	Sh	Ng	Bi	Σ	%	
Glasgow	**2.3**										**58.8**	**46.4**	Interregional ie non-London-centric non-B'ham-centric
Edinburgh	**0.8**	2.71											
Newcastle	**1.6**	1.89	0.87										
Liverpool	**2.2**	1.05	0.37	1.07									
Manchester	**1.3**	1.95	0.71	2.34	6.47								
Leeds	**2.5**	1.76	0.67	2.69	2.75	9.61							
Sheffield	**1.3**	0.89	0.34	1.18	1.50	5.08	5.94						
Nottingham	**0.7**	0.42	0.16	0.49	0.69	1.87	1.57	1.81					
Birmingham	**2.6**	1.47	0.53	1.50	2.67	5.74	3.86	3.08	2.51		**21.3**	**16.8**	B'ham
London	**8.0**	3.33	1.20	3.24	3.65	7.72	6.53	4.70	3.25	13.0	**46.6**	**36.7**	London
Total Quantum of Interregional / Interconurbation Connectivity											**126.8**	**100**	

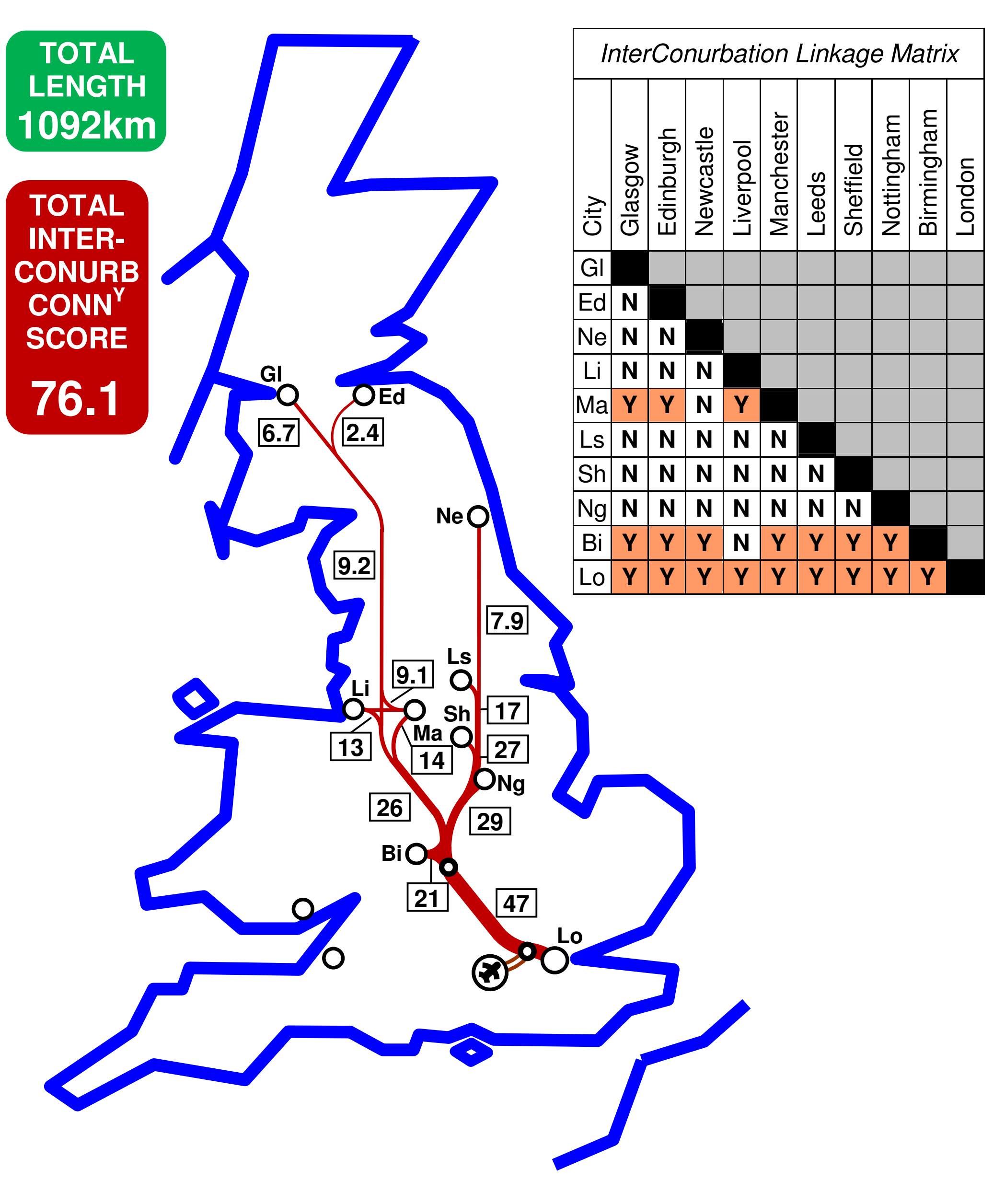
InterConurbation Connectivity Matrix
(adjusted with normalising constant)

Fig Q3: InterConurbation Connectivity Matrix

Q6.1 Review of InterConurbation Connectivity

- *Fig Q4: HS2 : Relative InterConurbation Traffic Volumes*
- *Fig Q5: High Speed North : Relative InterConurbation Traffic Volumes*

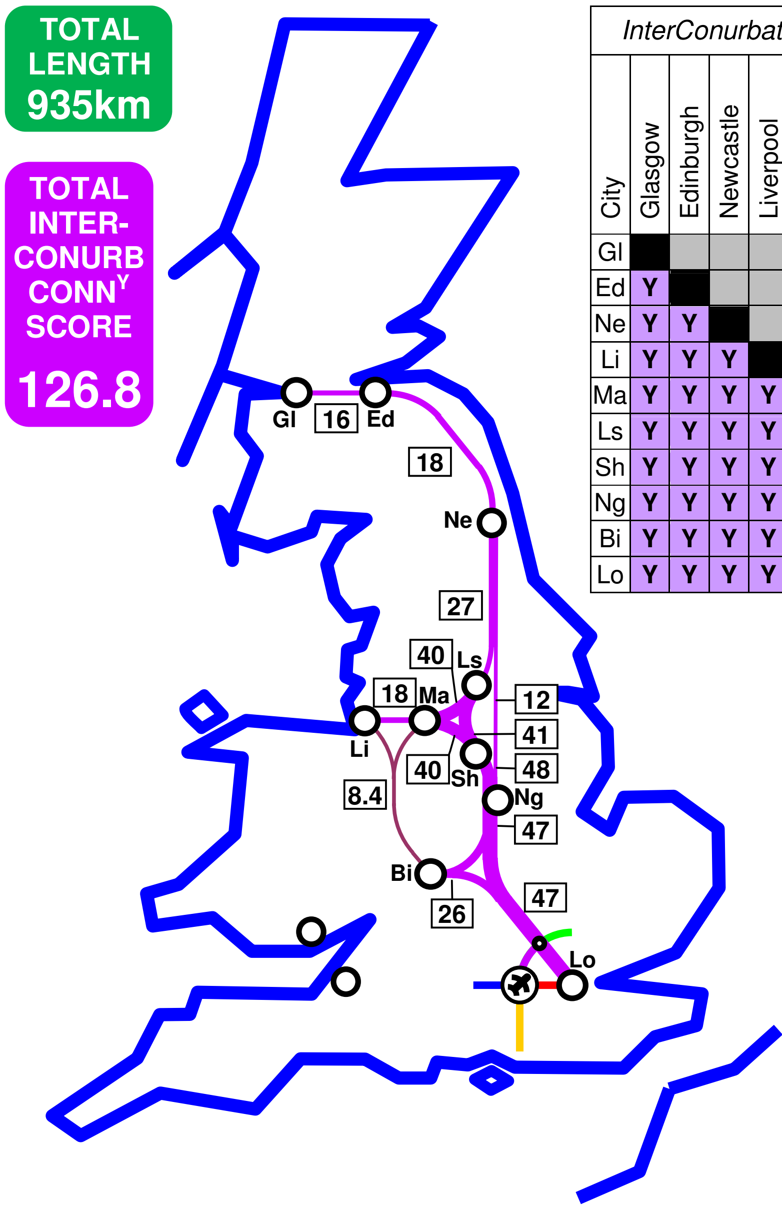
The ICC scores from the InterConurbation Connectivity Matrix have been collated to define the interconurbation flows (ICF) on each section of route. These ICF values are transcribed onto the network diagrams of the two candidate schemes (Heathrow flows are not included).



InterConurbation Linkage Matrix

City	Glasgow	Edinburgh	Newcastle	Liverpool	Manchester	Leeds	Sheffield	Nottingham	Birmingham	London
Gl										
Ed	N									
Ne	N	N								
Li	N	N	N							
Ma	Y	Y	N	Y						
Ls	N	N	N	N	N					
Sh	N	N	N	N	N	N				
Ng	N	N	N	N	N	N	N			
Bi	Y	Y	Y	N	Y	Y	Y	Y		
Lo	Y	Y	Y	Y	Y	Y	Y	Y	Y	

Fig Q4: HS2 : Relative InterConurbation Traffic Volumes



InterConurbation Linkage Matrix

City	Glasgow	Edinburgh	Newcastle	Liverpool	Manchester	Leeds	Sheffield	Nottingham	Birmingham	London
Gl										
Ed	Y									
Ne	Y	Y								
Li	Y	Y	Y							
Ma	Y	Y	Y	Y						
Ls	Y	Y	Y	Y	Y					
Sh	Y	Y	Y	Y	Y	Y				
Ng	Y	Y	Y	Y	Y	Y	Y			
Bi	Y	Y	Y	Y	Y	Y	Y	Y		
Lo	Y	Y	Y	Y	Y	Y	Y	Y	Y	

Fig Q5: High Speed North : Relative InterConurbation Traffic Volumes

It must first be stressed that the ICF values have no real meaning, in an absolute sense; their true significance is relative, in allowing objective comparisons to be drawn between candidate schemes, and in determining priorities for new railway construction.

Reviewing Figures Q4 and Q5, key conclusions are as follows:

- The ICF of 47 on the first sections north of London is common to both candidate schemes, and indicates the northward intercity flow from London to the major conurbations of the Midlands, the North and Scotland.

- For the ‘Y’ of HS2, the splitting of the routes north of Birmingham progressively shows reduced ICF values, and therefore reduced potential flows. With ICF values of less than 10 for routes north of Liverpool/Manchester, and north of Leeds, the economic viability of new line construction, over considerable distances, must be regarded as questionable.
- Although there is an inevitability, in flows on spurs to peripheral cities being less than on core sections, this is greatly exacerbated by the funnel-like configuration of HS2, concentrating flows upon London and Birmingham, with little attention paid to harnessing interregional traffic. While it might be possible to provide interregional high speed services, the location of each key city on its own separate spur off the trunk line makes it impracticable to do more than link individual city pairs, for which only small flows would accrue; intermediate cities would tend to be linked by peripheral parkway stations. It should be noted that the viability of current Transpennine and CrossCountry flows is dependent upon linking several primary cities, at city centre stations.
- The ‘spine and spur’ configuration of High Speed North would generate much stronger interregional flows, connecting multiple regional hubs. Transpennine high speed services could link Liverpool, Manchester, Leeds, Newcastle, Edinburgh and Glasgow; CrossCountry high speed services could link Scotland and the North-East to Leeds, Sheffield, Nottingham, and Birmingham (New Street) with onward running to either Bristol or Cardiff.
- The potential strength of Transpennine flows can be seen in the ICF value of 40 for the section east of Manchester, crossing the Pennines along the Woodhead corridor, and linking a) to Leeds, and to destinations further north, and b) to Sheffield, and to destinations further south. This represents Greater Manchester’s connectivity to all other principal conurbations, with the single exception of the West Midlands.
- The concentration of flows, and the greater interregional connectivity available through spine and spur, allows strong flows even at the periphery of the core network, with ICF values of 18 to Liverpool, and 16 to Glasgow. The latter is over twice that achieved via the HS2 ‘Y’, and is attributable to strong flows along the Edinburgh-Glasgow corridor, and onwards to the North-East of England. Further benefits would accrue from this section also forming a key link in enhancing Glasgow’s connectivity to regions north of the Forth-Clyde line (which is generally regarded as the natural limit to northward new railway construction).
- The concentration of high speed trunk services to Northern and Scottish destinations onto a single east-sided spine route achieves ICF values of greater than 40 – of the same order as the London-Midlands flow – as far north as Leeds and Manchester. This is attributable to the fact that the East and West Midlands would contribute approximately equal north- and southbound flows to a spine route.
- The lowest ICF value (8.4) under the High Speed North proposals applies to the northward flows from the West Midlands to Merseyside and Greater Manchester. With the trunk flows to Liverpool and Manchester diverted via Woodhead, this is a purely interregional flow, and new high speed line construction is not deemed a priority along this corridor. With limited construction of new cut-off lines in the West Midlands, and other enhancements facilitated by the diversion of trunk WCML flows to the east-sided spine route, it appears practicable to achieve a 1 hour timing from Birmingham to Manchester along decongested existing lines, at conventional speeds.

It is worth recording the InterConurbation Connectivity scores for both candidate schemes, when completed. HS2 would achieve an ICC score of 76.1, for a total route length of 1092km. High Speed North would achieve an ICC score of 126.8 (the maximum possible) for a shorter total route length of 935km. A greater capability to connect communities, for a shorter length of new construction, would appear to indicate a superior business performance.

Q6.2 Consideration of Capacity of 2-track High Speed Line

It is necessary to determine whether an InterConurbation Flow value of 47, in the context of a general quadrupling of interconurbation flows, would actually require the high speed line north of London to comprise 4 tracks, rather than 2.

For both HS2 and High Speed North, the initial sections from London to the Midlands are intended to comprise the single conduit for express passenger traffic to the Midlands, the North and Scotland, along the axes currently served by West Coast, Midland and East Cost Main Line. The current intercity flow northwards from London comprises 18 trains per hour, on West Coast (9tph), Midland (4tph) and East Coast (5tph) Main Lines.

Most of these services comprise what would be deemed interconurbation services (ie from London to Birmingham, Manchester, Liverpool, Glasgow, Nottingham, Sheffield, Leeds and Newcastle/Edinburgh – all except the latter pair to individual cities), that would naturally transfer to the high speed line; the remainder serve cities/regions (ie Chester/North Wales, and various 'second-tier' Yorkshire and North-East communities) that might reasonably aspire to be directly connected, and so also enjoy the benefits of the multi-billion pound investment.

The problem for HS2 arises from the fact that the total northward intercity flow, addressing contemporary traffic levels, already comprises 18 trains per hour. This is generally reckoned to be the maximum that a 2-track high speed line is capable of handling. The requirement to handle up to four times the number of passengers might be addressed by the use of trains of double the seating capacity, operating at twice the load factor (albeit with major concerns as to the dispersion of large train loads of passengers, arriving relatively infrequently at high speed hubs possibly remote from the local network).

Yet the funnel-like configuration of HS2 dictates separate services to all 9 regional conurbations, and this effectively speaks for all the available train paths. It will not be possible to offer services at greater frequency to the conurbations, or any high speed services to any of the second tier cities; this will greatly restrict the degree of integration that is possible. 4-tracking would increase capacity, and thus allow a greater range of services; but along the heavily-engineered and highly-sensitive HS2 Chiltern alignment, such an option appears to be impracticable, both economically and politically.

With High Speed North, many more options are available. Its 'spine and spur' configuration puts several cities on the same route (eg London to Sheffield, where the train could split for Leeds, and for Manchester and Liverpool – or London to Newcastle and Edinburgh, where services could split for Glasgow and for northern Scottish destinations). This allows a much simpler service pattern, with fewer individual services necessary and therefore much superior frequency. The interregional connections that would also be available might be considered a bonus.

Some double decker high-capacity trains might be provided, for services that run exclusively on the new high speed line, but in the main lower capacity 'classic compatible' trains will operate. These will be similar to the Eurostar Class 373 trains, with perhaps two-thirds of the capacity of HS2's proposed double deckers, and with the capability of splitting.

On the simplistic basis of train capacity, this might indicate that High Speed North would require to operate more trains than HS2 would, to service the same northward flow from London. But there are more variables to be considered. High Speed North's capability to operate at a higher load factor (as demonstrated in Section 4.9) would greatly reduce HS2's advantage in operating double decker rolling stock. But High Speed North's much greater integration with the existing rail network, both inside and outside conurbations (as demonstrated in Section 4.8) will tend to draw more traffic flows onto the high speed line.

Taking the balance of the above considerations, it is clear that High Speed North has a greater requirement for 4 tracks on its most critical southern section, from London to the trifurcation near Rugby (where the spurs for Birmingham and the West Coast/Trent Valley route diverge). However, the problems associated with constructing a 4-track route along the easier topography of the M1 corridor will be of an order of magnitude less than for constructing a 2-track route through the sensitive environment of the Chilterns, and rural areas further north.

4-track construction is proposed for High Speed North from the M25 to Leicester. North of Leicester, it is possible to take advantage of the greater capacity available on the existing rail network. In the coalfield areas of the East Midlands and Yorkshire, the existing trunk railway routes were generally constructed for 4 tracks, of which 2 have been either been abandoned (with the decline of the coal industry) or are only lightly used. With appropriate upgrades, this parallel capacity on the existing lines will make good any shortfall in capacity on the dedicated 2-track high speed line.

Q6.3 Translation of Connectivity into CO_2 Emissions

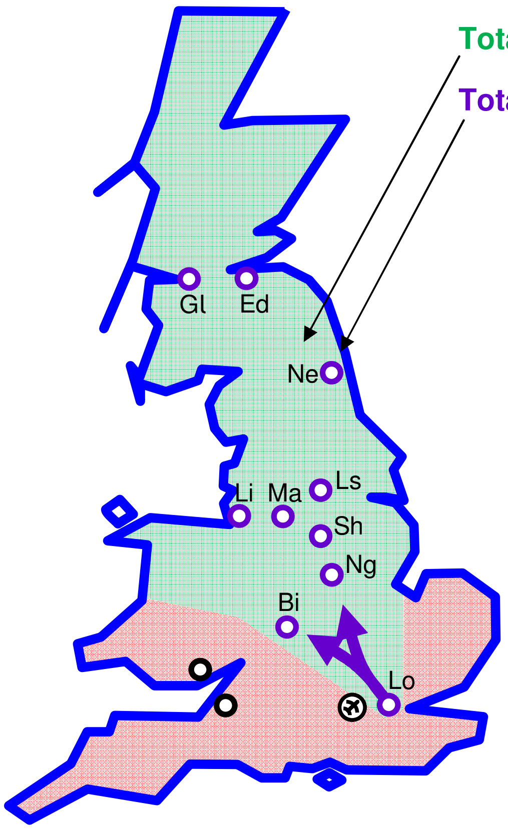
The potential flows between conurbations, noted in Item Q6.2, do not directly translate into savings of CO_2 emissions, generated by virtue of conversion of road traffic to rail. As noted in Item Q5.2, CO_2 emissions are proportionate to the product of flow and distance, and (with flow itself inversely proportional to distance) this reduces to the following basic relationship:

$$(CO_2)_{1-2} \propto P_{C1} \times P_{C2}$$

ie transport CO_2 emissions are related to the populations linked, but not to the intervening distance.

As with the InterConurbation Connectivity Matrix (ICCM), this allows emissions to be calculated for all conurbation pairs, to generate an InterConurbation Emissions Matrix (ICEM). Again, the numbers are relative, rather than absolute.

With an added dimension of distance applied to the relative flows, it can be seen that the while interregional journeys account for 45.4% of flows, they only represent 30.7% of emissions. This is attributable to the generally longer distances implicit in interconurbation trips to London.



Total Green Zone population P_{GZ}: 40M

Total conurbation population ΣP_C: 23M

Calculation of convertible CO_2 by means of northern HSL			
Green Zone population product	$(P_{GZ})^2$	a	1600
Conurbation population product	$(\Sigma P_c)^2$	b	543
Internal conurbation population product	$\Sigma(P_c)^2$	c	94
Interconurbation population product	**(b – c)**	d	449
Percentage convertible emissions	**d/a**		28%

InterConurbation Emissions Score

$= P_{C1} \times P_{C2}$

City	Pop	Gl	Ed	Ne	Li	Ma	Ls	Sh	Ng	Bi	Lo	Σ	%	
Glasgow	**2.3**											**68.9**	**30.7**	Interregional ie non-London-centric non-Birming'm-centric
Edinburgh	**0.8**	1.84												
Newcastle	**1.6**	3.68	1.28											
Liverpool	**1.3**	2.99	1.04	2.08										
Manchester	**2.5**	5.75	2.00	4.00	3.25									
Leeds	**2.2**	5.06	1.76	3.52	2.86	5.50								
Sheffield	**1.3**	2.99	1.04	2.08	1.69	3.25	2.86							
Nottingham	**0.7**	1.61	0.56	1.12	0.91	1.75	1.54	0.91						
Birmingham	**2.6**	5.98	2.08	4.16	3.38	6.50	5.72	3.38	1.82			**33.0**	**14.7**	B'ham
London	**8.0**	18.4	6.40	12.8	10.4	20.0	17.6	10.4	5.60	20.8		**122.4**	**54.6**	London
ΣP_c	**23.3**	Total Quantum of InterConurb Emissions Score										**224.3**	**100**	Total
		Total Quantum of InterConurb Population Product###										**448.6**		

Interconurbation population product includes also 'reflected' data from greyed out squares ie double InterConurbation Emissions Score

Fig Q6: InterConurbation Emissions Matrix

Q7 Timescale for Completion of National System

The third step is to assess the relative timescales to completion for the candidate schemes. The earlier increased capacity can be provided, the greater the total quantum of emissions reductions.

- *Fig Q7: HS2 : Stages of Emissions Reductions*
- *Fig Q8: High Speed North : Stages of Emissions Reductions*

Figures Q7 and Q8 indicate a 4-stage completion strategy for the two candidate schemes, to form a national system extending from London to all primary conurbations. As far as possible, the stages for each represent the same proportionate steps in achieving the respective planned goals, approximately as follows:

1. London to Midlands
2. First stage of development to the North
3. Second stage of development to the North
4. Completion to Scotland

At each stage of completion, the InterCity Emissions (ICE) score is noted, as calculated in the InterConurbation Emissions Matrix detailed in Item Q6.3. This is presented as a proportion of the total CO_2 emissions saving that might be achieved, assuming that a comprehensive high speed rail network, covering (and interconnecting) all 10 primary conurbations, were implemented.

Timing is clearly critical, in assessing the CO_2 impact over a specified period. This will be taken to be the 40 year 'currency' of the Climate Change Act, until 2050. For HS2, timescales are taken from the projections detailed in the official reports:

1. 2025 – first stage to Birmingham and WCML complete.
2. 2028 – western arm of 'Y' to Manchester complete, but NOT the eastern arm to Sheffield and Leeds, as noted in the HS2 reports. Simultaneous completion of western and eastern arms, only 3 years after completion of first stage to Birmingham, is not considered credible, and has so far been promulgated to assuage regional political concerns.
3. 2031 – eastern arm to Sheffield and Leeds.
4. 2041 – completion of national system. 10 more years allowed, noting length of extra construction (approx same as first 3 stages) and relative difficulty of terrain.

For High Speed North, the following timescale is assumed:

1. 2017 – first stage to West and East Midlands complete, accessing WCML and MML.
2. 2021 – east-sided spine route extended northwards to Yorkshire, accessing ECML, and over Pennines to Manchester. Transpennine and CrossCountry flows facilitated.
3. 2025 – extension along ECML axis to North-East, and enhancement of Grand Junction corridor from West Midlands to North-West.
4. 2030 – completion of national system, extending to Glasgow and Liverpool.

W 2038 – implementation of equivalent capacity improvements on Great Western axis, as 'High Speed West'.

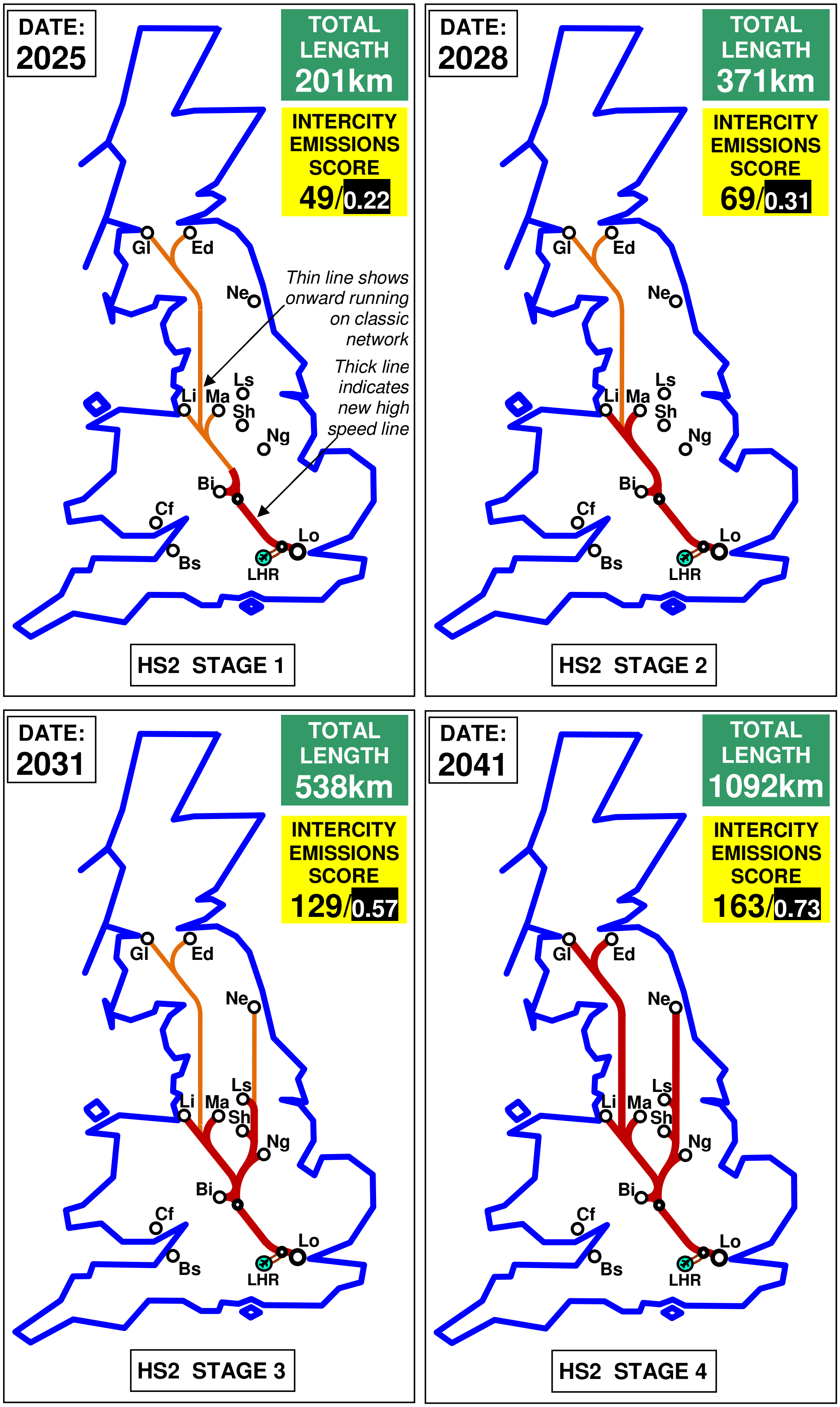
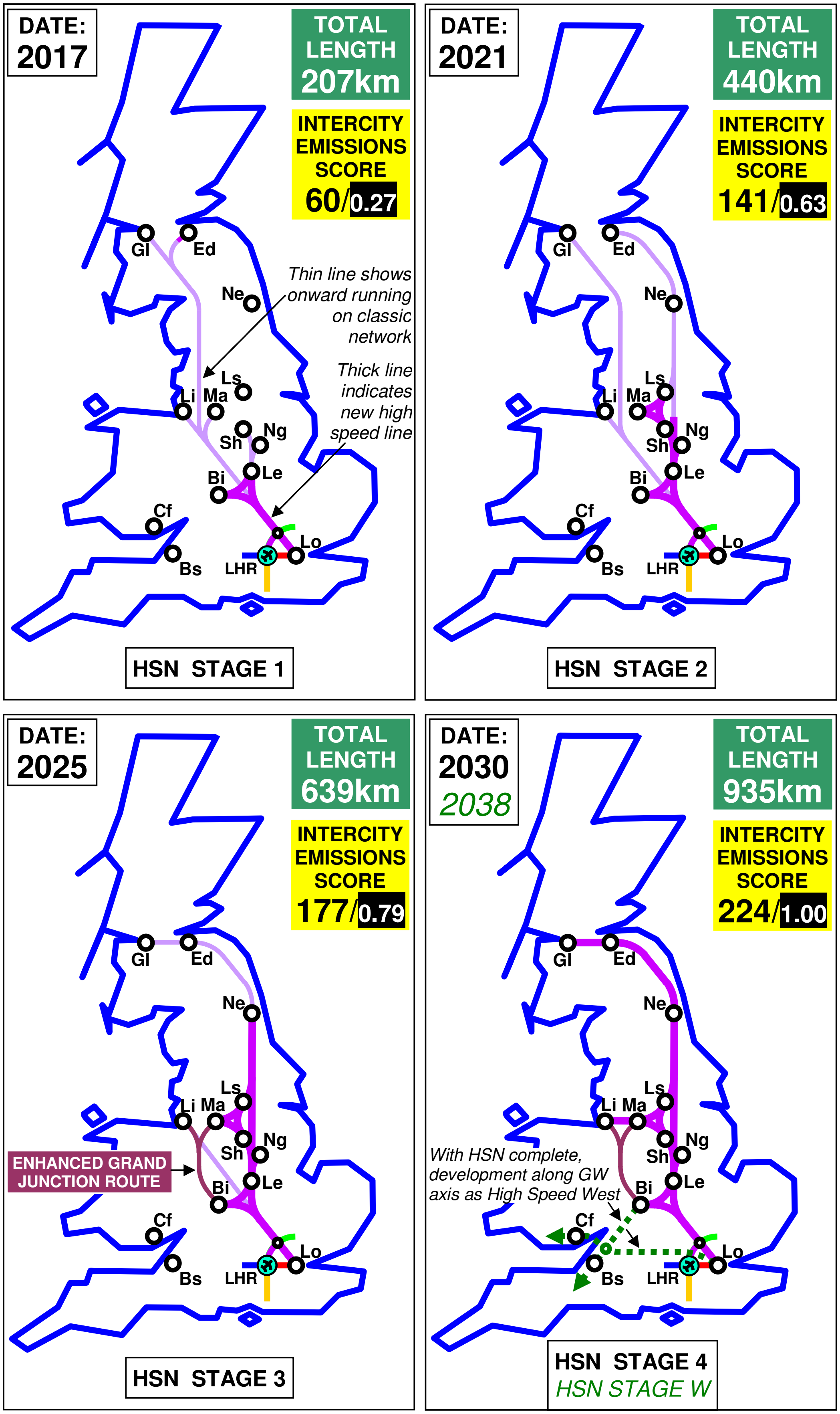


Fig Q7: HS2 : Stages of Emissions Reductions



The

Fig Q8: HSN : Stages of Emissions Reductions differing timescales reflect in part the difference in philosophies behind the candidate schemes. HS2 is primarily conceived as a means of generating economic benefit, and addressing rail capacity issues along the West Coast Main Line corridor; in a wider sense it conforms to the 'business as usual' agenda of the post-war era, under which national infrastructure has developed at a very slow pace, and environmental benefits have only been paid scant attention. With many interconurbation corridors not addressed, HS2 cannot offer a complete solution, in terms of maximised potential modal shift and consequent emissions reductions.

High Speed North is conceived on a broader scale, addressing all corridors through its 'spine and spur' configuration. It will achieve the same economic and railway capacity aims of HS2 and deliver more besides, but its primary goal is to realise a low-CO_2 UK transport system, compatible with contemporary environmental concerns and the requirements of the 2008 Climate Change Act. On such an agenda, timely action to avert the worst effects of climate change is essential, and it seems reasonable to assume that schemes which can deliver step-change reductions in CO_2 emissions would be accorded the necessary priority.

Even in the quasi-wartime scenario, that the fight against climate change will constitute, such priority cannot be given to a railway scheme, regardless of economic cost, or environmental intrusion. Both considerations still require to be optimised, to ensure speedy realisation of the resulting environmental benefits.

On grounds of simple cost, High Speed North easily outscores HS2, through requiring of the order of 160km shorter route length (935km vs 1092km route kilometres, and generally avoiding the more difficult topography of the west side of the country. With 1km of double track high speed line valued at circa £30M, the difference in cost will be at least £5 billion.

On grounds of environmental intrusion, High Speed North also outscores HS2, through its much greater adherence to existing transportation corridors. Here, the marginal additional impact of a new railway alongside a motorway will be very small (if not absolutely minimal) and public opposition is likely to be of an order of magnitude lower than will apply for HS2's chosen route through the Chilterns AONB and onwards through rural Buckinghamshire, Northamptonshire and Warwickshire.

Quite how fast a UK high speed rail system could be implemented is a matter for debate. The pace at which infrastructure can be developed is finite, governed not only by cost but also by planning procedures and availability of scarce resources and skills. The timescale set out for High Speed North, approximately twice as fast as applied for HS1, would be extremely demanding but feasible, even under current conditions. This might be termed 'accelerated business as usual'.

But with priorities dictated by the 'wartime' imperative to mitigate the consequences of climate change, even more seems possible. It should not be forgotten that the Mulberry Harbours, vital for the D-Day landings, were developed from initial concept in barely a year; or that the 2000+km Alaska Highway, necessary to guard against invasion of the North American continent, was constructed in only 8 months. To a large extent, the pace of development is proportional to the importance of the goal.

So, if High Speed North can be completed in less than 20 years, achieving step-change environmental benefits realised, it seems reasonable to assume that the pace of development would continue. This would probably entail the focus shifting towards Wales and the West Country, to create a truly national high speed rail system. A notional allowance has accordingly been made in this calculation.

- *Fig Q9: High Speed Rail proposals : Calculation of Corridor Factor*

Whatever 'wartime' analogies might be drawn, it remains the case that public and political opposition is certain to mobilise against environmentally intrusive proposals. This will have the effect of greatly impeding progress, or even putting a stop to the entire project. There appears to be a fundamental logic in following existing transportation corridors, particularly motorways, where the environmental damage has already been done, and the additional 'marginal' intrusion will be minimal.

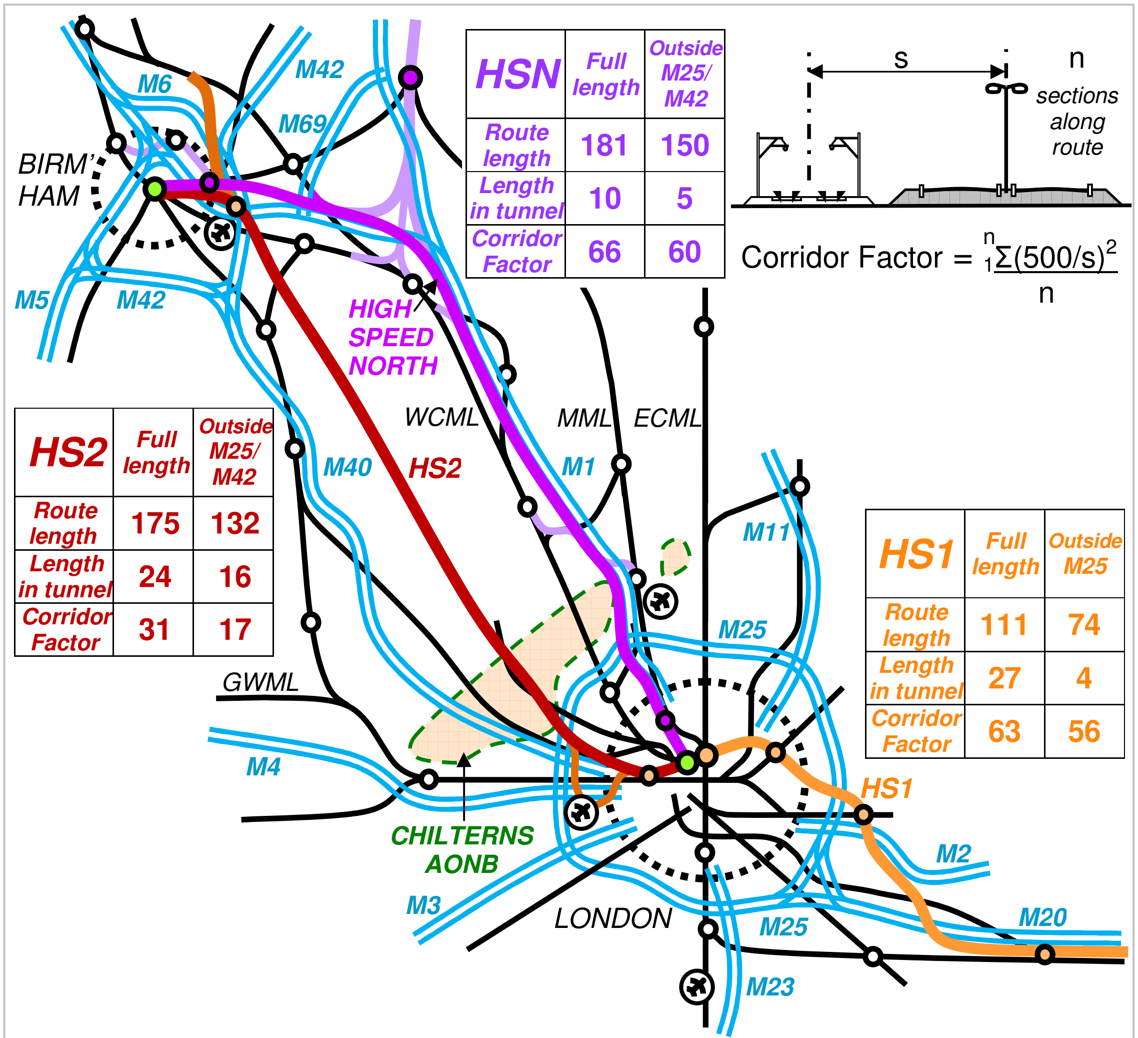
Moreover, the present environmental nuisance has deterred major residential developments close to the motorway, and owners of the few properties in the path of the new line could well be happy to sell up (given a favourable valuation) and move to a quieter *locale* within their own community. This logic will continue to apply, even in the 'wartime' scenario posed by advancing climate change.

However self-evident the case for adherence to existing corridors, it is still useful to be able to quantify the level of mitigation that this brings to the candidate schemes. The concept of 'Corridor Factor' has been developed, to score both HS2 and High Speed North for how closely they succeed in following existing corridors. It is derived from a measurement (at 1km intervals) of the offset between centrelines of new railway and existing motorway (or railway). Highest local 'Corridor Factor' equates to closest practicable proximity, and overall 'Corridor Factor' is a simple average of the results along the entire route length. This calculation is only practicable when detailed alignments have been developed, and the comparison is therefore restricted to the London to Birmingham sections.

The methodology of the Corridor Factor assessment is outlined in Section D5, and the results are set out in Figure Q9. As a control, and to set the calculated values into context, a parallel assessment has been undertaken for the HS1 route, from London to the Channel Tunnel. Results are tabulated both for the full route lengths, and for the rural lengths clear of the encircling motorways ie M25 and M42. In terms of rural intrusion, where the main environmental debate is focussed, this latter result appears to be the key consideration

The comparison is stark. Both High Speed North and HS1 (constructed in close proximity to M2 and M20 for most of its length) score highly, at 60 and 56 respectively. But HS2, which has avoided any motorway or dual carriageway corridor en route to Birmingham, scores very poorly, at 15. Any positive scoring is attributable to its following part of the route of the former Great Central, and even here (noting the fact that the railway was abandoned nearly 50 years ago) significant local opposition may occur.

Any proposal of the magnitude of a national high speed rail scheme is certain to attract considerable public opposition. This carries the attendant risk of increased cost and timescale, and in extreme cases such as HS2's questionable proposed route through the Chilterns Area of Outstanding Natural Beauty, loss of political support that might ultimately lead to cancellation of the entire project, and failure to realise the desired environmental goals.



HSN	Full length	Outside M25/ M42
Route length	181	150
Length in tunnel	10	5
Corridor Factor	66	60

HS2	Full length	Outside M25/ M42
Route length	175	132
Length in tunnel	24	16
Corridor Factor	31	17

HS1	Full length	Outside M25
Route length	111	74
Length in tunnel	27	4
Corridor Factor	63	56

Fig Q9: High Speed Rail proposals : Calculation of Corridor Factor

Adherence to existing transportation corridors, where the addition of a high speed line will only have marginal environmental impact, would seem to greatly reduce (if not largely eliminate) potential opposition. Hence, although there is no direct linkage between Corridor Factor and CO_2 emissions, it is possible to infer such a link from the delayed realisation of the environmental benefits. Corridor Factor appears to be a fair indicator of achievable environmental mitigation and thus public and political acceptability, and ultimate viability of any high speed line proposal and the associated emissions reductions.

On such a measure, High Speed North would appear to considerably outperform HS2, and the wisdom of HS2, in abandoning the best practice established by HS1, must be called into question.

Q8 Wider Integration Issues

The fourth step is to assess the degree to which the new high speed line can be integrated with the operation of the existing railway. All indications are that greater integration results in a greater capability of high speed rail to bring about emissions reductions, and (in terms of this calculation) to achieve a higher conversion level ie the proportion of total transport emissions convertible to rail through the specific intervention of a northern high speed line/system. As noted in Item Q5.2, the fundamental conversion level of a comprehensive high speed rail scheme, efficiently interlinking all primary conurbations, can be taken to be of the order of 28%, which is nominally reduced to 23% to allow for a greater preponderance of commuting flows.

Q8.1 Benefits of Integration with 'Second Tier' Communities

The question of integration is central to the modal shift, and therefore CO_2 emissions reductions, that high speed rail can generate. Integration is essential, to ensure that the intervention of high speed rail (which in its 'purest' sense is geared for journeys between principal conurbations) can extend to the next tier of 'second tier' population centres ie the towns and cities of perhaps 50,000 or more.

These cities are key contributors of traffic to the existing intercity network, however with the prospect of high speed rail 'siphoning off' the largest interconurbation flows, the likelihood is that second tier centres (such as Coventry and Stoke) will see their services reduced, or operating at much poorer load factors. This points up the crucial importance of integration.

- *Fig Q10: InterPopulation Emissions Matrix*

The benefits of integration can be seen in quantified form in Figure Q10. This is an extension of the interconurbation emissions matrix already presented in Figure Q6. This indicated that interconurbation emissions might represent around 28% of total 'Green Zone' transport CO_2. But if high speed rail can be integrated with the existing intercity network, then its target market grows from the aggregate conurbation population of 23 million by a further 5 million to 28 million.

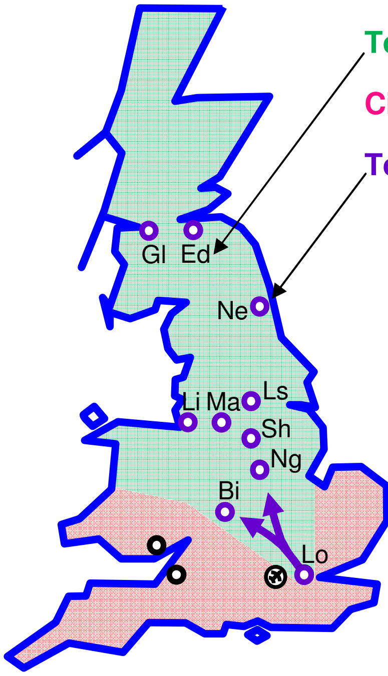
Now the greater connected population would represent 43% of total CO_2 emissions. In terms of practicable conversion level, as before, this figure would reduce to circa 38% to allow for commuting, and possibly by another 5% to allow for the fact that the second tier centres would remain on their existing main lines, with largely uniaxial connectivity; it would not be possible for high speed rail, designed primarily to link conurbations, to provide the full 360º connectivity.

This will inevitably limit achievable modal shift, and a conversion level of around 33% would appear to be the maximum achievable by means of a northern high speed line, a worthwhile and proportionate contribution to the overall targets of the 2008 Climate Change Act ie CO_2 emissions reduced to 20% of contemporary levels, over a 40 year timescale.

Total Green Zone population P_{GZ}: 40M

City+conurbation population ΣP_{CC}: 28M

Total conurbation population ΣP_C: 23M



Calculation of convertible CO_2 via HSL to North			
Green Zone population product	$(P_{GZ})^2$	a	1600
Conurbation population product	$(\Sigma P_c)^2$	b	543
Internal conurbation population product	$\Sigma(P_c)^2$	c	94
Inter-conurbation population product	(b–c)	d	449
Percentage convertible emissions *through total conurbation connectivity*	d/a		28%
Conurbation & city population product	$(\Sigma P_{cc})^2$	e	784
Internal conurbation population product	$\Sigma(P_c)^2$	c	94
Inter-conurb & city population product	(e–c)	f	690
Percentage convertible emissions *through total conurbation/city connectivity*	f/a		43%

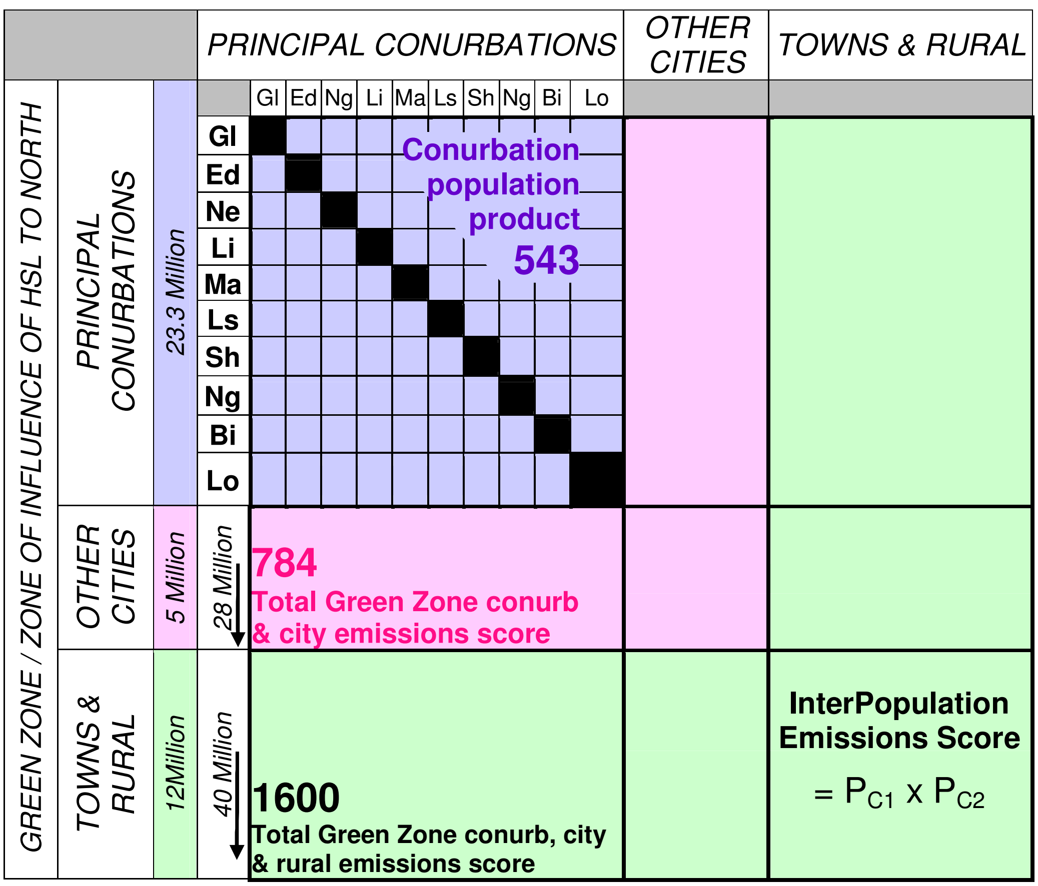
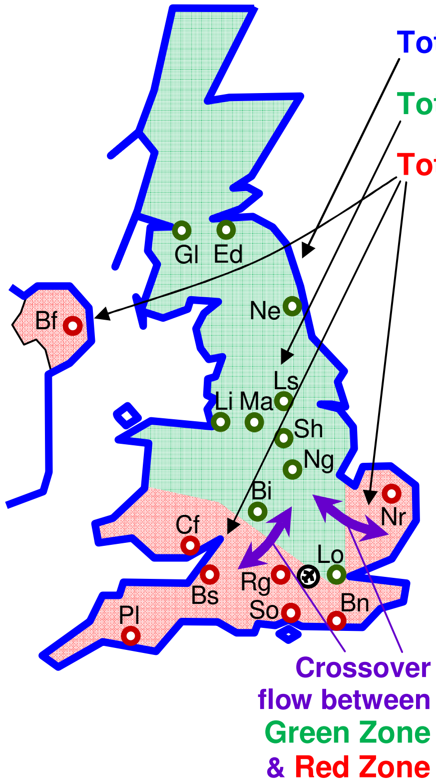


Fig Q10: InterPopulation Emissions Matrix

Q8.2 Further Consideration of Red Zone / Green Zone Split



Total UK population ΣP_{UK}: 60M

Total Green Zone population P_{GZ}: 40M

Total Red Zone population P_{RZ}: 20M

Allocation of CO_2 emissions by Zone of Influence			
Total UK population product	$(P_{UK})^2$	a	3600
Green Zone population product	$(P_{GZ})^2$	b	1600
Red Zone population product	$(P_{RZ})^2$	c	400
Green Zone / Red Zone crossover	**a-b-c**	d	1600
%age exclusive GZ emissions	**b/a**	e	44%
%age exclusive RZ emissions	**c/a**	f	11%
%age crossover flow emissions	**d/a**	g	44%
%age GZ emissions from simplistic GZ/RZ split		h	66%
Further conversion of crossover emissions req[d] to justify 66% figure	**e+g-h**	i	22%
Percentage conversion of crossover emissions	**i/g**		50%

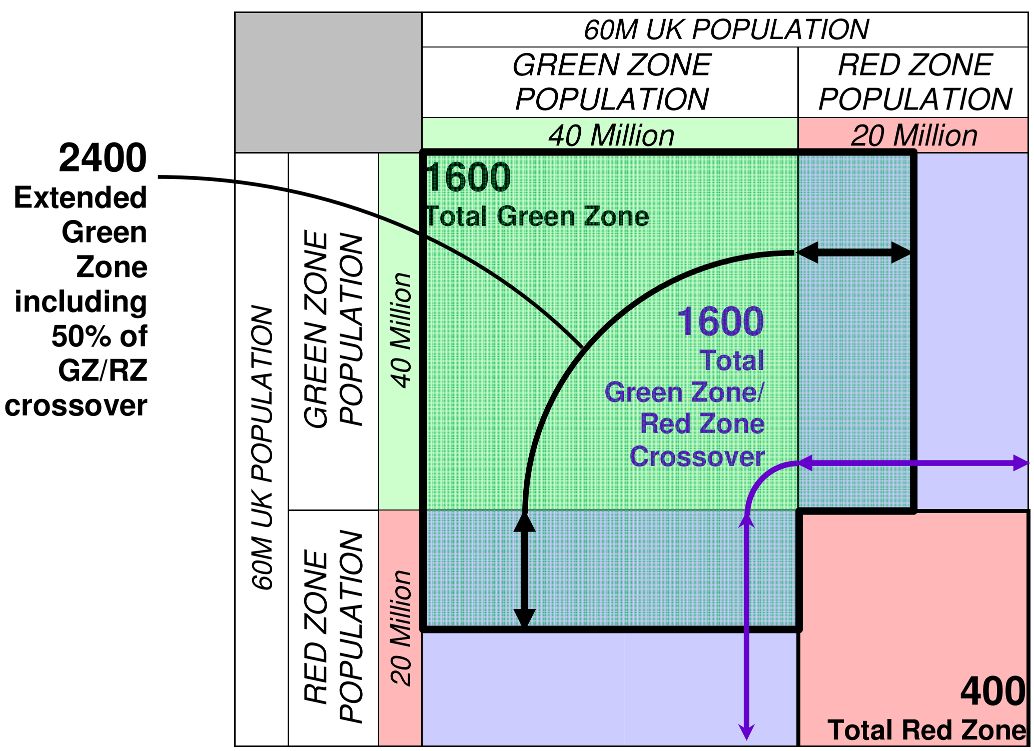


Fig Q11: InterZonal Emissions Matrix

It now becomes necessary to re-examine the assumption made at the beginning of this section, of a simplistic split in UK CO_2 emissions, based upon the relative 'Green Zone' and 'Red Zone' populations ie those inside and outside the Zone of Influence of a northern-oriented high speed line. Such a split ignores the 'crossover' flows between the two zones, which must represent a major proportion of total emissions.

On the basis of a 2:1 split into populations of 40M and 20M, Figure Q11 calculates the relative magnitude of intra- and interzonal emissions:

- exclusively Green Zone : 44% (or four ninths),
- exclusively Red Zone : 11% (or one ninth),
- crossover between Green and Red Zone : 44% (or four ninths),

To sustain the assumption so far made, of the Green Zone accounting for two thirds of UK transport CO_2 emissions (from which calculations as to the emissions reduction potential of a northern high speed line are made) it would be necessary to include half of the crossover emissions (ie 22% of the total). These would represent journeys between the zones, with a considerable length within the Green Zone, for which the intervention of a northern-oriented high speed line would make a significant difference.

It is clear that while many flows from the Red Zone, extending no further than London or Birmingham, would not be influenced by the creation of a northern high speed line, there are still significant longer-distance interzonal flows that would benefit. These are tabulated quantitatively in terms of 'population product', as per previous calculations to establish relative emissions. The Red Zone is divided between geographic areas, while the Green Zone is divided between conurbations as for other calculations (but taken as being representative of wider population distribution):

	Pop^n P$_c$ (M	Strathclyde	Lothian	North-East	Merseyside	G.Manchester	West Yorks	South Yorks	East Midlands	West Midlands	Greater London
Pop^n P$_c$ (M)		2.3	0.8	1.6	1.3	2.5	2.2	1.3	0.7	2.6	8.0
East Anglia	3.3	7.5	2.6	5.2	4.3	8.2	7.2	4.3	2.3	8.5	26
South Coast	3.1	7.0	2.4	4.9	4.0	7.6	6.7	4.0	2.1	7.9	24
Thames Valley	2.2	***5.0***	***1.7***	***3.5***	***2.8***	***5.4***	***4.8***	***2.8***	***1.5***	***5.7***	17
Wessex	2.9	***6.6***	***2.3***	***4.6***	***3.8***	***7.2***	***6.3***	***3.8***	***2.0***	***7.5***	23
Greater Bristol	2.0	***4.6***	***1.6***	***3.2***	***2.6***	***5.0***	***4.4***	***2.6***	***1.4***	***5.2***	16
West Country	2.6	***6.0***	***2.1***	***4.1***	***3.4***	***6.5***	***5.7***	***3.4***	***1.8***	***6.7***	21
South Wales	2.2	***5.0***	***1.7***	***3.5***	***2.8***	***5.4***	***4.8***	***2.8***	***1.5***	***5.6***	17
Northern Ireland	1.8	4.1	1.4	2.9	2.3	4.5	4.0	2.3	1.3	4.7	14

Convertible emissions	236.2	51%	100%
Non-convertible emissions	228.7	49%	
CrossCountry emissions	***180.8***	***39%***	

Fig Q12: InterZonal Emissions Subdivided

The above would appear to justify approximately half of crossover emissions being considered potentially convertible, through the intervention of a northern high speed line. However, these gains can only be realised if flows from outside the Green Zone can be fully integrated with high speed rail operations within the Green Zone.

It is particularly significant to note the high proportion of the crossover flows that are covered by the present 'CrossCountry' network (indicated in ***bold italics***). These flows are focussed upon Birmingham New Street, extending to the extremities of northern Scotland, the Cornish peninsula and the English South Coast. It would seem essential that this functionality is maintained in any future high speed network.

The assessment of relative integration must of necessity be largely restricted to the first stages of the two candidate schemes, from London to the Midlands; only in this area does sufficient detail of the HS2 proposals exist (to allow fair comparison to be made, it has been assumed that the north-eastern arm of the HS2 'Y' will include an East Midlands station, constructed between Nottingham and Derby, broadly according with High Speed North proposals). It is considered that this comprises a sufficient sample to allow an informed judgment to be made.

Q8.3 Comparison of Integration between Candidate Schemes

The actual degree of integration, and the achieved level of emissions reductions, are difficult to quantify, either in an absolute or a comparative sense. This aspect of the calculation of reduced emissions appears to be best addressed in an empirical manner, whereby comparisons are made against a series of 'key performance indicators'. From these KPI's, a judgment will be made as to the conversion level that each candidate scheme is capable of achieving.

Comparison will be made on the following criteria:

- Capacity of proposed trains.
- Degree of interoperability.
- Efficiency of interconnection to local networks in primary conurbations.
- Connectivity to subsidiary centres within conurbation.
- Second tier communities bypassed, or accessed by means of through running.
- Blight or benefit to these second tier communities.
- Benefits to total network connectivity.
- Benefits to total network capacity.
- Railway network access to Heathrow Airport.
- Resilience to disruption.

To inform the comparisons, reference should be made to the detailed descriptions of the two candidate schemes, supported by the route plans in Figures Q13, Q14, Q15 & Q16. The comparisons are presented in Table Q17, with a simple judgement made (indicated by red for poor integration, and green for good integration) on each of the criteria. Considering the overall performance of both schemes, a further judgement will be made as to the likely 'conversion level' that each will achieve.

Q8.4 HS2 : Proposed Route from London to Birmingham

- *Fig Q13: HS2 : Connectivity along London-Midlands Corridor*
- *Fig Q14: HS2 : Connectivity in London & South-East*

HS2's proposed London terminal will be at Euston Station, the present terminus of the West Coast Main Line (WCML). To accommodate the increased number of longer intercity trains, along with the existing commuter traffic, it is proposed to expand Euston by circa 50m to the west, into adjacent residential/mixed use property. The existing Tube connections (ie both Northern branches and the Victoria Line) will remain, with no enhancements proposed.

The high speed line will head westwards from Euston as a 2-track railway in tunnel, as far as Old Oak Common (OOC). Here, an interchange station will be constructed on railway land just north of the Great Western Main Line (GWML). The HS2 platforms will be located within a massive concrete box, similar to the HS1 station at Stratford, and footbridges will link to the surface level platforms on the GWML. This will provide interchange with CrossRail and Heathrow services, and possibly West and North London Lines also. Road access is currently very poor, and would require considerable enhancement to permit good quality local bus access.

HS2 will continue in tunnel beyond OOC, surfacing at Park Royal adjacent to the LUL Central Line (9.2km overall length of tunnel from Euston). HS2 will then follow the largely redundant corridor of the OOC – Northolt Junction freight line, and then the Chiltern Line to West Ruislip. It appears possible to construct the new railway to a virtually straight alignment, with relatively minor impact on adjacent residential property.

West Ruislip marks the edge of the Greater London conurbation, and here, HS2 will swing to the north-west on a new alignment. It will first pass over the Colne Valley SSSI on a 3km long viaduct, and then, approaching the Chiltern Area of Outstanding Natural Beauty (AONB), pass into a 9km long tunnel that will take the line under Amersham, and into the Misbourne Valley. With further tunnelling (an extra 1.5km of tunnel is required near Hyde Heath) to mitigate the worst effects on the AONB, the line will emerge onto a surface alignment near Great Missenden, and pass out of the Chilterns at Wendover.

HS2 will proceed through rural Buckinghamshire on a north-westerly alignment, following the trackbed of the former Great Central Railway for 20km until Brackley. Now in Northamptonshire, the line will continue on a new alignment through a largely unspoilt rural landscape. A scarp slope near Southam will require a 2km long tunnel, but elsewhere cuttings and embankments over 20m deep/high will be necessary to fit the line onto the extremely undulating topography.

The new line will pass between Leamington and Kenilworth, and then along the 'Coleshill Corridor' already occupied by M6 and M42. This alignment, grazing the eastern edge of the Birmingham conurbation, will continue north-west to join the WCML at Lichfield, with services continuing to points north on the existing railway.

Interchange with Birmingham Airport was a desired aim, but it was not possible to bring the HSL even as close as the existing Birmingham International Station. Instead, Birmingham 'Interchange' will be located 1.5km to the north-east, with a dedicated shuttle link that will access both the airport and the nearby National Exhibition Centre. Aside from this shuttle, no access to the classic railway network will be provided at Birmingham 'Interchange'; local connectivity will be largely road-based, with excellent access to the motorway network.

HS2 will access central Birmingham via a spur from the trunk high speed line. This will follow the existing CrossCountry main line westwards from Water Orton (along the 'Water Orton' corridor). With Birmingham New Street unable to accept the 400m long double-decker rolling stock proposed for operation on HS2, a new terminus station (Fazeley Street) will be constructed adjacent to the existing Moor Street Station. Passengers requiring to access the regional services, and the majority of local services that emanate from New Street will be compelled to make their own way across the city centre between the two stations. This transfer would require a walk of between 600 and 1000m (dependent upon the passenger's position in a 400m long train) and would take at least 10 minutes; this would seem to negate most of the benefits accruing from high speed operation.

HS2's London to West Midlands services will operate largely independent of the existing railway, and no physical interconnection is currently proposed (and, given the proposed alignment, little worthwhile connection appears to be possible). This will effectively bypass intermediate communities, which in certain cases will see services greatly reduced.

A particular concern is Coventry, a key stop on the existing Birmingham to London intercity service which currently enjoys 3 trains per hour (tph) to London. But with trunk Birmingham-London services diverted onto HS2, Coventry's main line service is projected to be reduced to 1tph, with longer journey times.

Such a reduction would seem to indicate that, at least locally, rail use will be deterred, and there will be an increase in transport CO_2 emissions. An alternative outcome might be that local political considerations (for Coventry, and other bypassed cities) will dictate a greater level of express (ie 200kph) services remaining on the classic line; this in turn will limit the potential for achieving increased capacity on the WCML, and associated CO_2 reductions.

One further consequence of the chosen HS2 alignment, well to the west of the concentration of major population centres along the M1 corridor (ie Luton, Milton Keynes and Northampton), is that the new line can do nothing to address local rail connectivity. The cities along the M1 corridor, along which both Midland and West Coast main lines pass, will remain effectively disconnected[6], and the motorway, and car travel, will remain the primary means of communication between these major population centres. As such the proposed routeing of HS2 represents a significant lost opportunity to effect local CO_2 emissions reductions.

[6] The almost total separation of West Coast and Midland Main Line routes results in there being no rail connection between Luton and Milton Keynes / Northampton / Coventry, or between Milton Keynes / Northampton and Leicester. This lack of connectivity is illustrated in Figure B12.

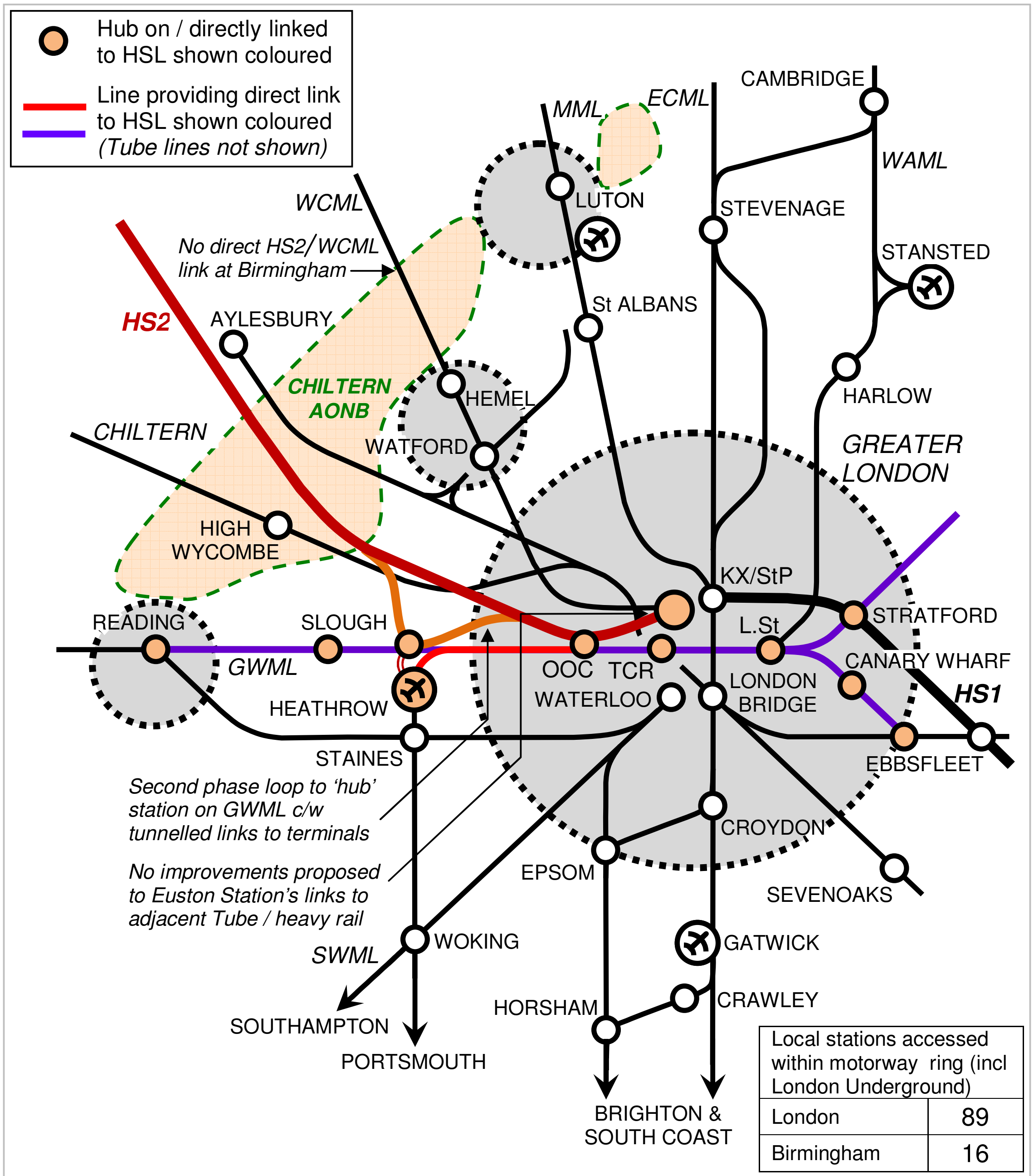
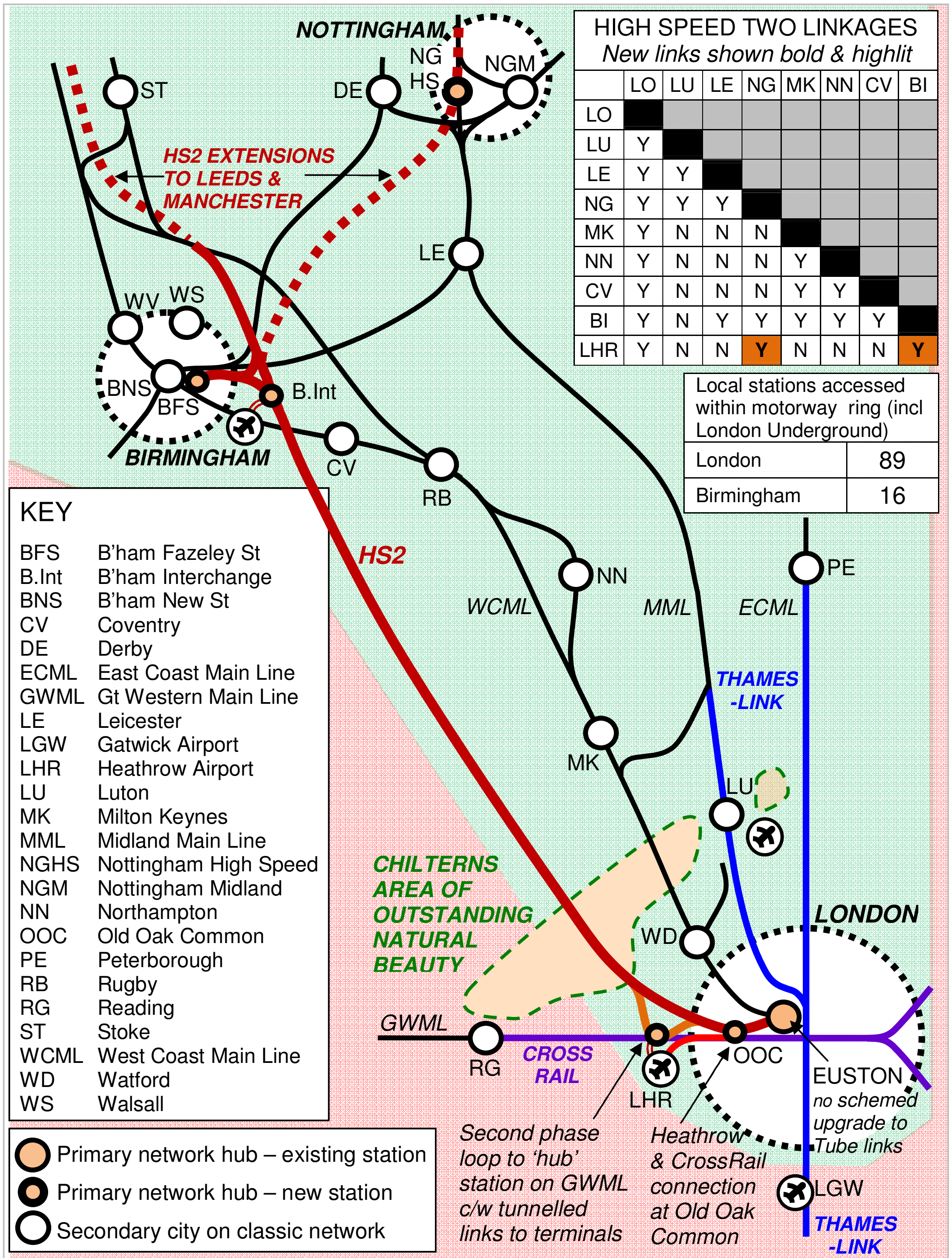


Fig Q13: HS2 : Connectivity in London & South-East



HIGH SPEED TWO LINKAGES
New links shown bold & highlit

	LO	LU	LE	NG	MK	NN	CV	BI
LO								
LU	Y							
LE	Y	Y						
NG	Y	Y	Y					
MK	Y	N	N	N				
NN	Y	N	N	N	Y			
CV	Y	N	N	N	Y	Y		
BI	Y	N	Y	Y	Y	Y	Y	
LHR	Y	N	N	**Y**	N	N	N	**Y**

Local stations accessed within motorway ring (incl London Underground)	
London	89
Birmingham	16

Fig Q14: HS2 : Connectivity along London-Midlands Corridor

Q8.5 High Speed North : Proposed Route from London to Birmingham

- *Fig Q15: High Speed North : Connectivity along London-Midlands Corridor*
- *Fig Q16: High Speed North : Connectivity in London & South-East*

As with HS2, the proposed London terminal of High Speed North (HSN) will be at Euston. Here, the similarities largely end. Under HSN proposals, Euston's commuter traffic will be diverted from the WCML (at Willesden Junction) to the GWML (at Old Oak Common), by means of a 2km long interconnecting chord. This will hugely benefit WCML commuters, in offering a much greater range of central London destinations, without the need to detrain at Euston and pack onto congested Tube services; it will also benefit the high speed line proposals, in clearing sufficient space at Euston to allow construction of the new terminal within the existing station footprint, and in greatly reducing local Tube congestion.

Major enhancements are proposed to Euston's present mediocre Tube connectivity, to be achieved through the provision of a tunnelled light rapid transit (LRT) link to adjacent Tube hubs (Kings Cross/St Pancras for HS1, Thameslink et al, Tottenham Court Road for CrossRail and the Central Line). This will be located on a transverse alignment, crossing immediately below the 400m long high speed platfornms, approximately at mid length. Overall, the enhanced terminus at Euston will connect to both cross-London heavy rail links, and 7 out of 10 central London Tube lines. These will collectively achieve a direct link to 253 stations within the M25 ring.

HSN will head north from Euston, crossing from WCML to MML corridors via a 2km long tunnel, and continuing parallel to the MML and M1 to clear the Greater London conurbation just east of Watford. Overall tunnelling requirement within the M25 ring is 5km.

A suburban interchange will be created on railway land adjacent to the North Circular Road at Cricklewood (adjacent to the proposed Brent Cross redevelopment, with which it should fully harmonise). This will provide an interchange with the proposed Northern Orbital Arm of a 'Compass Point' network of local/regional railways, centred upon Heathrow Airport (using the existing Heathrow Express lines, but transformed from a terminating railway into a through route). This mostly exploits existing routes, and requires only 20km of new railway to form a comprehensive network, linking to all radial main line corridors to the west and north of London.

The fundamental aim of the Compass Point Network is to provide main line links to Heathrow (requiring only a single change of trains) from most UK regional centres. This in itself will bring about major CO_2 savings, in converting Heathrow's predominantly motorway-based connectivity. But it will also offer circumferential links that will greatly improve suburban links to all northern main line corridors.

North of the M25, HSN will follow the M1, generally on a close parallel alignment. A 4km long tunnel will be required to avoid suburban development (and a poorly aligned motorway) at Luton. But elsewhere, the motorway is sufficiently well aligned to permit speeds of up to 360kph, without major deviation.

Near Rugby, the route to Birmingham will swing to the west from the HSN trunk route to northern destinations (which will follow the M1 corridor to Leicester). The HSN Birmingham route will enter the Birmingham conurbation at Water Orton, where a suburban hub will be created in a severed triangle of land between motorway (M42/ M6 toll), and two railways (the converging Derby-Birmingham and Leicester-Birmingham lines).
Water Orton Parkway will have both motorway and local rail connectivity, with links (via the Sutton Park line) to Walsall and Wolverhampton, and to Nuneaton, Tamworth and Burton. It

will also allow the splitting of trains, to create shorter portions capable of entering existing West Midlands stations, particularly Birmingham New Street.

HSN will follow the Water Orton corridor into Birmingham with new parallel tracks, and continue to New Street along the existing route. This is the priority, to establish optimum regional and local connectivity (40 local stations directly accessible within M42/M6 ring). But if it is deemed necessary to provide a Eurogauge-compliant terminal for Birmingham (for future European services), it would be possible to provide a limited facility (perhaps 2 platforms) at the HS2-preferred site at Fazeley Street (which might be termed Fazeley Street-*lite*??).

The routeing of HSN along the M1 corridor presents several opportunities for interconnection with the existing rail network:

- North-west of Luton, the coincidence of MML and M1 allows a northward connection from Luton to HSN.
- South-east of Milton Keynes, a chord can be provided to link HSN to the Bedford-Bletchley line, and (with an E to N chord at Bletchley) to the WCML and Milton Keynes.
- South-east of Rugby, a chord from HSN to the Northampton Loop can provide links to both the Rugby-Coventry-Birmingham line, and also the main Trent Valley route to the North-West and Glasgow.
- North-west of Rugby, a triangular connection linking back to HSN trunk route to Leicester (and beyond).

This will allow the following:

- Regional cross-corridor service from St Pancras to Luton, Milton Keynes, Northampton, Coventry, Birmingham International to Birmingham New Street.
- Regional cross-corridor service from Euston to Watford, Milton Keynes, Northampton to Leicester and Nottingham – connecting to major destinations further north along HSN.
- Effective interconnection between MML and WCML corridors, linking Luton, Milton Keynes, Northampton and Leicester, and also St Pancras-Luton-Milton Keynes-Northampton-Coventry-Birmingham
- Intercity services to Birmingham via Coventry and Birmingham International.
- Avoidance of 'perverse geography', whereby Birmingham is closer (by timing) than Coventry is to London.
- Multiple diversionary routes to allow for emergencies and planned maintenance.
- Superior connections to Birmingham Airport, with northward links possible towards Leicester.
- No imperative for early construction of high speed spur to Birmingham; capacity concerns along Rugby-Birmingham corridor can be addressed by means of electrifying Nuneaton-Water Orton route to provide alternative electrified route from WCML to Birmingham.
- Instead construction can proceed to other areas (eg Transpennine) where greater marginal gains may accrue.

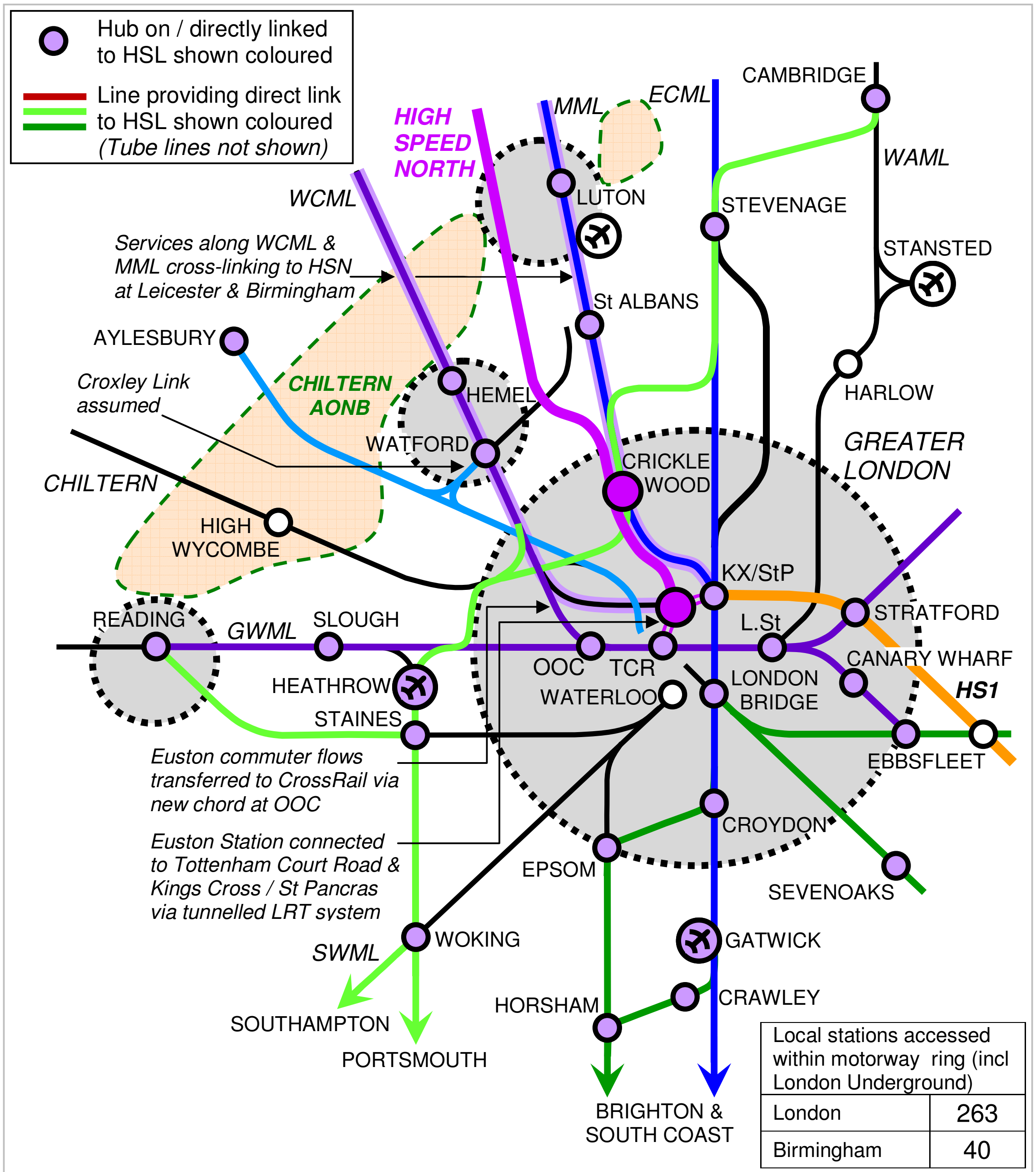
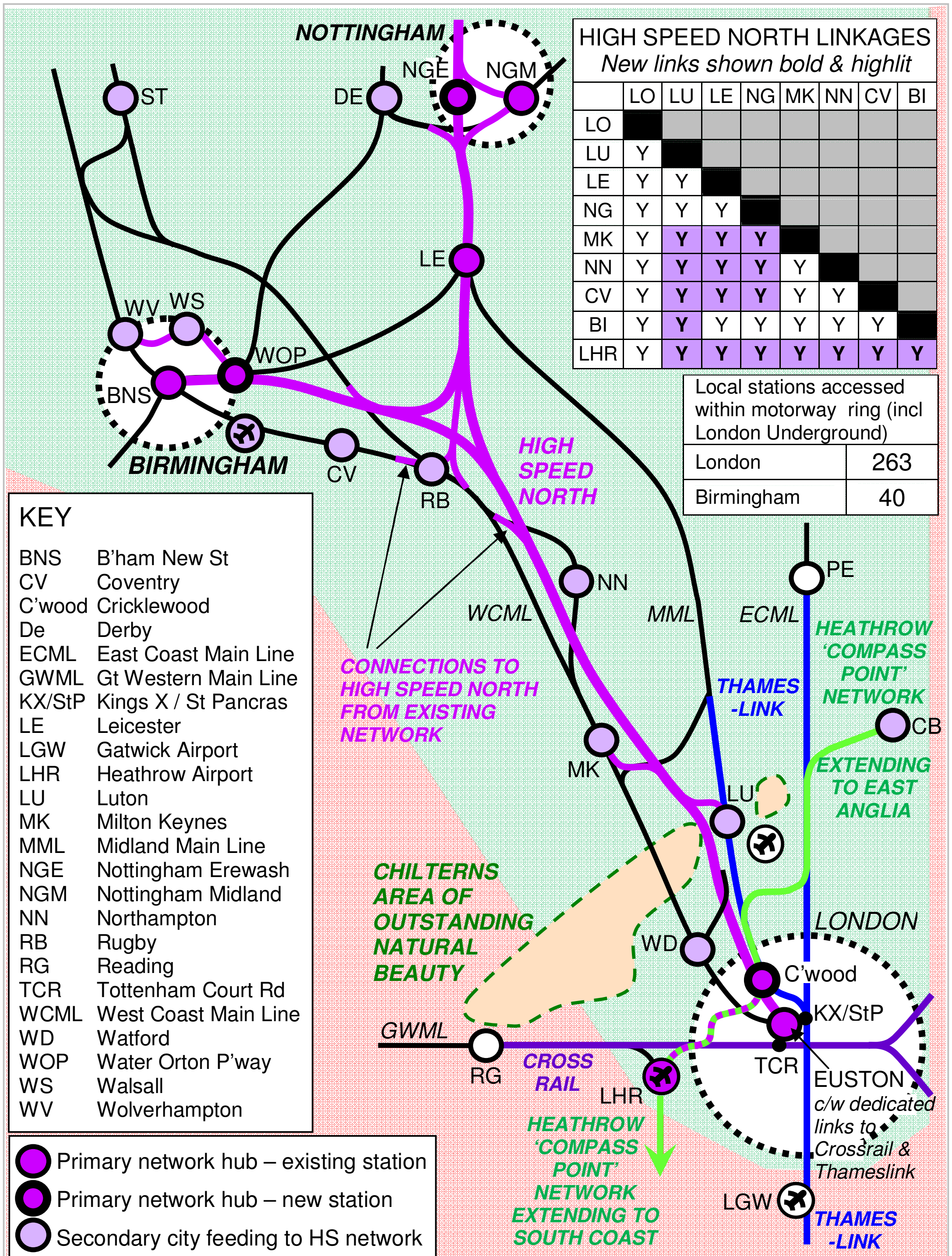


Fig Q15: High Speed North : Connectivity in London & South-East



	LO	LU	LE	NG	MK	NN	CV	BI
LO								
LU	Y							
LE	Y	Y						
NG	Y	Y	Y					
MK	Y	**Y**	**Y**	**Y**				
NN	Y	**Y**	**Y**	**Y**	Y			
CV	Y	**Y**	**Y**	**Y**	Y	Y		
BI	Y	**Y**	Y	Y	Y	Y	Y	
LHR	Y	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**

London	263
Birmingham	40

Fig Q16: High Speed North : Connectivity along London-Midlands Corridor

Q8.6 Review of Integration Issues within 'Green Zone'

The relative performance of HS2 and High Speed North in respect of integration issues is compared and contrasted in the following table with a simple judgement made (indicated by red for poor integration, and green for good integration). Reference should be made to Figures Q13, Q14, Q15 and Q16, and route descriptions, on the preceding pages.

Issue	**HS2**		**High Speed North**
Train capacity	~1100 seats in double decker Eurogauge trains 400m long. But note interoperability issues onto existing lines.		~750 seats in UK-gauge trains 400m long, in 2x200m units, splitting to access key hubs such as Birmingham New Street
Inter-operability	Eurogauge cross-section & 400m length confines HS trains to HS line.		UK-gauge HS trains capable of accessing all existing intercity network, with parallel existing routes available for diversions.
Route capacity	Chiltern route effectively limited to 2 tracks, no opportunity for 4 tracks. Hence circa 15tph, 16500 passengers per hour.		M1 alignment capable of 4-track construction. Hence circa 30tph, 22500 passengers per hour.
Speed (*assuming it to be important!!*)	More direct route to Birmingham (by 7km) & slightly faster route out of Greater London makes HS2 ~3 min faster whilst in motion.		Avoidance of secondary stop at Old Oak Common saves ~5 min from HSN timing. Overall, for same top speed, HSN 2 minutes faster to Birmingham.
Interchange to London local networks	Dual terminal policy of Euston & Old Oak Common delivers overall poor connectivity. Only **88** stations within M25 ring directly linked. No improvement proposed to Euston's poor Tube links. CrossRail-only linkage at OOC vulnerable to disruption.		Concentration upon Euston as 'Gateway to North', with dedicated shuttle links to nearby Tube hubs (and commuters diverted to CrossRail) connects to 7 (out of 10) Tube lines and both cross-London heavy rail lines. **253** stations connected.
Links to north & west London	Limited enhancements available with connection at OOC, but very poor road links, hence bus opportunities restricted.		Creation of Compass Point network, with interchange at Cricklewood (adjacent to North Circular) allows much greater connections (rail & bus) across N & W London. Connectivity improvements also available through unification of MML & WCML corridors.
Interchange to Birmingham local networks	HS2 terminal at Fazeley Street remote from New St, cross-city walk required to connect to regional network there. Direct access only to **16** suburban stations on (GW) Moor St network.		HSN focussed upon New St. for optimum connectivity to regional network. Also direct access to **40** suburban stations on LNW/ Midland network, plus feasible access to all of Moor St network..
Connection to subsidiary centres	Available via Birmingham 'Interchange', but reliant on road transport, no effective public transport access.		Available via Water Orton Parkway, with rail links to Walsall, Wolverhampton et al, motorway access also. WOP also provides splitting point.

Effects on second tier centres	With HS2 diverting trunk Birmingham-London flows, Coventry services reduced in frequency, and slower.		Integration of high speed and classic network allows Coventry services to be maintained, and possibly accelerated.
Network capacity implications	Need to maintain services to second tier centres, and continuation of intercity trains along WCML, restrict capacity gains accruing from HS2.		Interconnection with HSN avoids need for long distance express services on WCML. Reduced number of legacy 200kph services optimises capacity.
Connectivity issues: M1 corridor to HS network	Poor linkage to national network that will develop with HS2. Note that MK, Northampton & Coventry will continue to connect to Birmingham New St, while HS services will operate from Fazeley Street. Only tertiary centres along route of HS2, hence no opportunity for connection.		Routeing of HSN along M1 corridor, with frequent connection to classic network, allows new links between MML & WCML, and links all principal second tier centres (Luton, MK, Coventry) to trunk HS network at Leicester & Birmingham New St.
Connectivity issues: along M1 corridor	Existing disconnection between MML & WCML corridors left unaddressed.		Coherent rail links along the M1 corridor ie Luton to MK to Northampton to Leicester and Coventry also.
Construction emissions	HS2 generally requires heavier construction, with more massive earthworks and greater length of tunnelling (>20km).		Adherence to motorway corridor in more favourable topography reduces carbon footprint of construction, with shorter overall tunnelled length (circa 10km).
Heathrow access	Inconvenient transfer at OOC (first stage) offers poor alternative for interlining passengers, hence need for short haul connections to Heathrow (& associated CO_2 emissions) will remain. Second stage development of tunnelled loop will improve rail access to Heathrow, but limited geog. scope of improved links will remain. Hence most provincial journeys to Heathrow continue by road, hence high CO_2 emissions continue.		'Compass Point' network developed around Heathrow to extend to local communities and radial main lines. Only limited new build required to connect existing routes. HSN's efficient spine & spur configuration allows capacity for hourly dedicated HS trains direct to Heathrow CTA, via Compass Point network, offering effective interlining & wider connectivity. Most of UK either directly linked to Heathrow, or with single change of trains.
Resilience to disruption	Reliance on Eurogauge double deckers, too large & long to fit existing network, allows no diversionary route, hence HS2 vulnerable to disruption, with high CO_2 cost for undertaking essential maintenance. Issue compounded by remoteness of HS2 as 'stand alone' railway.		HSN use of interoperable trains allows diversion onto classic main lines, easily accessible by frequent interconnections. This offers greater capacity and resilience; line closures for maintenance activities much more practicable, with no significant CO_2 cost.

Table Q17: Summarised comparison of relative integration of HS2 & HSN

The issue of integration exists on two levels, both positive and negative. In a positive sense, it represents ‘value added’ to the basic function of an efficient interconurbation high speed rail scheme, in extending the benefits to a greater number of communities, and therefore an emissions conversion level of more than 23%. But in a negative sense, it represents ‘value deducted’, through poor interconnection to the local networks of the conurbations that it is remitted to serve, and hence unachieved modal shift / CO_2 reductions.

Reviewing the table on the preceding pages, it is clear that the High Speed North proposals would achieve a level of connectivity and integration of an order of magnitude greater than could be accomplished by HS2. This will lead both to greater opportunities for rail travel as an alternative to road transport (and, in the case of Heathrow, aviation also) and to greater capacity and operational resilience on the combined high speed and classic networks. All this will lead to greater potential for modal shift, and greater potential reduction in CO_2 emissions.

Moreover, this illustrates how, if correctly configured, the benefits of high speed rail can extend to journeys far more local than the 200km that has generally been assumed to date. With the scope of high speed rail extended to much shorter journeys, emissions reductions can be far greater than has previously been imagined.

It seems reasonable to infer that the integrated High Speed North proposals should be capable of converting most inter-conurbation road and air traffic, and to considerably enhance the existing intercity network to allow modal shift gains to extend towards the next tier of UK cities (the so-called secondary communities). On this basis, a conversion level of 33% has been allocated.

But HS2 offers little or no integration with the existing intercity network, and instead, the potential for considerable blight. Moreover, its basic function to provide interconurbation connectivity is compromised through poor links to the local rail networks of London and Birmingham. Hence it is difficult to see how a conversion level of more than 18% could be achieved, even along the restricted corridors that HS2 accesses.

Q8.7 Connectivity Determined by Stations Directly Linked??

Much of the foregoing comparisons centre around the connectivity of the proposed high speed terminals. Although such connectivity would ideally be measured through a detailed analysis of the journeys that residents of London and Birmingham (living in their various suburbs) would need to make to access the high speed line, it can be assessed fairly simplistically from the number of suburban/Metro stations directly linked.

This is not to infer a linear relationship between connectivity and usage ie that double the number of stations linked equates to double the number of passengers using the high speed line. But it seems reasonable to assume that there will be some sort of 'positive' relationship, with patronage of the new high speed line rising with increasing ease of connection to the new facility. This is supported by data developed by HS2 to support their proposals for London terminals.

Table 4.20 shows daily passenger flows to London & SE destinations (split into Greater London, Outer London and Heathrow Airport) for various combinations of London central and satellite terminals. The respective numbers of Metro/Tube stations directly linked are also tabulated.

The combinations considered by HS2 comprise:

- Euston acting as sole London HS terminal, with no enhancements to existing connectivity to Tube and local rail network,
- Euston (as existing) acting in combination with Old Oak Common,
- Euston (as existing) acting in combination with Heathrow Hub.

The above appears to comprise the range of interventions actively considered by HS2, for which detailed calculations of passenger flows have been undertaken. However, it must be noted that this range of potential solutions – either 'do nothing' (with respect to local connectivity), or hybrid twin-terminal – are not representative of historic good practice in developing intercity railway systems. This has almost invariably comprised the concentration of terminal activity at a single focal point, and enhancement of local rail connectivity there.

This is the essence of the alternative High Speed North proposal (of a dedicated distributor system connecting to Kings Cross / St Pancras and to Tottenham Court Road), and this is also presented, for purposes of comparison:

- Euston acting as sole London HS terminal, but with major enhancements to link to wider Tube and local rail network through provision of dedicated distributor links to Kings Cross / St Pancras and Tottenham Court Road.

Consideration of the various HS2 alternative proposals indicates a generally positive relationship between passenger flows, and numbers of stations directly connected. HS2's favoured combination of Euston and Old Oak Common directly connects to more suburban stations than Euston alone (87 vs 60, within 25km range) and the passenger numbers are approx 7% higher. Likewise Old Oak Common (with Euston) outscores Heathrow Hub (with Euston) due to the greater number of CrossRail station within close (25km) range.

It is not immediately apparent why Euston (acting alone) should attract more passengers overall than Euston and Heathrow Hub (acting in combination). This can possibly be attributed to a speed-sensitive transport study model, whereby the small increase in timings caused by the deviation via Heathrow Hub has led to a major reduction in passengers attracted to high speed rail[7].

No comparable passenger flow data exists for High Speed North. However, the massively greater number of stations directly connected to the high speed line, both within a 25km suburban ring (roughly approximating to the M25) and further afield across the entire London & SE region, would indicate that its potential to attract passengers to the high speed line is correspondingly increased.

Proposal	HS2			High Speed North
London terminal configuration	Euston alone	Euston plus Old Oak Common	Euston plus Heathrow Hub	Euston, with developed links to adjacent hubs
Destination	*Forecast users of satellite terminal (Old Oak Common or Heathrow Hub)*			
Greater London		31200	13800	figures not available
Outside London		17400	24400	
Heathrow		1400	2000	
Total		50000	40200	
Destination	*Forecast users of London terminal (Euston)*			
Greater London	113200	84000	79200	figures not available
Outside London	20000	11000	9200	
Heathrow	1000	0	0	
Total	134200	95000	88400	
Destination	*Total users of London & Satellite terminals*			
Greater London	113200	115200	93000	figures not available
Outside London	20000	28400	33600	
Total Heathrow	1000	1400	2000	
Total non-LHR	133200	143600	126600	
	Stations accessed along Tube/Metro corridors			
No of stations directly linked	Northern (x2) Victoria	Northern, Victoria CrossRail	Northern, Victoria CrossRail	Northern (x2) Victoria, Met/Circle Central, CrossRail, Thameslink, Piccadilly
Within 25km	60	87	76	263
Outside 25km	0	9	20	70##
Total	60	96	96	333

Approx figure – dependent upon precise coverage of CrossRail & Thameslink

Table Q18: Passenger Distribution at HS2 London & Satellite Terminals

It is noted that the High Speed North London terminal strategy discussed in this section does not include a 'Heathrow component'. This issue is covered separately in Appendix F.

However, it is worth pointing out at this stage the difference in magnitude, as revealed in the HS2 data, between passenger flows to Greater London (for which a central London terminus, with appropriately developed connectivity, would be the optimum solution) and passenger flows to Heathrow. Although there is no doubting the political and economic importance of achieving high speed rail access to Heathrow, these flows are almost

[7] The degree to which a small increase in journey time might deter passengers from taking the train, rather than the car or the plane, is a highly debatable matter. A full discussion of issues surrounding speed, and journey time savings, is contained in Appendix B7.

insignificant, in pure statistical terms. There appears to be a clear danger that the solution that is required for the many (ie the 100000+ making intercity/interconurbation journeys) may be unduly influenced by the needs of the relatively few (ie the 1000-2000 making journeys to Heathrow, according to HS2 data).

The passengers who might take advantage of connections at Old Oak Common or Heathrow Hub for destinations in the Thames Valley along the CrossRail corridor cannot be ignored. But unlike flows to Heathrow (for which a national/regional interest argument can be advanced) there seems to be no reason why the needs of passengers to communities along the CrossRail corridor should be unduly prioritised over those en route to destinations (say) along the many Thameslink routes that will spread south and north of London. The needs of all passengers should be considered in a balanced manner, with a view to achieving an optimised and integrated solution.

These issues are discussed in greater detail in Item Q8.8. In the case of Thames Valley passengers, appropriate integration between 'Green Zone' and 'Red Zone' would facilitate a variety of options for connection to the high speed line. See Figures Q19, Q20 and Table Q21.

Q8.8 Integration between 'Green Zone' and 'Red Zone'

A key goal of any high speed rail proposal is to optimise both emissions reductions and business performance through maximised modal shift. The physical extent of the high speed line must, of necessity, be restricted to a certain part of the country, and that in turn must restrict its ability to facilitate modal shift outside of its 'Zone of Influence'.

For a northern-oriented high speed line, that Zone of Influence has been termed the Green Zone, in which 40 million of the UK's 60 million population live; the remaining 20 million, one third of the population inhabit the Red Zone. As shown in Figure 4.5, emissions attributable to exclusively Green Zone journeys represent 44% of the total, while Red Zone journeys represent 11%; crossover flows between Green and Red Zone account for the balance (ie 44%).

It is clearly vital that any northern high speed line (which by definition will remain within the Green Zone) should capture as many as possible of these Red Zone crossover flows. This demands optimised integration, so that passengers may either make a convenient interchange to high speed services, or travel on high speed services originating from within the Red Zone.

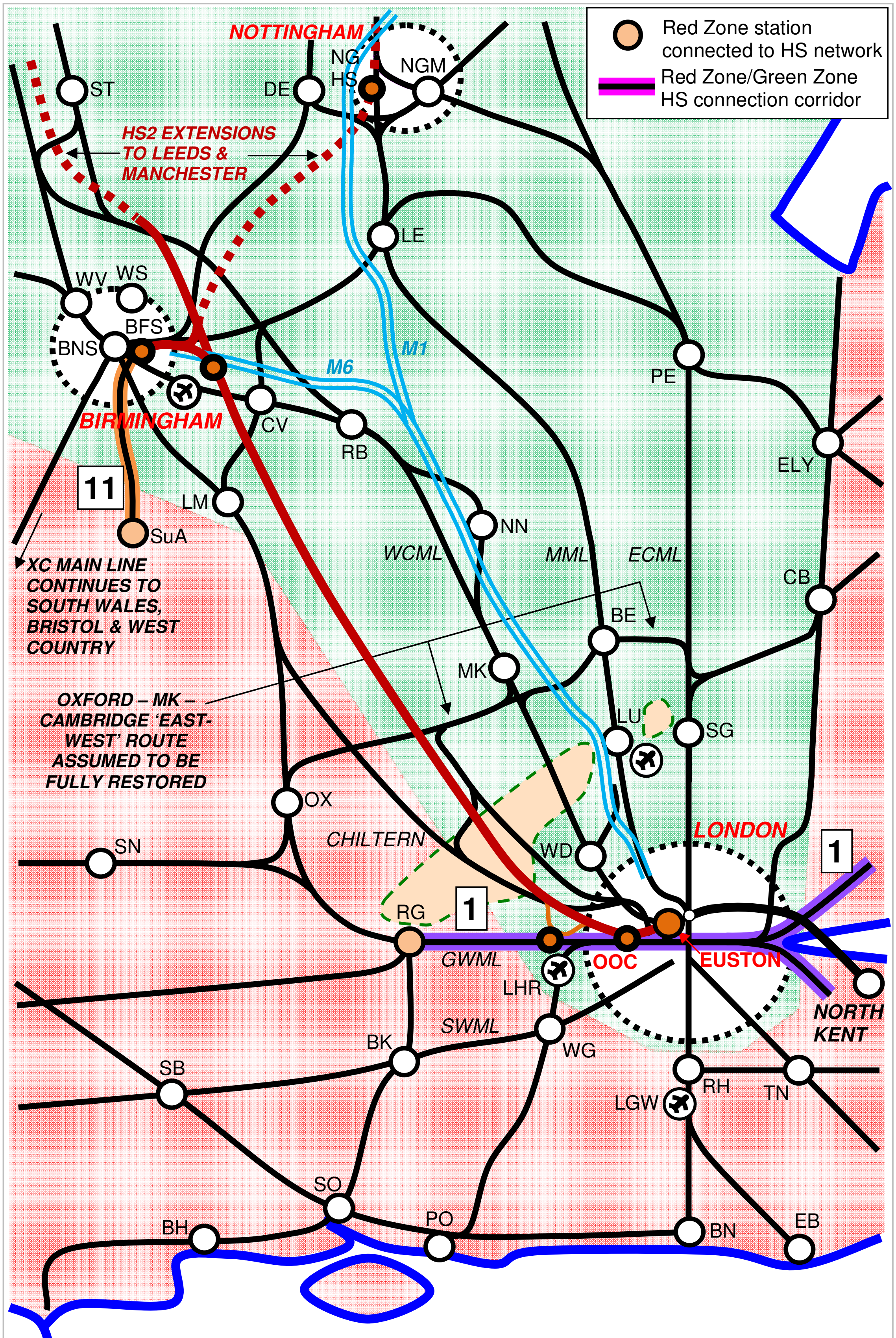


Fig Q19: HS2 : Connectivity into Red Zone

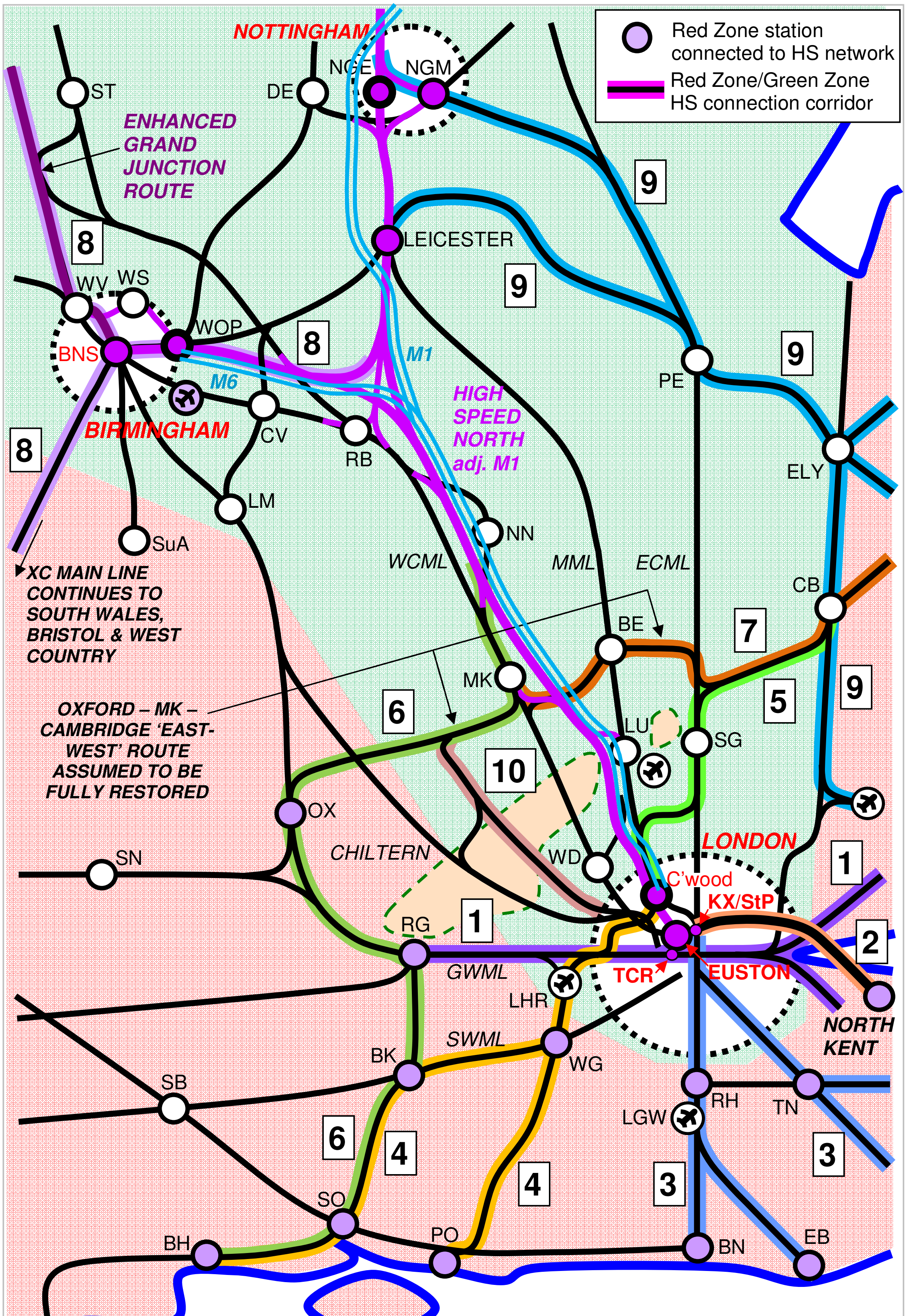


Fig Q20: High Speed North : Connectivity into Red Zone

- *Fig Q19: HS2 : Connectivity into Red Zone*
- *Fig Q20: High Speed North : Connectivity into Red Zone*

Figures Q19 and Q20 illustrate the potential connectivity between Red and Green Zones, with 'interconnection corridors' identified by a boxed number. These are clarified in Table Q21 below, with commentary as follows:

Interconnection corridor		HS2	High Speed North
1	CrossRail: Reading to NE & SE London	HS2 link to CrossRail at Old Oak Common	Transfer from CrossRail, Thameslink and Kent Coast HS services facilitated by terminal integration with LRT shuttle connection from KX/StP-Euston-TCR
2	Kent Coast HS services	No connection proposed between Euston & KX/StP	
3	Thameslink to South Coast		
4	Heathrow Compass Point services from Wessex	Only limited improvement offered to Heathrow connectivity	Orbital services focused on Heathrow permit Cricklewood connection
5	Heathrow Compass Point services from East Anglia		
6	Wessex & Thames Valley intercity to EM, North & Scotland, via restored East-West Route & Milton Keynes	No intermediate connection points along HS2 between London & Birmingham	Integration of HSN with WCML route in SE Midlands area permits access from East-West route and Milton Keynes onto high speed line, to allow through HS services from South Coast
7	Local services along East-West route to Milton Keynes		
8	S. Wales, Severn Valley & West Country intercity to East Midlands, North & Scotland	Difficult connection to HS services at Birmingham due to separation of New St and Fazeley St	Focus of HS services on New St allows through HS services from South-West, matching existing service patterns.
9	East Anglia intercity to East Midlands, North & Scotland	Not proposed by HS2, north-facing connection from Nottingham (central) not viable with 'fan' format, and Leicester bypassed by HS2	East Anglian connection much more viable with HSN 'spine & spur' configuration. Northward connection from Nottingham allows through routeing, Leicester allows hub connections
10	Chiltern Line extended to connect with East-West route at Milton Keynes for access to national network	HS2 trunk route bypasses all major (ie second tier) intermediate communities	East-West route and HSN transform MK's hub connectivity, linking to all parts of national network
11	Stratford (upon Avon) line commuter services	Facilitated through proximity of Moor St and Fazeley St stations	Focus on New St reduces connectivity to Moor St services, but achieves wider local and regional connectivity

Table Q21: Interconnection Potential between Red Zone & High Speed Line

It is clear, from all of the above comparisons, that High Speed North will integrate far better with the wider UK rail network. This is a vital consideration, both for optimising potential modal shift and consequent CO_2 emissions, and also for preserving the integrity of existing rail services.

A particular case in point is the existing CrossCountry network, which is focussed upon New Street Station in Birmingham. With the divisions in the main line network created by the multiplicity of London terminus stations, it is Birmingham New Street that, more than anywhere else, provides the 'glue' of the UK rail network. The volume and scope of intercity journeys that are dependent upon through running, or connections, at Birmingham New Street, is set out in Table Q12. These amount to nearly 40% of the 'crossover' emissions between Red and Green Zones, or nearly 20% of convertible UK transport CO_2 emissions.

It is difficult to avoid the conclusion that HS2's proposed segregation between high speed services (at Fazeley Street) and classic services (at New Street) will act as a major deterrent to longer-distance journeys between from Scottish, Northern and East Midlands cities to destinations in Wales, the West Country, and along the South Coast. As such, it would seem certain to greatly damage the existing intercity network, and, rather than promoting modal shift and emissions reductions, would do precisely the opposite.

Hence the Fazeley Street proposal, comprising a segregated terminus station in a major inland city at the heart of the existing UK rail network, would appear to be unfit for purpose.

Q9 CO_2 Value of Modal Shift

The foregoing sections have collectively defined the proportion of existing transport emissions that might be convertible, given the intervention of high speed rail. But the degree by which transport emissions will actually be reduced is dependent upon the differential between the emissions of road (and aviation), and the emissions of high speed rail. This is termed the Differential Environmental Performance Indicator, or EPI_{diff}.

The fifth step therefore is to assess the environmental performance of high speed rail (in terms of grams of CO_2 per passenger kilometre) that will apply for each candidate scheme. This will be based upon the RSSB figure of $92g_{CO2}$/pass.km, applicable for 300kph speed and 30% load factor, and modified to take due account of operating speed and load factor deduced for each candidate scheme.

- *Fig Q22: Differential EPIs between private car, domestic aviation and HSR, for varying rail speeds*

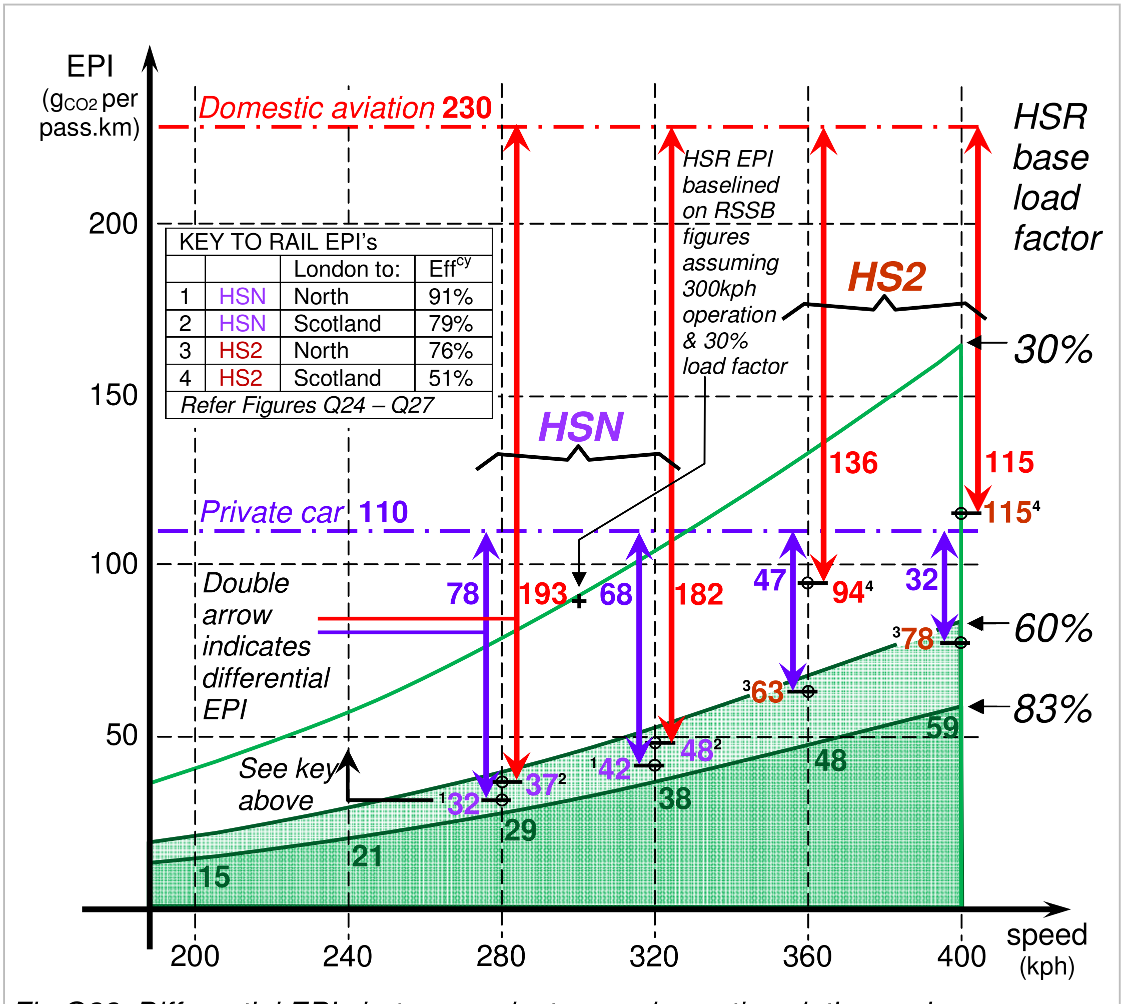


Fig Q22: Differential EPIs between private car, domestic aviation and HSR, for varying rail speeds

Figure Q22 on the preceding page summarises the calculation of differential EPIs for varying speed and load factor conditions. The following assumptions are made:

- EPI varies proportionate to the square of speed.
- EPI is adjusted to reflect higher load factors anticipated for semi-forced modal shift conditions, whereby CO_2 and fuel supply concerns compel travel choices according to lowest feasible environmental cost.
- 83.3% load factor (reflecting a moderate 20% overprovision of seats to cater for day to day peaks and troughs in demand) is assumed. This figure also encompasses any marginal variance in EPI due to increasing mass of passengers relative to rail vehicle.

The 83.3% load factor line forms the base line against which more precise EPIs are calculated, taking into account the variance in achievable load factor / relative operational efficiencies that will apply to different route configurations.

Q9.1 Operational Efficiency Leading to Superior EPI

- *Fig Q23: Greater Operational Efficiency from Concentration of Services onto Core Route*

It must be appreciated that different route configurations have different fundamental efficiencies. There is a basic inefficiency in any railway operation, resulting from the basic incompatibility of fixed train units (in high speed rail terms, likely to comprise individual or paired coupled multiple units, each of 200m length) against flow rates that vary both through the day, and to a lesser extent, also seasonally.

Figure Q23 illustrates an idealised scenario, by which train units are fitted onto a diurnal traffic flow with morning and evening peaks, and lesser flows at other times, diminishing to zero at either end of the day. The grey areas of the blocks, above the variable flow line, represent empty seats, and load factor can be calculated from occupied seats divided by total number of seats.

The scenario illustrated in Figure Q23 is broadly analogous to that of Manchester, Leeds and Sheffield, whereby the 3 conurbations might be connected to London by separate routes (as per the current intercity rail network, or under HS2 proposals) or by a core (or 'spine') route (as with High Speed North) which might split at Sheffield, and continue separately on the relatively short sections to Leeds and Manchester.

Under HS2 proposals, the proposed network will operate largely as a London-centric 'fan', and (with few if any worthwhile intermediate stops) the conurbation at the end of the route is responsible for filling the train. If each route has to operate individually, then under service levels unlikely to exceed 3 trains per hour, the relatively crude adjustment that it is possible across the day (ie 3, 2 or 1 train per hour) will inevitably entail a considerable number of empty seats, and a relatively low load factor.

There is a much higher inherent efficiency under the High Speed North proposals. The concentration of the routes to all 3 Northern conurbations onto a single spine effectively combines the three individual diagrams into a composite diagram, and the fitting of train blocks onto the larger composite shows relatively less grey space. This implies higher load factor, and this can be confirmed by a simple counting of the train units represented by the blocks.

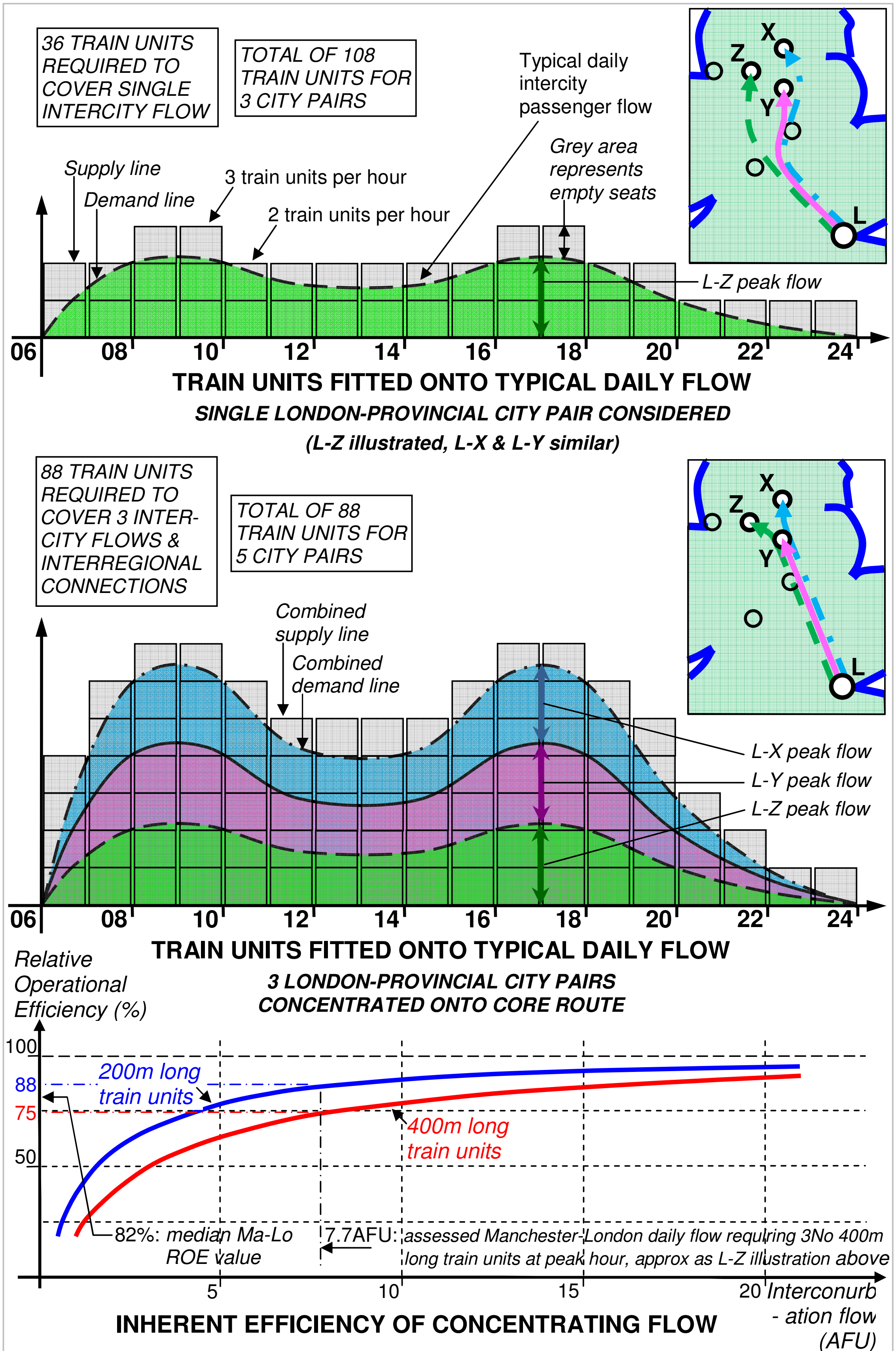


Fig Q23: Greater Operational Efficiency from Concentration of Services onto Core Route

The individual diagrams require 36 train units to cover a day's service, or 108 for all 3 separate routes; but if the 3 services can be combined onto a single core route, then only 88 train units are required, and an interregional service is also provided. This implies higher route capacity and higher operational efficiency (through fewer trains to cover the same flow), in addition to better load factor; and from all this, superior environmental performance will also result.

Figure Q23 also details the Relative Operational Efficiencies (ROE) that will apply for varying traffic flows (measured in AFU's, or Arbitrary Flow Units, as derived from the InterConurbation Connectivity Matrix, see Figure Q3), for both 200m and 400m long train units. A median value of ROE, reflecting mixed use of 200m and 400m long train units, is used in the subsequent calculation of corridor-specific ROE.

Q9.2 Calculation of Corridor-Specific Relative Operational Efficiency

It is important to be able to quantify the benefits of efficient routeing, in terms of the detail of the candidate schemes, route lengths and populations of the conurbations served, and considering flows on the following grouped high speed corridors:

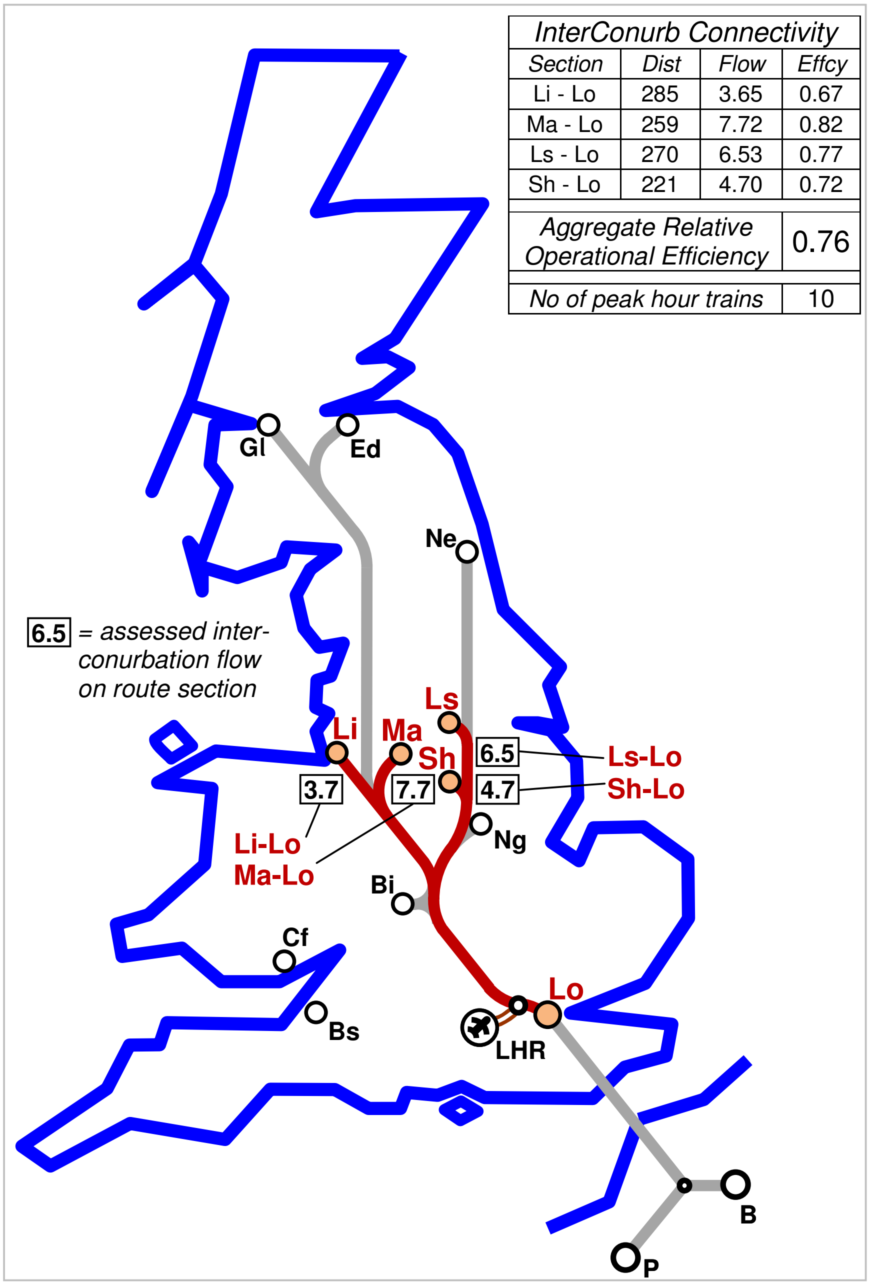
- from London to Northern cities,
- from London to the North-East and Scotland, and also
- from Birmingham to East Midlands, Yorkshire and the North-East.

- ➢ *Fig Q24: HS2 : Northern InterConurbation Connectivity*
- ➢ *Fig Q25: High Speed North : Northern InterConurbation Connectivity*

The flows shown on Figure Q24 are the respective ICC scores for Liverpool, Manchester, Leeds and Sheffield's traffic via the HS2 'Y' to London (as set out in the InterConurbation Connectivity Matrix shown in Figure Q3). The flows shown on Figure Q25 are also derived from the ICCM, but are aggregated to reflect the sum of the possible journeys available via High Speed North. In both cases, possible extra stops in the Midlands ie Birmingham 'Interchange' for HS2, or Nottingham (Erewash) and Leicester for High Speed North, are discounted from the calculation.

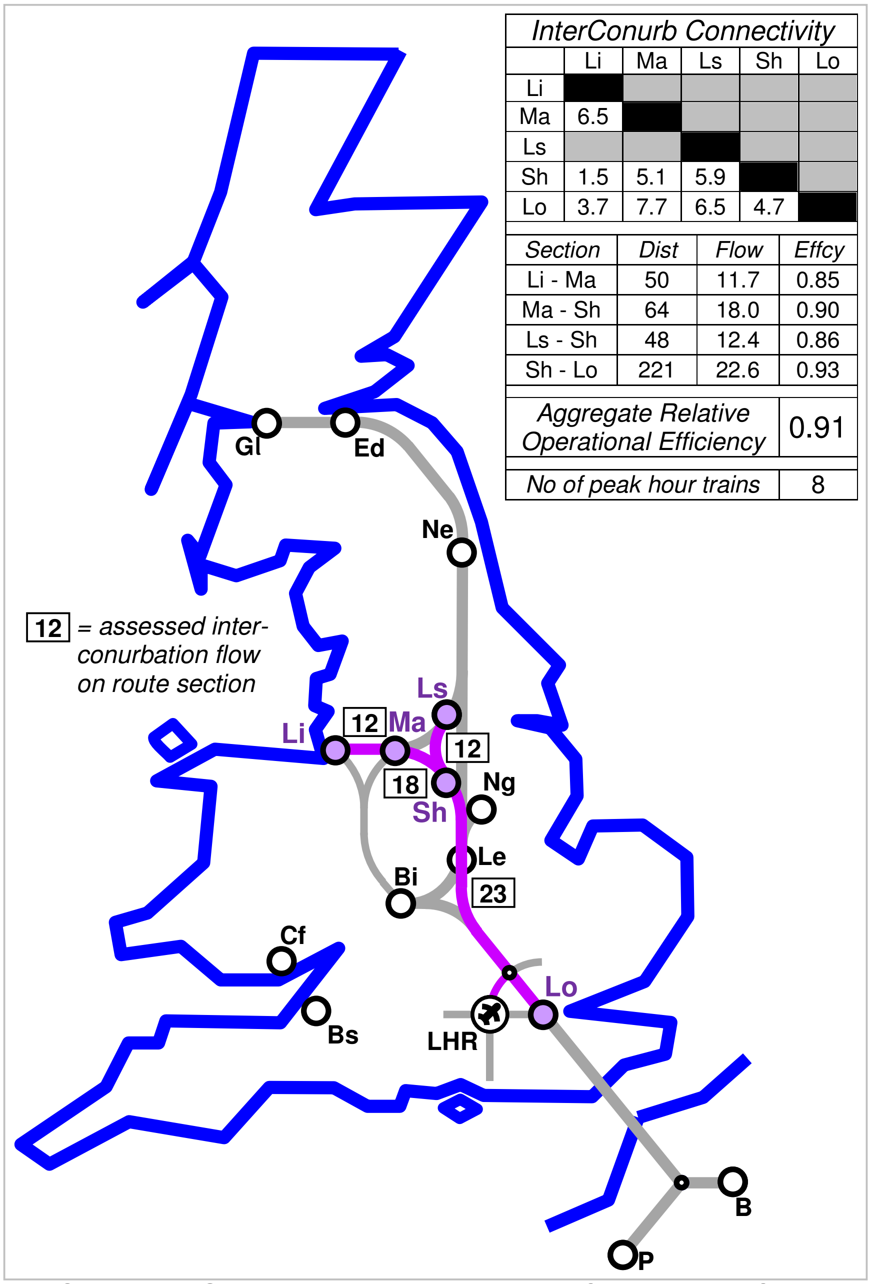
The achievable efficiency of each flow is assessed, by reference to the graph in Figure Q23, and the results are aggregated into a single average Relative Operational Efficiency (ROE), taking due account of flow/connectivity and distance. High Speed North shows an approximate 20% advantage over HS2 (0.91 vs 0.76).

It should be noted that the location of Sheffield, at the splitting point between routes to Manchester/Liverpool and to Leeds, could offer further efficiencies for an intensively-operated service working at high load factors. Booking of seats is presumed to be essential, and, in the case of a train splitting at Sheffield for (say) Manchester and Leeds, passengers for Sheffield could be allocated to either portion of the train, dependent upon whether bookings are higher for Leeds or Manchester on a particular service on a particular day. This would allow practicable base load factors even higher than the 83.3% currently assumed. No account has been taken so far of this factor, but it should indicate even greater efficiencies for the 'spine and spur' configuration of High Speed North.



InterConurb Connectivity			
Section	*Dist*	*Flow*	*Effcy*
Li - Lo	285	3.65	0.67
Ma - Lo	259	7.72	0.82
Ls - Lo	270	6.53	0.77
Sh - Lo	221	4.70	0.72
Aggregate Relative Operational Efficiency			0.76
No of peak hour trains			10

Fig Q24: HS2 : Northern InterConurbation Connectivity



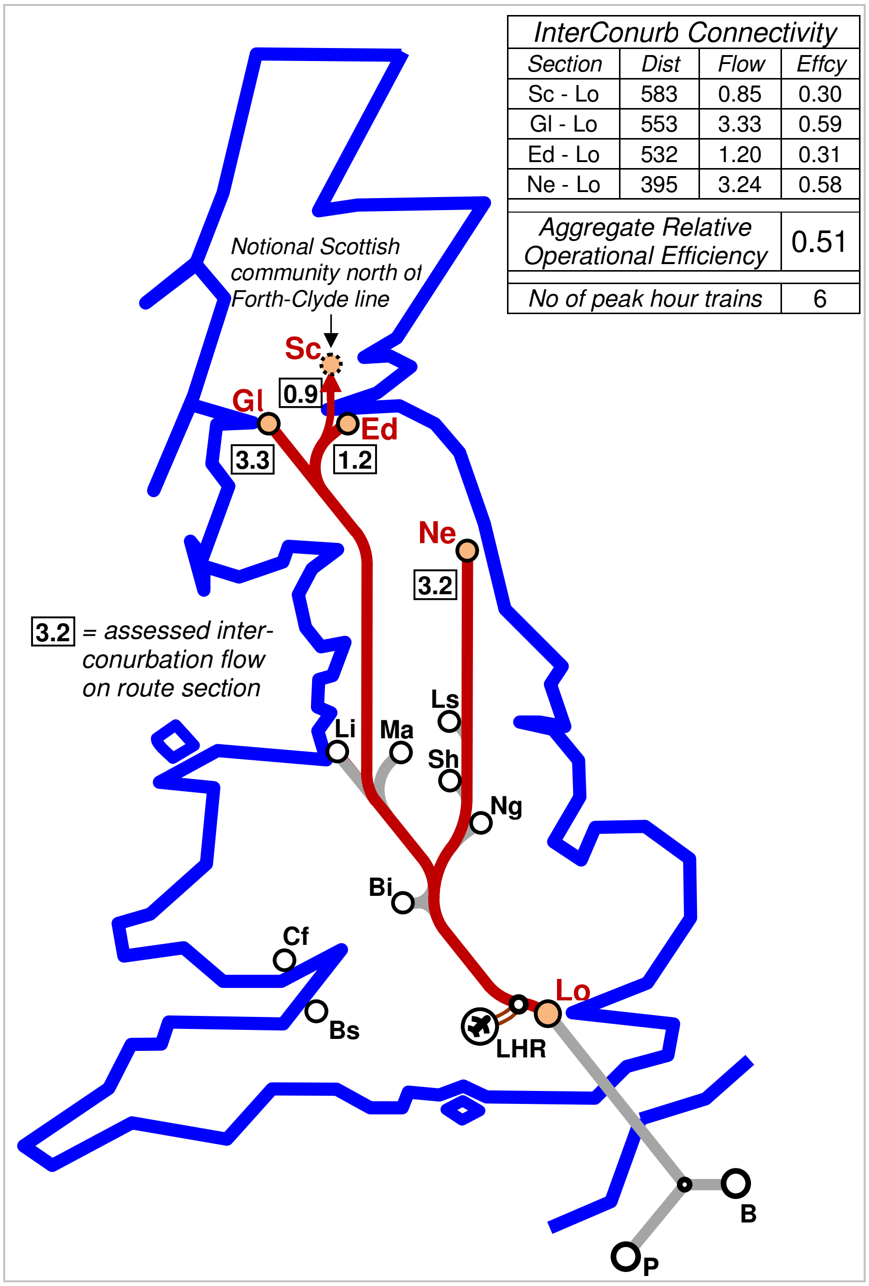
InterConurb Connectivity					
	Li	Ma	Ls	Sh	Lo
Li					
Ma	6.5				
Ls					
Sh	1.5	5.1	5.9		
Lo	3.7	7.7	6.5	4.7	

Section	*Dist*	*Flow*	*Effcy*
Li - Ma	50	11.7	0.85
Ma - Sh	64	18.0	0.90
Ls - Sh	48	12.4	0.86
Sh - Lo	221	22.6	0.93

Aggregate Relative Operational Efficiency	0.91
No of peak hour trains	8

Fig Q25: High Speed North : Northern InterConurbation Connectivity

- *Fig Q26: HS2 : N.E & Scottish InterConurbation Connectivity*
- *Fig Q27: High Speed North : NE & Scottish InterConurbation Connectivity*



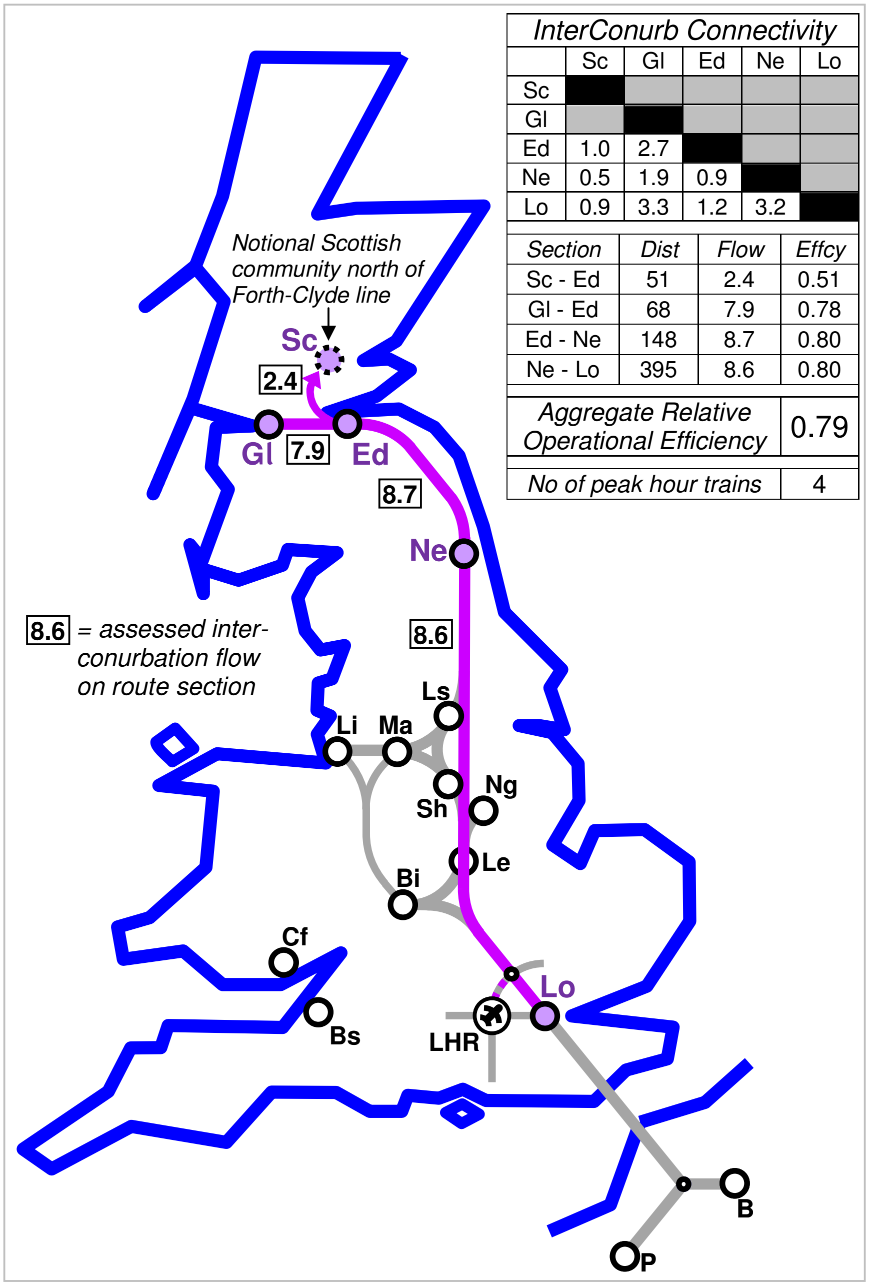
InterConurb Connectivity			
Section	*Dist*	*Flow*	*Effcy*
Sc - Lo	583	0.85	0.30
Gl - Lo	553	3.33	0.59
Ed - Lo	532	1.20	0.31
Ne - Lo	395	3.24	0.58
Aggregate Relative Operational Efficiency			0.51
No of peak hour trains			6

Fig Q26: HS2 : N.E & Scottish InterConurbation Connectivity

Figures Q26 and Q27 illustrate the flows to the most northerly conurbations ie Newcastle, Edinburgh and Glasgow. Noting the connectivity requirement for communities to the north of the Forth-Clyde line, and the need to fully convert Scottish air flows, a notional northern Scottish community, equivalent to Aberdeen, Dundee, Perth and the Fife towns has also been modelled, at a notional population of 600,000, with an assumed route via either Cumbernauld and Stirling, or via the Forth Bridge (ie for HS2, independent of both Edinburgh and Glasgow).

As with Liverpool, Manchester, Leeds and Sheffield, HS2's routeings to the North-East and to Scotland require 4 separate train patterns to operate relatively low flows. Any splits that might occur would take place in relatively unpopulated areas, either in mid-Lanarkshire (similar to the present Carstairs Station) or at a parkway on the fringes of Edinburgh or Glasgow. This represents an inefficiency, in uneven pairings with no major balancing traffic joining at the splitting point.

High Speed North would operate a much more efficient spine route, passing through the centres of Newcastle and Edinburgh en route to Glasgow and splitting at Edinburgh for northern Scottish destinations. Flows on individual sections would be of the order of 2½ times that achieved by the HS2 'Y'. In terms of ROE, High Speed North shows an approximate 55% advantage over HS2 (0.79 vs 0.51).



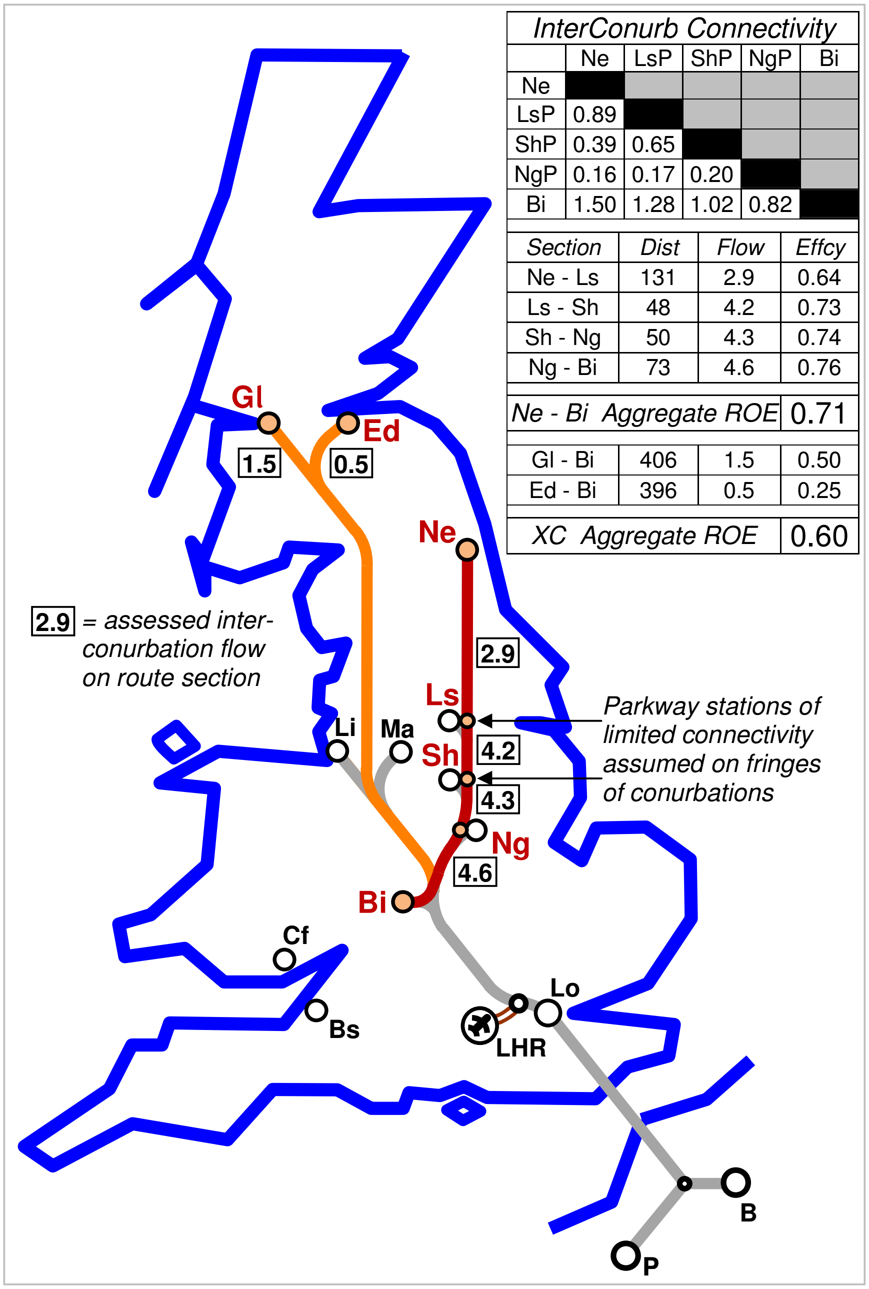
InterConurb Connectivity	Sc	Gl	Ed	Ne	Lo
Sc					
Gl					
Ed	1.0	2.7			
Ne	0.5	1.9	0.9		
Lo	0.9	3.3	1.2	3.2	

Section	*Dist*	*Flow*	*Effcy*
Sc - Ed	51	2.4	0.51
Gl - Ed	68	7.9	0.78
Ed - Ne	148	8.7	0.80
Ne - Lo	395	8.6	0.80

Aggregate Relative Operational Efficiency	0.79
No of peak hour trains	4

Fig Q27: High Speed North : NE & Scottish InterConurbation Connectivity

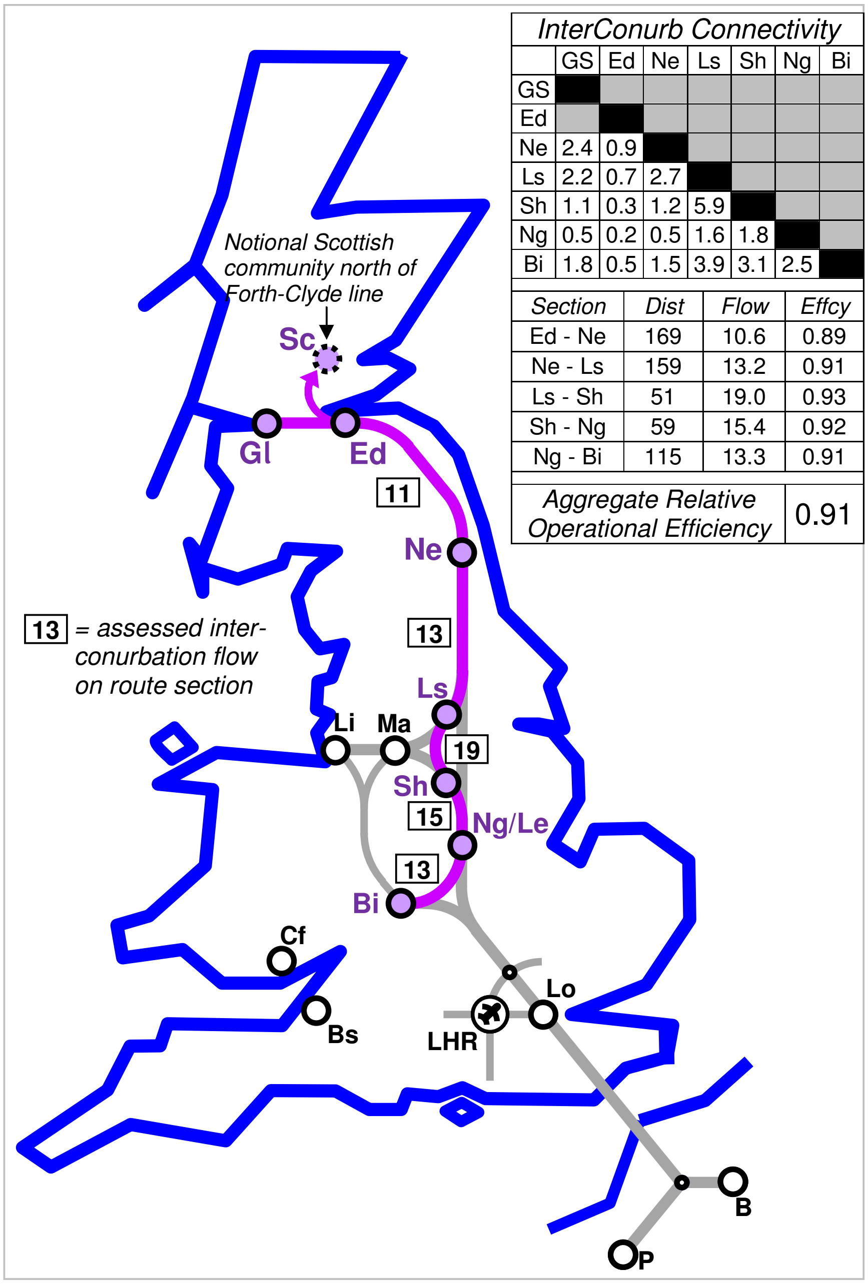
- *Fig Q28: HS2 : CrossCountry InterConurbation Connectivity*
- *Fig Q29: High Speed North : CrossCountry InterConurbation Connectivity*



InterConurb Connectivity	Ne	LsP	ShP	NgP	Bi
Ne					
LsP	0.89				
ShP	0.39	0.65			
NgP	0.16	0.17	0.20		
Bi	1.50	1.28	1.02	0.82	

Section	*Dist*	*Flow*	*Effcy*
Ne - Ls	131	2.9	0.64
Ls - Sh	48	4.2	0.73
Sh - Ng	50	4.3	0.74
Ng - Bi	73	4.6	0.76
Ne - Bi Aggregate ROE			0.71
Gl - Bi	406	1.5	0.50
Ed - Bi	396	0.5	0.25
XC Aggregate ROE			0.60

Fig Q28: HS2 : CrossCountry InterConurbation Connectivity



InterConurb Connectivity

	GS	Ed	Ne	Ls	Sh	Ng	Bi
GS							
Ed							
Ne	2.4	0.9					
Ls	2.2	0.7	2.7				
Sh	1.1	0.3	1.2	5.9			
Ng	0.5	0.2	0.5	1.6	1.8		
Bi	1.8	0.5	1.5	3.9	3.1	2.5	

Section	*Dist*	*Flow*	*Effcy*
Ed - Ne	169	10.6	0.89
Ne - Ls	159	13.2	0.91
Ls - Sh	51	19.0	0.93
Sh - Ng	59	15.4	0.92
Ng - Bi	115	13.3	0.91

Aggregate Relative Operational Efficiency	0.91

Fig Q29: High Speed North : CrossCountry InterConurbation Connectivity

Figures Q28 and Q29 illustrate north-eastward high speed flows from Birmingham to Edinburgh and Glasgow, via the westerly arm of the HS2 'Y', and to Newcastle, via the easterly arm. For High Speed North, all these flows can be encompassed on the single spine to the north. As befitting a CrossCountry service, all intermediate cities/conurbations are modelled to maximise the available traffic.

The HS2 westerly arm is presumed to follow an alignment parallel to the WCML, with no conurbation calling points en route. With no available fast route through Manchester, on a north-south axis (short of a very long tunnel, unlikely to be deemed viable for the relatively low traffic reliant on such infrastructure) it does not appear possible to include Manchester on the Birmingham – Scotland high speed route, unless with major time penalties that would probably be deemed unacceptable.

The HS2 easterly arm is presumed to comprise a time-sensitive trunk line that avoids all intermediate conurbations en route to its final destination in the North-East, with central Nottingham, Sheffield and Leeds all bypassed, and parkways located on the city fringes. Such parkways are generally poorly located, asymmetric to the centroid of the wider conurbation that they are intended to serve, and with perhaps one-third of the traffic-generating potential of a city centre station. For the purposes of this exercise, the ICCM has been recalculated with Nottingham, Sheffield and Leeds valued at one third[8] of their true conurbation populations.

Separation of the time-sensitive trunk route to the North-East and Scotland from the 'Yorkshire Loop' (formed from the two Transpennine approach arms) enables a CrossCountry route capable of far better integration with local networks at Sheffield (Meadowhall) and Leeds (City). Nottingham would still comprise a parkway, but is modelled as a city centre station, noting proximity of Leicester (with a proposed integrated high speed / classic hub at the existing London Road station).

As with London – Scotland flows, the concentration of connectivity onto a single core route would result in much greater and more efficient flows and in turn give rise to higher load factors. In terms of ROE, High Speed North shows an approximate 50% advantage over HS2 (0.91 vs 0.60) along the CrossCountry axis.

However, the relatively low flows indicated on the 'West Coast' route from Birmingham to Scotland (1.5 to Glasgow and 0.5 to Edinburgh) must cast doubt upon whether such a service would be viable in non-stop 'high speed' mode, or whether it would be more appropriate to retain the current slower 'classic' service, based upon frequent intermediate stops to maximise passenger numbers.

The figures indicate that the HS2 'CrossCountry' along the eastern arm of the 'Y' would have a greater fundamental viability (albeit still significantly underperforming with respect to High Speed North). But if only the eastern arm were to operate, the completeness of Birmingham's high speed rail connectivity would be compromised, and the entire HS2 proposition would become still more London-centric.

Results are summarised as follows for the sample flows considered.

<table>
<tr><th></th><th colspan="4">HS2</th><th colspan="4">High Speed North</th></tr>
<tr><th>Flow / Route</th><th>Relative Operational Efficiency</th><th>No of train patterns</th><th colspan="2">Peak tph from London</th><th>Relative Operational Efficiency</th><th>No of train patterns</th><th colspan="2">Peak tph from London</th></tr>
<tr><td>London to North</td><td>0.76</td><td>4</td><td>10</td><td rowspan="2">Σ16</td><td>0.91</td><td>2
(1 if split at Sheffield)</td><td>8</td><td rowspan="2">Σ12</td></tr>
<tr><td>London to NE & Scotland</td><td>0.51</td><td>4</td><td>6</td><td>0.79</td><td>2
(1 if split at Edinburgh)</td><td>4</td></tr>
<tr><td>CrossCountry from Birmingham</td><td>0.60</td><td>3
(2 if split at Carstairs)</td><td colspan="2"></td><td>0.91</td><td>1</td><td colspan="2"></td></tr>
</table>

Table Q30: Summary of Relative Operational Efficiency and Service Levels

[8] This is supported by Greengauge21 research, which indicates that a central Birmingham station would contribute flows approximately 3 times greater than a 'parkway' located near Birmingham Airport (close to the proposed location of HS2's Birmingham Interchange).

Q9.3 Calculation of Differential Environmental Performance Indicator

The Relative Operational Efficiency (ROE) scores are applied to the base EPI values, relating to particular speeds and load factors. This has the effect of reducing the EPI attributable to the base load factor, to an EPI specific to the relevant flow, either English interconurbation, or Anglo-Scottish. For the former, a differential EPI is then calculated against roads emissions (typically $110g_{CO2/pass.km}$); for the latter, a differential EPI is calculated against aviation emissions (typically $230g_{CO2/pass.km}$).

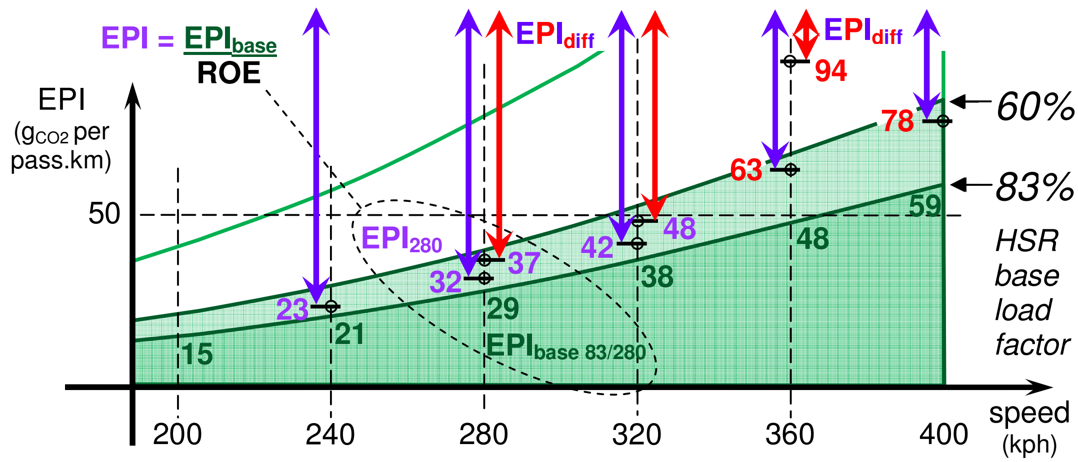


Fig Q31: Differential EPIs between private car, domestic aviation and HSR, for varying rail speeds

Mode	Conversion to Rail	High Speed North			HS2	
EPI	HSR speed (kph)	240	280	320	360	400
%age	EPI_{HSR} @ 83% LF	21	29	38	48	59
Car	ROE to North	0.91	0.91	0.91	0.76	0.76
110g	Modified EPI_{HSR}	23	32	42	63	78
52.5%	Differential EPI_{HSR}	87	78	68	47	32
%age of total CO_2	Average EPI_{diff} / %red^n	$77g_{CO2/p.km}$ /		70%	$47g_{CO2/p.km}$ /	43%
Plane	ROE to Scotland	0.79	0.79	0.79	0.51	0.51
230g	Modified EPI_{HSR}	27	37	48	94	115
1.5%	Differential EPI_{HSR}	203	193	182	136	115
%age of total CO_2	Average EPI_{diff} / %red^n	$187g_{CO2/p.km}$ /		81%	$136g_{CO2/p.km}$ /	59%
Lorry/van	Rail Freight speed (kph)	125kph, as existing			125kph, as existing	
Z g	$EPI_{FREIGHT}$	Z/3			Z/3	
35%	Differential EPI_{HSR}	2Z/3			2Z/3	
%age of total CO_2	Percentage Reduction			67%		67%
representing 89% of total CO_2	Overall %age reduction			71%		50%

Table Q32: Calculation of Potential Operational Emissions Reductions through Modal Shift to High Speed Rail

The differential EPIs are expressed as a percentage reduction against roads and air emissions, and are combined as a weighted average, noting the proportions of CO_2 attributable to roads and air (52.5% and 1.5%). It is necessary also to take account of the 35% of transport emissions arising from road haulage (ie HGVs and LGVs), and for this, a simple assumption is made, that the transfer of freight from road to rail will result in an overall reduction to one third[9] of current emissions.

Taken as a whole, the lower speeds and greater routeing efficiency of High Speed North allow an intercity/interconurbation rail journey to be made at 29% (71% reduction) of the emissions of the equivalent road journey. HS2's higher speeds and less efficient routeing result in only a 50% saving being made. These figures are applied in the overall emissions reduction table (Table 4.11) in Section 4.10.

Q9.4 Other Operational Considerations

The superior load factors achievable through the 'spine and spur' configuration of High Speed North have other benefits, aside from simple emissions savings. Assuming constant numbers of people travelling, higher load factors translate as lesser numbers of trains operating. This has clear benefits, both environmental and financial; but possibly the most important benefit lies with the extra line capacity released.

Table 4.32 indicates that at peak times, High Speed North needs to run 12 trains per hour to Northern (8tph) and Scottish destinations (4tph); but to cover the same flows to the same destinations, HS2 would have to operate 16tph (10+6). To these flows must be added the traffic from the West and East Midlands, perhaps another 4tph.

16-20 trains per hour on HS2's trunk route from London to the West Midlands would effectively consume all the available line capacity on a 2-track trunk route through the Chilterns (HS2 project an initial 14tph line capacity, rising to 18tph with developing signalling technology). This of course raises questions of 4-track construction (see Item Q6.2). Although there is no doubt that this would be technically feasible, even through the Chilterns, this could only be accomplished at major additional intrusion and engineering cost (particularly the doubled requirement for 2-track tunnels). All of this would appear to be both politically and economically unacceptable. The Chiltern route would also appear to be incapable of subsequent quadrupling.

However, with only a requirement for 12-16tph under the High Speed North proposals, there is a degree of 'slack' in the system. (Note that along the M1 corridor, 4-tracking appears to be far more feasible without undue cost or environmental penalties.) This provides an invaluable opportunity to extend the scope of high speed rail beyond the principal conurbations to the second tier centres, and thus achieve the integration that is essential to maximise modal shift and CO_2 emissions reductions.

This superior performance is also reflected in the figures (in Table Q32) relating to the number of train patterns required.

[9] http://www.freightonrail.org.uk/FactsFigures.htm states the overall CO_2 impact of railfreight as being 70% less than the equivalent road journey. This appears to take into account the general need for road transfer at either end of the journey, with road-based local distribution networks. Other studies appear to make a more simplistic comparison, considering CO_2 per tonne-kilometre for road and rail, and show a much greater advantage for rail (up to a factor of 10). But for the holistic purposes of this study, an assumption of a 67% cut in freight emissions, through transfer from road to rail, will be made.

Q9.5 Heathrow Considerations

The greater routeing efficiency of High Speed North also allows the possibility of devoting a proportion of total line capacity to delivering comprehensive regional services to Heathrow, and thus effectively connect the nation to the national airport. This of itself will generate further reductions in CO_2, both through allowing virtually full elimination of internal aviation as feeder service to long-haul flights, and also allowing rail to supersede road transport as the principal means of surface access.

This is only possible through the inherent efficiencies of High Speed North's spine and spur configuration, whereby the concentration of services onto a spinal 'core' route allows a single train to serve (with splitting) up to 4 regional conurbations. With only 3 train operating diagrams, it is possible to serve all the principal conurbations of the Midlands, the North and Scotland:

- Newcastle, Edinburgh, Glasgow and Scottish northern communities (with split at Edinburgh).
- Sheffield, Leeds, Bradford, Manchester and Liverpool (with split at Sheffield).
- Birmingham, Nottingham and South-East Midlands communities along the M1 corridor (with split at Rugby or Milton Keynes).

The concentration of services along the spine of High Speed North simultaneously addresses both issues that afflict 'spur' access to airports:

- the need to run a large range of airport trains additional to the intercity/ interconurbation services that should comprise the core business of a high speed line.
- the disaggregated nature of airport flows, that results in low (and therefore uneconomic) flows to any individual city.

These are the considerations that appear to have driven HS2, configured in less efficient 'Y' format, to a route predicted upon Heathrow (ie running sufficiently close to enable either 'shuttle' or 'loop' access (see Figure F2). This carries massive extra infrastructure costs and environmental intrusion, particularly in the Chiltern Area of Outstanding Natural Beauty, and gives rise to:

- major delays in implementation,
- incomplete network coverage, and
- inefficient operation.

Together, these drawbacks result in poor environmental performance, with HS2's attributable CO_2 emissions being around 330MT greater (over a 40 year period) than those of High Speed North.

These issues are explored fully in Appendix F.

Appendix A : Environmental Issues

A1. Implications of Climate Change Act

It is important to recognise the magnitude of the challenge posed by the emissions reductions targets of the 2008 Climate Change Act. CO_2 emissions arise principally from the burning of hydrocarbon fossil fuels to produce energy, and high energy consumption is the fundamental driver for the living standards enjoyed by high-consuming Western societies such as the UK. This is illustrated in the very close linkage in the rise of atmospheric CO_2 levels, energy consumption and living standards, since the start of the Industrial Revolution, over two centuries ago.

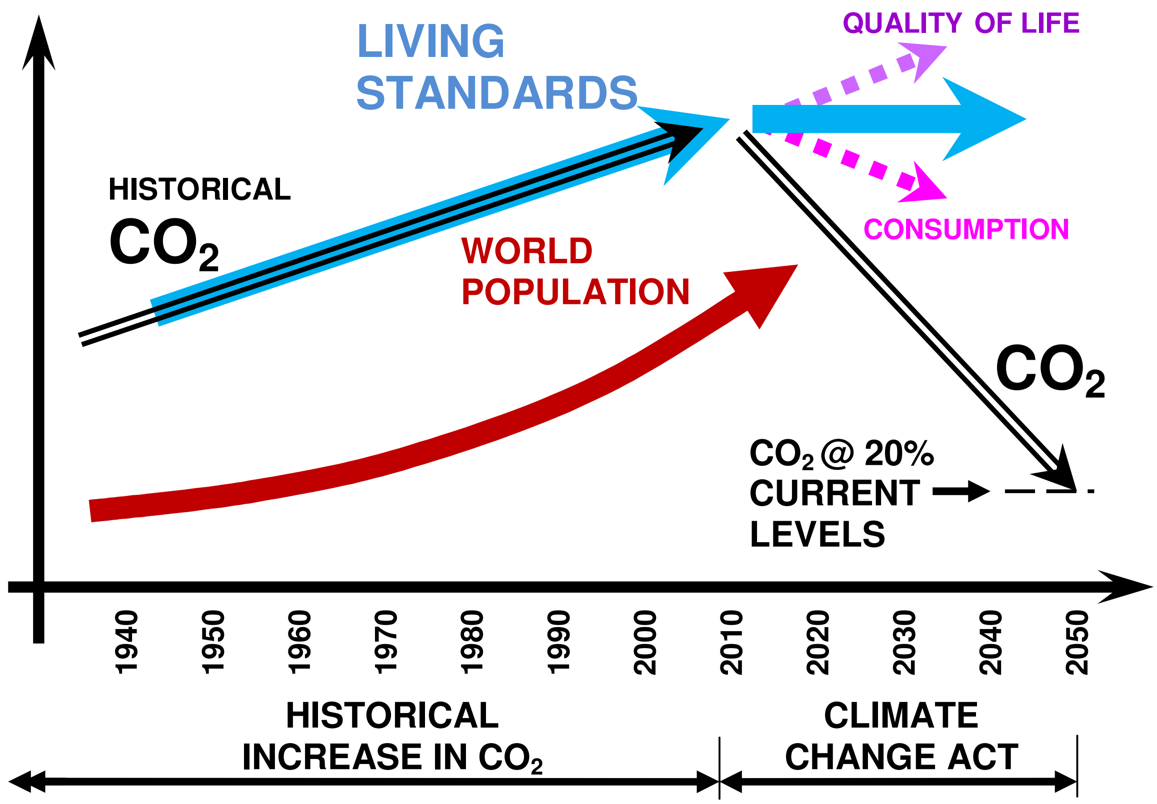


Fig A1: Requirements of 2008 Climate Change Act

The challenge facing Government, businesses and individuals alike, is to achieve the required 80% reduction in CO_2 emissions whilst maintaining living standards approximately at current levels. Such a decoupling would be unprecedented, and the strategies by which present ways of life are restructured have yet to be laid out. The challenge is made even more extreme by the fact that the requirements are absolute, rather than per capita. With UK population projected to rise by around 25% over the 40 year period of the Climate Change Act, an absolute reduction to 20% (ie one fifth) of contemporary levels amounts to 16% (ie one sixth) on a per capita basis.

With the potential crisis of rising sea levels and devastated ecosystems and economies so extreme, radical structural changes to the way we live, and travel, are unavoidable. Present 'business as usual' finance-driven strategies, predicated upon historic norms of increased consumption and (in the case of transport) increased speed delivering greater economic benefits, seem unable to deliver such changes. The one certainty is that the legally-committed reductions will not happen on their own. It will require a coordinated programme of major Government-led interventions to bring about the necessary changes.

Such a programme would be a 'war on all fronts' with no special cases (such as airport expansion or high speed trains running at unnecessarily high speeds) allowed. Every infrastructure project would have to be part of the grand strategy, and make its own contribution, large or small, to the ultimate goal of achieving the emissions reductions deemed necessary for mitigating climate change. In the case of HS2 (likely to comprise the most radical intervention in UK intercity transport over the next 50 years) it would be fair to expect it to have been planned to deliver a major proportion of the required CO_2 reductions (and indeed comply with the legal requirements of the 2008 Climate Change Act).

However, even the briefest examination of projected CO_2 emissions shows this not to be the case. HS2's projections show CO_2 reductions amounting to a median 4.6 million tonnes over the coming 60 years. Over the same period, UK transport will emit 8.4 ***billion*** tonnes (assuming annual emissions of 140MT to continue at current rates). If these figures are normalised onto the 40 year period of the Climate Change Act, HS2's projections can be seen to represent one fifth of one percent of the total required savings in annual CO_2 emissions.

It is difficult to see how a project with such low ambitions in respect of legally-committed climate change targets can gain the necessary broad consensus of support, either political, public or environmental. How much this is due to over-prioritisation upon economic aims is a matter for conjecture; it is however clear that a different set of priorities, driven by fundamental principles of environmental sustainability, must emerge.

A1.1 The Alaska Highway Analogy

A useful alternative perspective can be gained through analogising with wartime considerations. The issue of climate change has been described in politicians' rhetoric as "the greatest challenge faced by civilisation since World War 2"; and if this is true, then, as with a 'total war' such as World War 2, any practicable means or opportunities to win the war must be taken. In a war, these tactical decisions are taken, almost regardless of financial considerations; in the current crisis, it would be hoped that a more measured strategic approach could be taken, in which a financial discipline still applies (albeit less onerous than pertains at present), yet priority is still accorded to environmental sustainability . Essentially, it is a question of priorities, doing what is most important to preserve civilised life for now, and for the future.

In wartime, most engineering effort is concentrated upon the specific operational military hardware. But engineering of a more civil nature has also proved crucial, most notably the Mulberry Harbours that made the D-Day landings logistically possible (and neutralised the Axis strategy of denying port facilities to the landings). Almost without exception, these landmark projects are characterised not only by their huge scope, but also their extremely short timescale between conceptualisation and realisation.

In the field of transport, perhaps the prime example is the construction of the Alaska Highway. With the onset of the Pacific war, and Japanese naval dominance immediately after Pearl Harbour, the isolated American territory of Alaska became vulnerable to invasion. It had no road (or rail) links either to Canada (its immediate neighbour) or to the 48 US mainland states, and it was considered essential to establish land communications. Construction of the 2237km Alaska Highway was started in March 1942, and completed in October of the same year.

Although there are clear differences between a) the construction of a dirt road through uninhabited coniferous wilderness and tundra, and b) the creation of a new system of high speed railways in a densely populated country, there are parallels also. In both cases, the goals – either the prevention of invasion of the North American mainland, or the imperative for radical reductions in transport CO_2 emissions – are of unquestioned strategic national and international importance, with implementation vital in the shortest possible timescale.

The above logic is only valid if high speed rail can be shown to have the potential to bring about step-change reductions in CO_2 emissions. This makes the environmental argument absolutely key. If high speed rail can become central to delivering on environmental targets (along with all other business and connectivity aims), the case for its realisation becomes unanswerable. And, in a populous and democratic country such as the UK, this makes it more essential than ever that speedy implementation is assured though avoidance of unnecessary environmental intrusion and impact.

A2. UK Transport Emissions & the High Speed Solution

The UK transport sector (ie covering Great Britain and Northern Ireland, but excluding international communications, particularly aviation) accounts for 143MT of CO_2, or 26% of total emissions. As indicated in Figure A2 below, road traffic (passenger and freight) is responsible for the vast majority, over 90%, of UK transport emissions; by contrast, railways and domestic aviation make a relatively small contribution, both less than 2%.

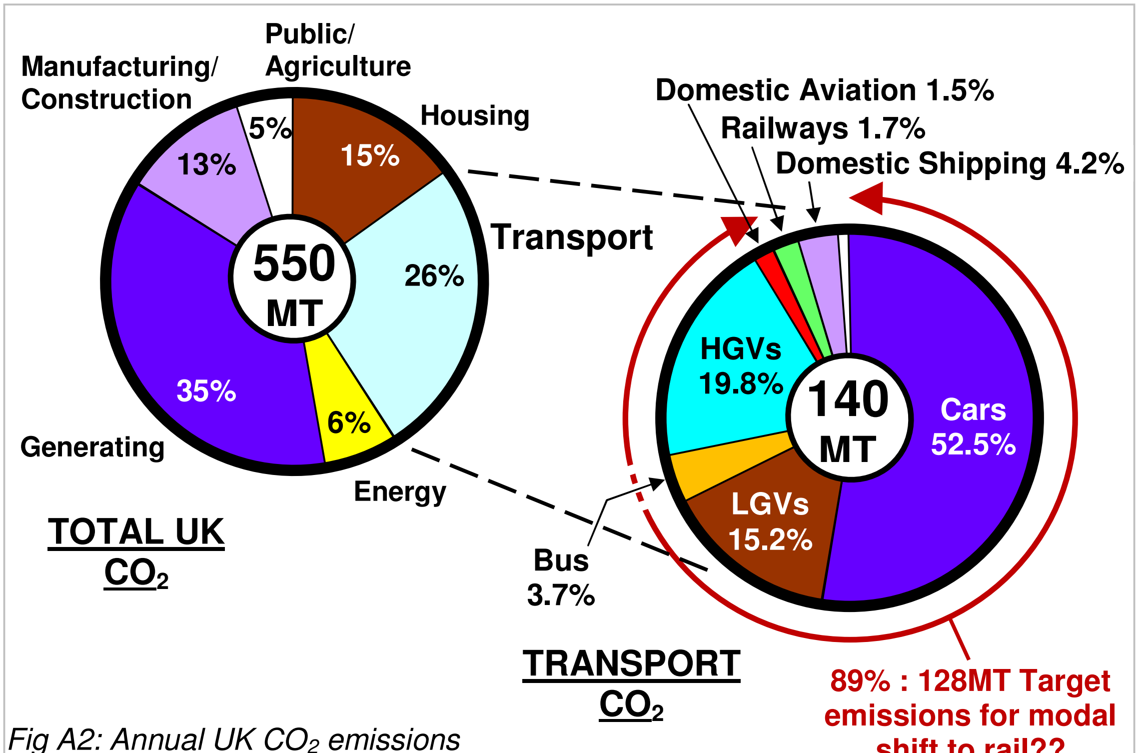


Fig A2: Annual UK CO_2 emissions

To date, most high speed rail schemes have been conceived as a means of long distance, mostly London-centric transport, that is in competition primarily with domestic aviation. Although the likely outcome, ie the elimination of most internal flights, would be welcome, and the conversion of journeys from plane to train would result in significant savings in CO_2 emissions, these are small gains with respect to the strategic overall aim of an 80% reduction.

If high speed rail is to constitute a transport solution relevant to contemporary environmental concerns, it is essential that it is specified and configured to maximise potential gains. This means targetting not just the domestic aviation sector, but also as great a proportion as practicable of the circa 90% of UK transport emissions attributable to road transport.

A2.1 Relevance of High Speed Solution?

However, there is an apparent mismatch that must be resolved. The proposed solution ie a UK high speed rail system, would traditionally be considered applicable to London-centric journeys at least 160km in length, whereas the principal problem ie road transport emissions, mostly derives from trips that are much shorter, and more interregional in nature. A closer match would seem to be with conventional intercity or regional rail.

It is therefore necessary to reconsider the traditional model of high speed rail. This has developed in countries such as France and Spain, where population centres are generally highly dispersed, with upwards of 200km between principal cities, and a natural focus upon a centrally-located capital city. In the UK, major centres such as Leeds, Sheffield, Manchester and Liverpool are no more than 60km apart, generating through their proximity major interregional flows, in addition to the flows to London.

It would seem appropriate to develop high speed rail in such a way that either addresses these shorter flows directly, or enables enhancement of the existing rail network to accomplish the same end. This would be a bespoke model of high speed rail specifically relevant to UK geography and demography. With capacity being the priority, rather than speed, the solution might not even comprise high speed rail, per se. Whatever the case, full integration between new and existing networks would seem essential.

A3. Strategies for Reduction in Transport Emissions

There is a clear imperative for society to retain the ability to travel, but to do so at acceptable environmental cost, with vastly reduced CO_2 emissions. These require fundamental step changes, ‘shifts’ which will have to happen, if the daunting challenges set by the Climate Change Act are to be met.

Three major ‘shifts’ are considered in the following sections:

- Behavioural – *in which the basic need to travel is questioned*.
- Technological – *in which technologies underpinning existing modes of transport are developed to improve energy efficiency*.
- Modal – *in which traffic flows migrate to the most energy efficient mode*.

Collectively, the three shifts must deliver the required 80% cut in CO_2 emissions, and at the same time allow for the adverse effects of a fourth shift ie the continuing rise in UK (and world) population.

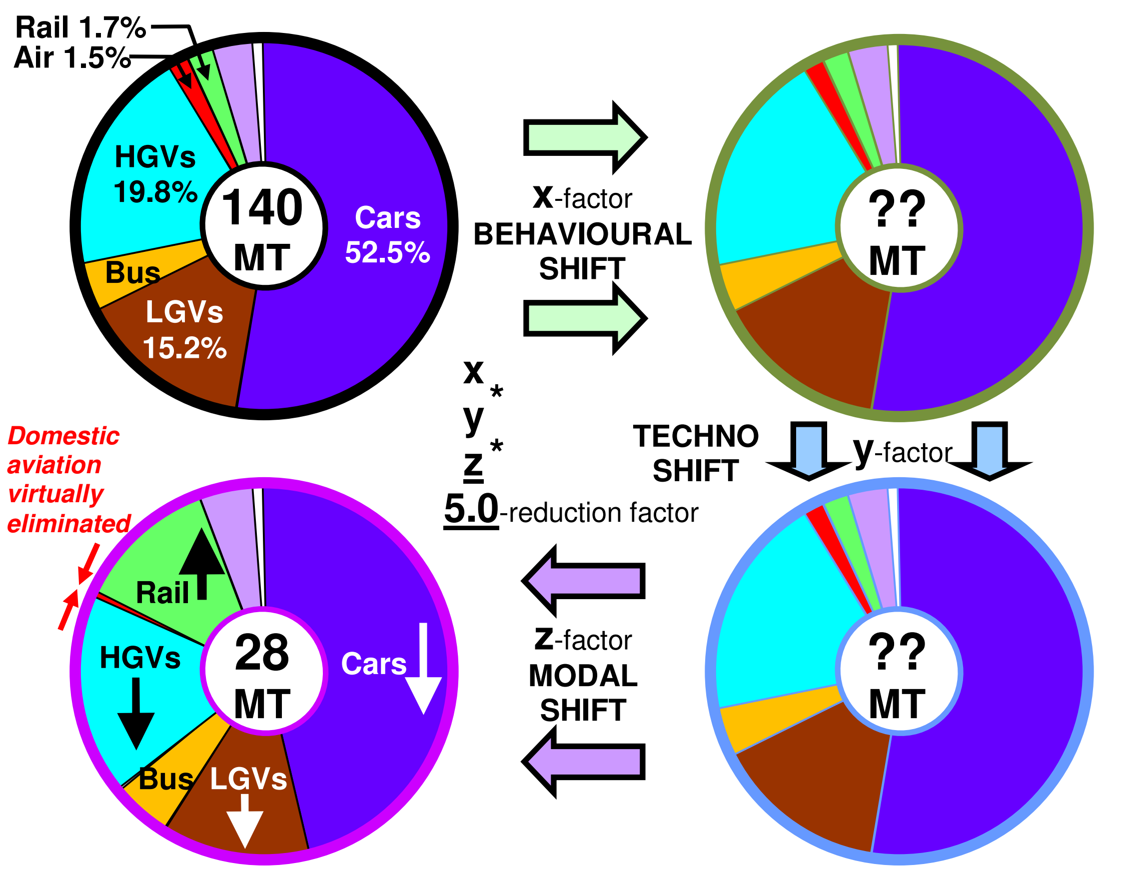


Fig A3: 'Shift' methodologies to achieve fivefold cut in CO_2 emissions ie to 20% of current levels

These shifts are outlined in Figure A3 above. This sets out a 'roadmap' towards the ideal, of transport emissions reduced to 20% of contemporary levels by 2050. Under such a scenario, domestic aviation would be virtually eliminated (with the probable exception of routes to Northern Ireland) and roads emissions would be greatly reduced, in terms of both absolute magnitude and as a proportion of transport emissions as a whole. The one sector showing an increase would be the rail sector, on account of major modal shift, both from air and road transport; although its proportionate share would be greatly increased, in absolute terms, the increase in rail's emissions would be relatively small, through the greater load factors that would apply. This of course assumes 'reasonable' high speed of the order of 300kph.

A3.1 Behavioural shift

Although the fundamental human desire and need to travel will remain, developing information and communication technologies will allow more people to work from home or from local hubs, rather than commute long distances. Similarly, meetings can be conducted by audio and video links. As lifestyles adapt to a lower-carbon world, facilitated by newer 'green' technologies, there should be a natural tendency towards less travel. This will lead directly to lower energy use and lower emissions.

This runs directly counter to current business-led strategies for high speed rail development. These generally presume an expanding travel market, essential for achieving the increased revenues from which the high investment costs can be recouped. Yet such a presumption would appear to be fundamentally unsustainable in its requirement for increased energy and consequent increased emissions. This again demonstrates the imperative for society to re-examine its values as it moves towards a lower-carbon economy.

Detailed consideration of behavioural shift, as a means towards CO_2 reductions, lies outside the scope of this largely technical study. It is sufficient to note that behavioural shift must happen, if society is to meet its daunting targets for emissions reductions, and if the countervailing effects of natural emissions growth due to expanding human population is to be addressed.

A likely scenario is that behavioural shift will broadly balance the effects of rising population, and that the total quantum of travel will remain broadly the same.

A3.2 Technology shift

Technology shift comprises a process of continuous technical improvement that should enable transport of people and goods to be undertaken with greater energy efficiency, and hence lower CO_2 emissions. This can take the form of:

- enhanced aerodynamic performance of vehicles (particularly road and rail) to reduce energy losses through air resistance;
- developments in engine / motive power technology, without fundamental change.
- alternative 'sustainable' hydrocarbon fuels, such as biofuel derived from palm oil, or other organic source.
- migration of road vehicles from internal combustion engine to hybrid or full battery power.
- manufacture of lighter airframes using carbon fibre in lieu of aluminium, requiring less power to stay airborne.
- exploitation of greater fundamental efficiency of electric traction over diesel, through further electrification of the railway system.
- migration of national electricity grid from 'dirty' coal to cleaner and more sustainable alternative sources of power.

All the above, to a greater or lesser extent, comprise 'technology shift', and all should allow lower-energy, lower-CO_2 transport to develop. The key issue is the scale and pace at which any particular intervention can deliver improvements, and the undesirable side-effects that might arise from adoption of the new technology. It is generally the case, that true shifts to alternative technologies, rather than incremental developments (eg cleaner-burning internal combustion engines or smoother-profiled vehicles) will bring greater benefits; yet experience has shown that the introduction of any new technology carries a much higher level of risk.

This can manifest itself in a variety of ways, for instance:

- the ongoing problems being experienced by Boeing in their development of the (mostly) carbon fibre 'Deamliner' aircraft,
- the sustainability of lanthanum, a rare earth metal used as battery electrodes in the Toyota Prius hybrid car, or
- the devastating effects on tropical ecosystems of industrialised cultivation of palm oils (a common raw material used in the manufacture of bio-fuels).

All of these issues will greatly constrain both the scale and pace by which proposed new technologies for aviation and road transport can be introduced.

By contrast, railway electrification represents established technology with no major technical or sustainability issues, and with significant energy efficiency benefits in its own right. However, these advantages are already accounted for in the Environmental Performance Indicators (EPIs) developed for high speed rail, and modified in this study. Rail's environmental performance will also benefit from the continuing 'greening' of electric power generation, and (being the least weight-sensitive of all major transport modes) it is in a good position to make early use of developing battery and fuel cell technologies.

All other things being equal, technology shift should favour the carbon footprint of rail above other modes. However, the railway industry cannot rest on its laurels in its position as 'market leader', claiming to operate the greenest form of mass mechanised transport. It is vital, from both an environmental and commercial perspective, for rail not only to keep pace with developing technologies to improve energy efficiency, but also (as previously noted) to exploit the established electrification technology to the full.

Although the benefits of new technologies are not in doubt, it is crucial to understand their limitations. Any new technology essentially comprises an alternative (and hopefully superior) means of exploiting the laws of physics; it does not allow these laws to be broken. The laws of thermodynamics, of conservation of energy (with the inevitable decay of useful mechanical energy into heat), and of fluid dynamics, continue to apply.

Perhaps the most significant law of physics applicable to high speed rail is the 'K-V-squared' rule, governing the relationship between speed and energy use. In simple terms, this states that resistance to motion (principally air resistance) rises proportional to the square of speed; hence energy use, and (all other things being equal) CO_2 emissions also rise proportional to the square of speed.

This of course has a clear implication for the selection of the speed at which the proposed high speed system will operate. However, in strict terms, the choice of speed is not an issue of technology shift, but a decision on how any particular proposal is to be designed and operated. The effects of speed are discussed in greater detail in Section B7.

For the purposes of this study, it is assumed that any new technologies, relating to speed or otherwise, will be equally available to any high speed rail proposal, and are thus neutral, in the question of differentiating between rival schemes.

In an absolute sense, the scope of technology shift to meet the targets of the Climate Change Act would seem to be limited. All the advantages of electrification are already implicit in any high speed rail proposal, and rail will be reliant on other, external developments such as the greening of the electricity grid, to deliver major savings.

Noting also the difficulties currently being experienced by Boeing in their development of the Dreamliner aircraft (for which 20% weight savings were predicted at project inception, but are proving difficult to realise), it would seem prudent not to over-estimate the potential CO_2 reductions achievable through technology shift. A figure of the order of 33% - or a reduction factor of 1.5 – would seem to be appropriate as a realistic target.

With behavioural shift largely negated by projected population growth, it would appear to be left to the third shift – ie modal shift – to deliver the balance of the required savings in CO_2 emissions, by a factor of between 3.0 and 3.5.

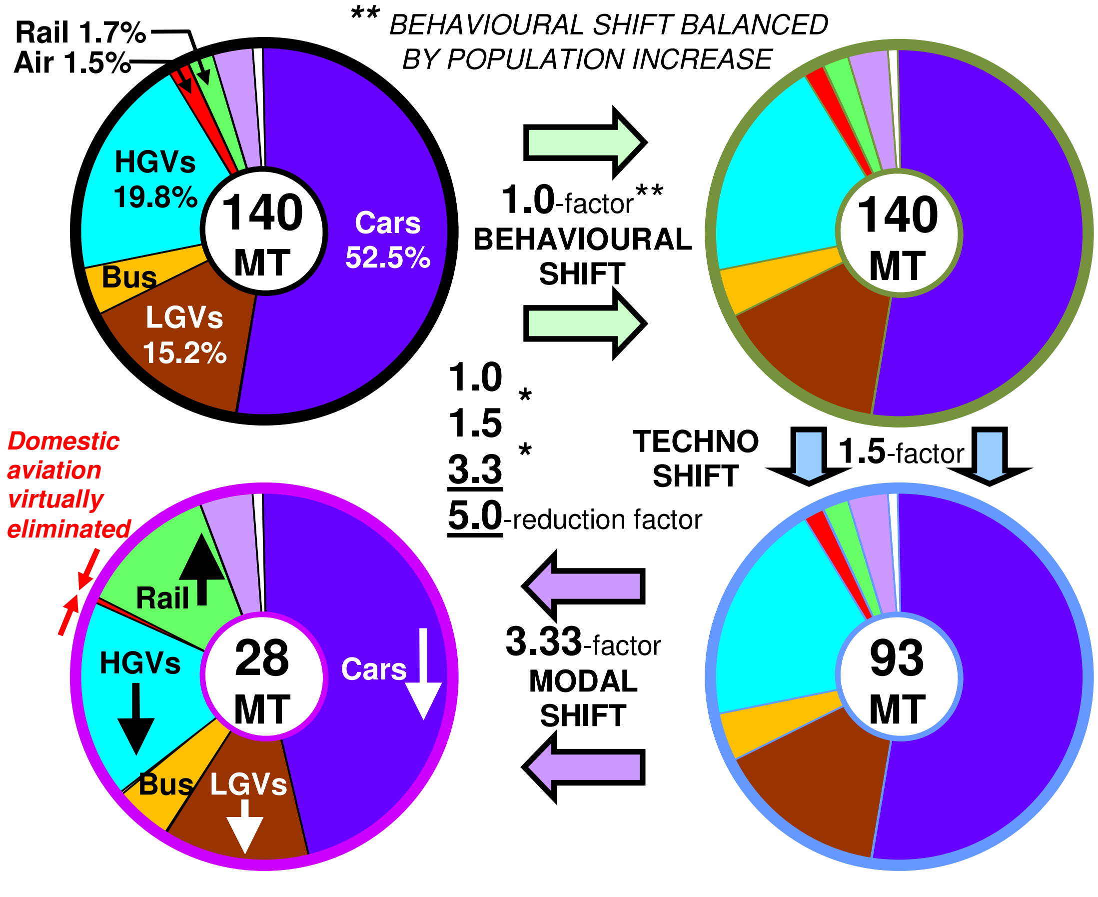


Fig A4: Quantified 'Shift' methodologies to achieve fivefold cut in CO_2 emissions

A3.3 Modal shift

A large proportion of transport's emissions are attributable to the basic energy inefficiency of the dominant modes ie road/private car for short distances, and aviation for longer distances. If this traffic can be transferred to more energy efficient modes, then major emissions savings should result.

The purpose of this study is to consider how high speed rail as a new intervention in transport might optimise reductions in CO_2 emissions. But high speed rail comprises only one of many potential interventions, with its primary applicability focussed upon longer-distance interregional journeys. For the shortest car journeys, walking and cycling comprise the obvious (virtually) zero-CO_2 alternative. For journeys above a few kilometres, bus and light rail are the appropriate solutions (still with major CO_2 advantages over car travel), gradually migrating into heavy rail as the journey length increases.

There is certainly no doubting rail's environmental advantage over air or road, in terms of the fundamental energy efficiency of moving vehicles containing a given number of seats. The steel wheel on the steel rail, running along well-engineered reserved alignments, does not suffer the frictional losses of the rubber tyre rolling on tarmac, or require the intense effort of powering an aeroplane at speeds sufficient to generate lift.

The problem for rail is that it works efficiently only in relatively large units, and its environmental advantages are only realised when there are sufficient passengers to fill the seats. If high load factors can be achieved, rail can demonstrate excellent performance; conversely, there is nothing more environmentally inefficient than an empty train.

With high speed rail under specific consideration, speed is another factor that will have a major influence upon environmental performance. Issues surrounding speed are discussed in Section A4.5.

A3.4 Environmental Performance Indicators

The issue of load factor is encapsulated in the metric that is commonly used to measure relative environmental performances of different transport modes. Rather than simply consider the emissions of the vehicle – for which *grams of* CO_2 *per vehicle kilometre* would be appropriate – the issue of load factor is captured through measuring *grams of* CO_2 *per passenger kilometre*. This figure (which always needs to be baselined against a given speed and load factor) is termed the Environmental Performance Indicator (EPI).

The EPI, or more precisely its relative value against other competing modes (ie the differential EPI, or EPI_{diff}), is crucial in the determination of the environmental benefits of modal shift from road to rail. These issues are discussed in greater detail in Appendix B.

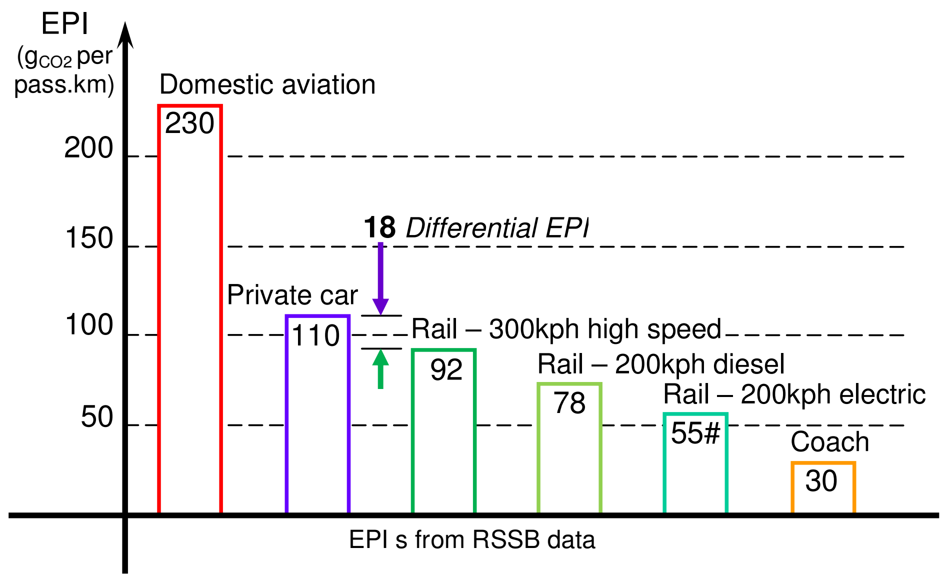


Fig A5: Environmental Performance Indicators for different transport modes

As noted previously, for high speed rail to comprise a worthwhile solution that delivers significant environmental benefits, it must offer major transformational advantages in the conversion not only of airline flows, but also of private car travel (which alone accounts for over 50% of UK transport emissions). For this latter conversion to take place, high speed rail must be capable of demonstrating a significant advantage in terms of differential EPI over the private car.

A3.5 Differential EPIs against Competing Modes

However, in this latter respect, the official data is not encouraging, at first sight. The private car is assessed at an EPI of 110g_{CO2}/pass.km, while high speed rail shows only a 18g_{CO2} advantage at 92g_{CO2}. Such a marginal advantage would not seem to offer a major benefit per se, or a benefit proportionate to the huge investment and effort necessary to establish high speed rail in the UK. Given the uncertainties inevitable in such 'broad-brush' statistics, and the potential for subsequent variances, a continuing doubt would exist as to whether the small predicted emissions savings could ever be realised.

It is important to understand the provenance of the EPI figure of 92g_{CO2}/pass.km attributed to high speed rail. At present there are no true high speed rail journeys within the UK (the Eurostar operation from St Pancras is essentially an international link to Paris and Brussels); but with the only element exclusively in the UK comprising the London-Ashford (Kent) section, this was categorised as a commuter journey. Thus a typical load factor of 30% was accorded to high speed rail, in line with the EPI figure generically allocated to commuting journeys.

This fails to reflect the 60% load factors achieved by Eurostar on an operation connecting strong (capital) city pairs. With UK high speed rail projected to operate between similarly strong city pairs with few intermediate stops, it is reasonable to assume that a load factor of the order of 60% could also apply.

This would transform the comparison the comparison with road transport. With the EPI for high speed rail reduced to 46g_{CO2}/pass.km, the differential with the private car increases from 18g_{CO2} to 64g_{CO2}/pass.km. This would now appear to be a worthwhile benefit, and would greatly increase the scope of high speed rail to achieve major environmental benefits.

A3.6 Energy and Carbon Accountancy for High Speed Rail

However, it is important to re-emphasise the fact that the EPI for high speed rail is dependent not only upon load factor, but also upon speed and electricity generating characteristics. The above EPI figures – already modified to address load factor issues – relate specifically to Eurostar operation at 300kph, and CO_2 emissions typical of the entire range of UK electricity generation.

The figures would become considerably less favourable if higher speed operation were to be specified, with the differential EPI 'going negative' (ie high speed rail CO_2 emissions greater than the private car) for certain combinations of speed and load factor (refer Figure 4.8).

Such undesirable indicators tend to be masked through projections for the 'greening' of the electricity grid, whereby greater adoption of renewable and nuclear energy will greatly reduce the overall levels of CO_2 emitted in the production of energy. This is clearly a desirable outcome, so far as CO_2 emissions are concerned; however, there are wider questions that must be addressed, in particular:

- environmental issues associated with nuclear power
- issues of energy sustainability and security of supply.

Against this background, it seems essential that a major development such as high speed rail is optimised not just against CO_2 emissions, but also fundamental energy consumption. This must lead to a natural presumption against excessive speed, and would demand a rigorous business and environmental case to be made for the adoption of any specific speed in 'high speed' rail operation.

Accordingly, no attempt has been made to take advantage of projected 'greening' of electricity supply, in the adoption of source data for rail's environmental performance. The EPI figures used assume, rightly or wrongly, a continuation of contemporary generating characteristics, with a major contribution from higher-CO_2 coal.

A4 Conversion Levels

High speed rail as a comprehensive intervention can bring about reductions in CO_2 emissions on several levels.

- It has the potential to become the dominant mode of transport between principal conurbations.
- If correctly aligned with the existing rail network, it can achieve major benefits for journeys between second tier cities.
- Through transfer of existing intercity/interregional traffic from the classic network, it can provide a step-change in capacity on local routes. This will benefit both local/ commuter flows and freight traffic.

With these disparate influences to consider, it is difficult to precisely quantify the 'conversion level' ie the percentage of road transport that is capable of conversion to rail, as either a direct or indirect consequence of establishing a high speed rail network. Passenger and freight flows (categorised in emissions statistics as private car, light goods vehicles (LGVs) and heavy goods vehicles (HGVs)) can all, to a greater or lesser extent, be transferred to rail.

It is important to note that in this analysis, bus (PSV) flows are considered to comprise useful and efficient public transport, and as such are not targeted for conversion to rail. With buses generally appropriate to more local networks, they are capable (possibly in combination with trams or other light rapid transit) of addressing a different sector of car emissions than either conventional or high speed rail. There are also powerful synergies in bus (and tram) networks delivering passengers to rail hubs for longer distance journeys.

This study remains focussed on the road traffic flows that are deemed convertible to rail, through high speed rail as a transport intervention. The convertible journeys will tend to be the longer ones, and although these might represent a small proportion by number, the proportion by distance (and therefore emissions) is much larger.

However, there are additional synergies through the abstraction of intercity flows away from existing lines. Such lines, often carrying intensive intercity services through densely-populated areas, are unable also to provide the local services appropriate to the needs of these communities, owing to the inherent conflicts between through and stopping trains (see Figures B2 and B3).

A prime example can be seen on the Transpennine route between Leeds, Huddersfield and Manchester, where the 4 trains per hour of the Transpennine Express intercity service limits local stopping services along a highly populated corridor to 2 trains per hour. But with intercity flows diverted to the high speed line, the existing line would at last be able to fulfil its proper role as a local railway, with a frequent 'metro' level of service that would connect passengers not just to Leeds and Manchester, but also to the wider intercity network. This will address suppressed local demand for rail services, and will in turn facilitate modal shift and CO_2 reductions.

The potential of high speed rail, to achieve optimised emissions reductions, will only be realised if these synergies are exploited to the full. As noted previously, the intervention of a new 'high speed' railway will primarily provide extra capacity and speed along specific interconurbation corridors, and enhance longer distance journeys.

Consideration of the relativities between CO_2 emissions (refer Section 4.8), arising from interconurbation flows and from the total traffic flows within a given area, indicate that a high speed rail system linking all conurbations could achieve a conversion level of around 28%.

This assumes that the high speed system has efficient interconnection with the regional and local networks in all conurbations. This seems unlikely with certain models of high speed rail, in which a city's 'high speed' hub will be remote from its local rail hub, apparently requiring passengers to walk between the two. This raises serious questions as to whether there will actually be the passengers to fill the high speed trains, and would appear to considerably reduce the prospective conversion level.

Even full trains may not be an unalloyed benefit. The diversion of trunk interconurbation flows from the existing intercity route will leave the second tier cities (which will remain on the classic network) with a reduced service. This will tend to make rail an unattractive option for many travellers, resulting in modal shift form rail to road, and a consequent rise in CO_2 emissions. This would seem to further reduce the conversion level.

Alternatively, local political considerations will dictate the retention of intercity services along the classic route, and thus restrict its potential to offer more local and freight services. This will have the effect of limiting total network capacity, and hence potential to accommodate modal shift.

The problem can be encapsulated in the issue of integration (or rather, lack of it). A system of high speed railways that is imposed upon an existing intensively-trafficked intercity railway, but with minimal interconnection, would seem to detract from the total 'railway product' that is on offer, and the 'trickledown' benefits that should accrue on a more local level will be lost.

It thus seems essential that a UK high speed rail model is developed that:

- achieves full integration between high speed and existing networks, both local and intercity.
- functions on a level appropriate to a densely populated island, with major conurbations spaced as close as 50-60km.

On such a basis, a conversion level as high as 33% appears to be feasible.

The conversion level is also highly dependent upon external factors, such as:

- the degree to which pricing mechanisms are adjusted in recognition of rail's environmental advantages,
- the restrictions (such as road pricing, strategic lorry bans etc) that are placed on road traffic,
- the level of accountability that is placed upon companies and individuals to travel at the least environmental cost,
- the degree to which the predicted environmental crises are realised, and intrude upon public and political consciousness.

With the exception of the last item, these are all political considerations that are in the gift of Government to determine. Although the historic record of Government, in doing the right thing for the environment, is generally very poor, growing pressures from the public, from the international community, and from the simple fact of the 2008 Climate Change Act (a statute for which the civil service is duty-bound to report progress), seem likely to compel serious action.

For the purposes of this study, conversion levels of between 13% and 33% of total road transport flows (measured in passenger- or tonne-kilometres) will be considered in the calculation of CO_2 emissions resulting from modal shift. Results will be presented accordingly.

Appendix B : Consequences of Modal Shift

B1 Requirement for New Lines

It is fairly self-evident, that if up to 33% of total road transport flows were to transfer to the rail, this would bring about massive increases in current rail flows that would seem likely to overwhelm the existing network. Considering a one third reduction in road flows, spread evenly between passenger and freight traffic, an approximate fourfold increase in rail traffic would result.

With railway network capacity already under pressure along most main line axes, the introduction of extra passenger and freight traffic accruing from modal shift will create a demand for a step change in capacity. There will be considerable opportunity to restore abandoned railways, and to add extra tracks to existing routes. Also, it may be possible to increase both frequency and length of trains. But such an incremental policy has clear limitations as to its scale and pace, and it will be necessary also to construct completely new alignments.

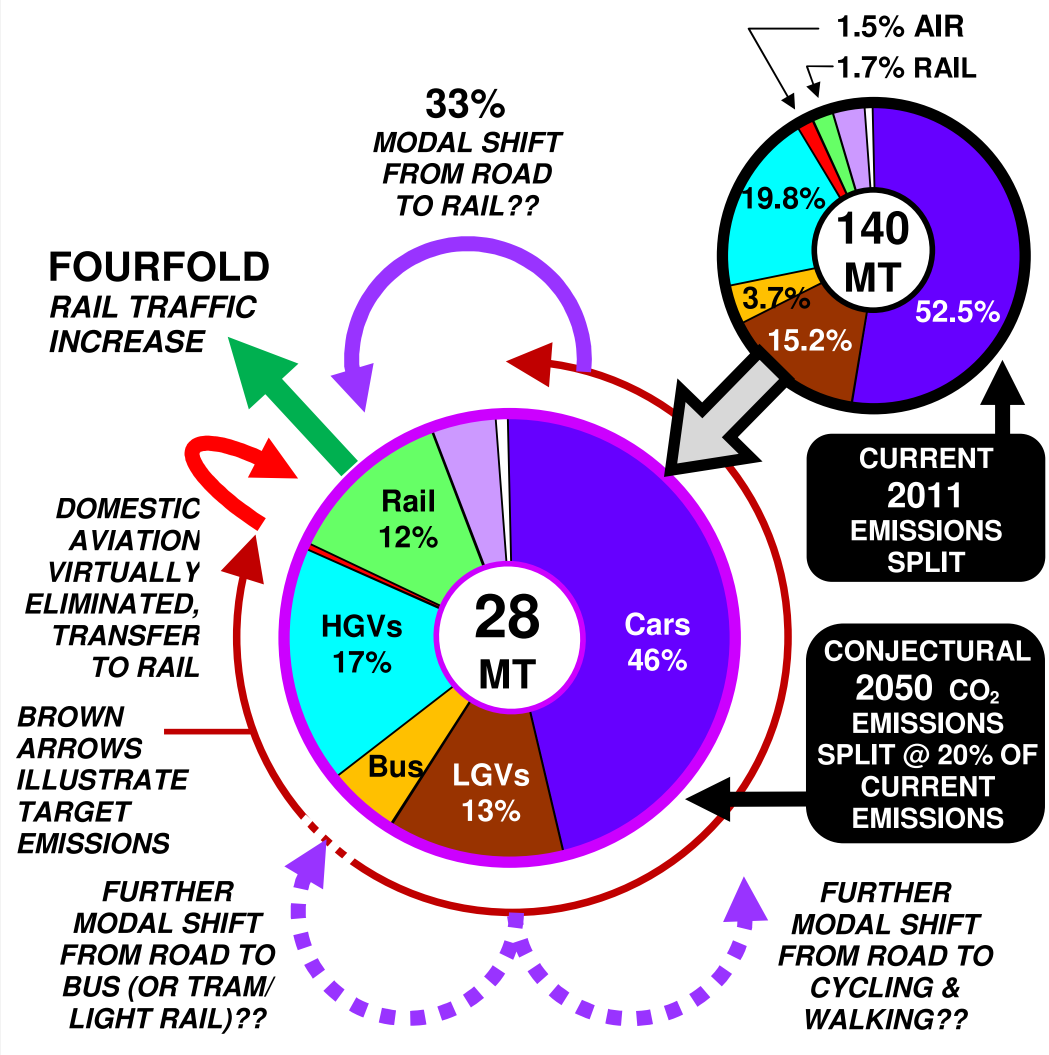


Fig B1: Step-Change Increase in Rail Traffic arising from 33% Modal Shift: Other Emissions Reductions Strategies also illustrated

If correctly located, such new lines can not only add capacity but also new routes to the network, opening up new journey opportunities to rail. It is significant that the existing rail network was developed in a largely ad-hoc fashion in the Victorian era, not especially efficient in respect of addressing even contemporary needs in the 19th Century. Given the major growth and redistribution of population, the reorientation of the economy and the establishment of new transport hubs (in particular airports, but also new towns) there must be considerable additional traffic that will accrue through updating the network to match 21st Century needs.

In a generic sense, the solution would appear to comprise new lines along most principal intercity axes. Two extra tracks constructed parallel to two existing can increase capacity (to operate trains) by a factor of between 3 and 4. This step-change – accruing from the extra tracks in themselves, and from the segregation achieved between long-distance expresses and slower local passenger and freight traffic – is one of the principal advantages traditionally adduced to high speed rail proposals, or indeed any new railway proposal. When the opportunity to run longer trains is also taken into account, an approximate quadrupling of capacity could result.

This point is illustrated by the diagrams in Figures B2 and B3. These show the effects upon capacity of a 'mixed traffic' operation along a typical 2-track main line; with a speed differential of 75kph between express passengers (200kph) and freight or local passenger traffic (125kph overall average), capacity is approximately halved. If the speed differential were to increase through high speed operation along conventional lines (assuming track alignment and signalling to permit this) it can be seen that the loss in capacity would be even greater. This is clearly unsustainable, and hence new lines for high speed operation *and* higher capacity operation are invariably required.

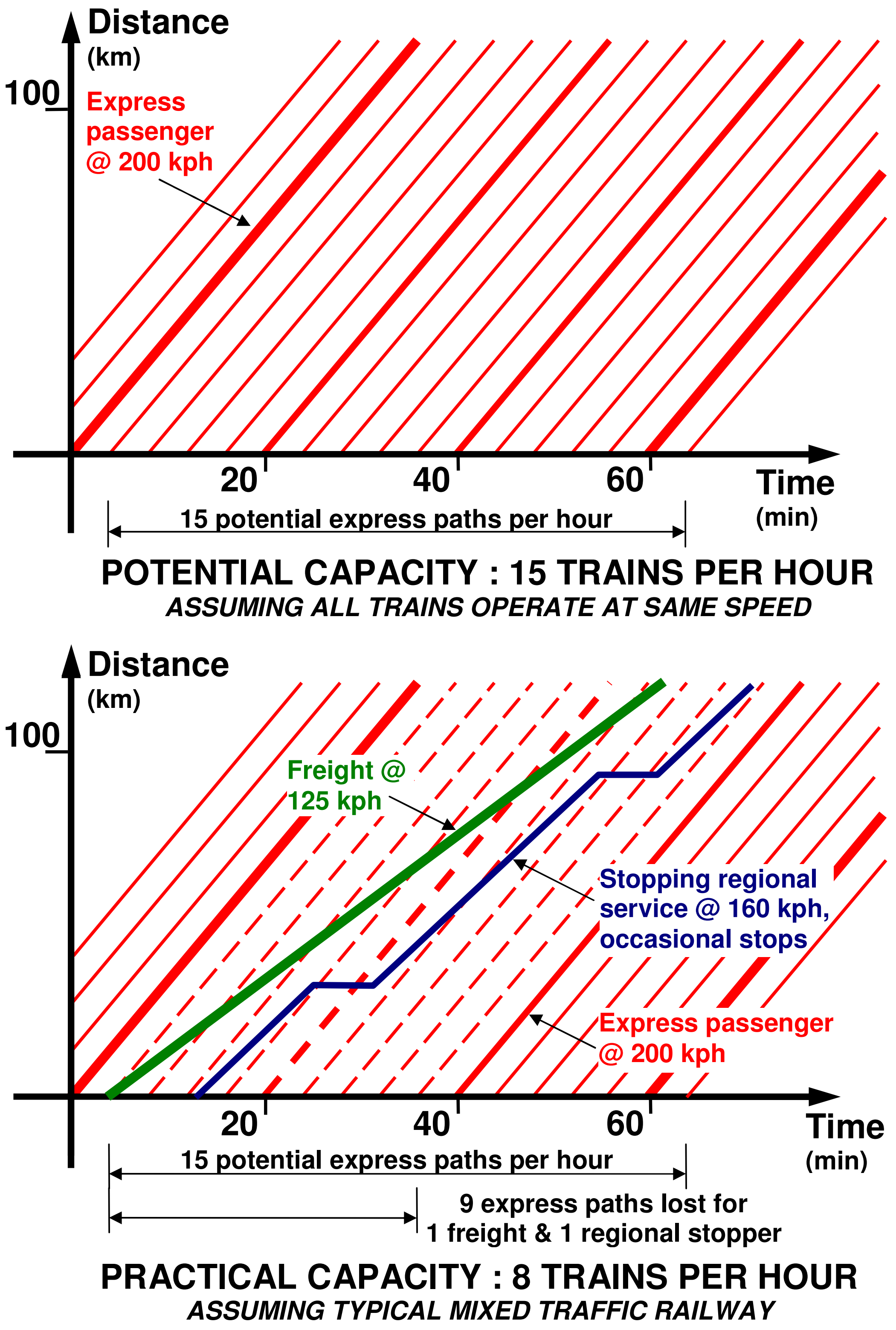


Fig B2: Line Capacity Losses through Speed Differentials

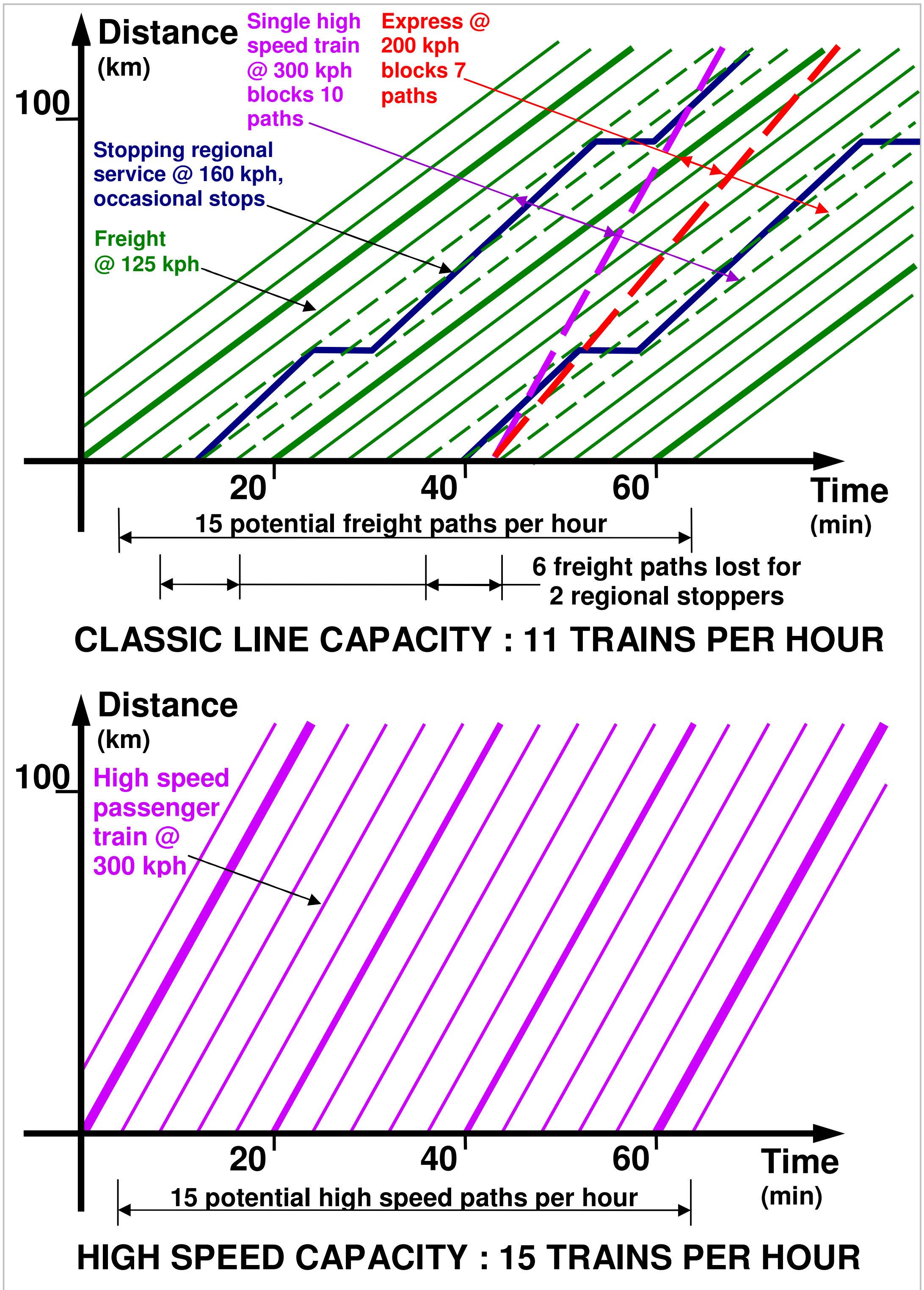


Fig B3: Capacity Gains through Introduction of Parallel High Speed Line

B2 Design Criteria for Development of Network

It seems reasonable to conclude from the preceding paragraphs that the requirement for new lines is primarily driven by the need for capacity, rather than speed. Speed is just one of the many considerations for which the new lines would be designed, to optimise business and environmental performance.

Other considerations would comprise:

- coverage of network,
- timescale for establishment of network,
- integration between high speed and classic rail network (and other networks)
- operational efficiency of network,
- capital cost of network.

All the above carry major implications for CO_2 emissions. But before such analysis can be carried out, it is necessary to be able to assess the traffic flows on all elements of the proposed networks, both London-centric and interregional. This is the first step towards the calculation of emissions attributable to these interconurbation flows, and to the reductions that will come about through modal shift.

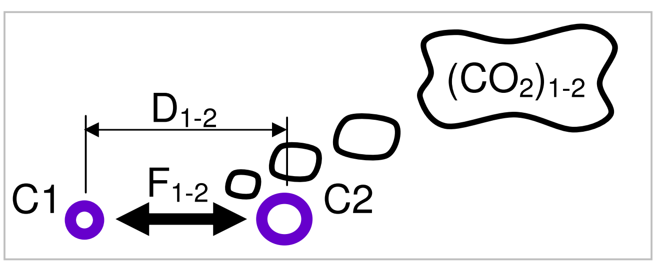
B3 Determination of Traffic Levels

An appreciation of the strength of interconurbation flows can be gained by means of a gravitational model. This assumes an analogy between the traffic flow between two population centres, and the gravitational force between two objects.

Newtonian gravitational theory states that the force between the two objects is equal to the product of the two masses ($m_1 \times m_2$), divided by the square of the intervening distance (d_{1-2}), with the gravitational constant G applied.

$$\text{Gravitational force} = G \times \frac{m_1 \times m_2}{(d_{1-2})^2}$$

On a similar basis, potential traffic flow between two population centres (C1 and C2) can be considered to be proportional to the product of the two populations (P_{C1} and P_{C2}), divided by a function of the distance between (D_{1-2}).



$$\text{Intercity flow} = C \times \frac{P_{C1} \times P_{C2}}{(D_{1-2})^n}$$

Eliminating constant term...

$$\text{Intercity flow} \propto \frac{P_{C1} \times P_{C2}}{(D_{1-2})^n}$$

This is essentially Tobler's First Law of geography, which states: "Everything is related to everything else, but near things are more related than distant things." Its basic thesis is that all population centres, irrespective of geographical location, are capable of the same interaction with other population centres to generate flows of people and goods, diminishing with increasing distance (which implies the associated deterrent factors of time and cost). Tobler does not explicitly define the value of the exponential 'n' that is applied to distance, but it is commonly held to be between 1.0 and 2.0.

The contemporary predominance of journeys towards London tends to contradict Tobler's basic concept, that all populations have equal power to generate and attract traffic flows. But this disparity reflects the present London-, or capital-centric nature of the UK economy, a tendency which is reinforced by the focus of the national transport infrastructure (particularly rail and air networks) upon London, and the concentration of investment in that area.

It has long been Government policy to redress this 'economic tilt' towards London and the South-East, and development of high speed rail has been advanced as a driver for regional regeneration. But with most high speed rail proposals tending to focus connectivity primarily upon London, and with connectivity strongly related to economic performance[10], it can be seen that there is a major risk whereby high speed rail development has the effect of exacerbating, rather than redressing the current 'North-South divide'.

The development of a new high speed rail system presents a unique opportunity to address the London-centric nature of the existing network, and the quasi-linear geography of the UK (a unique feature not displayed in other major industrialised nations) makes this a practicable possibility. However, this is not reflected in current trends in high speed rail development, with most proposals either focussed upon London, or comprising a 'Y' that divides in the West Midlands, and continues both sides of the Pennines. These will address longer-distance north-south flows, and would seem also to improve connectivity to the West Midlands; however, they make little or no attempt to meet the needs of Northern and Scottish communities for comprehensive interconnectivity. This is despite major congestion (arising from capacity constraints, indicating major potential for CO_2 emissions reductions) particularly on Transpennine axes.

This will tend to perpetuate the London-centricity of the UK economy, but possibly more importantly, will offer an incomplete solution, in terms of the connectivity, and associated environmental benefits, that might be gained. Through focussing the high speed solution upon London, of the order of one half of the potential connectivity (and consequent capacity gains and associated emissions reductions) of a northern high speed line (or system) will not be realised.

This can be seen in Figure B4 below, in which individual intercity linkage scores (ICL) are calculated for all conurbation-pairs (with a unity exponential applied to distance). Unsurprisingly, the strongest flows (37% of the total) are to London, with a further 17% concentrated upon Birmingham. But 46% is between the remaining conurbations, with particularly strong flows between the major population centres either side of the Pennines.

The adoption of a unity exponent in the calculation of ICL embodies the assumption that the tendency to travel is in inverse linear proportion to distance. This is supported by the fact that both the principal deterrents to travel – journey time and cost – also vary proportionally with distance.

[10] The reliance of the UK economy upon good transport connectivity was one of the principal findings of the Eddington Transport Study (HMG 2006).

This seems a reasonable hypothesis, so long as the difficulty in making the journey does not increase disproportionately with distance. For people in transit, this will hold true until distance becomes too great to make a ‘there and back in a day’ trip; and with high speed rail offering sub-3-hour journey times between all principal conurbations, this ideal of connectivity will apply for most UK intercity journeys.

City	P_c	Gl	Ed	Ne	Li	Ma	Ls	Sh	Ng	Bi	Σ	%	
Glasgow	**2.3**												
Edinburgh	**0.8**	2.71											
Newcastle	**1.6**	1.89	0.87										
Liverpool	**1.3**	1.05	0.37	1.07									
Manchester	**2.5**	1.95	0.71	2.34	6.47						**58.8**	**46.4**	Interregional ie non-London-centric non-Birming’m-centric
Leeds	**2.2**	1.76	0.67	2.69	2.75	9.61							
Sheffield	**1.3**	0.89	0.34	1.18	1.50	5.08	5.94						
Nottingham	**0.7**	0.42	0.16	0.49	0.69	1.87	1.57	1.81					
Birmingham	**2.6**	1.47	0.53	1.50	2.67	5.74	3.86	3.08	2.51		**21.3**	**16.8**	B’ham
London	**8.0**	3.33	1.20	3.24	3.65	7.72	6.53	4.70	3.25	13.0	**46.6**	**36.7**	London
	23.3	Total Quantum of InterConurbation Connectivity									**126.8**	**100**	

InterConurb Linkage Score = $\frac{P_{C1} \times P_{C2} \times C_{onstant}}{(D_{1\,2})^{1}}$

Fig B4: InterConurbation Connectivity Matrix (Unity exponential)

However, while business and leisure travellers might be tolerant of journeys of perhaps up to 4 hours, this is not true of commuting traffic, where a much lower ‘tolerance horizon’ of perhaps 2 hours might apply. This will tend to enhance the proportion of local journeys.

City	P_c	Gl	Ed	Ne	Li	Ma	Ls	Sh	Ng	Bi	Σ	%	
Glasgow	**2.3**												
Edinburgh	**0.8**	4.95											
Newcastle	**1.6**	2.04	1.07										
Liverpool	**1.3**	0.93	0.33	1.15									
Manchester	**2.5**	1.70	0.63	2.69	13.7						**95.7**	**56.5**	Interregional ie non-London-centric non-Birming’m-centric
Leeds	**2.2**	1.55	0.62	3.53	4.05	19.0							
Sheffield	**1.3**	0.73	0.29	1.33	2.11	9.53	12.8						
Nottingham	**0.7**	0.32	0.12	0.49	0.89	2.91	2.38	3.83					
Birmingham	**2.6**	1.09	0.40	1.35	3.56	8.08	4.76	4.41	4.42		**28.1**	**16.6**	B’ham
London	**8.0**	2.12	0.78	2.44	3.25	7.19	5.97	4.74	3.72	15.4	**45.6**	**26.9**	London
	23.3	Total Quantum of Interconurbation Connectivity									**169**	**100**	

InterConurb Linkage Score = $\frac{P_{C1} \times P_{C2} \times K_{onstant}}{(D_{1-2})^{1.5}}$

Fig B5: InterConurbation Connectivity Matrix (1.5 Exponential)

For completeness, the InterConurbation Connectivity Matrix has been reevaluated for 1.5 and 2.0 exponentials on distance, as shown in Figures B5 and B6. These show ICL values for Increasing exponentials indicate an increased tendency for local travel, at the expense of the longer-distance London-centric journeys.

City	P_c	Gl	Ed	Ne	Li	Ma	Ls	Sh	Ng	Bi	Σ	%	
Glasgow	**2.3**										**150**	**66.6**	Interregional ie non-London-centric non-Birming'm-centric
Edinburgh	**0.8**	8.01											
Newcastle	**1.6**	1.95	1.17										
Liverpool	**1.3**	0.74	0.26	1.09									
Manchester	**2.5**	1.32	0.50	2.74	25.8								
Leeds	**2.2**	1.22	0.51	4.12	5.30	33.6							
Sheffield	**1.3**	0.53	0.22	1.33	2.65	15.9	24.7						
Nottingham	**0.7**	0.22	0.09	0.43	1.03	4.01	3.21	7.19					
Birmingham	**2.6**	0.72	0.27	1.08	4.22	10.1	5.21	5.62	6.92		**34.2**	**15.2**	B'ham
London	**8.0**	1.20	0.45	1.64	2.57	5.95	4.85	4.24	3.78	16.2	**40.9**	**18.2**	London
	23.3	Total Quantum of InterConurbation Connectivity									**225**	**100**	

InterConurb Linkage Score = $\frac{P_{C1} \times P_{C2} \times Q_{onstant}}{(D_{1-2})^2}$

Fig B6: InterConurbation Connectivity Matrix (2.0 exponential)

An exponential of 2.0 would follow the gravitational analogy; with the inverse-squared assumption, two-thirds of all inter-conurbation links would be independent of both London and Birmingham. However, this does not appear to be borne out in fact. Even with an exponential of 1.5, which might best reflect the total distribution of trips, non-London and Birmingham flows would comprise 56% of all flows, which would still appear to be unlikely.

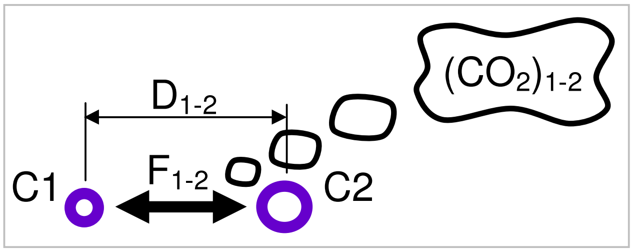
An alternative way of rationalising the situation might be to consider commuting journeys as a separate strand from the intercity, interconurbation journeys for which high speed rail is postulated to be the solution. This would then allow longer-distance flows to be calculated as inversely proportional to distance, which seems intuitively to be correct.

For the purposes of this study (which aims to demonstrate the increased potential for new rail networks to capture interregional flows, generally shorter in journey length than London-centric flows) it will be conservatively assumed that potential traffic flows are inversely proportional to (linear) distance.

$$\text{Intercity connectivity (or traffic flow } F_{1-2}) \propto \frac{P_{C1} \times P_{C2}}{D_{1-2}}$$

B4 CO_2 Emissions arising from Calculated Connectivity

From the determination of connectivity/potential traffic levels by means of the InterConurbation Connectivity Matrix, the calculation of CO_2 emissions naturally follows. Traffic flow can only be accomplished with the application of force to propel a vehicle, and this directly implies use of energy and consequent emission of CO_2. Taking speed and load factor (whether or road or rail vehicle) to be broadly constant across the network, the only other determinant on energy/ CO_2, aside from traffic flow, is route length. (This is analogous to work = force x distance, or the effort required to push fluid along a pipe).



Hence it can be deduced that CO_2 emissions between two points C1 and C2 is proportional to traffic flow (F_{12}) and intervening distance (D_{12}):

$$(CO_2)_{1-2} \propto F_{1-2} \times D_{1-2}$$

As demonstrated previously

$$F_{1-2} \propto \frac{P_{C1} \times P_{C2}}{D_{12}}$$

Therefore $$(CO_2)_{1-2} \propto \frac{P_{C1} \times P_{C2}}{D_{1-2}} \times D_{1-2}$$

Simplifying $$(CO_2)_{1-2} \propto P_{C1} \times P_{C2}$$

The notion that CO_2 emissions might be independent of distance, appears at first consideration to be counter-intuitive. However, it reflects two opposite but equal effects. The tendency to travel between two conurbations has been shown to decrease with distance, in approximate inverse (linear) proportion. But CO_2 emissions rise in direct (linear) proportion with distance. Thus the two effects balance each other. This leaves the magnitudes of the two populations connected as the only remaining variables.

This relationship allows the development of an InterConurbation Emissions Matrix (ICEM), similar to the InterConurbation Connectivity Matrix (ICCM).

City	P_c	Gl	Ed	Ne	Li	Ma	Ls	Sh	Ng	Bi	Lo	Σ	%	
Glasgow	**2.3**													
Edinburgh	**0.8**	1.84												
Newcastle	**1.6**	3.68	1.28											
Liverpool	**1.3**	2.99	1.04	2.08										
Manchester	**2.5**	5.75	2.00	4.00	3.25							**68.9**	**30.7**	Interregional ie non-London-centric non-Birming'm-centric
Leeds	**2.2**	5.06	1.76	3.52	2.86	5.50								
Sheffield	**1.3**	2.99	1.04	2.08	1.69	3.25	2.86							
Nottingham	**0.7**	1.61	0.56	1.12	0.91	1.75	1.54	0.91						
Birmingham	**2.6**	5.98	2.08	4.16	3.38	6.50	5.72	3.38	1.82			**33.0**	**14.7**	B'ham
London	**8.0**	18.4	6.40	12.8	10.4	20.0	17.6	10.4	5.60	20.8		**122.4**	**54.6**	London
ΣP_c	**23.3**	Total Quantum of InterConurb Emissions Score										**224.3**	**100**	Total

Fig B7: InterConurbation Emissions Matrix

Whilst the ICCM placed a high value on connectivity between the closely-located conurbations of the North, this effect is flattened out with the InterConurbation Emissions Matrix. Now the greater weight of population in London and the SouthEast – over one third of the population within the Zone of Influence of a northern high speed line – has the effect of reducing the proportion of emissions attributable to journeys that have neither Birmingham nor London as their focus. However, these journeys still represent 31% of the total, and as such must be taken into account in the development of any national scheme aimed at optimising emissions reductions.

If the ICEM is presented as a double-sided matrix (notwithstanding the implicit 'double-counting') it can be seen that the emissions figure attributable to each conurbation is broadly proportional to its population.

City	P_c	Gl	Ed	Ne	Li	Ma	Ls	Sh	Ng	Bi	Lo	Σ	%
Glasgow	**2.3**		1.84	3.68	2.99	5.75	5.06	2.99	1.61	5.98	18.4	48.3	10.8
Edinburgh	**0.8**	1.84		1.28	1.04	2.00	1.76	1.04	0.56	2.08	6.40	18.0	4.0
Newcastle	**1.6**	3.68	1.28		2.08	4.00	3.52	2.08	1.12	4.16	12.8	34.7	7.7
Liverpool	**1.3**	2.99	1.04	2.08		3.25	2.86	1.69	0.91	3.38	10.4	28.6	6.4
Manchester	**2.5**	5.75	2.00	4.00	3.25		5.50	3.25	1.75	6.50	20.0	52.0	11.6
Leeds	**2.2**	5.06	1.76	3.52	2.86	5.50		2.86	1.54	5.72	17.6	46.4	10.3
Sheffield	**1.3**	2.99	1.04	2.08	1.69	3.25	2.86		0.91	3.38	10.4	28.6	6.4
Nottingham	**0.7**	1.61	0.56	1.12	0.91	1.75	1.54	0.91		1.82	5.60	15.8	3.5
Birmingham	**2.6**	5.98	2.08	4.16	3.38	6.50	5.72	3.38	1.82		20.8	53.8	12.0
London	**8.0**	18.4	6.40	12.8	10.4	20.0	17.6	10.4	5.60	20.8		122.4	27.3
ΣP_c	**23.3**	Total Quantum of InterConurb Population Product										**448.6**	**100**

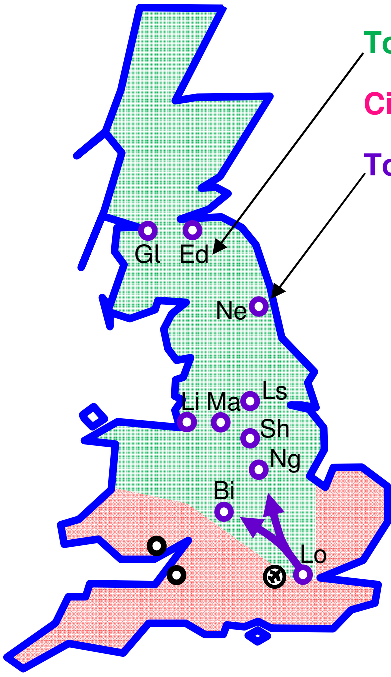
Fig B8: InterConurbation Population Product

The sum of the entire matrix can be taken to be representative of the total quantum of interconurbation emissions. The only elements discounted are the blacked out squares, which would represent emissions internal to each conurbation, and, being principally convertible by more local interventions, not relevant to this analysis.

Taken on a wider level, the principle of emissions being proportional to connected populations can be extended across the entire Zone of Influence of a northern high speed line. As shown in Figure B9, a population of 40 million indicates a population product of 1600 (=40^2) while the population of the conurbations (23.3 million) has its own population product of 543 (=23.3^2). After the intra-conurbation flow effects are deducted, the interconurbation population product reduces to 449.

This is 28% of the total population product, which itself is representative of the target emissions of 85MT per annum. Hence it can be deduced that a high speed rail scheme that delivers comprehensive connectivity and capacity between the conurbations of the Midlands, North and Scotland might be capable of a conversion level up to 28%.

But if the scope of the high speed rail project can be extended to the next tier of ‘secondary’ cities (which together approximately constitute another 5 million), then it appears to be possible to achieve a conversion level of up to 43%. In practice, the conversion level will be significantly lower due to the imperfect connectivity offered by the existing railway network, which cannot be fully remedied by a new high speed line system focussed on the conurbations.



Total Green Zone population P_{GZ}: 40M

City+conurbation population ΣP_{CC}: 28M

Total conurbation population ΣP_{C}: 23M

Calculation of convertible CO_2 via HSL to North			
Green Zone population product	$(P_{GZ})^2$	a	1600
Conurbation population product	$(\Sigma P_c)^2$	b	543
Internal conurbation population product	$\Sigma (P_c)^2$	c	94
Inter-conurbation population product	(b–c)	d	449
Percentage convertible emissions through total conurbation connectivity	d/a		28%
Conurbation & city population product	$(\Sigma P_{cc})^2$	e	784
Internal conurbation population product	$\Sigma (P_c)^2$	c	94
Inter-conurb & city population product	(e–c)	f	690
Percentage convertible emissions through total conurbation/city connectivity	f/a		43%

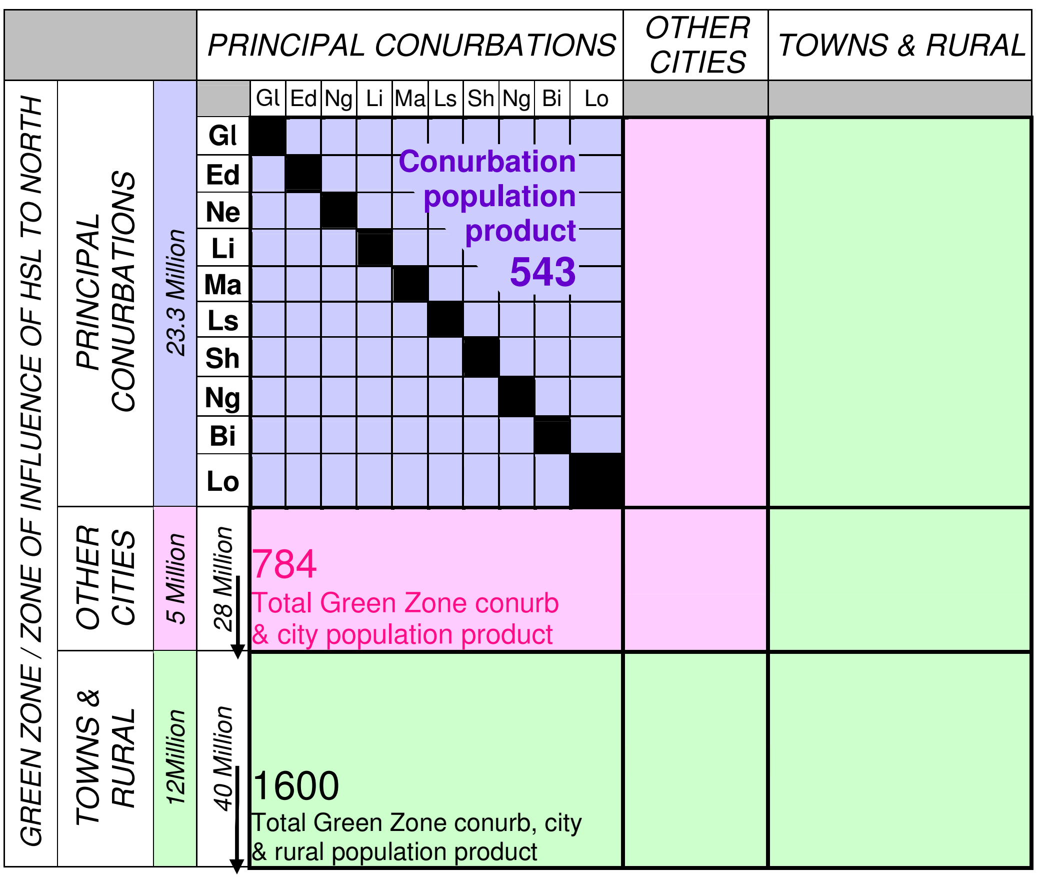


Fig B9: InterConurbation Emissions Matrix

B5 Coverage of Network

Network coverage is a crucial consideration in the design of a network aimed at optimising reductions in CO_2 emissions. It is only possible to achieve modal shift along a particular intercity axis if new rail capacity is provided along that same axis; this must (along with other regional political considerations) drive the development of a comprehensive interregional network linking all major conurbations.

A major weakness of most high speed rail schemes is that they essentially constitute a London-centric ‘fan’, with few if any interregional enhancements offered. An appreciation of the strength of interregional flows (ie those not focussed upon London) can be gained through calculating potential flows between conurbations, using a gravitational model.

The predominance of journeys towards London tends to contradict Tobler’s basic concept, that all populations have equal power to generate and attract traffic flows. But this disparity reflects the present London-, or capital-centric nature of the UK economy. It has long been Government policy to redress this ‘economic tilt’, but with the national transport infrastructure (particularly rail and air networks) tending to focus upon London, economic activity has continued to concentrate in London and the South-East. This trend could be reversed with the advent of high speed rail.

The development of a new high speed rail system presents a unique opportunity to address the London-centric nature of the existing network. However, this is not reflected in contemporary trends in high speed rail development, with most proposals either focussed upon London, or comprising a ‘Y’ that divides in the West Midlands, and continues both sides of the Pennines. These will address longer-distance north-south flows, and would seem also to improve connectivity to the West Midlands; however, they make little or no attempt to meet the needs of Northern and Scottish communities for comprehensive interconnectivity. This is despite major congestion (arising from capacity constraints, indicating major potential for CO_2 emissions reductions) particularly on Transpennine axes.

This will tend to perpetuate the London-centricity of the UK economy, but possibly more importantly, will offer an incomplete solution, in terms of the connectivity, and associated environmental benefits, that might be gained. Through focussing the high speed solution upon London, of the order of one half of the potential connectivity (and consequent capacity gains) of a northern high speed line (or system) will not be realised. In terms of emissions reductions potential, the impact is almost as great.

B6 Operational Efficiency of Network

The concept of operational efficiency covers many considerations, but essentially it can be defined as the ratio between the desired outputs and the inputs required (to achieve the output). This might comprise number of city pairs linked against number of train units – or on-board staff – required to achieve these links. Or it might comprise a simpler consideration of the load factor (ie percentage of seats occupied as opposed to vacant).

High operational efficiency clearly implies superior financial performance. But equally, it is an indicator of superior environmental performance. For instance, a higher load factor (ie more passengers on the train and fewer empty seats) results in a superior EPI, in other words a lower figure for grams of CO_2 per passenger kilometre, compared with a train that is poorly filled.

There are many considerations that determine load factor, for instance ticket price, service frequency, on-board facilities and ambience. Speed might be an issue, and is discussed further in Section B7. These are essentially operational issues that are largely independent of the infrastructure.

The configuration of the infrastructure also has a powerful influence upon operational efficiency. This issue has been largely unrecognised in the development of UK high speed rail systems, which (in operational terms if not in precise layout) will for most proposals comprise a London-centric fan, with separate services to each principal regional centre. This has so far been assumed to represent the ideal operational model (and indeed, largely reflects the current *modus operandi* on the existing rail network). Figure B10 illustrates high speed services from London (city L) to 3 Northern cities of equal population (cities X, Y and Z, which might be analogised to Leeds, Sheffield and Manchester). However, on simple examination it would appear not to represent optimum efficiency.

Development of rail routes to these cities has been greatly influenced by the presence of the Pennine chain (separating Manchester from Leeds and Sheffield), and the location of these Yorkshire cities in separate valleys. In the 19th Century, these topographic issues prevented the development of a single time-sensitive route that might serve all 3 cities, and instead they are now separately served by West Coast, East Coast and Midland Main Line networks.

With most high speed rail proposals essentially configured in a similar manner, but without any major intermediate calling points, each high speed service is dependent upon the city at its end to fill the trains. This would not be a problem, if service frequency and train capacity could be varied to precisely fit demand, which varies both seasonally and through the day, with morning and evening peaks. However, the reality of intercity railway operation is a fixed timetable, with fixed-formation trains operating at set frequencies. This entails an inherent level of inefficiency, with capacity of necessity exceeding demand, and rising (and falling) in steps that reflect the provision of increasing 'units' of capacity at 'integer' frequencies (ie 1, 2, 3 etc trains per hour) to cover the peaks and troughs of daily flows.

This is illustrated in Figure B10. The grey areas of the blocks, above the diurnal demand line, represent the empty seats, and from this a relatively low load factor can be inferred, from independent operation of high speed services from London to Northern cities.

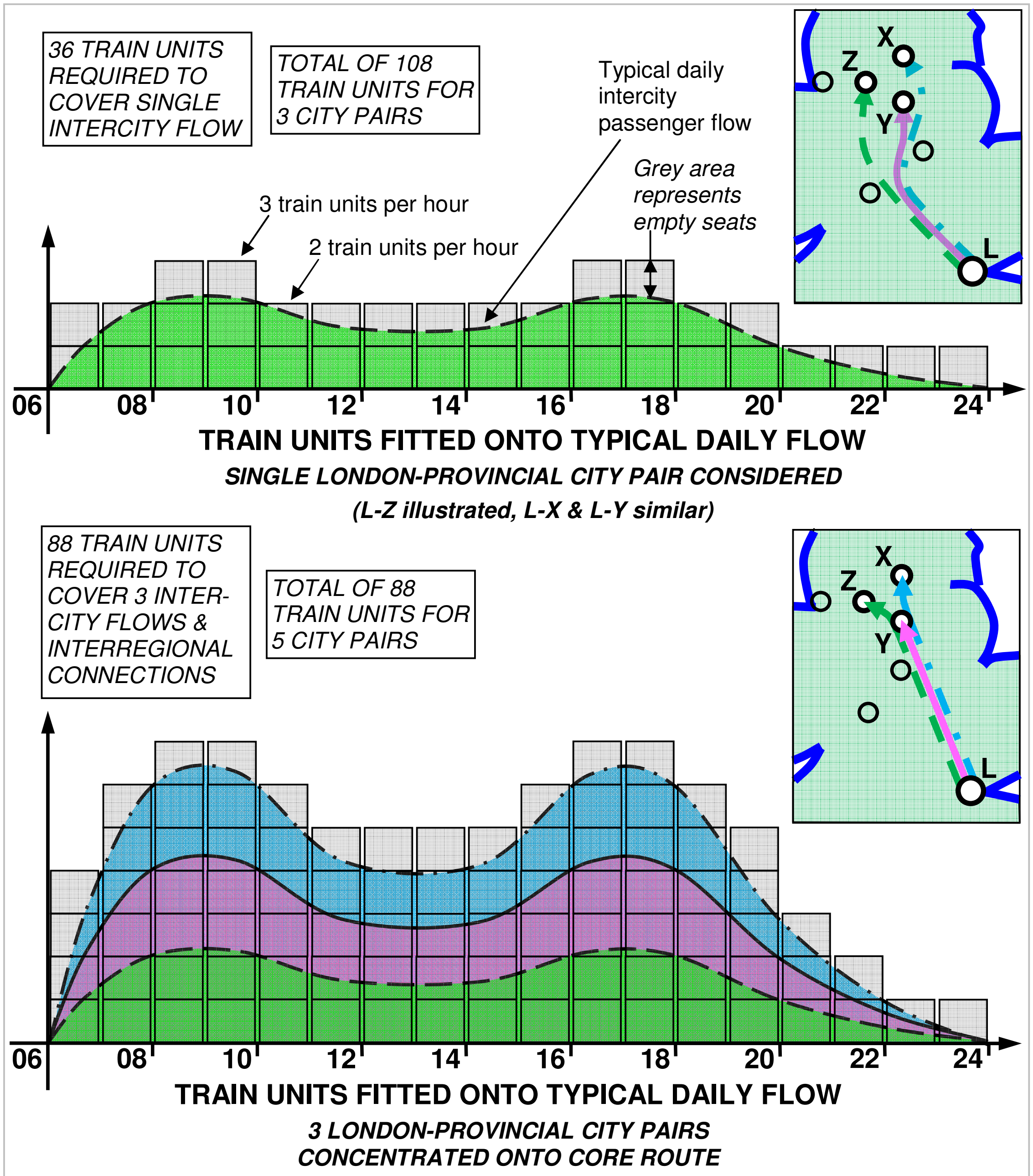


Fig B10: Greater Operational Efficiency from Concentration of Services onto Core Route

It is important to appreciate the relative geographical location of Leeds, Sheffield and Manchester. Although separated by the Pennine chain, they are only 60km apart, but 300km from London. In simple geometric terms, it would appear possible to develop a single core route to Sheffield, splitting there for Leeds and Manchester. The reality of the matter is that routeing issues are somewhat complicated by the presence of the Pennines, but the Woodhead corridor offers a feasible Transpennine route, albeit locally at lower speed and heavily engineered to mitigate environmental issues, that will deliver competitive journey times to a central Manchester terminal.

The core route is also modelled in Figure B10. With Manchester-, Leeds- and Sheffield-London flows all concentrated onto a single spine route, the 3 diurnal diagrams (equal in respect of idealised cities X, Y and Z) are added to form a larger single diagram. When the same blocks, representing individual trains, are fitted onto the diagram, the 'above the line' proportion in grey is a lesser proportion of the total, thus reflecting a higher load factor.

Higher load factor implies lower grams of CO_2 per passenger kilometre, and thus superior environmental performance. But in simpler terms, this comes about through the operation of fewer trains to transport the same number of passengers. The example illustrated in Figure B10 shows 36 trains in a daily city-pair diagram, or 108 trains for the 3 city pairs; but when concentrated onto a spine route, only 88 trains are required. This indicates circa 18% increased efficiency / load factor and reduced CO_2 emissions; but fewer trains operating for the same passenger flow also translates as increased effective line capacity.

A further benefit is the greater connectivity offered by focussing the route upon city Y (ie Sheffield). The more efficient core/spine route (requiring 88 daily trains) connects 5 city pairs, and creates the interregional (Transpennine) links essential to promoting development in the UK regions; whereas the 3 city pairs linked by the 'fan' (requiring 108 daily trains) comprises a London-centric system with no interregional links.

B7 Effects of Speed

There is a continuing trend for increasing speed, rising from 300kph (typical of the first generation of European high speed rail, such as the French TGV-Midi and Eurostar on HS1, towards the contemporary 350kph limit). HS2 now aspire to go one stage further, with an anticipated initial operating speed of 360kph, and an ultimate goal of 400kph operation (for which the line has been designed).

To date, design development has succeeded in 'pushing the envelope' to the extent that each upward increment of speed has shown an approximately linear rise in energy consumption[11]. This is attributable to the development of progressively more efficient rail vehicle dynamics to permit the achievement of higher speeds, and it undoubtedly represents genuine technical progress.

However, there is a clear danger that speed will be pursued as an end in itself, a competition with other nations to run the world's fastest railway, rather than as a response to a commercial or an environmental requirement. There is a danger also that this linear relationship – effectively a mitigation of the more exponential CO_2 impacts of speed – will tend to disguise the more fundamental 'K-V-squared' relationship, whereby energy use rises proportional to the square of speed. This relationship applies for any given vehicle, however aerodynamically 'smooth' or 'rough'.

The simple problem with speed is that it leads inevitably to higher energy use, and higher CO_2 emissions. Hence, whatever the optimised energy consumption (and therefore CO_2 emissions) of a train designed for, and operating at 400kph, these attributes will be vastly superior at lesser speeds.

B7.1 Application of 'K-V-squared' rule

Table B11 below illustrates the 'K-V-squared' relationship between speed and CO_2 emissions, baselined upon a median high speed of 300kph.

Speed (kph)	200	240	280	300	320	360	400
Relative CO_2 emissions	0.44	0.64	0.87	1.00	1.14	1.44	1.78

Table B11: Relationship of Speed to Energy Use & CO_2 Emissions

From the above table, it might be inferred that a train operating at even a modest 'high speed' – say 320kph/200MPH – has an energy consumption and emissions characteristic around 2½ times greater than conventional operation at 200kph/125MPH. However, the effects of higher speed are greatly mitigated by the much smoother running, without frequent station stops and conflicts with other traffic, that is possible on new lines dedicated to express passenger use.

When the higher load factors that are possible with high speed rail (brought about through trains remaining well loaded for a greater proportion of their journey) are also taken into account, then high speed rail operating at circa 300-320kph can show a carbon footprint no worse than a classic intercity train at a conventional 200kph. This might be termed the 'transitional' effect.

[11] RSSB research paper T618 Traction Energy Metrics, undertaken by Professor Roger Kemp of Lancaster University, provides definitive information on energy consumption of a wide range of rail vehicles, both high speed and conventional.

It must be stressed that this is a benefit that accrues not from higher speed running per se, but from the transition from classic mixed traffic railway operation to new lines dedicated to express passenger use. The transitional effect is separate from the effects of speed; only the 'K-V-squared' rule applies, when considering the relative emissions of different speeds.

As set out in Table B11, the effect of speed upon CO_2 emissions is dramatic. 360kph running will cause 44% greater CO_2 compared with 300kph, and at 400kph, the differential increases to 78%. As can be seen from Figure B11, at these speeds the environmental advantages over roads is greatly reduced from what might be achieved at lesser speeds. There would have to be very powerful benefits, in terms of enhanced modal shift and consequent emissions reductions, to justify the increased emissions arising from the greater speed.

B7.2 Relationship between Speed and Rail's Market Share

The degree to which rail's market share (from which emissions reductions might be inferred) is dependent upon speed is a matter for considerable debate. There has been a historic tendency to value any transport proposal, road, high speed rail or otherwise, on the projected savings, measured in minutes of reduced journey times. This still considerably influences Government assessment of transport proposals, and is a key factor in tools such as WEBTAG.

However, anecdotal evidence tends to support an alternative view, at least for rail transport. Passengers appear to place greater value on:

- service frequency,
- reliability and punctuality,
- availability of through journeys without change of train (or mode), and
- on-board facilities and general comfort,

than they do on outright speed. With the advent of mobile telephones, laptop computers and wi-fi internet, time spent on a journey no longer represents lost time that needs to be mitigated through increased speed. On the contrary, a business person's (or other traveller's) time on a train is free of distractions and can constitute a high-value work opportunity. This would seem to indicate that the historical value of speed in attracting passengers to rail may be exaggerated, in contemporary terms.

This is by no means a universal truth; the dominance of aviation over rail on Anglo-Scottish journeys (approx 85%:15% modal split) is primarily attributable to the speed / timing advantage of air travel. This has driven the fundamental requirement for any high speed rail scheme to achieve a London to Glasgow journey time of less than 3 hours (an improvement from the current 4h30m), to enable rail to offer total journey times competitive with domestic aviation. Such timings are achievable only with trains running at speeds approaching 300kph, and this would seem to dictate a requirement for a degree of high speed (ie greater than conventional 200kph), at least on Anglo-Scottish runs.

B7.3 Journey Time Gains from High Speed Operation

Elsewhere, however, there appears to be less of an imperative for high speed operation. For most key UK city pairs eg London to Manchester, Leeds or Birmingham (on which journey times of 2h05m, 2h05m and 1h22m currently apply) rail is already comfortably the quickest mode, and the value of further reducing these timings has to be carefully considered.

Although the quoted timings relate to 200kph running, this only represents the maximum operating speed. For much of the journey, speed restrictions and signal checks due to conflicting train movements have the effect of greatly reducing operating speeds. Migration to 200kph 'high speed' operation on dedicated tracks with no intermediate constraints would reduce timings to circa 1h40m/1h40m/1h00m. Increased speed would allow further reductions, to circa 1h20m/1h20m/0h50m at 300kph, and to circa 1h00m/1h00m/0h40m at 400kph.

Viewed from the perspective of a journey from London to Birmingham, each 100kph speed increment would save around 10 minutes, but result in an approximate doubling of energy use, and therefore CO_2 emissions also. It is difficult to see how such small journey time savings can result in benefits that could justify the much greater environmental consequences of running at higher speeds.

It is also significant to note that the timing gains achieved through migrating from classic mixed traffic operation to a dedicated express passenger railway (ie non-stop running, but at conventional 200kph) are as great as those accruing from an increase in maximum speed from 200kph to 400kph.

Another strategy by which similar if not greater timing gains might be generated is through improved connectivity. This comes about through integration benefits such as:

- optimised interchange between high speed and existing network,
- avoidance of such interchange with integrated through running to destinations on the classic network.
- configuration of high speed rail network, to address connectivity defects in existing networks, particularly to improve interregional axes.

B7.4 Speed vs Capacity and Connectivity

It seems reasonable to infer from the above that speed has a real value when it can enable rail to gain a competitive edge over aviation; but when (as applies for most journeys within England) rail is already the fastest point-to-point transport mode, there appears to be little or no benefit in pursuing extreme speeds which will generate more in the way of extra CO_2 emissions, than could possibly be saved through extra modal shift attracted by the higher speed.

Reduced congestion through the construction of new lines, and improved connectivity through greater integration, seem to offer a far superior strategy than extreme speed.

There is a clear potential conflict between the higher speed that might be dictated by the need to compete with domestic aviation on the London-Scotland axis (necessary to convert the still higher emissions from domestic aviation) and the lower speed that appears to be required (to optimise emissions) for journeys within England. On a 2-track railway, this conflict would seem impossible to resolve, while retaining maximised capacity.

The danger must be that the relatively minor (if extremely totemic) benefits achieved through eliminating domestic aviation will be compromised by the sub-optimal environmental gains that will accrue through the operation of shorter-distance routes at unnecessarily high speeds. 4-tracking of critical sections may offer a solution that will optimise reductions in operational CO_2, at the expense of a one-off increase in emissions associated with the construction of the enlarged infrastructure.

B7.5 'Perverse Geography'

A further danger of extreme speed is that it can have the effect of distorting established geographical relationships. A prime example is Coventry, a key calling point on the London to Birmingham intercity service. Coventry's proximity to London relative to Birmingham (152km vs 185km) is reflected in the respective journey times (59 minutes vs 1 hour 22m).

But under HS2 proposals, these relativities will be reversed, with London-Birmingham journeys accelerated to 49 minutes, while Coventry's will actually have slower and less frequent trains (in lieu of the present 3tph service, HS2 projections allow for 1tph from Coventry to London, with more intermediate stops). Comparison with journey times to HS2's proposed Birmingham 'Interchange' (38 minutes, and located only 15km from Coventry) paints an even starker picture.

This phenomenon, which might simplistically be described as 'perverse geography', seems certain to have the effect of blighting Coventry, and pushing development towards new development hotspots, either in central Birmingham, or (more likely) in the vicinity of Birmingham 'Interchange'. With this latter station effectively disconnected from the local public transport network but handy for the motorway network, this undesirable 'development shift' would seem certain to bring about an increase in CO_2 emissions through adding traffic to the local road network.

B7.6 Technological Risks from Increased Speed

Although railways are commonly acknowledged to be by far the safest form of land transport, there is always a residual level of risk that can never be fully eliminated. Risk is influenced by a huge range of factors, amongst which speed must be one of the key elements. It is clear, from simple considerations of kinetic energy, that (all other things being equal) a collision or derailment at higher speeds will have greater catastrophic consequences than one at lower speed.

This is not to doubt the professional efforts of those who will do their utmost to design the necessary safe systems, from crash-worthy rail vehicles to resilient bogies to fully interlocked and validated in-cab signalling. But with any advancing technology, there is a level of risk that cannot be fully eliminated as new factors come to the fore. In the case of high speed rail, it should in particular be noted that it is proposed to operate HS2 at the unprecedented speed of 360kph, with alignment design allowing for a possible further increase to 400kph. With no history of sustained operation at these speeds (high speed test runs, reaching speeds greater than 500kph, cannot uncover long-term fatigue issues such as gauge corner cracking), it is impossible to fully predict material stresses at the rail-wheel interface, especially on curves.

Even at conventional speeds of 200kph, this interface has proved difficult to manage.
This is exemplified in the gauge corner cracking crisis which followed the Hatfield derailment in 2000. With confidence lost in the safety of rail operations, and massive overcrowding resulting from the consequent speed restrictions, this left the network effectively crippled for several months. This had a major immediate CO_2 impact, in the short-term diversion of traffic to the roads, and a longer-term impact upon the railway through loss of reputation.

With proposed and possible speeds of the order of twice that which applied at Hatfield, there are clear risks in managing the rail-wheel interface (and other issues, as yet undefined) at such speeds, at which no railway in the world has ever operated. Although the risks will be assessed and monitored with the utmost skill and professionalism, they will remain risks; and there is no doubting the magnitude of the potential consequences of a derailment at 360 or 400kph.

Gauge corner cracking and the rail-wheel interface are issues of particular concern because of their close relationship to rail gauge (ie the distance between the rails) and flange depth (ie the distance to which a train wheel projects below the rail head, to guide the train and prevent derailment). Both are parameters that would ideally be scaled up, to give greater stability with increasing speed; but this is not possible, due to the overriding need for interoperability on a common system.

However, these considerations represent only one more obvious aspect of the risks associated with operating at extreme speed. It is impossible to predict what other issues might come to the fore, as railway operation enters uncharted territory.

With no compelling case for such speeds on a small island, it would seem prudent to avoid 'pushing the envelope' in this particular direction.

B7.7 Higher Train Availability through Increased Speed?

It must be conceded that higher speed can sometimes bring benefits through allowing a service to be 'diagrammed' with fewer trains. For instance, HS2's proposed 49 minute timing from Euston to Fazeley Street might allow a train to start from London at (say) 9AM, set off on the return journey at 10AM, and be back at Euston in time for another northbound journey at 11AM. In this way, 6 train units would be required to cover a 20 minute service frequency, whereas 7 train units might be required if lower speeds applied, and the journey time were (say) 59 minutes.

Hence reduced costs might be inferred from the operation of faster trains:

- Fewer units required, hence lower capital costs.
- Reduced staffing costs.

But against this must be set several countervailing effects:

- Increased energy costs (continuing operational effect).
- Higher maintenance costs (due to generally higher stress operation).
- Increased construction costs to create straighter alignment.

It is not possible in this study to conclusively resolve this issue. However, it is valid to observe that while the factors driving reduced cost appear to vary linearly with speed, a squared relationship would seem to apply to the opposing factors showing increased cost.

It should also be noted that increased speed is not the only mechanism by which rolling stock utilisation might be maximised. This outcome can also be achieved through efficient network configuration that optimises load factor, and thereby requires fewer trains (and fewer staff) to serve a given number of passengers. These issues are discussed in greater detail in Section B6, and Section 4.9.

B8 Integration of high speed services with classic network

The concept of integration applies on several levels. Most simply, it should address efficient interconnection between new high speed and existing classic network. However, it is a much wider concept, and as an issue it must be addressed on all levels if CO_2 emission reductions are to be maximised.

The following aspects of integration must be considered:

- Exclusive or integrated operation?
- System resilience against disruption
- Efficient Interconnection at city centre hubs
- Greater Focus on Subsidiary Centres?
- Out of Town Parkway Stations?
- Enhancement of existing network to offer greater journey opportunities
- Onward running from high speed network onto existing lines
- Avoidance of blight to existing routes and bypassed communities
- Optimisation of total network capacity

B8.1 Exclusive or integrated operation?

With the proposed high speed network comprising a 'new railway', there will be a legal/regulatory requirement to construct the new infrastructure to common European standards (TSI's) that will ultimately permit pan-European operation of high speed rail services. This dictates that any new high speed line must be capable of accommodating 'Eurogauge' wide-bodied double-decker trains of 400m length; these would be wider, taller and longer than any train presently operating on the classic UK network[12].

Trains manufactured to Eurogauge have considerably greater seating capacity than those conforming to classic UK 'W6' gauge. It is anticipated that 400m long double decker trains (as might operate on HS2) would accommodate up to 1100 passengers, while Class 373 Eurostars (as currently operate on HS1, also 400m long but manufactured to UK gauge) carry 750, and 250m long Class 359 Pendolinos (operating on the West Coast Main Line) carry 450.

There are obvious benefits for line capacity, in operating the maximum possible size of trains. However, there are considerable drawbacks also. The constricted nature of many main line hubs (in particular Birmingham New Street) places limits on train cross-section and length, and precludes the operation of the 400m long double-decker rolling stock. This then compels the establishment of separate 'high speed' terminals, remote from the existing central stations.

Noting the fact that a conurbation's central hub station is not the final destination for the majority of intercity passengers, the disconnection between high speed and classic stations must represent a major inconvenience and deterrent to rail travel, that would seem to outweigh the advantages that should accrue from operation of higher capacity (but lower accessibility) trains.

[12] In technical terms, the requirement is for conformance to UIC-C structure gauge, also referred to as Eurogauge, or (slightly erroneously) Bern Gauge. This requires overline structures such as bridges and tunnels to be considerably larger than 'classic' UK railway infrastructure, tracks to be set further apart and platforms set further away from the track. Fortuitously, track gauge in the UK and on the continent is identical.

The inevitable consequence, of equipping the projected UK high speed system with trains that are too large to fit onto the classic network, would be a high degree of 'exclusive' operation, in which the premier trains are restricted to the new premier line, and the accruing benefits similarly restricted to a few select cities. With opportunities for interchange also limited (owing to the difficulties in accessing the existing principal hubs, as already discussed), there seems a real prospect of a 'two-tier' railway system developing, with investment concentrated on a prestigious superfast railway that serves relatively few, while the existing network, and the second tier cities on it, will be blighted through reduced connectivity.

In such a scenario, with little or no integration between new and existing, it is difficult to see how meaningful modal shift to the railway, and associated reductions in CO_2.

B8.2 Resilience against Disruption?

A particular concern relating to exclusive operation is that of vulnerability to disruption. If high speed rail in the UK is to comprise a system of new lines operated by rolling stock too long and too large in cross-section to fit onto the classic network, with few physical interconnections provided, there will be little or no opportunity to divert services in the event of line blockages etc. This will leave the system unable to cope with emergency situations, and will make it difficult to organise necessary maintenance activities.

This would indicate advantages in a more integrated solution, whereby UK-gauge high speed trains could run along either the high speed or the classic network, with transfer possible at many interfaces between high speed and classic lines.

B8.3 Efficient Interconnection at City Centre Hubs

Interconnection seems the first prerequisite of an integrated network. The most efficient interconnection (both commercial and environmental) will be created if the high speed system can access the hubs (such as Birmingham New Street, Manchester Piccadilly and Leeds City Station) upon which these conurbations' local rail (and wider public transport) networks are already focussed, and the greatest number of suburban centres are accessible.

However, as previously noted, there is a price for accessing existing city centre hubs (for which Birmingham New Street can be taken to be the prime exemplar, effectively constituting the UK railway version of the Panamax[13] criterion for shipping). This will restrict train capacity (at least of trains arriving at New Street) effectively to the existing Pendolinos.

There is no realistic prospect of widening the approaches to New Street station, nor of the wholesale station reconstruction necessary to accommodate longer, taller and wider Eurogauge trains. But alternatives exist. For instance, 400m long UK gauge trains (with around two thirds of the capacity of a double-decker Eurogauge train of the same length) might operate from London to the West Midlands conurbation, splitting at a suburban hub, with one half serving central Birmingham (and points beyond?) and the other directed towards subsidiary centres such as Walsall or Wolverhampton.

[13] 'Panamax' is a size standard to which most merchant shipping conforms, determined by the maximum size of vessel that will pass through the locks of the Panama Canal.

B8.4 Greater Focus on Subsidiary Centres?

This would reflect the true nature of potential passenger flows to a conurbation, especially in the context of the radically increased rail traffic that will result from major modal shift. Rail already holds the major market share for centre to centre journeys and there is only limited value in delivering more long-distance passengers to a city centre hub. The greater part of the potential modal shift will tend to be on flows to the subsidiary centres, and suburbs, which are more accessible to the road and motorway networks; this is the area where rail connectivity – either via direct connections or preferably by means of through running – must developed.

Splitting trains might add around 5 to 10 minutes to a journey from London to the West Midlands; but the value of speed and accelerated journey times on such short routes is somewhat questionable. It could be argued that the best use of speed is to facilitate such splitting, to increase the connectivity and scope of the high speed line.

Another advantage of splitting trains to serve subsidiary centres is that it will tend to divert flows away from the central hub station of the conurbation, the natural interchange point. These hubs are already considerably congested, and if the possible quadrupling of rail traffic were to occur with step-change modal shift, congestion levels seem likely to go critical. This limitation – possibly more critical than simple line/route capacity, and certainly more difficult to resolve – must drive development of high speed rail towards fully integrated 'through running' between classic and high speed networks.

B8.5 Out of Town Parkway Stations?

Outer-suburban hubs have considerable potential value, in that they allow the connectivity of the high speed line to be spread to many suburban areas that are currently poorly connected to the main line network. This is particularly critical for achieving full conversion of road flows to rail, on relatively short intercity axes such as London to the West Midlands.

For residents of the northern and western suburbs of London, and of the southern and eastern suburbs of Birmingham, the intercity rail links (conventional or high speed) between the centres of the two cities are generally of little attraction. Some suburban communities located close the West Coast Main Line (or the Chiltern Line) can indirectly access the intercity network, by changing at intermediate stations such as Watford Junction or Milton Keynes.

But for most, the city centre terminals are only accessible by means of a time-consuming 'against the flow' journey, which generally attracts both higher ticket price and higher CO_2 emissions; the relatively short drive up the M1 or M40 journey represents a far more convenient and cheaper alternative.

This issue has long been recognised by rail planners, leading to the development of outer-suburban hubs such as Watford Junction, Luton Airport Parkway or Stevenage. However, local connectivity to these stations has been largely limited to the respective uniaxial main line corridor (ie WCML, MML or ECML). Figure B12 shows the disconnection between main line corridors, extending to the centre of the cities.

This led to the planning of more radical parkway stations directly accessing the M25 orbital motorway. Only these latter stations (never realised) would have had the broad connectivity, capable of attracting traffic from the northern suburbs; but this would of course have been reliant on the road network, particularly the M25, and subject the endemic congestion on that artery.

To enable optimised modal shift along intercity corridors such as London to Birmingham, it would seem necessary to establish suburban hub stations, effectively connected by rail (or possibly bus or tram) across a wide hinterland. For this it would be necessary to construct circumferential/orbital railways; however, such links have rarely been advanced as a serious and viable proposition.

Instead, proposals have tended to concentrate upon classic 'parkway' stations on city outskirts, usually at locations that are only well-connected to the road and motorway network, and often in 'Green Belt' land. At these locations, usually with poor or non-existent public transport interchange, the following outcomes seem likely:

- the private car will take a dominant role in local distribution,
- the existing 'classic' rail network will be blighted through poor connectivity to the new network,
- undesirable planning pressures are created for 'out of town' development,
- much of the potential reductions in CO_2 emissions, and other environmental advantages that might accrue from the new high speed network will be lost.

B8.6 Existing network enhancement with greater journey opportunities

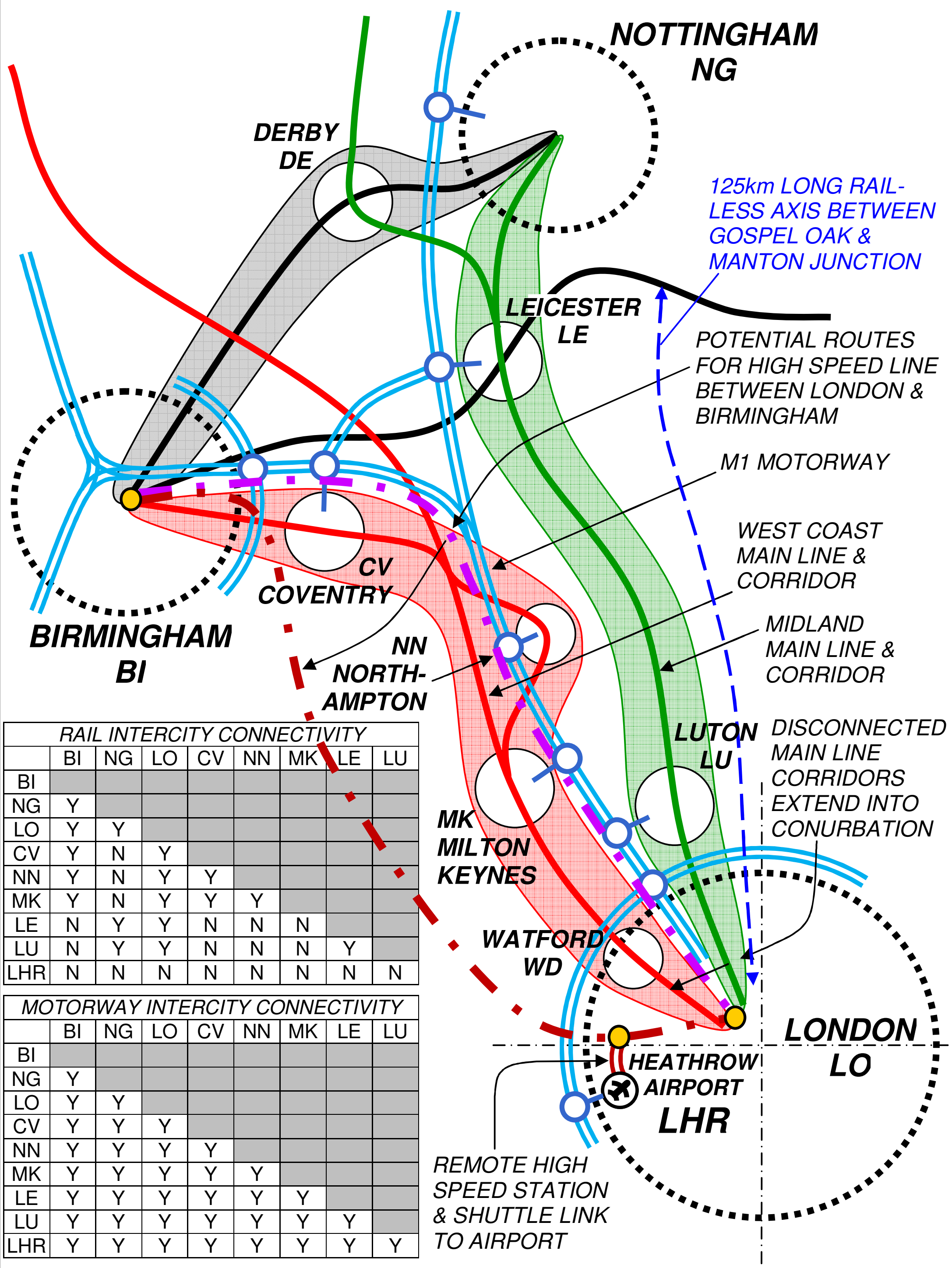
It must be recognised that the existing rail network is far from perfect in its configuration, and in the connectivity that it offers. This is partly attributable to the 'Beeching' cuts of the 1960's, in which over one third of the network's route mileage was lost, including most of the lines offering east-west links between the radial main lines ie WCML, MML and ECML[14]. However, it is chiefly attributable to the piecemeal and largely unplanned way in which the classic rail network developed, with even small towns served by several disconnected stations operated by independent railway companies, and thus few effective links between main line corridors.

This left much of the railway network vulnerable to closure in the face of rising road competition. The developing motorway network was much better able to satisfy the connectivity needs of communities, albeit at much higher cost in energy use. This consideration seemed largely immaterial back in the 1960's; but now, with both energy use and consequent CO_2 emissions assuming critical importance, a weak local railway network is poorly placed to compete effectively with a much stronger road and motorway network.

A particular case in point is the disconnection between Midland and West Coast Main Lines through the South-East Midlands. This leaves no practicable rail links between adjoining major communities such as Luton (on MML), with Milton Keynes, Northampton, Coventry and Birmingham (on WCML); or, in the reverse direction, from Milton Keynes and Northampton to Leicester and Nottingham. However, all these cities lie on the M1 or M6 corridors, and as such have excellent road links.

[14] An appreciation of the current lack of connectivity between main line corridors can be gained from the absence of any rail links between ECML and MML corridors, between Gospel Oak in North London and Manton Junction in the county of Rutland, approximately 125km to the north. All east-west rail routes across this axis were lost by the end of the 1960's, but since then, the connectivity implicit in the lost links has been replaced by one orbital motorway (M25) and one major east-west arterial link (A14).

The comparative connectivity between motorway and rail networks is illustrated in Figure B12, with the linkages between all regional centres tabulated.



RAIL INTERCITY CONNECTIVITY								
	BI	NG	LO	CV	NN	MK	LE	LU
BI								
NG	Y							
LO	Y	Y						
CV	Y	N	Y					
NN	Y	N	Y	Y				
MK	Y	N	Y	Y	Y			
LE	N	Y	Y	N	N	N		
LU	N	Y	Y	N	N	N	Y	
LHR	N	N	N	N	N	N	N	N

MOTORWAY INTERCITY CONNECTIVITY								
	BI	NG	LO	CV	NN	MK	LE	LU
BI								
NG	Y							
LO	Y	Y						
CV	Y	Y	Y					
NN	Y	Y	Y	Y				
MK	Y	Y	Y	Y	Y			
LE	Y	Y	Y	Y	Y	Y		
LU	Y	Y	Y	Y	Y	Y	Y	
LHR	Y	Y	Y	Y	Y	Y	Y	Y

Fig B12: Existing InterUrban Connectivity in South-East Midlands

It is important to note that the ‘M1 corridor’ cities comprise by far the greatest concentrations of populations in the South-East Midlands, reflecting the historic axis of communication that has existed since Roman times (as Watling Street/A5, followed by Grand Union Canal, London & Birmingham Railway/WCML and finally the M1 motorway); in terms of individual populations, only Oxford and Peterborough are comparable (approximately 50km to west and east respectively) but are far more isolated.

On a local level, the solution might seem to be a programme of railway reopening and possibly some entirely new lines. But the more national solution of high speed line construction also has potential to improve connectivity between local destinations. The key is to ensure that the high speed line is appropriately aligned. Figure B12 illustrates two potential high speed alignments between London and Birmingham, one along the M1corridor, and one taking a more westerly Chiltern route.

It is immediately clear which of the two is in a position to provide interurban rail connectivity between the major communities of the M1 corridor (assuming provision of the required capacity, by means of the 4-tracking that would in any case be necessary to address the needs of all stakeholders), and which is not. The juxtaposition with Heathrow Airport should also be noted.

B8.7 Onward running from high speed network onto existing lines

The skeletal nature of any proposed new high speed network inevitably means that its physical coverage as a new railway will extend only to the principal conurbations, and by implication to a limited number of stakeholders. But this need not restrict its total coverage. If the principle of onward running onto the classic network is established as an integral feature of ‘high speed’ operation, then the potential range of services, and the accruing benefits, can be spread much more widely. Intuitively, this would seem to greatly increase the scope for reductions in CO_2 emissions.

Taking the reverse scenario, by which ‘exclusive’ operation of the new high speed rail renders it able only to provide a very limited range of services, with doubledecker rolling stock unable to continue onto the existing network, there is a clear danger that the system will function largely independent of the existing intensively operated network, yet at the same time draw traffic from it, and effectively blight it.

This can be seen in the current HS2 proposals, whereby trunk Birmingham to London intercity flows will be drawn onto the new high speed line, and away from the classic route via Birmingham International and Coventry. Although Coventry enjoys a 3 trains per hour service to London, this is only viable in combination with the Birmingham-London flows; with HS2 abstracting the Birmingham traffic, Coventry’s service is projected to reduce to 1 train per hour, almost certainly slower than the existing 1 hour timing to London.

This reduced connectivity can only be to the detriment of a major second-tier city such as Coventry, with clear implications of economic blight and increased local transport emissions, as passengers opt to travel by car instead of public transport, and to start longer public transport journeys at the nearby Birmingham ‘Interchange’. Similar scenarios will prevail at other bypassed cities in the West Midlands, such as Wolverhampton and Stoke, and are highly likely also in other regions, as the high speed system extends northwards.

It should be noted that onward running from high speed to classic system is a scenario that must of necessity apply during the staged implementation of the new network – for instance, the first stage of HS2 will connect to the West Coast Main Line at Lichfield, with high speed services continuing to Manchester, Liverpool and Scotland. This will require a fleet of ‘classic compatible’ high speed trains, capable of full high speed operation but sized to fit onto the classic network.

This being the case, there would seem to be a degree of illogicality in the current preference for exclusive operation, with high speed services connecting only primary conurbations, and little or no attempt made to include secondary centres (which are instead bypassed).

A further concern exists with regard to the future of primary intercity routes, in particular the CrossCountry network focussed upon Birmingham. To the north of Birmingham, these follow the natural axes of the high speed system, as far north as Scotland; but to the south, these stray outside the ‘Zone of Influence’ of any northern-oriented high speed line. There is a clear incentive to provide improved ‘high speed’ services from Birmingham to the North-West, to the North-East and to Scotland; but if these services are either to comprise double-decker rolling stock, or to be focussed upon a new high-speed terminus (ie HS2’s proposed Fazeley Street) then it is difficult to see how the present functionality of the CrossCountry network could be retained. This would instead appear to demand fully integrated operation, focussed upon New Street Station.

B8.8 Optimisation of total network capacity and connectivity

In the context of a high speed rail strategy optimised to achieve maximum CO_2 reductions, capacity and connectivity become far higher priorities than simple outright speed. But neither of these considerations seem capable of optimisation under ‘exclusive’ modes of operation. Connectivity is lost through the establishment of dedicated high speed hubs, segregated of necessity by the adoption of new standards for train length and size.

Capacity is lost through too many intercity services having to remain on the classic line, either a ‘political’ gesture to maintain a higher level of service to bypassed cities such as Coventry, or through strict adherence to the vision of interconurbation-only flows on the high speed line. Whichever is the case, the result is that the classic railway is forced to operate to too great a degree as a ‘mixed traffic’ railway, accommodating freight, local passengers and intercity. This will inevitably compromise the total available capacity (see Figure B3), and hence the modal shift and consequent CO_2 reductions, that can be achieved.

B8.9 Conclusion

In all cases, the benefits of integrated operation, both commercial and environmental, seem self-evident. It must be recognised that the UK rail network comprises a sophisticated and intensively-trafficked system whose functionality on whatever level – intercity, regional or local – must be maintained as high speed rail is introduced.

It would seem that this can only be achieved through full integration between high speed and classic systems; to simply impose a new superfast and supersized railway upon the existing system is clearly inappropriate. And, notwithstanding the fact that the new infrastructure will be constructed to suit long, tall and wide-bodied rolling stock – in accordance with the aspiration for European services from key regional centres – it still seems likely that future high speed operation in the UK will principally comprise UK-sized trains.

Appendix C : Relative Environmental Performance

C1. Environmental Performance Indicators

These issues are encapsulated in the metric that is commonly used to measure relative environmental performances of different transport modes. Rather than simply consider the emissions of the vehicle – for which *grams of CO_2 per vehicle kilometre* would be appropriate – the issue of load factor is captured through measuring *grams of CO_2 per passenger kilometre*. This is termed the Environmental Performance Indicator (EPI).

This has the effect of favouring domestic aviation and long-distance coach services, which generally operate at high load factors (70-80%), over rail (30-40%) and the private car (mostly single occupancy, therefore circa 25%). However, as can be seen from the following table, even with the issue of load factor taken into account, rail generally outperforms other modes, with the single exception of the long-distance coach.

The apparent superiority of the long-distance coach illustrates the influence of speed, which is clearly reflected in the 'right-to-left' progression in figure below (excepting the private car). Coaches are limited to a maximum speed of circa 110kph, while trains operate at speeds up to 200kph, high speed rail 300kph and commercial aviation 900-1000kph.

With journey times a critical consideration in mode selection, making domestic aviation the 'mode of choice' for Anglo-Scottish trips, this progression also can also be seen to illustrate a tendency towards higher-energy (and higher-CO_2) transport for longer distances.

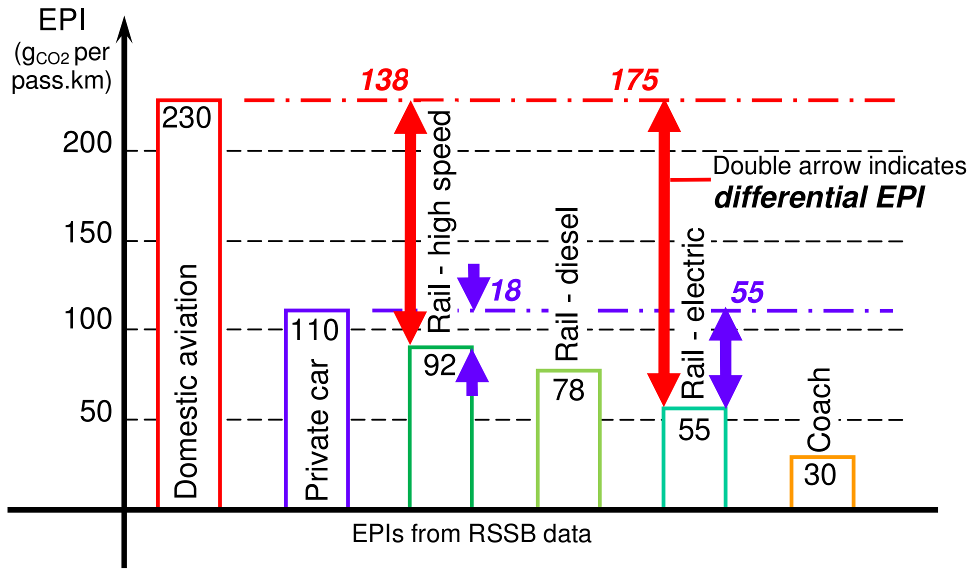


Fig C1: Differential EPIs based on RSSB Data assuming current load factors & speeds

In any calculation of environmental benefits arising from the transfer of a journey from a higher- to a lower-emitting mode, it is the difference between the above figures that defines the benefit. Hence conversion from domestic aviation to high speed rail shows an EPI differential of 135g_{CO2}/pass.km, while conversion from private car to high speed rail only indicates a differential of 15g_{CO2}/pass.km. On the basis of such a marginal benefit, the rationale for major investment in high speed rail as the 'green' alternative to car travel would have to be questioned.

C2 Contemporary Assumptions of Load Factors – Rail

However, it must be emphasised that the above analysis is totally predicated upon the low load factors currently attributed to rail transport. If, for instance, rail were to operate at twice the load factors (ie 60-80%), the situation would be transformed. High speed rail would now operate at an EPI of 48g_{CO2}/pass.km, showing a differential of 62g_{CO2}/pass.km over car travel.

This of course is merely conjectural; it is necessary to undertake a closer examination of the load factors attributed to rail to determine their validity, and their relevance in an increasingly carbon-critical world. The figures derive from an RSSB study document[15], which determined typical load factors of 30% for commuter services and 40% for longer-distance services. The load factor figures are low for a variety of reasons:

- Commuter services are characterised by intense peaks at rush hours, and relatively low flows in the intervening periods.
- Longer distance intercity services tend to be well loaded on leaving London, but empty with increasing distance from the capital.
- Unlike domestic flights and long-distance coaches, frequency levels and operating patterns are maintained at higher levels at periods of low demand, in the interests of providing a regular interval public service. This is vital to the cohesion of the wider rail network, and is a key selling point to passengers (despite the apparent environmental and cost benefits of the long-distance coach).
- Rail/road modal split is biased in favour of road owing to contemporary 'free market' conditions which tend to suppress demand for rail services through high rail fares, whilst maintaining the road system's status as 'free at the point of use'.

With greater numbers of travellers transferring to rail as the world adjusts to greater deterrents upon high-energy, high-carbon travel (ie aviation and the private car), it is reasonable to assume that increased load factors – perhaps of the order of 60% - will apply. This would indicate an EPI for conventional electrified rail reduced from 55 to 28g_{CO2}/pass.km.

C3 Contemporary Assumptions of Load Factors – High Speed Rail

The major concern with the RSSB data lies with to the environmental performance figures for high speed rail. It is believed that the data accurately reflected the higher energy required to propel a train at 300kph (albeit considerably mitigated by much smoother speed profiles and lack of conflict with other rail traffic) but mistakenly assumed a load factor of 30% (probably owing to Eurostar high speed services being deemed to provide a London-Ashford commuter service).

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[15] RSSB Report "The case for rail 2007: The first sustainable development review of the mainline railways of Great Britain". 25/06/07

Eurostar's data shows load factors of 60%, which are perfectly credible for a well-marketed service linking two strong city pairs (ie London-Paris and London-Brussels); these have few intermediate destinations at which passengers might disembark, and thereby reduce overall load factors (as is often the case with conventional rail). This would confirm the revised EPI of 46g$_{CO2}$/pass.km for high speed rail (as calculated earlier), and indicate a gain of 64g$_{CO2}$/pass.km.

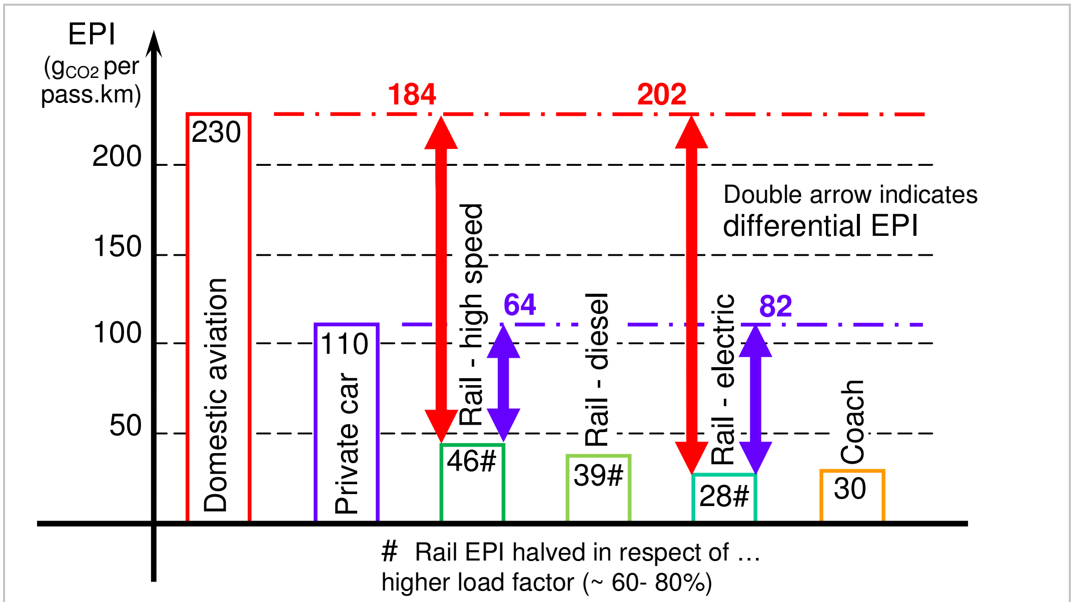


Fig C2: Differential EPIs assuming increased load factors & projected speeds

The above EPI figures by no means represent definitive statistics either for high speed rail, or for its relative performance against road transport. There are many variables to be resolved in the application of high speed rail into a UK environment, including speed, load factor and, possibly most importantly, operating philosophy; all of these will have a major influence in the optimisation of environmental performance.

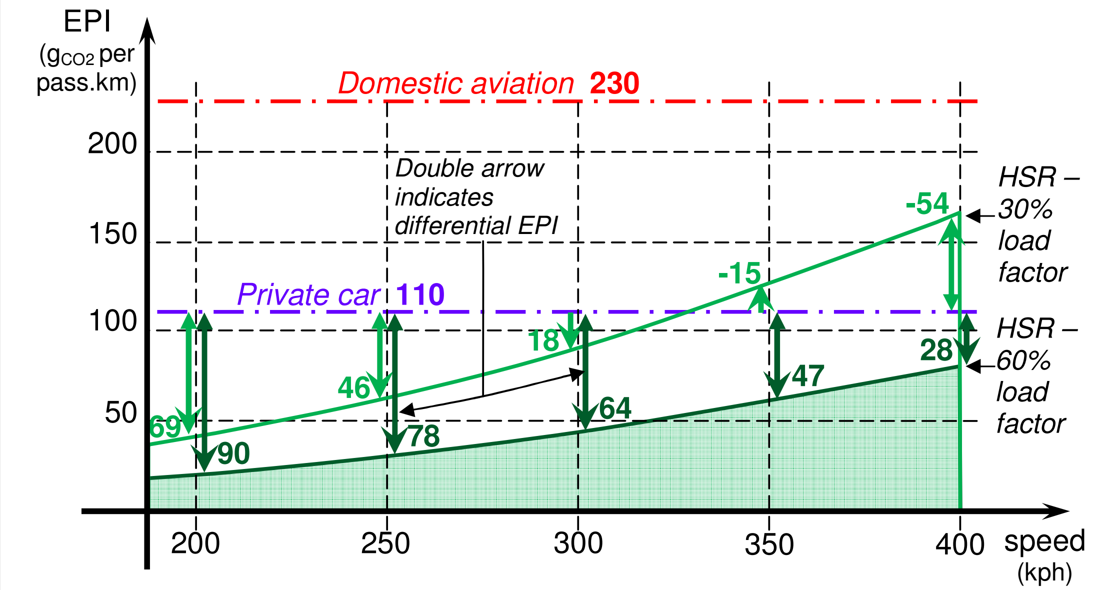


Fig C3: Differential EPIs between private car and HSR, for varying rail speeds

Figure C3 above illustrates the variances in the differential EPI between private car and high speed rail, for varying high speeds and load factors. If high load factors can be achieved at relatively low speeds (ie at or below 300kph), the differential EPI is highly positive; but with higher speeds (ie 350kph+) and lower load factors, there is a significant danger that the differential EPI will go negative, in other words, high speed rail's environmental performance would be worse than that of road transport.

C4 Contemporary Assumptions of Load Factors – Private Car

There is a considerable degree of uncertainty also in the EPI figure for private car travel (ie 110g_{CO2}/pass.km). This embodies similar assumptions of speed and car occupancy. Review of the RSSB data in the context of published manufacturer's data for medium-sized cars, such as the Vauxhall Astra (151g_{CO2}/pass.km, 45 miles per gallon) and the Ford Mondeo (158g_{CO2}/pass.km, 42 miles per gallon), indicates an assumption of an average car occupancy of circa 1.5.

But the close correspondence of the CO_2 emissions implicit in the fuel consumption data with those stated in the EPI indicates that the EPI relates only to the CO_2 that is produced by the burning of the fuel; no account appears to have been taken of the extra emissions attributable either to transport or refining of the fuel.

Another concern is that the manufacturer's data, derived from rigorous testing in idealised urban and inter-urban conditions, presumably with due allowance for traffic jams and other congestion, will almost certainly underestimate the fuel consumption realised by 'real' drivers. Professional test drivers are hired by car manufacturers to extract optimal performance and demonstrate the full merits of the particular car under test; 'real' drivers tend to have a more basic agenda, to get to their destination as quickly as possible. This seems likely to result in actual fuel consumption that is considerably greater than that claimed by the manufacturers.

By contrast, corresponding data for rail transport is based upon train operators' actual fuel consumption and demand for electric traction supplies from the National Grid (for which well-audited figures for primary CO_2 emissions exist). Hence this data would appear to be considerably more reliable.

C5 Potential for High Speed Rail to Reduce Road Emissions

It is not the purpose of this study to precisely define the relative magnitudes of road and rail emissions, but rather, to demonstrate that:

- high speed rail and conventional rail, either individually or in combination, have an environmental performance considerably superior to that of the private car.
- this relationship is highly sensitive to both speed and load factor.

On this basis, it is reasonable to conclude that an environmentally-optimised high speed rail scheme could and should be targeting not only domestic aviation, but also the much larger private motoring sector. This increases the potential of high speed rail to effect reductions in CO_2 emissions by several orders of magnitude.

For longer-distance journeys, of an inter-city or inter-conurbation nature, rail is an appropriate and environmentally-superior alternative, allowing the conversion of road journeys with major reductions in energy consumption and CO_2 emissions. It is clearly essential that the proposed high speed rail system is configured in such a way that will maximise the benefits, and this requires issues of integration to be optimised to extend the influence of high speed rail beyond the primary conurbations.

It must of course be recognised that it is not possible for rail, high speed or otherwise, to supersede all journeys presently undertaken by car. Most trips comprise only a relatively small distance, mostly undertaken along axes not covered by rail. For such journeys, cycling, bus or tram offer the solution, with no obvious synergies with broader-scope high speed rail proposals.

However, the development of high speed rail will have a powerful regenerative effect, for instance in the development of new or enhanced station facilities, or in the increased capacity on local routes through the diversion of intercity traffic. In this way, high speed rail has the capacity to bring about modal shift even on a local level.

Appendix D : Allied Sustainability Issues

D1 Peak Oil

It is important to recognise the parallels between the 'environmental' issues surrounding CO_2 emissions, and wider concerns of fuel sustainability. Within the transport sector, this concern largely relates to oil supply, and the projected shortfalls that will occur as rising global demand finally exceeds the world's capacity to supply. These shortfalls will be accompanied by massive price rises and a general destabilisation of the world economy (hitherto accustomed to cheap energy). This is commonly referred to as the Peak Oil scenario.

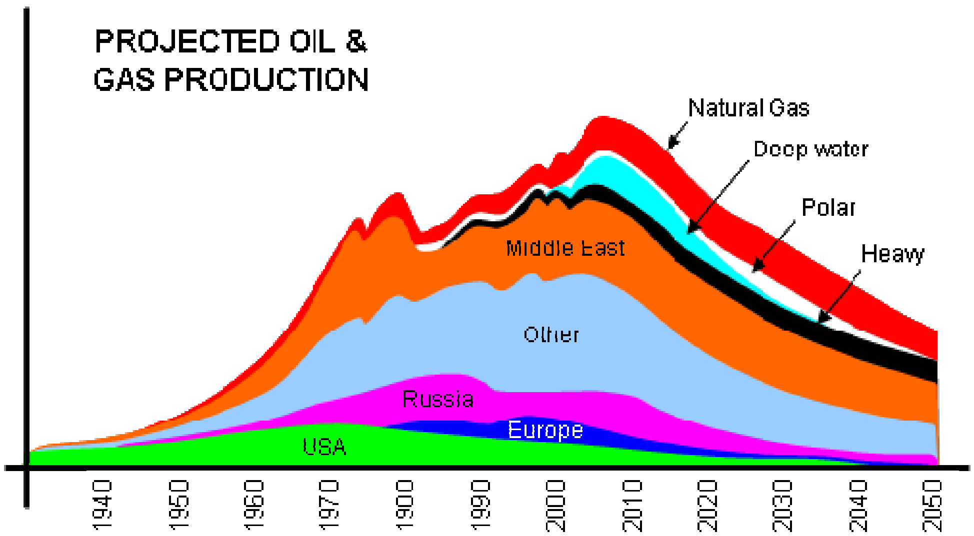


Fig D1: Projected 'Peak Oil' Scenario

Given the continuing lack of absolute scientific proof, that human-produced CO_2 is the root cause of global warming, the Peak Oil scenario is a useful alternative rationale with which to confront climate-change sceptics. There is clearly a finite, and diminishing quantity of extractable and combustible hydrocarbon in the earth's crust, and the only real debate is the point at which demand will exceed supply (certain projections indicate an imminent onset).

The key point is that although the CO_2 and the fuel sustainability questions are entirely unrelated (except insofar as they are both manifestations of unrestrained human consumption), the same solution seems to apply: a radical reduction in the consumption of fossil fuels, particularly oil. As with the imperative for CO_2 reduction, similar 'shift' strategies also apply: behavioural, technological and modal, and the same hierarchy prevails.

There has been much attention given to a variety of technical solutions, such as new marginal reserves eg deep sea or oil shales, new 'sustainable' sources eg biofuels and alternative energy sources eg battery cars. But all carry major concerns with regard to sustainability, or environmental impact; there can also be concerns with the extra energy (and therefore CO_2) required to extract and refine. Collectively, such interventions appear incapable of delivering the required step change reduction in oil demand.

Technology shift strategies also lack the primary focus upon achieving fundamental reductions in energy consumption, and thus addressing long-term energy security concerns (of which Peak Oil is just one aspect). This aim can be accomplished much more effectively by switching as much transport as practicable to the most energy-efficient mode ie rail.

Hence modal shift again appears to offer the most effective strategy within the transport sector to avert (or at least delay) the onset of Peak Oil, and to facilitate the transition to a lower-carbon world economy.

D1.1 Ring-fenced Electricity Supply for Rail?

Concerns have been expressed, that modal and technological shift on the scale envisaged in this study (ie a fourfold increase in rail traffic, and a general migration from diesel to electric traction) will result in a greatly increased demand for electricity to power the expanded railway. This ambition might appear to be incompatible with certain pessimistic projections for electricity supply, in which high-CO_2 coal-fired power stations are to be shut down, but the replacement generating capacity is not yet in place.

In contemporary free-market, 'business-as-usual' conditions, this might well be a major issue that would limit the expansion of the railways, and thus realisation of the anticipated environmental gains. But in the context of the quasi-wartime conditions envisaged in this study, and the radical restructuring necessary to meet the challenge of climate change targets, it would be necessary to take a more holistic view.

The projected modal shift from air and road to rail implies a massive reduction in the demand for oil, and it would thus seem reasonable to 'ring-fence' a proportion of this, to be used in the generating of electricity to power the railway. Noting the relative energy efficiencies of air, road and rail, this ring-fencing would require only a relatively small percentage of the oil that is saved.

In a technical sense, this should pose few challenges. It should be relatively simple to convert decommissioned coal-fired power stations to burn oil (and thus eliminate the burning of coal, the basic reason for the requirement to decommission). There would be no need to make changes to the more complex aspects ie the steam cycles by which the thermal energy of the coal or oil is converted into rotary energy (in the turbines) and finally into electricity.

D2 Land Use Considerations

As previously noted, modal shift of the magnitude required to have significant impact upon on transport's CO_2 emissions and energy use can only be achieved with a step-change increase in railway network capacity. This will necessitate a railway construction programme on a scale at least as great as the Victorian era, and of an order similar to the more recent motorway programme of the 1960's and 1970's.

This can only be accomplished with the acquisition of large swathes of land (assuming a typical footprint width of 30m, a network of new lines extending 1000km would require 30 square kilometres). All this land will be under some kind of occupation, be it residential, industrial, agricultural or amenity/leisure, and in the acquisition of this land it will be necessary to accommodate the interests of all stakeholders, variously owners, users and neighbours.

Proposals to construct HS2 through the Chilterns Area of Outstanding Natural Beauty and northwards through rural Buckinghamshire and Northamptonshire have already caused major controversy. Embankments and cuttings up to 22m high/deep, constructed to the classic trapezoidal profile, will require a landtake over 100m wide, to support a railway perhaps 12m wide. This will cause huge intrusion into largely unspoilt and cherished landscapes, with large tracts of valuable agricultural land lost in perpetuity. Powerful residents' and conservation groups are mobilising to oppose the scheme, and increased costs and lengthened timescales seem inevitable. This in turn delays implementation and realisation of the railway scheme's environmental gains, and hence has the effect of increasing CO_2 emissions

D3 Alignment with Existing Transport Corridors

Alignment of new railways with existing transportation corridors, in particular motorways, appears to offer a far superior strategy. Motorways such as the M1 and the M6, constructed through relatively easy topography (considerably more favourable than HS2's chosen route) with little need for sharp curves, can accommodate parallel high speed rail alignments with relatively small deviation. The proposed route for High Speed North, following the M1 from London to Leicester, and designed for 320/360kph maximum speed, can for most of its length be constructed parallel to the motorway, on a virtual 'hard shoulder' alignment, and for only 16% of its length does it stray more than 250m off-line.

This is within the zone already massively blighted by the noise and visual intrusion of the motorway, and the new high speed line will have little or no additional impact. It is also significant to note that the sheer presence of the motorway has discouraged adjoining residential development. These two effects combine to create a largely clear and uncontroversial corridor, which must greatly facilitate realisation of the UK high speed rail project.

When true parallel running can be achieved, further synergies are possible. Instead of the expansive trapezoidal embankment profile that an independent alignment would require, the parallel railway can be accommodated by enlarging the existing embankment or cutting. The inherently wasteful trapezoidal profile is replaced by a much more economic parallelogram, and the 100m landtake is vastly reduced.

It will of course not be possible simply to place a 12m wide high speed railway alongside the hard shoulder of a motorway. There will be a necessity for continual collision/incursion protection, probably a reinforced earth bund of the order of 4m wide, that will increase the landtake (but act as a very effective noise barrier to the benefit of local residents).

The demanding performance requirements of a high speed railway will also create significant geotechnical issues, in the widening of an existing embankment. This requires new fill material to be placed on top of existing. For a railway embankment, constructed in the 19th century, end-tipped with no meaningful and consistent compaction, the problems of 'retro-compacting' the existing material to avoid the risk of settlement and slip will probably be insurmountable. But for a motorway embankment, constructed in the modern era to contemporary standards of compaction, the issues should be relatively small, and manageable.

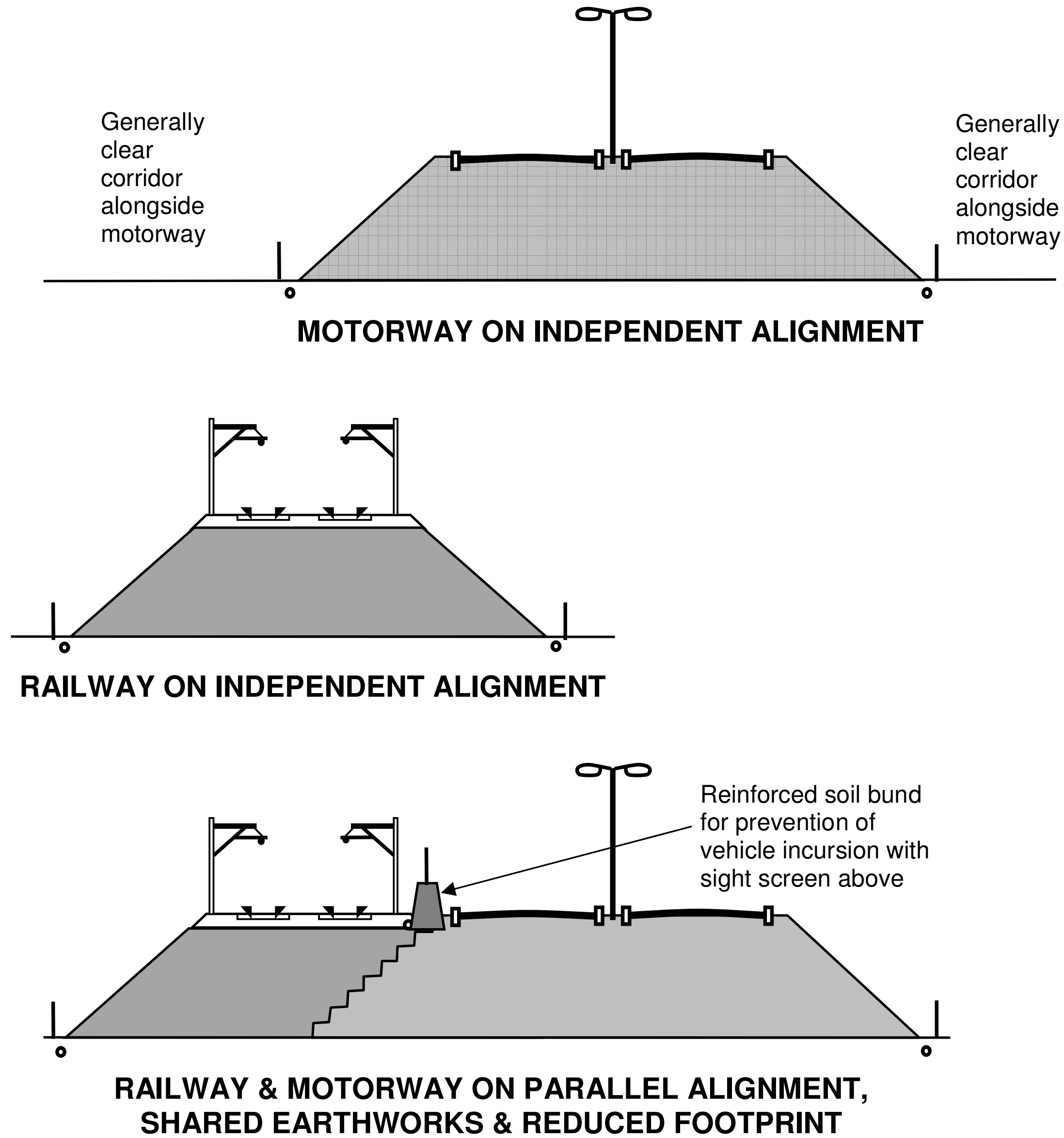


Fig D2: Reduced Landtake through Shared Earthworks

It is important also to consider the simple savings in muckshift, offered by parallel construction. A 22m high embankment, as an independent structure 12m wide at its crest and 100m wide at its base, comprises 1.2 million cubic metres of fill per kilometre. But constructed 17m wide at the crest, in 'parallelogram' format alongside an existing 22m high embankment (and incorporating a collision incursion bund approximately 4m x 4m in cross-section), less than 400,000 cubic metres of fill per kilometre would be required. Thus the impact of the construction activities on the local community should be an order of magnitude lower.

Embankment height (m)		2	6	10	14	18	22
Volume of fill per km ($m^3 \times 10^3$)	Independent	31.7	104	168	231	295	358
	Parallelogram	40.7	143	319	558	862	1229

Table D3: Earthworks Volumes for Varying Embankment Heights

D4 Planning Policy Issues

A high speed line aligned with a motorway (rather than through an Area of Outstanding Natural Beauty) accords closely with the natural presumption in planning policy against development of 'greenfield' sites, when equivalent 'brownfield' sites offer the same opportunity. This is generally regarded as a consideration of minimised environmental impact, an ideal with which most unquestioningly concur. But it is equally valid as a consideration of sustainability. The 'natural' landscape of the UK is a precious and irreplaceable resource. It is also highly valuable, in its contribution to tourism. As such, it seems vital that the landscape is conserved against unnecessary intrusion, and that development of new transport infrastructure is concentrated where practicable upon existing corridors.

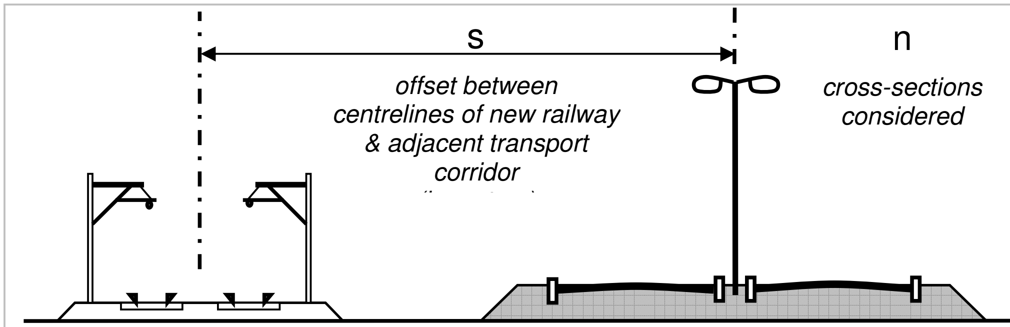
Aside from concerns of environmental intrusion, public protest and consequent delays, there is a degree of transport logic also in aligning new transport systems with existing corridors. The topographic and demographic considerations, that dictated the course of Roman roads, canals, railways and motorways, should also apply to a high speed rail line. It is significant to note that, in the case of the M1 corridor, Watling Street (the modern A5), the Grand Union Canal, the London and Birmingham Railway (the modern WCML) and the M1 remain in close proximity for most of the route length from Watford to Rugby. It is strange that a similar logic has not applied in the case of HS2, and a Chiltern alignment has been selected instead, with attendant environmental concerns that can only add cost and delay in the implementation of essential national infrastructure.

It thus seems reasonable to conclude that adherence to existing corridors delivers positive outcomes in every respect:

- Minimised visual and noise impact
- Minimised land take
- Minimised earthworks, hence minimised cost and CO_2 emissions from construction process
- Minimised loss of natural landscapes
- Clear corridor available alongside motorway, with historic environmental blight (noise, atmospheric and visual) over 50+ year period discouraging adjacent urban development
- Expeditious implementation of new high speed network (and earlier realisation of modal shift and consequent reduced CO_2 emissions) through uncontroversial routeing

To allow definitive comparisons to be drawn, a methodology has been developed to quantify the degree to which parallel routeing mitigates the adverse environmental intrusion of different high speed rail schemes. This is termed the 'Corridor Factor', and essentially comprises an inverse square sum of the offset 's' between centrelines of new railway and adjacent existing transport corridor, taken as an average over the length of route.

D5. Calculation of Corridor Factor



$$\text{Corridor Factor} = \frac{\sum_{1}^{n}(500/s)^2}{n}$$

Fig D4: Definition of 'Corridor Factor'

Calculation of Corridor Factor relies on the following assumptions:

- A busy motorway is more environmentally intrusive than a new high speed railway by an order of magnitude, on any conceivable criterion – noise, atmospheric or visual.
- High speed rail broadly matches conventional rail for environmental intrusion, and any significant exceedances are capable of mitigation by means of local noise barriers or similar.
- The transport corridor to which the new high speed line runs parallel is well aligned in a vertical sense, and the high speed line can follow this with only minor variance. Thus the calculation of the Corridor Factor needs only to consider horizontal offset 's' between centrelines of 'parallel' alignments as a variable.
- For construction adjacent to an existing motorway, environmental impact is inversely proportional to the square of the horizontal offset between centrelines, between the limits of 50m (maximum benefit) and 1000m (minimum benefit, decrementing to zero). The 1000m figure corresponds to the approximate extent of the noise 'halo', emanating from the motorway.
- For construction parallel to existing railways, benefit is only adduced where the new line runs close and parallel to an existing alignment, probably far closer than 50m. With the generally low environmental intrusion of railways (particularly in respect of noise), it would not be reasonable to claim benefit for any greater offset.
- Similar benefit is adduced for construction along trackbeds of redundant railways, where clear of residential and other development. However, there must be significant outstanding local concerns, in the reuse of redundant routes such as the Great Central (favoured by HS2 for several kilometres north of the Chilterns) which will have been closed for over 50 years by the time that HS2 is constructed.

A calculated Corridor Factor is only meaningful with track alignments determined at least to 1:50000 scale, and of the order of ±50m lateral accuracy. This effectively restricts the comparison between candidate schemes to the respective sections between London and Birmingham. As a control, it is useful to undertake the same calculation for the London-Folkestone section of HS1 which (like any stretch of high speed line running northwards from London) had to be constructed to exacting environmental standards.

Appendix E : CO_2 Emissions associated with creation of New Railway Infrastructure

The analysis in this study has so far concentrated upon the operational CO_2 emissions that will accompany the introduction of a new high speed rail system. But for full 'carbon accountancy', it is necessary also to understand the magnitude of the 'grey' emissions arising from the building of the new infrastructure, and from any future maintenance activity.

E1 'Embodied CO_2'

Studies have been undertaken to determine the 'embodied CO_2' in railway infrastructure iethe emissions associated with the production of the steel, concrete, granular fill, copper wire and other materials. These values, commonly expressed in tonnes of CO_2 emitted in the production of a single tonne of finished material, describe the entire process, from extraction of the ore, through refining and transport, as far as the 'factory gate'. Applying materials data developed by Bath University[16] to a cross-section of a typical railway, a figure of around 1,950T of CO_2 per kilometre has been calculated for a modern 2-track electrified railway, constructed 'at grade' in level terrain, with allowance for underbridge and overbridge structures.

With the greater volume of materials required in more complex railway structures, the carbon footprint of the railway infrastructure grows radically. Figures of 2900T_{CO2}/km have been calculated for a railway on a 6m high embankment, 13400T_{CO2}/km for a viaduct on piled footings, and 20300T_{CO2}/km for concrete-lined tunnels.

A breakdown of these figures is given in Table E1 below:

Infrastructure element	Embodied CO_2 (T_{CO2}/km)							
	At-grade	Embankment, height					Viaduct	Tunnel
		3m	6m	9m	12m	20m		
Rails	750	750	750	750	750	750	750	750
Sleepers	420	420	420	420	420	420	420	420
Ballast	60	60	60	60	60	60	60	60
Embankment fill	250	1050	2850	5350	8550	20700		
Fencing and drainage	25	25	25	25	25	25	25	25
Electrification System	200	200	200	200	200	200	200	100
Heavy infrastructure	250	250	250	250	250	250	12000	19000
Total	1950	2750	4550	7050	10250	22400	13450	20350
Non-earthworks	***1700***	***1700***	***1700***	***1700***	***1700***	***1700***	***13450***	***20350***
Earthworks	***250***	***1050***	***2850***	***5350***	***8550***	***20700***	***0***	***0***

Table E1: Embodied CO_2 emissions for 2-track electrified railway

Of the above elements, only fill materials (for earthworks) and heavy infrastructure (ie underbridge/ overbridge/ viaduct/ tunnel) would be deemed to comprise the groundworks necessary to fit the new line to the landscape. The remainder ie rails, sleepers, ballast, electrification system, even fencing and drainage, might be considered the 'prismatic section' which remains constant, regardless of the landscape, and mostly regardless of aspired speed.

[16] Inventory of Carbon and Energy, Hammond & Jones, Bath University 2008

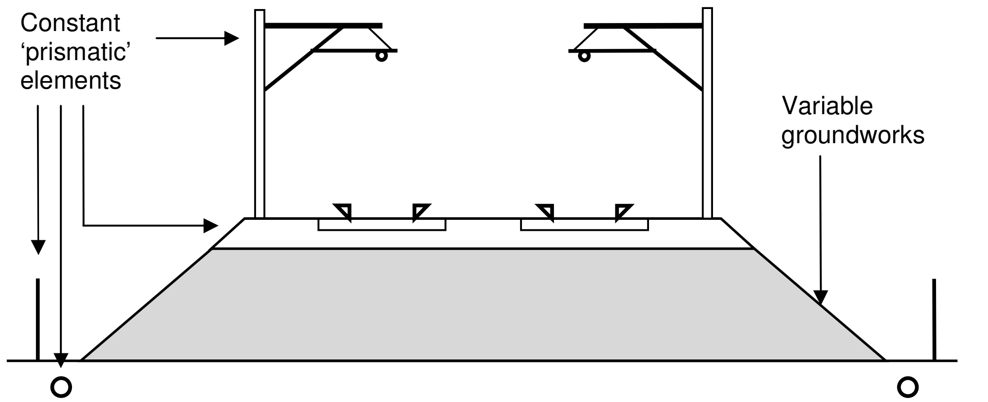


Fig E2: Elements in Calculation of Carbon Footprint of Infrastructure

For 'at-grade' construction, the constant 'prismatic' elements are dominant. But as topography becomes more undulating, the 'groundworks' element increasingly becomes the dominant factor in the calculation of embodied CO_2; massive volumes of fill are required to form embankments, and large quantities of much more CO_2-intensive concrete and reinforcing steel are consumed in the construction of viaducts, tunnels and retaining walls.

In terms of embodied CO_2, the earthworks element is by far the hardest to define accurately, with both its shape and constituent materials highly variable. An embankment can comprise quarried granular fill capable of a relatively steep slope angle, easy to compact but requiring to be imported over long distances.

Alternatively it can comprise locally won material (extracted from nearby cutting excavations in a 'cut and fill' operation) generally of lesser inherent quality, more difficult to compact and to sustain steep slope angles, but with lower CO_2 values on account of lesser distance transported and easier 'quarrying' process. It may also be necessary to stockpile the excavated material (thus requiring at least double-handling), with an intermediate drying or chemical treatment process to render the material fit for compaction into an engineered embankment.

All these uncertainties make the calculation of a definitive generic CO_2 value for engineered fill material difficult if not impossible. For the purposes of this study, all earthworks fill is presumed to comprise quarried granular material, with an 'embodied CO_2' value of $0.005T_{CO2}/T_{product}$.

E2 'Construction CO_2'

None of this takes any account of the CO_2 that will be emitted during the construction process. This largely equates to the fuel used in the delivery of the materials to site, and in the operation of construction plant. For high-energy materials, with high embodied CO_2 values (eg steel, rated at $2.7T_{CO2}/T_{product}$), the 'construction CO_2' represents a small proportion of the embodied CO_2. But for low-energy materials such as quarried earthworks fill (rated at $0.005T_{CO2}/T_{product}$), even a 30km delivery from quarry to site will incur CO_2 emissions almost the same as the embodied value. At least as much CO_2 again is likely to be emitted in the placing and compacting of the material in its designed location.

For ‘at grade’ construction, with a relatively small earthworks component, construction CO_2 will be a similarly small proportion of the embodied figure – perhaps 20-30%. But in areas where more heavy engineering is required – effectively to fit the smoothly-aligned high speed line onto much more variable topography, by means of either earthworks, viaducts or tunnels – construction activities seem certain to contribute a much higher figure, in both proportionate and absolute terms.

Emissions category	*Associated CO_2 (T_{CO2}/km)*							
	At-grade	Embankment, height					Viaduct	Tunnel
		3m	6m	9m	12m	20m		
Embodied CO_2	1950	2750	4550	7050	10250	22400	13450	20350
Construction CO_2 for earthworks (est.)	400	1500	4000	7500	12000	30000	0	0
General construction CO_2 (est.)	500	500	500	500	500	500	5000	10000
Total Infrastructure CO_2	2850	4750	9050	15050	22750	52900	18450	30350
Non-earthworks	***2200***	***2200***	***2200***	***2200***	***2200***	***2200***	***18450***	***30350***
Earthworks	***650***	***2650***	***6850***	***12850***	***20550***	***50700***	***0***	***0***

Table E3: Infrastructure CO_2 emissions for 2-track electrified railway

In the absence of reliable data on ‘construction’ CO_2, it is useful to visualise these emissions in terms of the fuel consumption that they represent, and to recognise the fact that the burning of 1 tonne of diesel fuel (approx 1200 litres) produces approximately 3.2 tonnes of emitted CO_2.

Further research is necessary to conclusively establish emissions from construction activities, but it is believed that the figures set out in Table E3 are of the correct order of magnitude, and should allow a reasonable determination to be made of the relativities between infrastructure and operational CO_2.

The figures can also be developed to address the possibility of 4-track construction, which is likely to apply for certain sections at the southern end of any proposed high speed line.

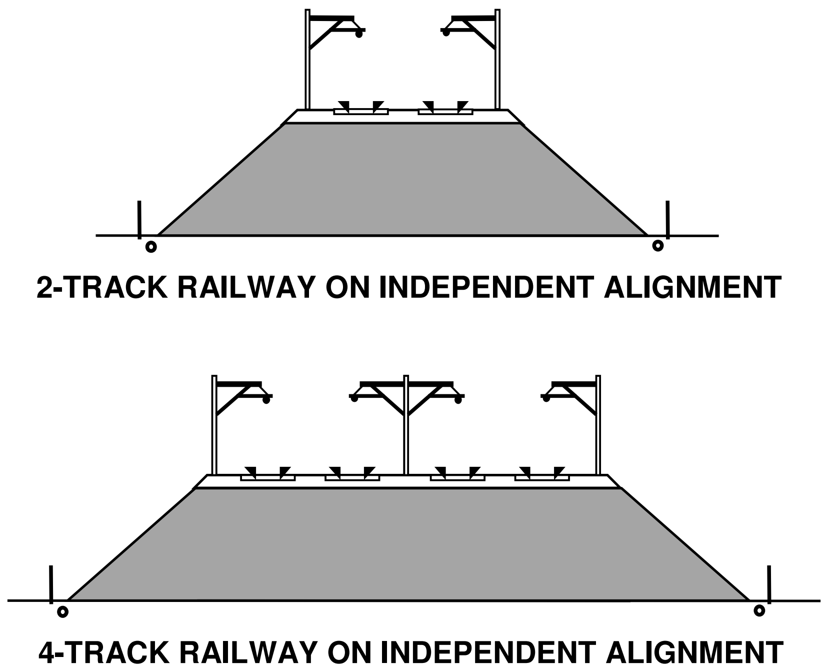


Fig E4: Comparison of 2-Track and 4-Track Construction

E3 Strategies for Lower Carbon Construction

E3.1 Alternative Construction Materials

All the above figures assume continued use of traditional construction materials such as steel and concrete, and copper for electrification wires. All these materials have relatively high carbon footprints, on account of the energy required to convert the raw material into a useful finished product.

It is important to recognise that many of the fundamental advantages of railways ie large payloads running at low friction along high quality alignments can only be achieved through the use of high strength (and also high-carbon) materials and heavy construction. Notwithstanding this, there is considerable ongoing interest in identifying ‘lower-carbon’ alternative materials.

However, it is difficult to envisage a substitute for steel in rails, copper in overhead electrification wires, or other crucial high-carbon materials; and to date no viable alternative materials capable of large-scale application have been found that would offer major reductions in the ‘carbon footprint’ of railway construction.

E3.2 New vs Recycled Materials

In the absence of viable alternative lower-CO_2 materials, the best hope would appear to be a greater use of recycled materials. There is a wide variance in embodied CO_2 values between new and recycled materials (2.7 vs 0.6 $T_{CO2}/T_{product}$ for steel), and this might at first sight encourage designers to attempt to meet CO_2 reduction targets simply by specifying the use of recycled materials.

It is necessary to strike a cautionary note at this point. Steel and most other high-value/energy/CO_2 materials (such as copper and aluminium) are already efficiently recycled, purely on account of their monetary scrap value. This effectively merges the 'new' and 'recycled' embodied CO_2 values into a common median value, and to an extent renders redundant the debate as to use of new or recycled materials. If one project were to insist upon exclusively using recycled steel, it would simply mean that others would be forced to use new steel; and no overall reduction in emissions would be achieved.

Whatever new materials or recycling strategies might be developed for lower-carbon construction, the following points must be emphasised:

- Such strategies are unlikely to offer a step-change transformation in the carbon footprint for railway construction (or indeed for the heavy construction associated with other transport infrastructure, eg roads or airports).
- Any gains that accrue would apply equally to any high speed rail proposal, and thus cannot be a determinant on scheme selection.

This points towards an alternative strategy. Rather than rely on new low-carbon materials, or questionable 'creative' accountancy for achieving lower-carbon construction, might better results be achieved simply through constructing less? The following sections explore various opportunities by which the quantity of construction might be reduced.

E3.3 Relationship of Design Speed to Carbon Footprint

There has already been much discussion as to the desirability of high speed rail, in terms of the extra energy use and consequent CO_2 emissions, inherent in the operation of trains at higher speed. This is considered in other sections of this study. But it is important also to examine the influence of speed upon the design of the infrastructure, and to establish whether a railway designed for 400kph operation will have a higher carbon footprint than one designed for 320kph.

That there is some interrelationship between design speed and scale of construction seems self-evident. In any naturally undulating landscape (typical of the UK and most other European countries), the undulations are commonly of such frequency and amplitude that it is not possible to fit a railway (or even a road) alignment designed for significant speed directly onto the contours. Instead significant groundworks are required, either cuttings or embankments, and (as variances between alignment and topography become more extreme) viaducts and tunnels.

As speed increases, the designed alignment (both horizontal and vertical) becomes of necessity straighter, and less able to fit itself to the landscape as the variance grows. This effect, of increasing radius, is proportional to the square of speed. So the size of the necessary structures, and their associated carbon footprint, must also grow.

These effects are exacerbated by the additional need for the new alignment to avoid settlements and other sensitive areas, or to be profiled into the landscape for reduced visual impact. This often greatly restricts options for alignment, thus precluding selection of the optimum solution. In recent years, this phenomenon has caused major increases in the engineering cost, and hence carbon footprint, of road construction. The same fundamental effect would clearly apply for new railways, and its magnitude would seem to grow with increasing speed.

There is no simple means of encapsulating the winding valleys, asymmetric escarpments, hills in seemingly random location and position of towns/ sensitive locations, into a mathematical equation representative of the UK landscape. It should particularly be noted that the size of earthworks etc is a function of the *difference* between ground profile and railway alignment, rather the simpler relationship with an arbitrary datum; this greatly complicates any mathematical relationship which might be established between topography, design speed and carbon footprint. But it is still important to understand the fundamental nature of the relationship ie whether CO_2 emissions are directly proportional to speed, or whether it is a squared, cubed or other exponential relationship.

Some understanding can be gained through a simplistic representation of 'typical' topography as a series of reversing circular curves, of varying amplitude and wavelength. Vertical curves appropriate to differing design speeds (with due allowance made for lengths of constant gradient at changes of curvature) can then be superimposed onto the topography. In order to obtain a true appreciation of the relationship between design speed and earthworks volume (and therefore CO_2 emissions) it is necessary to consider a wide range of amplitudes and wavelengths.

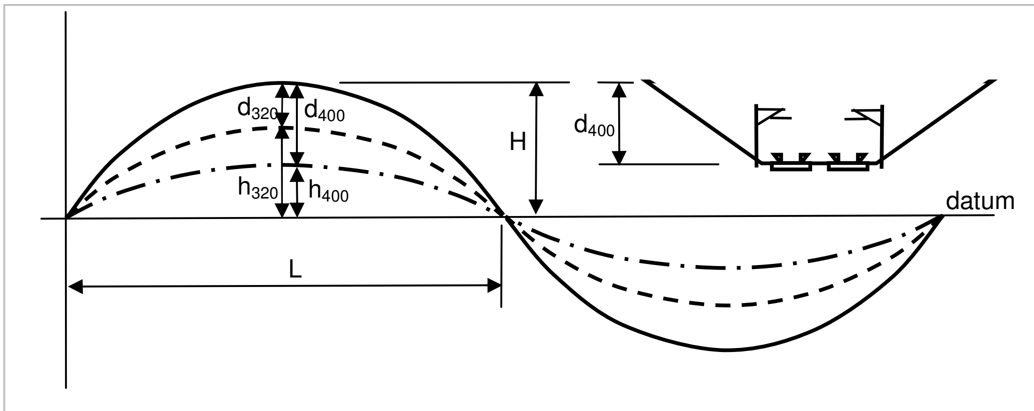


Fig E5: Idealised 'Sinusoidal' Ground Profile

The designed earthworks profiles of the HS2 route from London to Birmingham have been reviewed to determine a representative sample of earthworks heights and depths from which the exponential relationship between earthworks volumes (and therefore CO_2 emissions) can be deduced.

Proportion *for calculation of average*	H Half Amplitude / Speed	200 – 250kph increment	250 – 320kph increment	320 – 400kph increment
		Exponential n, whereby Volume = K x (speed)^n		
52%	0 – 5m	1.80	1.68	1.51
28%	5 – 10m			
11%	10 – 15m			
5%	15 – 20m			
4%	20m plus			
Half wavelengths considered:		500m, 1000m, 1500m, 2000m, 2500m		

Table E6: Exponential Relationship between Speed and Earthworks Volume

The above figures demonstrate a non-linear relationship whereby earthworks volume rise in approximate proportion to an exponent of (design) speed of around 1.5, for the speed range from 320kph to 400kph. It should particularly be noted that these exponentials are based upon an average across the combinations of amplitudes and wavelengths, which are drawn from HS2. At the extremes ie level ground (an ideal location, where no earthworks at all would be required) and 40m amplitude (generally unsuitable for railway construction) the proportionate difference between size of earthworks for varying design speeds is relatively small. However, in the median ranges more typical of UK topography, in which high speed lines would generally be constructed, the relationship between earthworks volume and speed is governed by a higher exponential.

So far, the analysis has only considered a 2-dimensional model, in which the railway has to cut through a uni-directional waveform, using earthworks as the sole means of dealing with the variance between railway alignment and ground level. No account has been taken of the point at which it might be deemed more expeditious to construct the higher-cost and higher-carbon alternative of viaducts and tunnels, or of the possibility for railways to deviate around hills (or other obstruction or sensitive feature) rather than pass through or over.

Just as carbon footprint increases with increasing speed for vertical undulations, it seems likely that a similar relationship would apply in respect of horizontal deviations to avoid obstructions (of whatever nature). But to develop the model to reflect the random and 3-dimensional nature of UK topography and define such a relationship would appear to be beyond the scope of simple mathematics. Instead, it is useful to examine anecdotal evidence concerning the effect of design speed upon routeing and requirement.

The Government's Command Paper that sets out the HS2 proposals notes the inability of the M1 corridor to accommodate a parallel 400kph high speed alignment as one of the principal reasons for discounting it (despite its clear environmental advantages) and adopting a Chiltern alignment instead. But comparison of the alignments of HS2 and High Speed North between London and Birmingham show circa 20km of tunnel for HS2, and 10km for High Speed North.

This comparison is to an extent coloured by the different requirements for tunnelling of proposed routes within the Greater London conurbation, an issue which is not related to topography. When the comparison is drawn between the sections of line passing through the Chilterns, the lengths of tunnelling are 12km for HS2 (via Amersham) and 4km for High Speed North (via Luton).

From this, it might be inferred that HS2's adoption of a 400kph design speed – 25% greater than 'conventional' high speed of 320kph (for which the M1 corridor is more than adequate) – has the effect of tripling the requirement for tunnelling. This would simplistically imply an exponential of between 6 and 9 in the relationship between length of tunnelling and speed.

However, with other factors (such as a perceived requirement to bring the line close to Heathrow Airport to facilitate airport interchange – see Appendix F) also influencing the choice of a route through the Chilterns, it would seem unreasonable to ascribe the increased length of tunnelling to increased speed alone. But it would still be fair to ascribe an exponential value at least that adduced earlier in the consideration of vertical profile.

Hence, for the purposes of comparison between high speed lines constructed for 320kph and 400kph, an exponential relationship is assumed, whereby earthworks volume, and therefore carbon footprint, rises proportional to design speed, raised to the power of 1.5.

$$\text{Volume} \propto (\text{speed})^{1.5}$$

E3.4 Savings arising from Parallel Construction

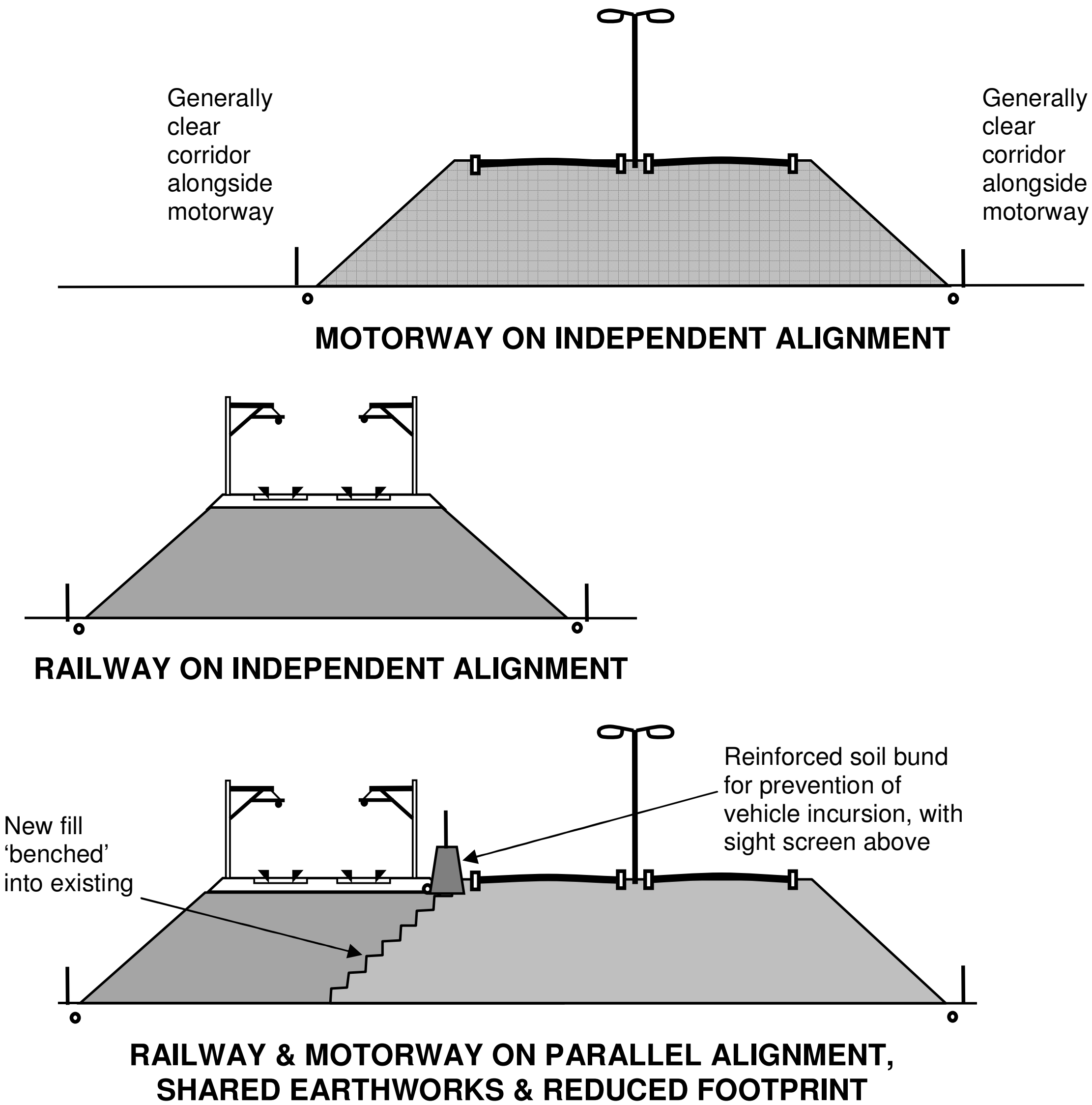


Fig E7: Reduced Construction Carbon Footprint through Shared Earthworks

If the new high speed line can be located close to, and parallel with an existing motorway alignment, then considerable savings in earthworks volumes can be achieved through not needing to construct separate cuttings and embankments. This issue has already been discussed in Section D2.

However, given the relative uncertainties in the sourcing of fill material (quarried granular fill or from balanced 'cut and fill'), and the additional uncertainties in the CO_2 attributable to the construction process (ie excavation, transport and placement), it is not proposed at this stage to draw quantified comparisons on this issue.

E3.5 Savings arising from Shorter Route Length

A further factor that will influence the carbon footprint of constructing the new high speed rail system is that of simple route length. It is clear that CO_2 emissions will rise with increasing route length, and accordingly the candidate scheme with a shorter total route length should give rise to lower 'grey' emissions.

Although different regional topographies (noting in particular differences between east- and west-sided routes to Scotland) prevent this being a truly linear relationship, it is considered, for the purposes of this high level study, to be sufficiently close. Hence carbon footprint will be considered to be directly proportional to route length.

E3.6 Comparative Estimate of Infrastructure CO_2

Table E8 sets out a calculation to determine 'Infrastructure CO_2' for both HS2 and High Speed North. The following issues are taken into account:

- London-Leicester section of High Speed North assumed to comprise quadruple track; all length of HS2 is double track (notwithstanding capacity concerns).
- HS2 route length assessed for proportion of tunnel and viaduct; proportion of tunnel and viaduct applicable to High Speed North factored down by 1.40 (ie ratio of speed raised to 1.5 power).
- High Speed North assessed for lesser speed, with both topography equivalent to HS2, and with easier topography (as assessed from a provisional vertical alignment).

Scheme	HS2	HSN (lesser speed)	HSN (easier topography)
Total length of new build (km)	1092	935	935
Length of quadruple track (km)	0	130	130
Design speed (kph)	400	320	320
Exponential on 400/320 speed	1.50		
Factor on tunnel/viaduct length	1.40 (= $(400/320)^{1.50}$)		
Proportion viaduct/tunnel	0.189	0.135	0.135
CO_2 per kilometre (T/km)	16900	16900	16900
Proportion earthworks	0.811	0.865	0.865
CO_2 per kilometre (T/km)	13100	9550	7700
Total Infrastructure CO_2	15.0M	11.3MT	9.6MT

Table E8: Total CO_2 Emissions for UK High Speed Networks

Appendix F : Heathrow Issues

F1 Relationship of Heathrow with UK high speed rail development

Elimination of domestic short-haul aviation has historically been taken as the primary environmental justification for high speed rail. The increased CO_2 emissions arising from the operation of trains at greater speeds can be offset against the greater reductions that should accrue from the transfer of passengers from short-haul aviation (particularly between London and Scotland) and lower-emitting rail, and environmental gains thus adduced.

This transfer demands considerable acceleration of current 4½ hour journey times from London to Glasgow and Edinburgh to below 3 hours, only possible with 'high speed' rail operation. 3 hours is commonly acknowledged (on the evidence of London-Paris Eurostar operation) as the 'tipping point' at which most passengers will opt to take the train, rather than the plane, with the rail alternative offering easier check-in, more space, superior frequency and interchange opportunities, and (for the majority of passengers) better-located city centre terminals.

This argument for high speed rail has had particular resonance in the debate surrounding the proposed expansion of Heathrow Airport (to a third runway and a sixth terminal). The opponents of expansion argued that the long-standing congestion problems at Heathrow could be attributed to the circa 25% of flights from outlying 'satellite' airports; if these short-haul flights could be transferred to rail, then Heathrow would be able to expand its range of long-haul flights (for instance, to South America, India and China) and also be better connected to its UK hinterland. This is in essence the argument for a 'better not bigger' Heathrow.

It was clear that much of the demand for internal flights from Heathrow (and other London and regional UK airports) was attributable to the long journey times offered by rail and other public and private transport. But if high speed rail could shorten these intercity journeys to less than 3 hours (and if the new system could be oriented to match the existing air flows), it was possible to envisage the elimination of most internal aviation, at least on the UK mainland.

However, it was also necessary to acknowledge Heathrow's unique status as the UK's only 'hub' airport. Of the order of half of the passengers on short-haul flights from outlying regional airports (60% from Manchester, 50% from Edinburgh and Glasgow) were 'interlining', connecting to long-haul flights. For these passengers, a high speed rail system only linking the UK's principal conurbations – addressing 'intercity' flows – was of little use. There was also a general desire for improved access to Heathrow from provincial centres. This rendered it essential that there should be a Heathrow dimension in any UK high speed rail solution.

F2 High speed rail to Heathrow?

These considerations have driven a strong political requirement for high speed rail to be developed in the UK, with a connection to Heathrow as an integral element. This politicisation was heightened with the (then) Government's launching of the HS2 project in January 2009, as it announced its backing for expansion at Heathrow. Whether it was expected that high speed rail would bring about environmental benefits that would somehow mitigate the damage of the third runway et al, or whether it was simply a crude political sop, is open to debate; but with expansion now cancelled, it seems to be considered more important than ever, that the UK high speed rail project is configured around Heathrow.

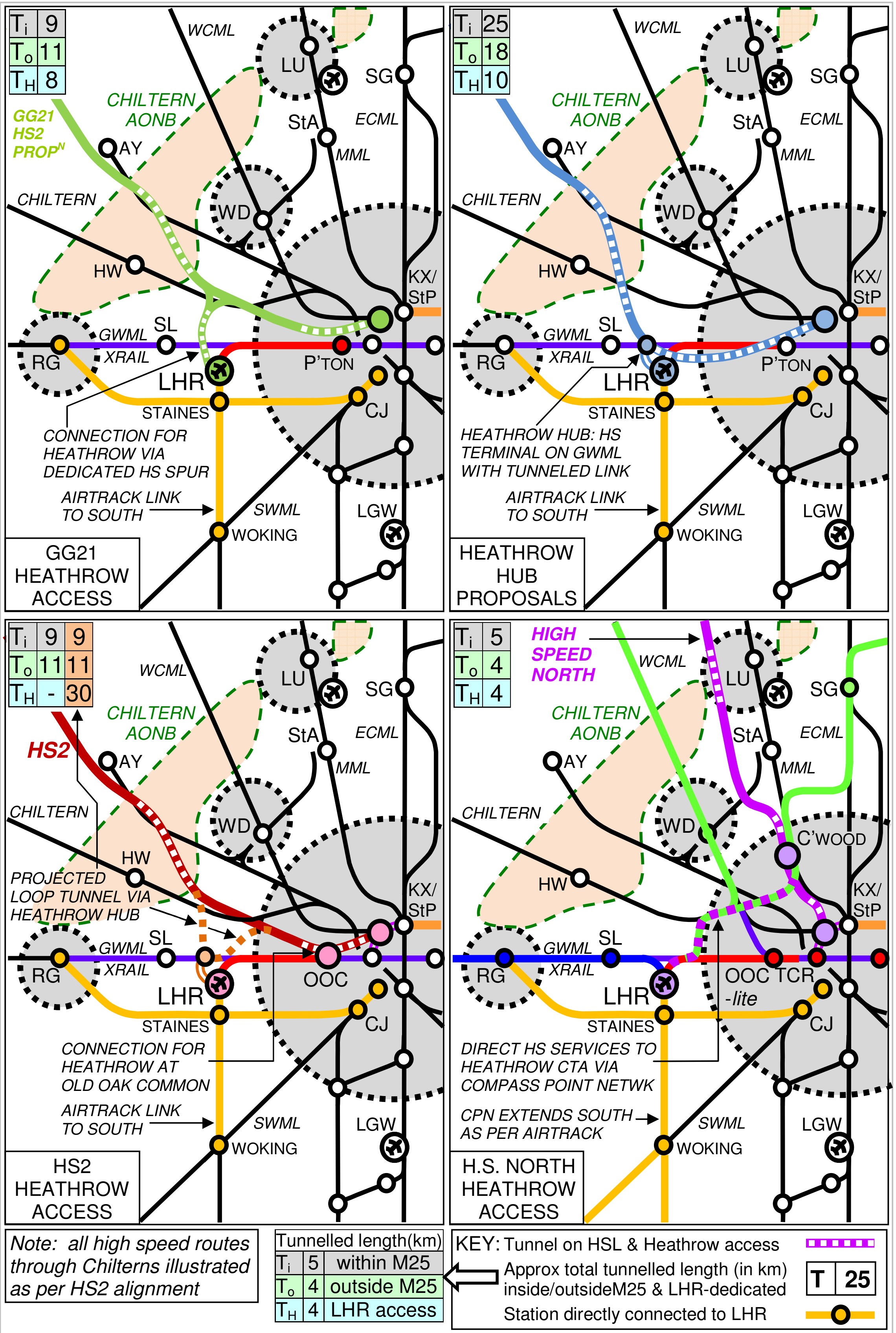


Fig F1: High speed rail schemes : Proposed Connections to Heathrow

The prioritisation upon Heathrow is reflected, to a greater or lesser extent, in all of the major high speed rail proposals so far advanced, as illustrated in Figure F1. This highlights the different 'models' of airport access adopted in the various schemes, which are illustrated in Figure F2. These are summarised as follows:

- ***Greengauge21: dedicated spur from high speed line (Model 1)***
  Direct services from regional cities to Heathrow along dedicated spur from high speed line, with significant tunnelling required to access airport (at Terminal 5). Spur configuration requires separate services to Heathrow in addition to services to London, thereby compromising main line capacity. Onward route to north through Chilterns, with further tunnelling required.

- ***Heathrow Hub: high speed line deviated via 'on-campus' station (Model 2)***
  Direct services from regional cities to Heathrow achieved through diversion of high speed line to dedicated station on Great Western Main Line north of airport, with new distributor network constructed to link across 'Heathrow campus' to airport. 25km of tunnel required to bring high speed line from central London to Heathrow Hub, up to 10km within Heathrow. Onward route to north through Chilterns, with further tunnelling required.

- ***HS2: shuttle connection from remote interchange station on high speed line (Model 3)***
  This model of Heathrow access, originally proposed in the March 2010 HS2 reports, provides no direct regional services to Heathrow. Instead, a remote hub is proposed at Old Oak Common on the Great Western Main Line corridor, interchanging with existing Heathrow Express airport services to deliver passengers to Central Terminal Area and Terminal 5. Adoption of a remote hub allows easier route within Metropolitan area, but onward route to north through Chilterns requires further major tunnelling.

- ***HS2: second stage development with loop[17] to 'on-campus' hub station (Model 4)***
  The present consultation documentation offers the possibility of a more direct connection to Heathrow, by means of a loop to an 'on-campus' station on the GWML corridor. This is proposed for implementation along with the second stage of route development, from Birmingham to Manchester and Leeds. The loop would deviate from the trunk route west of Old Oak Common, extend (in tunnel) to the hub station, and return (again in tunnel) to the trunk route close to the crossing of the M25. This element of the HS2 route would closely resemble the Heathrow Hub proposals, with a similar tunnelled distributor network required to access the airport terminals.

- ***High Speed North: integrated spur from high speed line along route created to facilitate regional services to Heathrow (Model 5)***
  Direct services from regional cities to Heathrow along 'northern orbital arm' of Compass Point Network (a system of lines radiating from Heathrow, with primary aim of connecting airport to main line network at outer suburban hubs) accessing CTA and Terminal 5 via existing Heathrow Express tunnels and underground stations. Onward route to north following M1 corridor, with much lesser requirement for tunnelling.

[17] Although certain HS2 promotional material appears to show the putative high speed connection to Heathrow as a spur, this further development will be considered throughout this study as a loop, additional to the previously established trunk route.

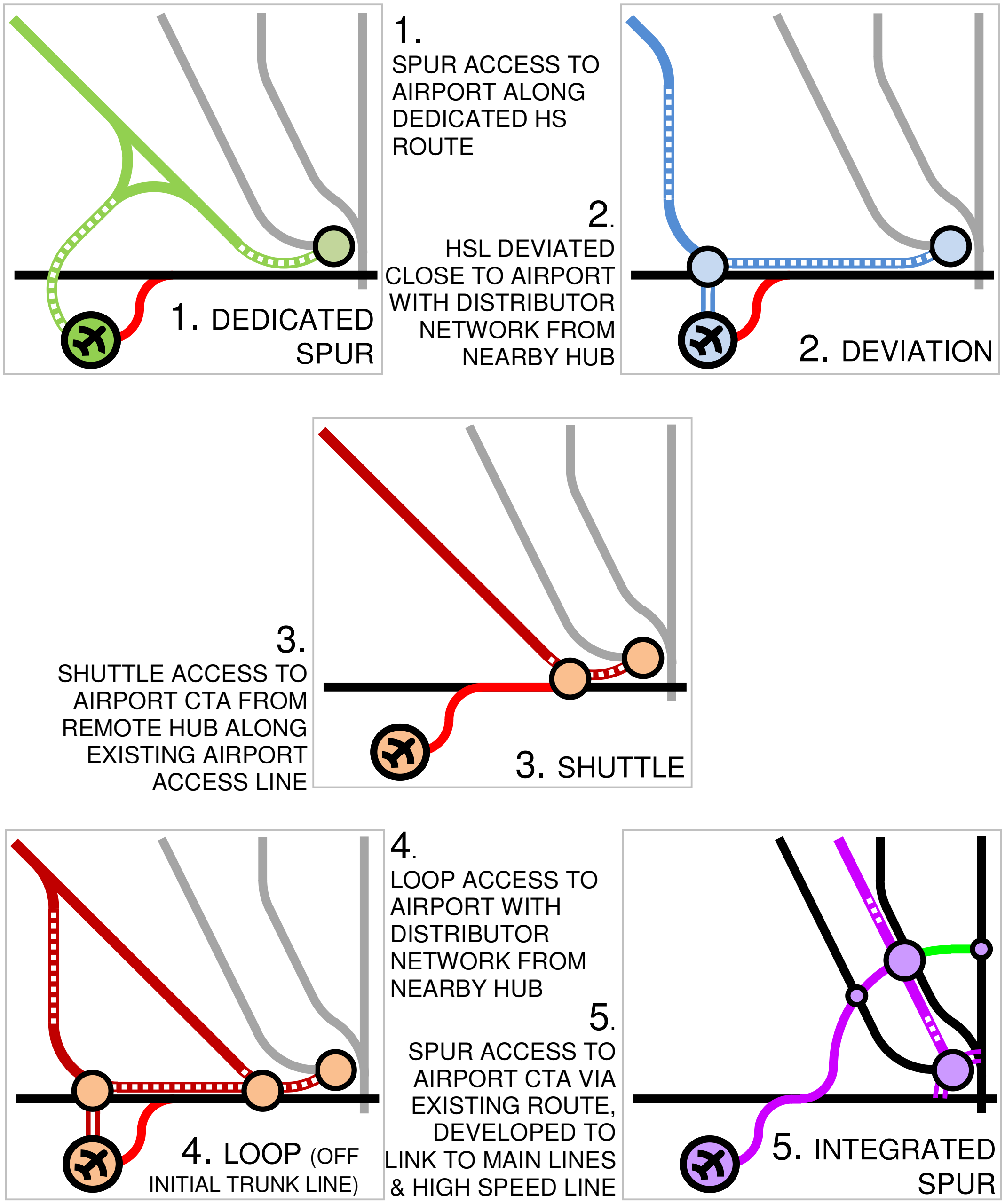


Fig F2: High speed rail schemes : Models of Airport Access

It is immediately apparent, from review of the above, that none of the proposals achieve the ideal interchange between airport and high speed rail, which might allow the arriving airline passenger to step down one level from the baggage reclaim area to an underground station on the high speed main line, and join a train to continue an onward journey. This ideal is rendered impracticable both by the multiplicity of airport terminals (in 3 geographically distinct areas) and by the disruption, difficulty and sheer risk (noting the collapse in 1994 during construction works for Heathrow Express) involved in excavating the large cavern for the underground station.

F3 Local Implications of Routeing High Speed Line via Heathrow

Duly deterred by the scale and complexity of the necessary infrastructure works, the developers of proposals that aspire to route the high speed line via Heathrow (ie Greengauge21, Heathrow Hub and HS2) have been forced into a degree of compromise. This compromise exists on several levels:

- With the high speed platforms located at some remove from the airport terminals, either at an 'at airport'/'on-campus' interchange station, or at a more remote hub, an intermediate shuttle is necessary to deliver the airline passenger to the train. Dependent upon the distance, time and difficulty of transfer at either end of the shuttle, this must considerably reduce the attractiveness of high speed rail for interlining passengers (which after all is the purpose of routeing 'via' Heathrow).
- The route to the north is lengthened significantly in its attempt to serve Heathrow. This is a simple consequence of the fact that while Heathrow lies due west of London, the target destinations for a high speed line to the north are located in a 'band' bearing approximately north-west to north-north-west from London. Around 30km are added to the distance from London to Leeds, by virtue of deviating via Heathrow and Birmingham (with the exit point from the Chilterns in the Aylesbury area, an onward direct route to Birmingham, and then splitting to go east or west of the Pennines, appears to be a logical follow-on from the Heathrow deviation).
- With the high speed line deviated well to the west of its ideal NW/NNW course, an onward route through the Chilterns Area of Outstanding Natural Beauty appears to be an inevitability. It must be noted that, regardless of the Chiltern's AONB status, it is not what might be deemed ideal railway building territory; no main line crossed the Chilterns until the late 19th Century[18], with the railway builders preferring the easier topography further east.
- Infrastructure costs (for which length of tunnelling is a prime indicator) appear to rise roughly in inverse proportion to the achieved proximity of the transfer point from high speed train to shuttle link. This relationship is somewhat masked by the requirement for 10-15km of tunnel through the Chilterns for whichever proposal, but it is still apparent from a quick comparison of various schemes. See Table F3.

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[18] Aside from the Maidenhead – High Wycombe – Aylesbury line (a single track route opened in 1868), the first main line to cross the Chilterns was the Metropolitan Railway in 1892. This became the Great Central's first route to the north, but, after much congestion and disputes with the Metropolitan, the Great Central / Great Western Joint line via High Wycombe was developed, opening in 1906.

19th Century railway development tended to concentrate on more established transportation corridors. The builders of the London & Birmingham Railway (which now forms the modern West Coast Main Line) followed very closely the route established by the Roman road builders (Watling Street) and the canal builders of the Georgian era (Grand Union Canal). The M1 later followed this same broad corridor.

	Greengauge 21	Heathrow Hub	HS2 (March 2010 release)	HS2 (March 2011 consultation)	High Speed North
Network configuration	West-sided	Y	Y	Y	Spine & Spur
Heathrow access model	Spur	Devia-tion	Shuttle	Loop	Integrated Spur
Tunnelled length within M25	9	25	9	9	5
Tunnelled length outside M25	11	18	11	11	4
Tunnelled length dedicated to Heathrow access	8	0	0	20	4
Tunnelled distributor network within airport 'campus' – est. @ 10km long	0	10	0	10	0
Total tunnelled length (km)	28	53	20	50	13
Total length of new railway to Chiltern north slope (@ 55km)	68	71	55	87	67

Table F3: Infrastructure Implications of High Speed Rail Access to Heathrow

Of all the Heathrow-oriented proposals, the first phase of HS2 has the least requirement for tunnelling in the vicinity of the airport. This corresponds to the furthest location of the proposed hub, at Old Oak Common, where airport passengers will transfer to Heathrow services, running along the Great Western Main Line and accessing the Central Terminal Area and Terminal 5 via the existing 'Heathrow Express' route. This minimises infrastructure costs directly attributable to Heathrow, but still requires construction of a massive station 'box', similar to that already existing at Stratford on HS1. The box would accommodate HS2's low level platforms, with footbridge or similar transfer required to access the ground level platforms on the GWML, from which services to Heathrow would proceed.

Considering all 5 proposals, and the balance between more expensive tunnelled and less expensive surface construction, High Speed North has the lowest requirement for new infrastructure. This again is indicated by the increasing remoteness of the proposed alignment of the trunk high speed route from Heathrow.

However, it must be stressed that cost and complexity of infrastructure, and even onward environmental impact in sensitive areas such as the Chilterns, are only part of the picture. It is necessary also to consider which access model comprises the most appropriate and effective means of transferring high speed rail passengers to Heathrow Airport.

F4 Implications of Different Airport Access Models

F4.1 Attractiveness of Shuttle Transfer to Heathrow

It is highly doubtful whether the high speed to shuttle transfer at Old Oak Common – as proposed for the initial phase of HS2 development – would be sufficiently attractive to airline passengers, who currently 'interline' from internal to long-haul flights Heathrow without the encumbrance of luggage. As such, regardless of whatever 'intercity' flows high speed rail might attract from aviation, it would be difficult to adduce conversion of 'interlining' aviation flows, who represent 50% or more of passengers on most domestic flights to Heathrow. Thus the somewhat politicised environmental goal, of elimination of Heathrow's short-haul flights, seems unlikely to be met.

If a 'shuttle' model were to be adopted, it would seem preferable to accomplish this at a dedicated station much closer to the airport (notionally within the airport 'campus'), where the possibility of baggage check-in might exist. This renders highly attractive the 'deviation' model offered by the Heathrow Hub scheme.

These issues seem to have been acknowledged in the latest development of the HS2 scheme, as represented in the proposals contained in the formal Government Consultation released on 28 February 2011. This proposes (in the second stage of roll-out beyond Birmingham) further development of a tunnelled loop from the HS2 main line. This would serve a station located north of Heathrow on the Great Western Main Line, with an onward dedicated shuttle connection to the airport terminals. In essence, this would comprise the Heathrow Hub proposal, albeit located on a 'loop' rather than on the main line itself.

With the additional tunnelling of the Heathrow loop, and with the tunnelling required to access the airport terminals, the upgraded HS2 proposals would require almost as much tunnelling as the Heathrow Hub, and (assessing also the total length of new railway) would have the greatest infrastructure requirements of all Heathrow-oriented high speed rail proposals. See Figure F3.

It would thus appear that while a 'shuttle' model of high speed rail access to Heathrow might have a fairly low infrastructure requirement, its fundamental inadequacy as a means of connection to Heathrow leads such proposals to migrate towards much more complicated and costly 'deviation' or 'loop' models of access. For either a 'deviation' or a 'loop' to be viable, it is clear that the trunk route must be aligned fairly close to Heathrow. As discussed in Item F7, this has an immediate consequence, in increasing the effective 'gravitational pull' of Heathrow, and reinforcing the perceived necessity to route the high speed line through the Chilterns, and rural areas beyond.

A more complete list of consequences of a Heathrow/Chilterns-oriented high speed line is given in Table F9.

F4.2 Issues with 'Spur' Routeing into Heathrow

Given these highly negative outcomes, it is essential that due consideration is given to the remaining alternative models of rail access to Heathrow ie the option of a 'spur'. With no requirement for a train routed via the spur to return to the main line, it would appear possible to align the high speed route at a greater remove from Heathrow. However, the length of the spur – with its own construction costs which will increase with distance, and difficulty of routeing – will create its own issues.

From review of Table F3, it can be seen that spur proposals overall have a considerably reduced infrastructure requirement, and might outwardly seem an attractive option for high speed rail access to Heathrow. But this is achieved at a price. There are major implications in the enforced split between Heathrow and London-bound services arising from a 'spur' configuration:

- All major conurbations are likely to demand their own direct train service to Heathrow. Considering the 9 Midlands, Northern and Scottish conurbations (as listed in Section 3.5) and assuming a reasonable (ie at least hourly) level of service to all regional destinations, this could introduce up to 9 additional trains per hour onto a trunk route line on which capacity is already critical. Thus there would seem to be a major risk of dedicated airport services compromising the primary function of the high speed line, to link conurbations. This in turn will restrict the ability of the high speed line to abstract express passenger traffic from the existing main lines, and thus generate the extra total network capacity necessary to enable major modal shift.
- The traffic flows from Heathrow to an individual regional centre do not appear to be sufficient to justify dedicated airport services. On the evidence of existing 'interlining' flows from Manchester and Glasgow (see figure F10), and considering also research undertaken by Greengauge21[19] in respect of flows from Birmingham, 1000 passengers per day from an individual conurbation of circa 2M population can reasonably be estimated. This would translate to an hourly flow of less than 100, and would seem to be neither economically viable, nor a worthwhile use of valuable main line capacity.

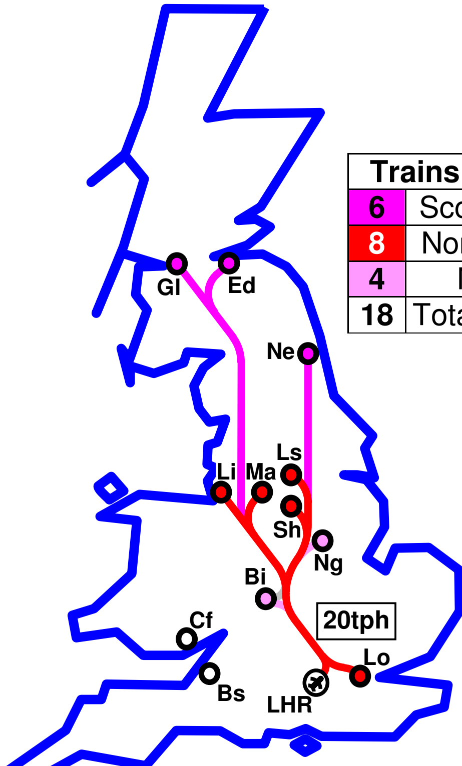
The above commentary is applicable to the 'London-centric fan' configuration favoured by most high speed rail proposals, including the HS2 'Y' and earlier proposals by Greengauge21. In operational terms, the location of individual conurbations on separate arms of the 'fan' demands separate services from London to each conurbation. As detailed in Section 4.9, this has major consequences for load factor and general operational efficiency. It also tends to result in a system that is focussed upon London, with little opportunity for improving interregional connectivity.

[19] In 2008 Greengauge21 undertook research on behalf of Birmingham City Council, to demonstrate the need for high speed rail services to that city. Annual flows were calculated for the following:

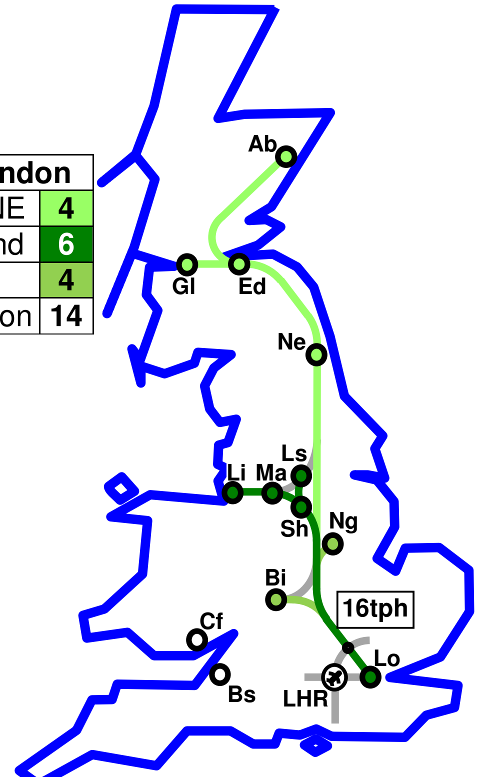
- central Birmingham to central London: 3.9 million passengers
- Birmingham International to central London: 0.8 million passengers
- central Birmingham to Heathrow: 0.3 million passengers

The latter figure translates as a daily flow of circa 1000, and an hourly flow of no more than 100. For this, 2 direct trains per hour from Birmingham to Heathrow were proposed.
No explanation has ever been offered for how this service could be financially viable, or how it could be accommodated on a capacity-critical high speed route.

HS2's modelling (detailed in the March 2010 reports) predicts 1400 daily HSL passengers to Heathrow with an interchange at Old Oak Common, or 2000 with an 'at-airport' station located on a loop (detailed in the March 2011 HS2 Consultation document as the preferred option, to be implemented during the second phase of development (ie the arms of the 'Y').

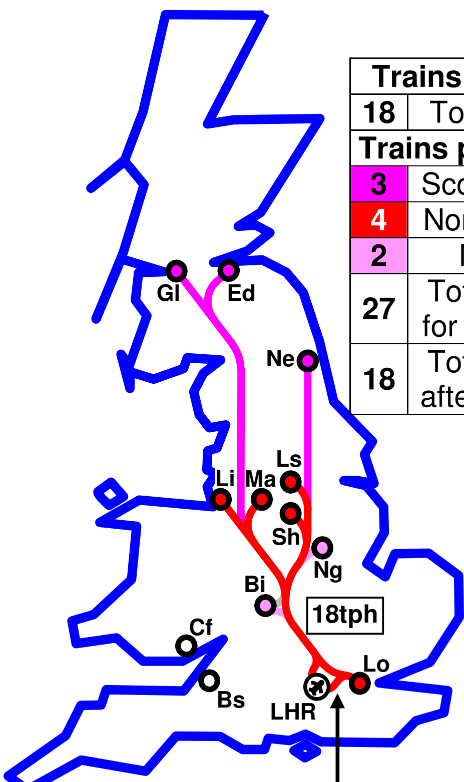


Trains ph to London		
6	Scotland & NE	4
8	North England	6
4	Midlands	4
18	Total to London	14

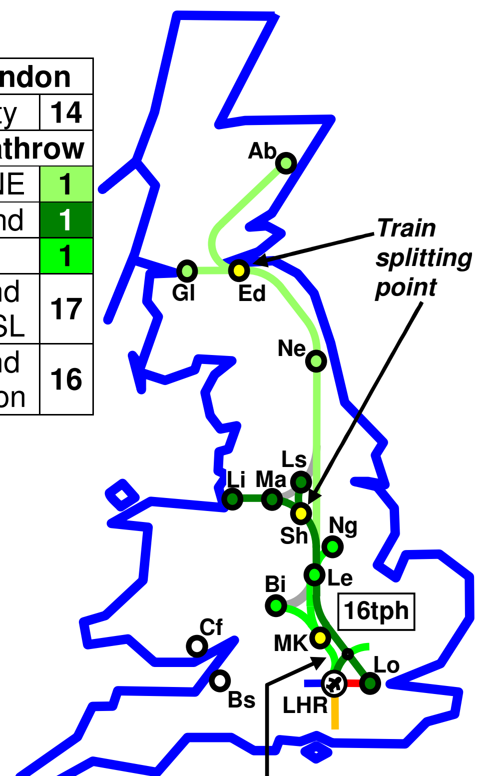


Y-SHAPED NETWORK WITH HEATHROW SPUR

SPINE & SPUR NETWORK WITH COMPASS POINT NETWORK



Trains ph to London		
18	Total intercity	14
Trains ph to Heathrow		
3	Scotland & NE	1
4	North England	1
2	Midlands	1
27	Total demand for tph on HSL	17
18	Total demand after mitigation	16



Mitigation: adopt loop to Heathrow rather than spur

Mitigation: divert Heathrow to Midlands service via WCML

Fig F4: High Speed Train Flows to London and to Heathrow

F5 Viability of 'Y' and 'Spine & Spur' Configurations

Figure F4 demonstrates the effects of combining intercity and airport flows on the critical southern section of a Y-shaped high speed line proposal. The tabulated train flows are derived from the comparisons detailed in Item 4.9.2, and are generally representative of each conurbation requiring (on average) a 2 train per hour intercity service to London (roughly comparable to that which currently applies). The combined flow of 20 trains per hour would exceed the maximum 18tph capacity of a 2-track high speed line. Hence it would seem clear that no extra services directed onto a Heathrow spur would be feasible. And even if sufficient line capacity were to exist, there would still be the problem of insufficient passenger numbers en route to any particular city, to comprise a viable train load.

Hence the only viable means by which a Y-shaped (or 'fan') high speed system can serve Heathrow (in a manner deemed acceptable to 'interlining' passengers) is the 'loop', or 'deviation', to an on-campus airport station. This allows intercity services from London to call at Heathrow, without the need for extra, dedicated 'airport' trains. It would also appear to address the issue of low (ie less than train load) flows to individual cities.

This explains the logic behind the heavy infrastructure requirements in the current HS2 proposals for further development of a largely tunnelled loop to access an 'on-campus' station near Heathrow. This will effectively supersede the 'shuttle' transfer originally proposed from Old Oak Common. (It also casts doubt on the viability of the 2007 Greengauge21 'HS2 Proposition', in which a spur into Heathrow was allied with essentially a wider high speed network configured in 'fan' format.)

It might simplistically be concluded from the foregoing, that the 'spur' model of rail access to Heathrow is not viable. However, this only holds true in relation to an assumed combination with a high speed network configured in 'fan' format (eg the Y-shaped system as favoured by HS2) with its inherent operational inefficiencies.

Figure F4 also illustrates the interaction between intercity and airport services, with the high speed network configured in an alternative 'spine and spur' format (as exemplified by High Speed North). This configuration allows several cities to be placed on a single core route, and this concentration of services (see Figure 4.19) both increases the payload on an individual train, and reduces the demands upon line capacity.

In terms of intercity services, only 16 trains per hour are required to provide the service levels that would demand 20tph on a Y-shaped system. This in itself will have beneficial economic and environmental effects. However, the much greater benefits lie with the rationalisation of airport services resulting from the concentration of routeings that is possible with spine and spur.

As postulated in previous paragraphs, disaggregated airport flows to individual provincial cities are likely to comprise no more than 100 passengers per hour. Considering a single city in isolation, 100 passengers would not comprise a viable train load on a capacity-critical high speed line. But with several major cities located on the route of a single train, and with the further possibility of splitting the train at advantageous node points to serve more destinations still, it becomes possible to efficiently cater for the relatively low Heathrow flows en route to any single city.

Considering an airport service covering several major northern centres (eg Liverpool, Manchester, Bradford, Leeds and Sheffield), this might comprise of the order of 300-350 passengers. Such a passenger load could be contained in reasonable comfort on a UK-gauge train, 8 cars / 200m in length. This is within the maximum train length which can be accommodated in the Heathrow Express underground station. Configuration of the train in standard 2x4-car format would allow the necessary splitting/joining at Sheffield.

On a similar basis, an airport service might cover all North-East and Scottish centres (eg Newcastle, Edinburgh, and splitting there for Glasgow and Aberdeen). Principal West and East Midlands centres could be covered by a further airport service, routed along the West Coast Main Line and calling at Watford Junction, Milton Keynes, Northampton, splitting for Coventry/Birmingham/Wolverhampton, and for Leicester/Nottingham.

With this latter train routed via the WCML for optimum coverage (note that speed is not critical for Heathrow to Midlands rail flows) the net effect of providing high speed services to Heathrow from a 'spine and spur' route such as High Speed North would be an additional 2 trains per hour. This would increase total train flows to 18tph, and would appear to be a relatively marginal and proportionate impact upon line capacity[20].

With UK-gauge trains configured for high luggage capacity and quick unloading capability at the airport, long-distance services can be integrated with Heathrow's existing railway operations. With trains capable of 'high speed' operation on a network configured for services calling at multiple provincial cities, airport flows can be accommodated without unduly compromising the much larger intercity flows.

Thus it would appear possible to achieve the twin aims of:

- Long-distance rail access direct to Heathrow CTA and Terminal 5.
- Comprehensive airport services to all major conurbations.

and at the same time realise a high speed route to the north following the optimum M1 corridor with marginal environmental impact, rather than a difficult and controversial route through the Chilterns.

These benefits, of efficient and comprehensive airport links, achieved at minimised environmental cost, appear to address the essential political remit for high speed rail access to Heathrow. But it is important to note that this is not accomplished by the direct response, of a high speed line to Heathrow. This would serve relatively few passengers, but carry massive costs for dedicated, single-use infrastructure.

Instead, these costs are minimised through the development of an integrated transport system along existing rail corridors, utilising and enhancing Heathrow's existing rail infrastructure to allow it to be exploited to its full potential. Most elements of the required 'Heathrow Compass Point network' are either already in place (eg the Heathrow Express underground stations and tunnels, and most of the required route length) or planned (ie the proposed Airtrack link to the Southern network at Staines, and a west-facing link to the Great Western network).

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[20] Although train flows are reduced compared with a Y-shaped configuration, this is still close to the feasible line capacity of a 2-track route, and further expansion of services – to address either a business or CO_2-reduction agenda – would not be possible. Hence, as discussed in Item 4.6.2, it will probably prove necessary, for both the 'Y' or for 'spine and spur', to construct the critical London-Midlands section in 4-track format. This would appear to be far more achievable along the M1 corridor, than within the sensitive Chiltern environment.

The step-change enhancement would come with the integration of all these disparate components into a harmonised system, addressing Heathrow's 360-degree connectivity requirement with rail links extending to south, west and north (in addition to the present eastward Heathrow Express route to central London). As noted, the southern and western elements are already envisaged; and with the key 'northern orbital arm' requiring only relatively short lengths of new infrastructure to link existing routes, a complete system would be created, connecting to all existing radial main lines and also to the high speed line.

F6 HSR Flows to Heathrow in context of other flows

It is important to consider high speed rail flows to Heathrow in the context of other traffic flows. Table F5 (condensed from Table 4.20) shows a summary of the passenger flows predicted by HS2 for passenger flows on HS2, for both 'intercity' and 'airport' journeys. It is immediately apparent that journeys to Heathrow represent a very small proportion (~1-2%) of total journeys on HS2.

Proposal	HS2			High Speed North
London terminal configuration	Euston alone	Euston plus Old Oak Common	Euston plus Heathrow Hub	Euston, with developed links to adjacent hubs
Destination	*Total users of London & Satellite terminals*			
Greater London	113200	115200	93000	*figures not available*
Outside London	20000	28400	33600	
Total non-LHR	133200	143600	126600	
Total Heathrow	1000	1400	2000	

Table F5: HS2 'High Speed' daily flows to Heathrow relative to intercity flows

These airport flows are scarcely any larger, when considered in the context of Heathrow's surface access flow of 70000 passengers per day (a number that increases considerably, when commuter flows of locally-based airport workers are also taken into account). Heathrow's passenger flows are summarised in Table F6, with a notional assessment of potential commuting flows of airport staff also included.

	Passengers
Passengers per day	100000
No of flights	640
Average passengers per flight	156
No of transfer passengers	30000
Surface access flow	70000
HS2 predicted high speed flows	2000

Table F6: Heathrow Airport : Passenger Flow Statistics

There appears to be a fundamental mismatch between intercity high speed rail (at least as established according to the HS2 model) and the requirements for rail access to airports. A high speed railway offers a largely uniaxial and long-distance transport solution, connecting only to the centres (or peripheral parkway locations) of major provincial centres. This may well explain, at least in part, HS2's low estimated flows to Heathrow.

Figure F7 highlights, in Venn diagram format, the almost complete disconnect between interconurbation flows and airport access flows, according to the HS2 model.

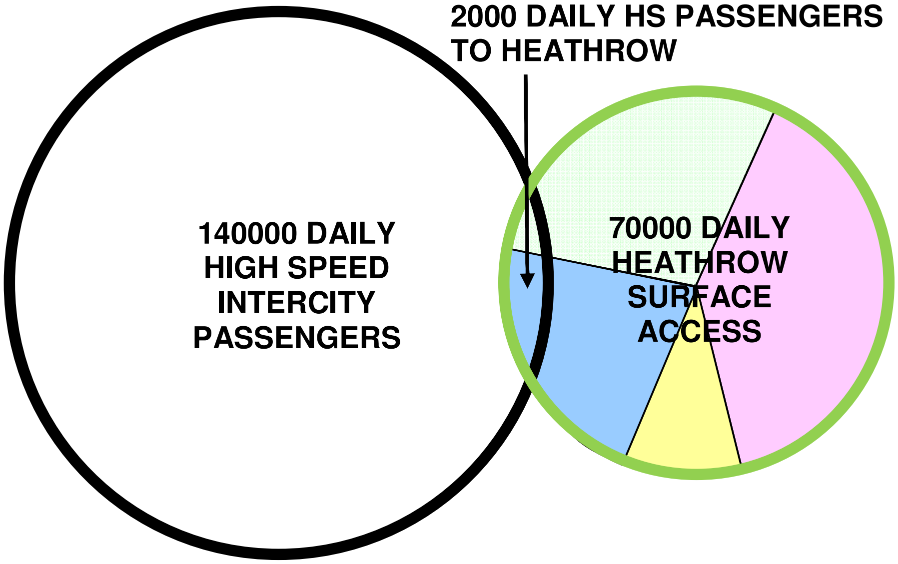

Fig F7: HS2 Flows to Heathrow in context of High Speed Intercity Flows and Heathrow Surface Access

The problem with the HS2 model would appear to be its failure to address the true nature of an airport's surface access flow. This is not simply to a select group of major conurbations, on a specific axis; instead, it is more 360º in nature, extending to communities near and far, small and large.

This wide geographic spread of airport flows has historically proved a difficult issue for rail to resolve. With airports occupying land left vacant after the urbanisation of the 19th Century, they are rarely located on existing railway corridors and this makes new construction necessary to provide connections to the national rail network. But with the 'disaggregation' of airport traffic (resulting in flows to any individual city usually too low to comprise a viable train load) it has generally only proved possible to justify construction of rail links to the centre of the city that the airport serves.

This is the case even for Heathrow, which has by far the greatest surface access flow of all UK airports. Its only rail links are along the eastward axis towards central London; and despite massive local road congestion, no rail connections exist either to south, west or north. Consequently these axes are dominated by road transport, but with huge inefficiencies and environmental damage.

There is no doubting the business value of establishing rail connections from the UK's national airport to its principal regional centres; there is also considerable environmental value in converting the domestic airline flows that dominate longer distance surface access. However, it must be questioned whether a high speed railway, oriented along a single axis and serving relatively few destinations, is an appropriate solution when so much of Heathrow's surface access issues will remain unresolved.

This raises issues of proportionality and indeed democracy; it would seem far more appropriate to configure the UK high speed rail solution in such a way as to allow a much greater proportion of the UK population to benefit from improved surface access flows to the UK's national airport. This should also deliver much greater environmental benefits, in terms of high-emitting road flows converted to rail, in addition to short-haul air flows. It should particularly be noted that much of this new rail surface access would be accomplished at conventional, rather than high speed.

F7 Disproportionate Influence of Heathrow on HSL Routeing?

With high speed flows to Heathrow so low, compared with interconurbation flows, it is necessary to examine whether the strong 'gravitational' attraction exerted by the airport is having an undue effect on development of the wider UK high speed solution. This gravitational pull would draw the high speed line well to the west of the ideal corridor (as favoured by builders of Roman roads, canals, railways and motorways, already noted in Sections B8.6 and D4) into less favourable Chiltern territory, and would seem to give rise to impacts such as:

- Heavier engineering and extra costs.
- Unnecessary local environmental impacts.
- Extra total length of new railway.
- Delay in implementation.
- Impaired network functionality.
- Impaired performance in respect of CO_2 emission reductions.

F7.1 Implications in Heathrow/Chiltern area

The extra engineering cost (as far as the north slope of the Chilterns) of focussing the high speed solution upon Heathrow can be assessed from a re-examination of the data presented in Table F3. The total lengths of new railway, and of tunnelling, are set out in Table F8 as marginal additional lengths, baselined upon whichever proposal scores least in each category.

The initial HS2 proposals (comprising a 'shuttle' model) would require the shortest length of new railway. This is attributable to the location of its airport connection at Old Oak Common, on the existing Great Western rail corridor to Heathrow; hence there appears to be no need for additional infrastructure. However, the outcome of this economisation of new infrastructure is the least satisfactory of all proposed connections to Heathrow. As noted previously, this would seem unlikely to offer the necessary quality of connection, to convert interlining air flows (or even to offer an acceptable standard of regional access to Heathrow), and this has led to further proposals (in HS2's second phase of development) to develop a 'loop' to access an 'on-campus' Heathrow station.

All other proposals involve significant additional lengths of new railway to facilitate improved access to Heathrow. The 'spur' and 'deviation' models show a modest 12-16km requirement for new railway; this includes the distributor network to the airport terminals, specified for the Heathrow Hub scheme.

	Greengauge 21	Heathrow Hub	HS2 (March 2010 release)	HS2 (March 2011 consultation)	High Speed North
Network configuration	West-sided	'Y'	'Y'	'Y'	Spine & Spur
Heathrow access model	Dedic^{d} Spur	Devia-tion	Shuttle	Loop	Integrated Spur
Extra length of new railway (km)	13	16	0	32	12
Extra tunnelled length (km)	15	40	7	37	0
Marginal cost of extra infrastructure (£M)	1154	2648	399	2845	276
Interest charges on capital expended @ 6%pa (£M)	69.2	159	23.9	171	16.6
Predicted daily passenger flow accessing Heathrow	2000	2000	1400	2000	16000
Predicted annual passenger flow accessing Heathrow (M)	0.72	0.72	0.50	0.72	5.76
Marginal cost per daily passenger (£M/passenger) (COBALT)	0.57	1.32	0.29	1.42	17.3
Interest charges per journey (NICKEL)	£96	£221	£48	£238	£2.88

Marginal costs of new infrastructure assessed from data developed by HS2: £23M/km for 2-track railway, £57M/km (=80-23) E/O for tunnelling.
Daily passenger flows taken from HS2 reports, or Table F22. Only 'prime user' flows ie passengers from regions connecting to flights from Heathrow, are considered

Table F8: Marginal Cost Impacts of High Speed Access to Heathrow

When length of tunnelling is considered, the future HS2 loop and the Heathrow Hub proposals show an approximately equal requirement, greatly in excess of other schemes. This can be attributed to the difficulties associated with constructing surface-level time-sensitive routes in built-up areas, and leaves tunnelling as the only acceptable option.

But with the high speed route set along easier corridors at a greater distance from Heathrow, the requirement for tunnelling is much reduced. In this comparison, High Speed North has the least requirement for tunnelling, with 10km on the trunk route and 5km on the proposed developed Heathrow access route (part of the wider Compass Point network[21]); whereas the current HS2 proposals (with no Heathrow-dedicated infrastructure, but with a Chilterns alignment dictated through proximity to Heathrow) require 22km, all on the trunk route. The marginal additional costs of achieving rail access to Heathrow (high speed or conventional) are also set out in Table F8.

[21] It should be noted that long-distance 'high speed' flows will only constitute a proportion of total flows on the proposed Compass Point network. Local and regional traffic will comprise the majority of the flow (see Tables F14, F15 and F16), and hence it might be argued that the required infrastructure works need not be primarily attributed to high speed rail. This would have the effect of further reducing the infrastructure costs of High Speed North. However, for the purposes of this comparison, all elements of the Compass Point network necessary to establish connection to High Speed North (and MML) at Cricklewood, and also to the WCML, have been deemed to constitute High Speed North's 'Heathrow link'.

These costs are derived from HS2 data, whereby a typical £23M/km cost was estimated for a 2-track surface route in difficult topography (either urban or rural), and £80M/km for a tunnelled route. From these two figures, the differential cost of placing a railway in a tunnel, rather than on the surface, can be taken to be £57M/km.

The calculated marginal costs – effectively the extra cost incurred by each proposal in accommodating the remit of serving Heathrow, above the more basic requirement to link major centres of populations – are then contrasted against the daily passenger flows that will benefit from the connection that is created. (Other 'incidental/ opportunistic' journeys, which might become possible with provision of rail connection to Heathrow, are ignored.) The costs are presented both as the 'COBALT' (Cost Of Building Airport Link per Traveller) and 'NICKEL' (Notional Interest Charge Kalkulated[22] for Extra Length (of route)) values ie both the investment required per daily passenger journey, and also (possibly more meaningfully) the interest charges that would apply per journey.

This is possibly the starkest comparison between the different models of rail access to Heathrow. Applying a notional interest rate of 6% to the £2.85 billion marginal cost of the HS2 'loop' proposals, and allowing for 2000 daily passengers predicted by HS2, a charge of nearly £240 would apply to each journey made. Applying the same considerations to the High Speed North proposals for airport access via the Compass Point network, a charge of £2.88 would apply.

This huge difference can be ascribed to two simple factors:

- Marginal costs reduced by a factor of circa 10,
- Number of beneficiaries increased by a factor of circa 8.

There appear to be three options by which the extra costs attributable to achieving high speed rail access to Heathrow might be apportioned:

- Extra subsidy from Government,
- Sharing costs with other high speed line users (which effectively amounts to cross-subsidy),
- Inclusion in rail fare (in addition to other cost elements relating to operating, maintenance and administration costs, inter alia).

The first two options would appear to be unreasonable, and unfair to the majority of users who are not en route to Heathrow. Only the third seems justifiable, under normal principles of cost accounting. However, inclusion of a £240 additional cost within HS2's fares to Heathrow would clearly exceed any notion of fairness or reasonability, in terms of what rail customers might expect to pay. And with no apparent means by which the additional costs of HS2's proposed rail access to Heathrow could acceptably be met, the entire rationale of these proposals – and hence the entire HS2 scheme – would seem to be open to question.

No such problem would be anticipated for the much smaller but more proportionate costs attributable to rail access to Heathrow, via High Speed North and the Compass Point network.

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[22] The mis-spelling of 'Kalkulated' is acknowledged, but the recent 'rekristening' of the royal bride has shown 'K' and 'C' to be totally interchangeable in the English language.

F7.2 Implications north of Chilterns

The foregoing paragraphs have described the greatly increased infrastructure (and cost) implications consequent upon HS2's attempt to satisfy the political requirement for high speed rail access to Heathrow with a Y-shaped, Chiltern-aligned route. However, there appear to be wider ramifications (uniformly negative in comparison with the alternative M1-aligned spine and spur format) that spread across the full extent of the proposed high speed rail system. These are summarised in Table F9.

As has already been outlined, the 'local' cost of achieving an acceptably close 'high speed' access to Heathrow amounts to several billion pounds (with clearly disproportionate impacts in respect of the relatively small number of users of such a facility). But this extra cost more than doubles, when the increased route length to complete the 'Y' to either side of the Pennines is also taken into account.

Arguably even more significant is the environmental cost of achieving high speed rail access to Heathrow. Routeing via (or close to) Heathrow dictates a route through the Chilterns, with major impacts upon landscapes, and massive associated controversy. It is not possible to ascribe a direct CO_2 cost to a destroyed vista, or even to the consequent loss of rail's 'green' credentials.

However, it is possible to quantify the CO_2 cost of the unnecessary delay (in comparison with the less controversial and expensive High Speed North alternative) in the construction of HS2. The relevant emissions figure (117MT) can be drawn from Figure 5.1. Similarly, approximate CO_2 costs can also be ascribed to other onward consequences of the adoption of the 'Y', such as restricted connectivity (92MT), lack of integration (one quarter of 172MT allocated, on account of misalignment with 'M1 corridor' communities) and poor load factor/operational inefficiency (52MT). See Table F9.

Overall, the CO_2 cost of adopting a Y-shaped configuration rather than spine and spur appears to be of the order of 334MT of CO_2 (or one third of a billion tonnes) over a 40 year period. With the 'Y' completely predicated upon a close alignment to Heathrow, it seems reasonable to ascribe this figure to the political requirement to achieve high speed rail access to Heathrow. 334MT dwarfs any savings that might arise from high speed rail displacing internal aviation; at 1.5% of contemporary transport emissions (of 140MT per annum), domestic flights would emit only 84MT over the same 40 year period. It should additionally be noted that this figure relates to all domestic air flows, the majority of which comprise interconurbation flows which could be 'converted' without any need for the high speed rail system to access Heathrow.

	Issue / Onward consequence	CO_2 or £ cost (ref)
	High speed line drawn excessively close to Heathrow on northward route from London, to satisfy remit for high speed access to Heathrow	
1	Increased infrastructure requirement imports massive extra cost to UK high speed rail project.	£2.9bn (Tab.F8)
2	Inappropriate model of rail access to Heathrow leaves private car as dominant mode for airport journeys.	24MT (#, 6F)
3	Close alignment with Heathrow leaves no apparent alternative to onward routeing through the Chilterns.	
	Major public opposition arising from routeing through Chilterns AONB	
4	Protracted planning process, legal action, civil disobedience etc imports circa 10 years' delay to UK high speed rail project	78MT (#, 2B)
5	No conceivable local benefit will accrue, further eroding public support	
6	Desire to mitigate environmental intrusion prevents consideration of likely necessity for 4-track provision along capacity-critical 'stem' of HS2	31MT (#, 1A)
7	Likely loss of rail's 'green' credentials, with knock-on effects on other necessary transport projects	????
8	Westerly alignment of HS2, emerging from Chilterns at Aylesbury, dictates onward 'direttissima' rural route to Birmingham	
	Excessively west-sided alignment clear of South-East Midlands communities along WCML corridor	
9	With continued intrusion into unspoilt rural areas and no mitigation from following existing transportation corridors, further expense and delays from local opposition seem likely.	19MT (#, 2B)
10	Bypassing of major 'second-tier' centres such as Luton, Milton Keynes, Coventry and Leicester leads to lost opportunities for integration with existing network, and enhancement of existing connectivity. Similar issues further north. Economic blight of these areas also seems likely.	43MT (#, 5E) £??
11	London-West Midlands first phase of HS2 only delivers onward links to the WCML; connections to East Midlands and onward links to MML delayed until second phase.	20MT (#, 2B)
12	West-sided alignment dictates that Birmingham is primary destination, with no apparent benefit in splitting the route at any point between London and West Midlands.	
	Location of splitting point in West Midlands dictates Y-configuration	
13	With HS2 'stem' reaching West Midlands before any splitting, logical onward progression is to Manchester (west of Pennines) and to Leeds (east of Pennines). This would comprise the 'Y'.	
14	Extensions of the route would continue either side of the Pennines, west-sided to Edinburgh and Glasgow, and east-sided to Newcastle. This would comprise the 'extended Y', with circa 160km greater route length compared with 'Spine & Spur'.	6MT £4bn
15	London-centricity implicit in 'Y' configuration will fail to address requirement for equivalent interregional connectivity, and extra capacity on these axes – particularly Transpennine.	61MT (#, 1A)
16	Adoption of Y configuration leads to inefficient performance (ie lower load factor and need to operate more trains) compared with 'Spine & Spur'.	52MT (#, 4D)
	# CO_2 tonnages are drawn from Figure 5.1, with reference to a specific row in the table (ie 1A, 2B etc). Where there is multiple reference to any particular row, a judgment is made as to proportioning of total CO_2 cost. Σ	334MT

Table F9: CO_2 and cost impacts of Y-shaped HS route via Chilterns

F7.3 The Heathrow Syllogism??

It is apparent that there is a degree of self-fulfilling prophecy in the adoption of the 'Y'. The initial belief that the high speed line (primarily oriented towards Birmingham and Manchester, England's second and third most populous conurbations) must pass close to Heathrow (in order to provide the required high speed access, and to enable the conversion of airline flows, without adding major volumes of poorly-filled airport services to disaggregated destinations) drives the selection of an excessively west-sided route through the Chilterns and onwards to Birmingham. With Birmingham the location of the splitting point for Manchester and Leeds, the 'Y' is formed.

And with the inefficiencies inherent in such a configuration (see Figure F4), the only way in which the resulting system can serve Heathrow without:

- unduly compromising trunk route capacity (of a line through the Chilterns which cannot practicably be more than 2 tracks), or
- uneconomic passenger volumes on individual airport trains,

is to adopt an alignment that passes close to Heathrow. This would appear to fully justify the initial assumption, to predicate the route upon Heathrow.

With a circular (or 'looped') logic path such as this, it can be appreciated how it might have been possible for HS2 to develop their proposals, without ever giving serious consideration to options other than the Chiltern route that was initially under consideration. Other possible routes (ie the M1 corridor) and configurations (ie spine and spur) appear to have been dismissed from consideration very early in HS2's selection process, primarily on account of a perceived inability to serve Heathrow[23].

No serious examination is then given to the outwardly counter-intuitive proposition that a network, formed around a trunk route that does not pass close to either Manchester, Birmingham or Heathrow, might actually provide a solution superior in every respect, with:

- lower cost through fewer route kilometres,
- greater benefit through more communities connected,
- lesser local environmental impact upon sensitive environments,
- massively reduced CO_2 emissions,
- comprehensive high speed rail links to the heart of Heathrow.

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[23] In addition to the Heathrow access issue, a variety of reasons is offered in HS2's reports as to why an M1-aligned high speed route would be unsuitable (and a Chiltern route preferable). Such reasons centre around the following:

- Indirect routeing to Birmingham,
- Inability to accommodate high speed alignments within acceptable deviation from motorway,
- Excessive requirement for tunnelling to avoid impacts on residential development.

The author has had the opportunity to review detailed alignments prepared by the developers of the High Speed North proposals, and can confirm that:

- Indirect routeing via M1 and M6 makes High Speed North around 7km longer, which might amount (at 300kph) to a 1.5 minute delay.
- A 360kph alignment is practicable north of the M25, without major deviation from the motorway.
- Residential development in the Luton area would dictate circa 4km of tunnel. Elsewhere, a largely tunnel-free route (with a total tunnelling requirement considerably less than that of HS2) appears to be possible.

A Tale of Two Railways...

UK high speed rail development is initially focussed along the WCML corridor, with Birmingham and Manchester the primary destinations, and connections to Heathrow also given high priority.	Noting lack of main line rail access to Heathrow, proposals are developed to expand the existing Heathrow Express system (operating as a terminating branch) into a regional 'Compass Point' network, extending to east, south, west & north and linking to all radial main lines with single change of trains at outer-suburban hubs.
Anticipating high flows along the high speed line from London to all northern communities, options for spur access to Heathrow (which would add extra trains to the trunk route and compromise capacity) are discounted. Instead, shuttle or loop access is preferred.	With advent of high speed rail, same operating principle can still apply, with Compass Point network providing 'shuttle' link to Heathrow.
This brings the HSL close to Heathrow, and dictates onward routeing through the Chilterns to the West Midlands.	This allows the HSL to be set onto optimum M1 axis, serving (initially) West and East Midlands.
With Leeds now also defined as a primary destination, the route will divide at Birmingham (to form the 'Y'), passing either side of the Pennines.	HSL develops into spine route following linear alignment of principal conurbations to east of Pennines, with spurs to serve west-sided centres.
Such a network will require separate trains (2tph assumed) to all 9 principal conurbations (in the Zone of Influence of a northern HSL), hence 18tph on trunk route to north. This will consume all available capacity on the high speed line.	Such a network allows several cities to be served by a single train, hence fewer trains are required to handle same passenger flow, at greater frequency. With circa 14tph on trunk route, capacity exists for dedicated Heathrow services.
Hence there seems to be no possibility of providing additional dedicated Heathrow services, routed to airport via spur. Instead, main line trains to north will pick up airport flows to north at satellite station on airport periphery (necessary due to 400m length of train). Shuttle transfer to terminals is then necessary.	Same principle of aggregation allows a single Heathrow train to serve several cities. With only 3 trains required to cover all 9 principal conurbations, dedicated Heathrow trains can operate on trunk route. With dedicated trains 200m long, airport services can access airport terminals via Heathrow Express.
This appears to justify the original decision to route the HSL close to Heathrow.	Thus a route whose spine is remote from Heathrow, Birmingham and Manchester appears to provide all with a superior service.

Or, to paraphrase Charles Dickens:

'It was the best of lines, it was the worst of lines'

F8 Quantification of CO_2 Inherent in Heathrow's 'Spoke' Connections

It is clear that the HS2 proposals will address only a small proportion of current flows – air or surface – to Heathrow. With a more comprehensive solution on offer, it seems likely that High Speed North, in combination with a 'Compass Point' network focussed upon Heathrow, would cater for much greater flows. Hence the potential for reduction in CO_2 emissions should also be considerably greater.

To assess these flows, and the associated CO_2 savings, it is necessary first to develop a reasonably accurate model of access to Heathrow. This must establish the nature ie mode of travel and originating point, of all the journeys that comprise Heathrow's 70000 surface access flow. However, it must also consider:

- 'interlining' flows, arriving by short-haul flights – *additional to surface access.*
- the component of surface access attributable to short-haul flights to European hub, Irish and mainland UK airports, generally available from regional airports – *which must be deducted from total surface access flow*.

A fundamental assumption will be made in the development of this model – that all UK citizens, irrespective of geographic location, have the same basic need for international/intercontinental connectivity. Within the UK, only Heathrow can provide this connectivity; aside from holiday destinations, regional airports offer very few flights extending beyond Amsterdam, Paris, Brussels and Frankfurt.

This of course is the clue to an understanding of the wider issue of the UK's international connectivity; with internal flights to Heathrow greatly constrained by lack of runway space there, the four European hubs of Amsterdam, Paris, Brussels and Frankfurt have taken a dominant role in providing 'hub' connections for much of provincial UK. Each of these four hubs equals or exceeds Heathrow's connectivity to (mainland) UK regional airports.

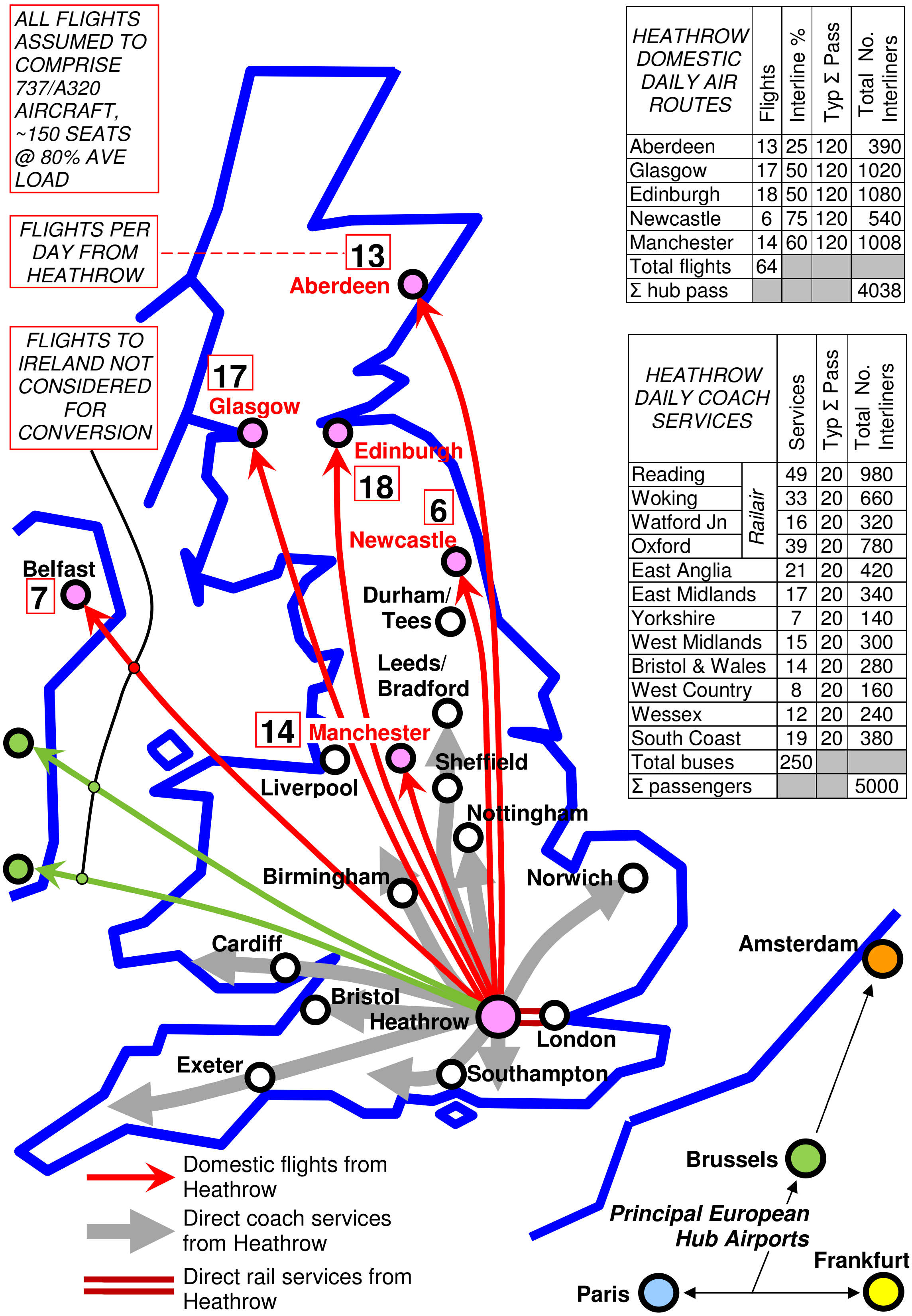
F8.1 Heathrow's 'Spoke' Connections, considered in isolation

Figure F10 – which focuses upon 'spoke' connections to Heathrow – is primarily useful for illustrating the inadequacies of existing links:

- Domestic flights only serve 5 mainland UK airports – Manchester, Newcastle, Edinburgh, Glasgow and Aberdeen.
- Direct rail links exist only to central London.
- A wider network of coach links exists, but these extend no further than Yorkshire and the East Midlands.

Although there is a rough 'match', in that the coach links generally extend only to areas not served by domestic flights exist, the overall picture seems highly asymmetric. In a qualitative sense, this 'bus/air' divide certainly does not display the equivalent standard of connectivity that should exist across the nation to its national airport. It is particularly concerning to note that Heathrow has no effective links to the national rail network, other than a difficult and (usually) congested Tube transfer between main line termini.

Overall, it seems reasonable to comment that the inconsistencies observed do not facilitate the creation of a model focussed exclusively upon Heathrow. To represent the UK's wider international connectivity, it would appear to be essential to make a broader consideration, examining also air flows to the continental hub airports (ie Amsterdam, Paris CDG, Brussels and Frankfurt).



HEATHROW DOMESTIC DAILY AIR ROUTES	Flights	Interline %	Typ Σ Pass	Total No. Interliners
Aberdeen	13	25	120	390
Glasgow	17	50	120	1020
Edinburgh	18	50	120	1080
Newcastle	6	75	120	540
Manchester	14	60	120	1008
Total flights	64			
Σ hub pass				4038

HEATHROW DAILY COACH SERVICES		Services	Typ Σ Pass	Total No. Interliners
Reading	*Railair*	49	20	980
Woking	*Railair*	33	20	660
Watford Jn	*Railair*	16	20	320
Oxford	*Railair*	39	20	780
East Anglia		21	20	420
East Midlands		17	20	340
Yorkshire		7	20	140
West Midlands		15	20	300
Bristol & Wales		14	20	280
West Country		8	20	160
Wessex		12	20	240
South Coast		19	20	380
Total buses		250		
Σ passengers				5000

Fig F10: 'Spoke' Connections from Airline Hub at Heathrow

In a quantitative sense, the situation also seems highly undesirable. Coach flows comprise the only link from to Heathrow either directly to provincial destinations within 300km, or to the wider intercity rail network via 'Rail-air' links at outer-suburban hubs. With around 250 coaches operating daily, with an average loading of 20 passengers, this might amount to around 5000 passengers per day.

Taking due account of the interlining/intercity split on domestic airflows (variable on different routes, but generally of the order of 50:50), around 4000 domestic air passengers might 'interline' at Heathrow.

Coaches and domestic flights collectively carry only a small proportion of Heathrow's total surface access flow of 70000 passengers per day; with the 4000 interlining air passengers already excluded from *surface* access statistics, perhaps only 5000 daily public transport journeys are made to Heathrow on non-London-centric axes. There are of course major surface flows focussed on central London, by train (ie Heathrow Express), by Tube (ie Piccadilly Line) and by bus. These are commonly reckoned to comprise around 50% of the total flow ie 35000 per day. But this leaves over 30000 daily passengers unaccounted for, and it must be assumed that the majority of these journeys are made by private car or taxi, in a 360º range of directions.

It is particularly important to note that in all this passenger flow accountancy, no cognisance has so far been taken of the considerable number of workers at Heathrow, most of whom (in the absence of adequate local public transport) are forced to commute to the airport by car. This study does not cover this primarily local flow.

Notwithstanding this omission, it would appear that the number of high-emitting car journeys to the airport, and the likely distances involved, indicate a significant level of emissions associated with surface access flows to Heathrow, additional to domestic air flows. If these flows can be converted as part of a comprehensive rail-based strategy to improve airport access, then major CO_2 savings should result.

F8.2 Wider Consideration of 'Spoke' Connections from UK Airports

To develop a model representative of 'spoke' connectivity to Heathrow, it is necessary first to take a comprehensive view upon the total demand for international long-haul flights from the UK regions. This must include consideration of flows from regional airports to European hubs at Amsterdam, Paris, Brussels and Frankfurt – which, as previously noted, are generally greater than local flows to Heathrow.

Figure F11 illustrates the scope of these airflows, detailing the full matrix of connections (listed by flights per day) from UK regional airports to the four European hubs. Assuming Boeing 737 (or similar) aircraft with 150 seats operating at 80% average load factor, and assuming also a generic 50:50 split between interlining passengers and those en route to the destination city (or points beyond, by land), then a figure for interlining passengers from each regional airport can be calculated.

It can be seen that overall, there appear to be of the order of twice the number of UK passengers interlining at the European hubs, compared with Heathrow. This has often been taken as a *prima-facie* justification for expansion of Heathrow, to a third and possibly fourth runway. Certainly, there are flights to Heathrow from only a very small number of UK regional airports, and all of these are located more than 300km from London.

		Heathrow	Schiphol	Paris CDG	Brussels	Frankfurt
Interlining %age			50	50	50	50
Aberdeen	25	13	3	3		
Glasgow	50	17	3	2		1
Edinburgh	50	18	6	4	3	1
Newcastle	75	6	3	4	3	
Durham Tees			3			
Leeds			5	1	3	
Manchester	60	14	7	7	6	6
Liverpool			3			
East Midlands			2	3		
Birmingham			7	6	4	4
Cardiff			4	1		
Bristol			4	4	3	
Exeter			1	1		
Southampton			3		1	1
Norwich			2			
Total flights		68	56	36	23	13
Σ hub pass/day		4038	7680			
Σpass.km/day		26M				
ΣCO_2 @ 230EPI		3000T				
Airline emissions for UK hub function						

ALL FLIGHTS ASSUMED TO COMPRISE 737/A320 AIRCRAFT, ~150 SEATS @ 80% LOAD FACTOR

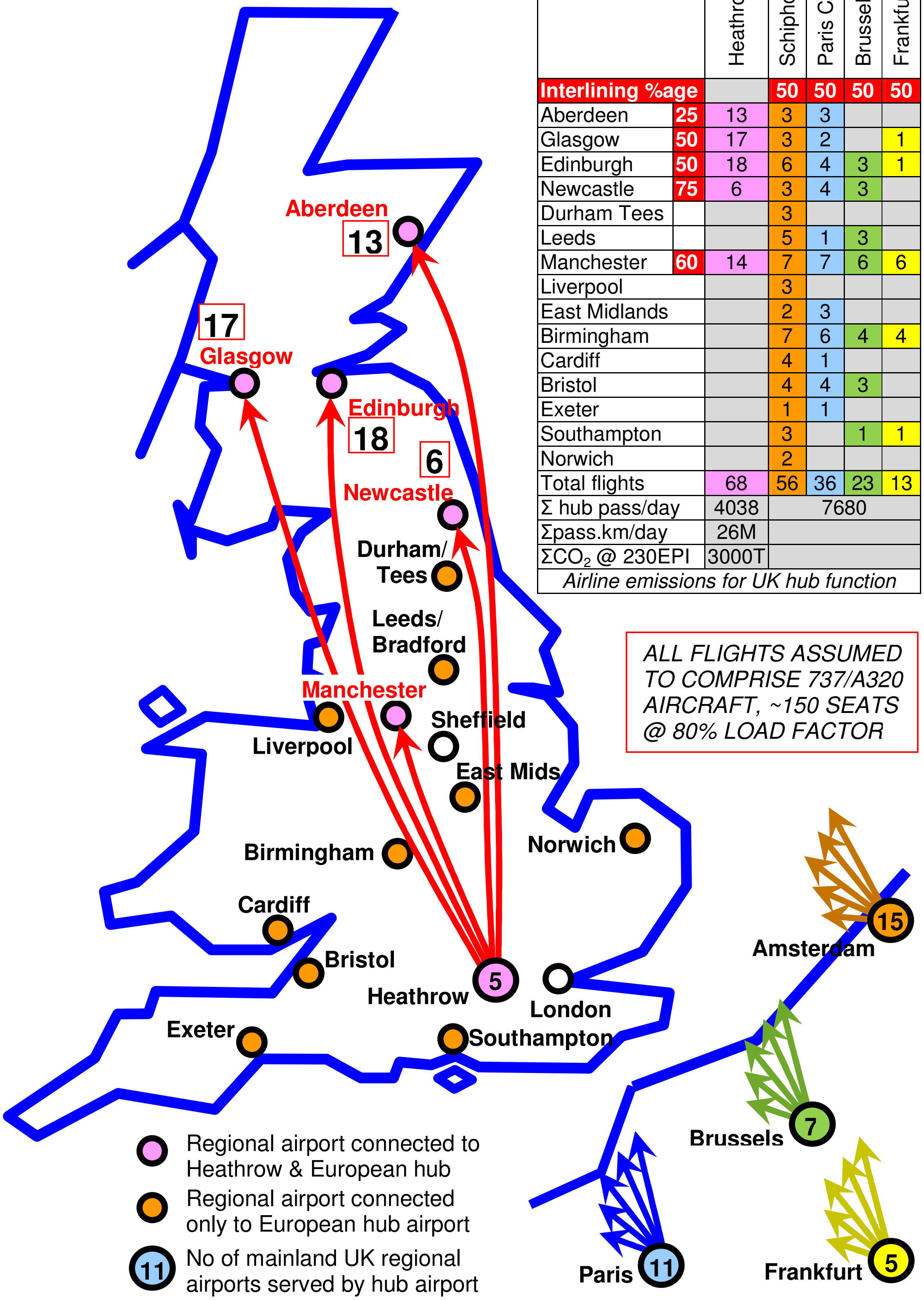


Fig F11: 'Spoke' Connections from Heathrow and European Hub Airports

It should not be surprising that airports such as Bristol, Birmingham and East Midlands do not have flights to Heathrow (or, for that matter, to Gatwick, Luton, Stansted or London City Airports). 300km is generally taken to be the shortest distance at which short-haul aviation might be viable; but it also describes a range within which the majority of the UK population reside. This points to the simplest reason for Heathrow's failure to attract more local custom – its basic lack of good quality public transport links, especially rail.

Figure F12 translates airflows from individual airports into airflows by UK region, with each airport allocated to its specific region. Seven regions are considered:

- Scotland,
- (English) North-East and Cumbria,
- Yorkshire and Lancashire (including Greater Manchester and Merseyside),
- East and West Midlands,
- South Wales and West Country,
- East Anglia, South Coast, and Wessex,
- Greater London.

The airflows attributable to each region are aggregated, and the populations of each region are listed. But airflows alone cannot fully describe the international connectivity of any UK region; it is necessary also to consider surface flows. These of course will only exist at any significant volume for Heathrow from within England; it can reasonably be assumed that there are no surface flows to the Continental hub airports, and that Scotland generates no surface flows at all, even to Heathrow.

No definitive data exists for Heathrow's surface access flows by UK region. However, it is possible to infer these flows by returning to the key assumption noted earlier, that the same basic requirement for international connectivity exists across the entire UK. With no significant surface flow from Scotland to Heathrow (or of course to any Continental hub airport), then this Connectivity Quotient – expressed (in inverse form) as number of interlining passengers per head of (regional) population – can be derived simply by dividing population by number of interlining passengers.

To obtain the same figure for other, closer-located regions (for which surface flows will exist to Heathrow), the volume of this surface flow is adjusted as necessary. It can be seen from Figure F12 that this flow rises rapidly from Scotland through the North-East to Yorkshire and Lancashire, and is broadly constant (per head of population) for other regions. This appears to be generally consistent with what might intuitively be expected, and as such would appear to comprise a credible model of Heathrow's hub connectivity.

All the deduced surface flows can then be combined, to derive a total surface flow to Heathrow of circa 34000 per day. This figure, together with the interlining component of domestic flights to Heathrow (4038), and the same component of short-haul flights to near-European hub airports (7680), represents the total long-haul connectivity requirement of the UK regions. The only major flow not accounted for under this logic is are the air flows from Heathrow to Amsterdam, Paris, Brussels and Frankfurt residents, to access long-haul flights from those airports.

Hub flights from regional airports		Air Flow	Surf. Flow	Pop^n (M)	Pop^n/ total flow
Aberdeen	19	4050 (2490)	0	5.2M	1282
Glasgow	23				
Edinburgh	32				
Newcastle	16	1320 (540)	559	2.4M	1282
Durham Tees	3				
Leeds	9	2280 (1008)	7041	13.2M	1282
Manchester	40				
Liverpool	3				
East Mids	5	1560 (0)	5074	8.5M	1282
Birmingham	21				
Cardiff	5	1080 (0)	5597	8.6M	1282
Bristol	11				
Exeter	2				
Southampton	5	420 (0)	9833	13.1M	1282
Norwich	2				
London	--	--	5892	7.6M	1282
Σ hub flow	196	11718	33996	58.6M	1282
LHR hub flow	68	(4038)			
LHR regl access		38034			

LHR hub attraction to regions	38034
Deduct Interlining air flows	4038
Add Short haul Euro air flows	12690
Add Tourists to London	23314
Add 'Capital City' effect	
Add Th.Valley-located business	
Heathrow surface access	70000

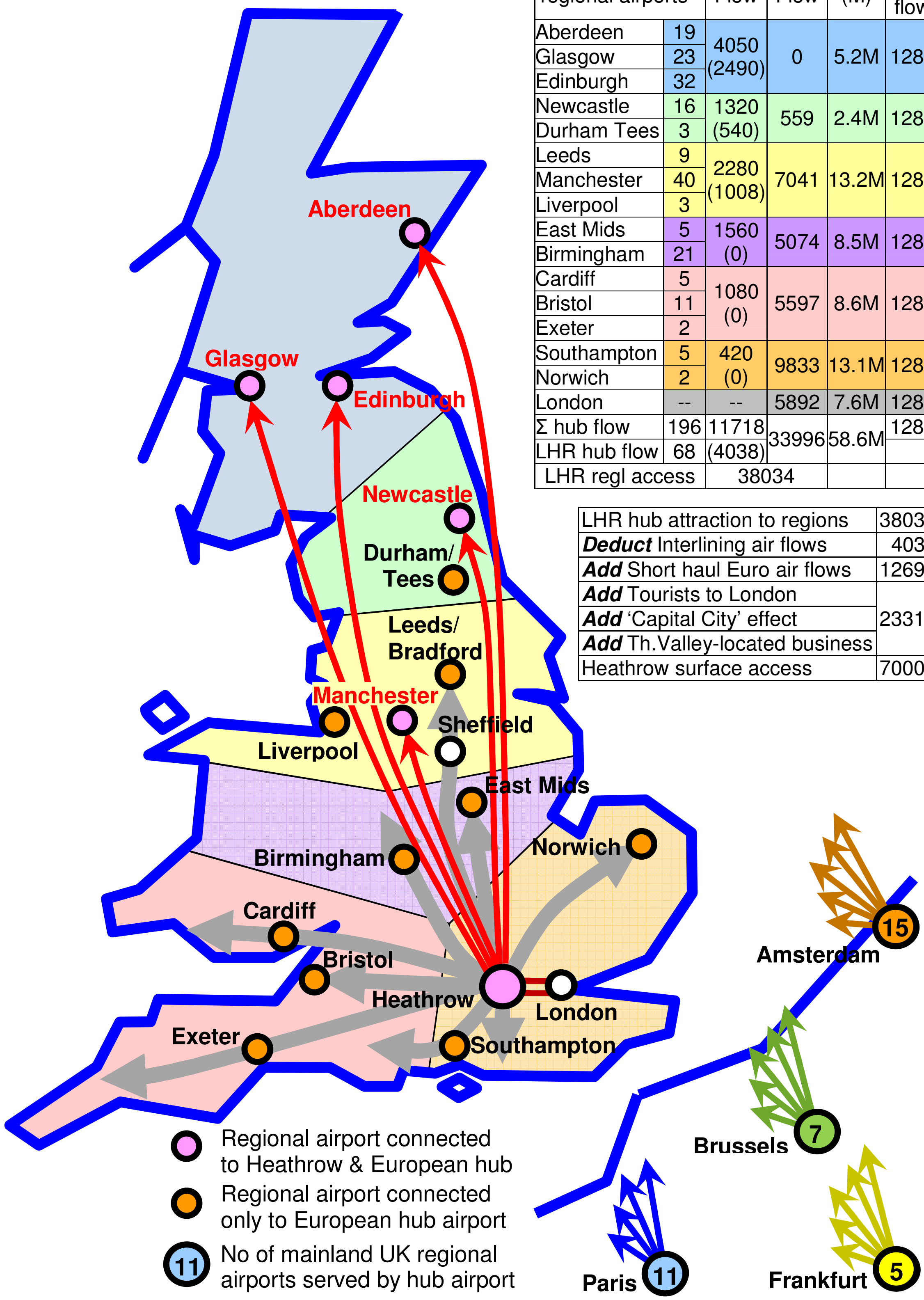


Fig F12: Assessment of Regional Surface Flows to Heathrow

F8.3 Local Flows from Heathrow

A further surface access flow stems from Heathrow's own short-haul flights, attributable to its function as 'London's local airport'. These flights can be categorised by the following generic destinations:

Destination Category	Destination Airports	No of flights per day	Passengers per flight	Surface/ transit split	Surface access flow
Ireland	Belfast Dublin Cork	34	120	70: 30	2856
Mainland UK	Manchester Newcastle Edinburgh Glasgow Aberdeen	68	120	4122: 4038	4122
European Hub	Amsterdam Paris Brussels Frankfurt	66	120	70: 30	5712
Total		168			12690

Table F13: Local Flows from Heathrow

With all these destinations served from UK regional airports, there is little logic in travellers from outside the 'Home Counties' making their way to Heathrow to catch any of these flights. Hence these flights would not contribute significantly to any demand for longer-distance rail services to Heathrow, high speed or otherwise, and it therefore seems appropriate to consider these separately as a local issue.

All of these flights, originating from the airline hub at Heathrow, will have a local component (which will generate a surface access flow) and an 'interlining' component (ie a transfer from a longer-haul flight). The interlining component within Heathrow's flights to UK regional airports is already defined, but for the Irish and European flights, no specific data exists. It will be assumed that for these flights the proportion of transit passengers will follow the generic 30:70 split that applies at Heathrow. It will also be assumed (as with domestic flights) that these airflows comprise Boeing 737 / Airbus A320 aircraft, with circa 150 seats operating at 80% load factor.

Together, Heathrow's local function is calculated to generate a surface access flow of 12690 passengers per day.

F8.4 'Capital City' Effect

The remaining category, accounting for the remainder of Heathrow's surface flow of 70000 per day (ie 23482 passengers per day), can be deemed the 'capital city' effect. This comprises international flows that are generated by London's status (unique among British cities) as a world-class economic, political, cultural and tourist centre. These are classified as follows, with approximate percentages allocated to each:

- International tourists for whom London would be natural first calling point on a tour of the UK (50%).
- Business and political travellers drawn to London through the commercial, administrative and cultural functions naturally existing in a capital city (25%).

- Travellers to multinational businesses whose location in the UK – generally in the Thames Valley, to the west of London – is predicated upon proximity to Heathrow (25%).

F8.5 Directional Assessment of Heathrow's Surface Access Flow

Considering the various components of Heathrow's surface access – ie regional, local, and 'capital city' – it is possible to classify these flows by direction and originating point. By this means, the potential of either a stand-alone high speed rail system, or of a regional 'Compass Pont' network, can be assessed.

The assessment should be carried out to reflect 3 potential scenarios:

- Existing surface access (the 'current scenario'),
- Projected surface access, with existing domestic airflows to Heathrow superseded by high speed rail, and replaced by longer-haul flights,
- Projected surface access as above, with regional airflows to European hubs eliminated in favour of surface links to Heathrow (the 'full conversion scenario').

It is important also to consider the major commuting flows to Heathrow, arising from the 68000 people who are employed at Heathrow Airport. Assuming a) 50% to be at work on an individual day, b) 50% to be employed at locations and at times compatible with rail access, and c) commuting flows to be evenly distributed on all axes, a potential 'worker flow' of 4250 per day might be deduced. Although these are likely to be principally local in nature, and will not contribute significantly to loadings on high speed rail services, worker flows will further underpin the economic case for providing coherent (ie not simply London-centric) rail services to Heathrow.

Daily passenger flows	Surface	N-E-S-W Split				Surface flow by direction			
to Heathrow	flow	N	E	S	W	North	East	South	West
Scotland	0	100	0	0	0	0	0	0	0
North-East	559	100	0	0	0	559	0	0	0
North	7041	100	0	0	0	7041	0	0	0
Midlands	5074	85	0	0	15	4313	0	0	761
S.Wales & South-West	5597	0	0	0	100	0	0	0	5597
H. Counties & E. Anglia	9833	31	31	32	6	3011	3057	3158	607
London	5892	15	70	15	0	884	4125	884	0
London & SE local	12690	25	45	26	4	3162	5747	3283	498
Tourism	11657	10	70	10	10	1166	8160	1166	1166
Political	5829	0	100	0	0	0	5829	0	0
Multinational	5829	25	25	25	25	1457	1457	1457	1457
Total	70000					21592	28375	9947	10086
Workers (68k employed)	17000	25	25	25	25	4250	4250	4250	4250
Total	87000					25842	32625	14197	14336

Table F14: Daily Surface Flows to Heathrow : Current Scenario

These scenarios are indicative of a progressive transformation of Heathrow's 'spoke' connectivity, to a model dominated by rail, with short-haul flights eliminated. Even in the current scenario (see Table F14), with these flights still operating, there appear to be strong regional flows; around 30% is directed along a northern axis, and together (ie northern, western and southern) comprise 60% of Heathrow's surface access, with only 40% directed eastbound towards central London.

To an extent, this contradicts the received wisdom, of the central London component comprising around 50% of Heathrow's surface access. However, this can probably be attributed to the poor quality of public transport accessing Heathrow; this will tend either to divert journeys via central London, to encourage the use of the private car, or to suppress the demand entirely.

With the conversion of domestic short-haul flights to rail, the regional proportion – particularly along the northern axis – will increase considerably. Under the ultimate scenario (see Table F16), of all short-haul connections to European hub airports eliminated in favour of surface links to Heathrow, the northern flow would become dominant, representing over 40% of Heathrow's surface access.

Daily passenger flows to Heathrow	Surface flow	N-E-S-W Split				Surface flow by direction			
		N	E	S	W	North	East	South	West
Scotland	2659	100	0	0	0	2659	0	0	0
North-East	1174	100	0	0	0	1174	0	0	0
North	8596	100	0	0	0	8596	0	0	0
Midlands	5419	85	0	0	15	4606	0	0	813
S.Wales & South-West	5977	0	0	0	100	0	0	0	5977
H. Counties & E. Anglia	10502	31	31	32	6.2	3216	3265	3372	649
London	6293	15	70	15	0	944	4405	944	0
London & SE local	8568	25	45	26	3.9	2135	3880	2216	336
Tourism	12450	10	70	10	10	1245	8715	1245	1245
Political	6225	0	100	0	0	0	6225	0	0
Multinational	6225	25	25	25	25	1556	1556	1556	1556
Total	74088					26131	28047	9934	10576

Table F15: Daily Surface Flows to Heathrow: Domestic Aviation Converted

Daily passenger flows to Heathrow	Surface flow	N-E-S-W Split				Surface flow by direction			
		N	E	S	W	North	East	South	West
Scotland	4601	100	0	0	0	4601	0	0	0
North-East	2134	100	0	0	0	2134	0	0	0
North	11733	100	0	0	0	11733	0	0	0
Midlands	7537	85	0	0	15	6406	0	0	1130
S.Wales & South-West	7585	0	0	0	100	0	0	0	7585
H. Counties & E. Anglia	11647	31	31	32	6	3566	3621	3740	719
London	6694	15	70	15	0	1004	4686	1004	0
London & SE local	2856	25	45	26	4	712	1293	739	112
Tourism	13243	10	70	10	10	1324	9270	1324	1324
Political	6621	0	100	0	0	0	6621	0	0
Multinational	6621	25	25	25	25	1655	1655	1655	1655
Total	81272					33136	27147	8846	12526
Workers (68k employed)	17000	25	25	25	25	4250	4250	4250	4250
Total	98272					37386	31397	13096	16776

Table F16: Daily Surface Flows to Heathrow: European Short-Haul Converted

All scenarios make due allowance for an increase in total airflows, arising from the progressive elimination of low-capacity aircraft (typically 150-seat Boeing 737 type on short-haul routes) and their substitution with high-capacity planes (typically 300-seat Boeing 777 type or 450-seat Boeing 747 type on longer-haul routes). Replacement of over 20% of flights to local destinations allows runway space to be devoted to new long-haul destinations, in particular in emerging markets such as China, India and Latin America. This will lead to a generally higher-value operation as Heathrow's hub function is enhanced.

The key to this improved function is the separation of the two elements of the role of the 'hub' airport ie 'trunk' (long-haul) inflows distributed via 'spoke' (short-haul) outflows (or vice versa). In the USA (the most highly developed aviation network in the world) such hubs normally work on the 'hub and spoke' model, whereby long-haul passengers are distributed to short-haul flights to (relatively) local satellite airports. But if Heathrow's 'spoke' links can be accomplished through surface access, linking to its entire UK hinterland, then the airport is free to concentrate on its primary long-haul function (effectively working as the UK's primary international gateway).

This could be regarded as the ideal of hub and spoke operation, and – if long-haul aviation is accepted as a valid means of communication between distant countries and communities – it would seem to offer major environmental savings through shorter and lower-emitting spoke connections. However, these advantages can only be realised with an efficient model of surface transport that is capable of:

- delivering the requisite volume of passengers to the hub airport,
- reaching the furthest extent of the hinterland, normally accessed by short-haul aviation,
- covering the wide range of closer destinations, normally accessed by road transport,
- offering a standard of connection to long-haul flights at least equivalent to the existing modes.

F8.6 CO_2 Emissions Implicit in 'Spoke' Flows to Hub Airports

Analysis of the UK's connectivity to Heathrow and European hub airports indicates the following key data:

<table>
<tr><th rowspan="2">Mode</th><th rowspan="2" colspan="2">Remark</th><th rowspan="2" colspan="2">Trips per day</th><th colspan="4">CO_2 emissions per day (T)</th></tr>
<tr><th colspan="2">Current scenario</th><th>Full conversion</th><th>Difference</th></tr>
<tr><td rowspan="4">Air</td><td rowspan="4">Interlining via Heathrow</td><td>Scotland</td><td rowspan="4">4038</td><td>2490</td><td rowspan="4">914</td><td>751</td><td rowspan="4">0</td><td rowspan="4">914</td></tr>
<tr><td>North & NE</td><td>1548</td><td>164</td></tr>
<tr><td>Midlands</td><td></td><td></td></tr>
<tr><td>Wales&West</td><td></td><td></td></tr>
<tr><td rowspan="4">Air</td><td rowspan="4">Interlining via Euro-hub</td><td>Scotland</td><td rowspan="4">7680</td><td>1560</td><td rowspan="4">2091</td><td>572</td><td rowspan="4">0</td><td rowspan="4">2091</td></tr>
<tr><td>North & NE</td><td>3060</td><td>822</td></tr>
<tr><td>Midlands</td><td>1560</td><td>376</td></tr>
<tr><td>Wales&West</td><td>1080</td><td>251</td></tr>
<tr><td></td><td colspan="2">Full conversion implies increased surface passenger-km from</td><td colspan="2">Passenger.km
4.8M to 8.9M</td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>Bus</td><td colspan="2">$30g_{CO2}$/pass.km, 125km ave. dist, 5000 trips/day</td><td>0.6M</td><td>0.6M</td><td colspan="2">19</td><td>19</td><td>0</td></tr>
<tr><td>Rail</td><td colspan="2">$40g_{CO2}$/pass.km</td><td>1.0M</td><td>8.0M</td><td colspan="2">40</td><td>320</td><td>(-280)</td></tr>
<tr><td>Car</td><td colspan="2">$110g_{CO2}$/pass.km, 1.5 multiplier for drop-offs</td><td>3.2M</td><td>0.3M</td><td colspan="2">526</td><td>45</td><td>481</td></tr>
<tr><td rowspan="3">CO_2 saving</td><td colspan="4">Tonnes of CO_2 per day</td><td colspan="2">3590</td><td>384</td><td>3206T</td></tr>
<tr><td colspan="7">Tonnes of CO_2 per year</td><td>1.17MT</td></tr>
<tr><td colspan="7">Tonnes of CO_2 over 40 year period of Climate Change Act</td><td>46.8MT</td></tr>
</table>

Table F17: Reduced CO_2 emissions from 'Full Conversion' of Spoke Flows

It is freely conceded that the above figures are highly conjectural. However, they do indicate the order of magnitude of CO_2 emissions associated with connecting UK communities to hub airports, to access long-haul aviation. They also indicate the potential savings – involving an almost 90% CO_2 reduction – that might be realised through introducing an efficient model of rail access to Heathrow to enable 'spoke' flows commensurate with the entire UK's requirement for international connectivity (which at present is satisfied by air routes to continental airports).

It is immediately apparent that the greatest gains stem from the elimination of short-haul aviation. This is currently the principal contributor to the CO_2 emissions in 'spoke' access to Heathrow (and other hub airports). As shown in Figure F12, around one third of these airflows (by volume) are from Scotland; and when the increased flying distance (either to Heathrow, or to Amsterdam, Paris et al) is also taken into account, flights to Scotland account for over 40% of 'spoke' emissions. This places an imperative on enabling rail flows from Heathrow to Scotland.

However, the reduction of CO_2 emissions is only one of many concerns in achieving an efficient model for spoke access to Heathrow. Many other considerations, variously economic, social and political, also apply.

F9 Development of Optimised Rail Access Model

Relative to UK transport emissions as a whole (140MT per annum) the CO_2 attributable to 'spoke' connectivity to long-haul flights (at Heathrow and elsewhere) is small, less than 1% of the total. However, given the dramatic savings that might be made with a more environmentally-efficient, rail-led means of accessing such flights, it is clearly an aim worth pursuing. This is aside from the more local environmental impacts that would apply, if UK airports were to be allowed to expand in the 'predict and provide' fashion envisaged by the 2003 Aviation White Paper[24].

There are also major economic and social benefits in developing rail as the preferred means of accessing Heathrow. Currently – as demonstrated in Figure F10 – Heathrow has a poor and highly asymmetric standard of surface connectivity, particularly to the Midlands and the North, and this has the effect of concentrating the economic benefits accruing from its international links to its immediate hinterland in London and the South-East. This contributes greatly to the prevailing 'hothouse' economy, and is a major factor in the continuing 'North-South Divide' that afflicts the British economy.

In terms of environmental performance and scale / critical mass of operation, rail seems ideally placed to address these deficiencies. Notwithstanding the defects identified in other sections of this study, the existing rail network generally offers a high standard of connectivity, functioning well on local, regional and national levels (particularly on London-centric axes) to a standard unmatched by other public transport networks. Most significant provincial centres already enjoy at least hourly express services to the capital, and this is considered to be one of the prime indicators of economic status.

[24] The 2003 Aviation White Paper comprised the underpinning legislation driving proposals to expand Heathrow (to a third runway and sixth terminal), and a general growth of aviation to around three times present levels, by 2030. Its underlying ethos was 'predict and provide', and it appeared to pay little or no attention to associated questions of increased CO_2 emissions and sustainability of hydrocarbon fuel supplies. It is now effectively superseded by the more contemporary requirements of the 2008 Climate Change Act; however, many of the concerns that it was intended to address, in particular the achievement of improved links to emerging economies in China, India and Latin America, remain unanswered.

If rail could offer a standard of connectivity to Heathrow similar to that on the existing intercity network, serving destinations near and far, then major benefits – both economic and environmental – would seem certain to accrue. This of course is the ideal – and it is the purpose of this study to determine how close the candidate proposals come, to meeting this ideal.

F9.1 Specification for Optimised Rail Access Model

Just as with the wider consideration of high speed rail as an optimised means of reducing CO_2 emissions attributable to longer-distance (ie > 50km) journeys, a similar hierarchy of criteria would appear to apply for hub airport access. Economic and environmental gains will be maximised if the candidate proposals (for what might be termed the Heathrow Airport Network) can be optimised against the following key criteria:

- ***Maximised coverage of airport network***
  This is determined from both geographical scope of, and population served by the dedicated airport network. This carries the proviso that the maximum feasible extent of the airport network is governed by the capability (or otherwise) to achieve journey times competitive with the aviation alternative.
- ***Timescale for implementation***
  Emissions reductions will be maximised through earliest practicable implementation.
- ***Integration of airport network with existing railway system***
  Integration is necessary to expand the reach of the airport network beyond its physical extent, by means of effective connectivity to the existing network.
- ***Efficiency of Operation***
  This will be optimised through avoiding operation at extreme speeds, and through configuring the airport network to maximise load factor.

F9.2 Differing Requirements of International Travellers

It is necessary also to consider the specific requirements and habits of travellers making international journeys. They are often travelling with large amounts of luggage, often very early or late in the 'travelling day' (ie 06h00 to 23h59), and this historically has proved a difficult 'fit' to rail, as a mode.

The timing of international flights – dictated by a huge range of considerations, including permitted landing times on another continent, onward connections, etc etc – often has the effect of placing the UK 'domestic' leg of the journey outside normal train operating times. In such cases, road transport to the airport, either by private car or taxi, appears to be the only option.

Even if a rail journey is possible, in terms of timing, it typically involves several 'changes'. Some might be eliminated by a taxi drop-off at the local intercity station (to catch a direct train to London), but in the Metropolitan area, these changes are at present unavoidable. And whether the traveller is encumbered with luggage, concerned at the intricacies of the changes and the possibility of missing a crucial check-in time, or panicked at the prospect of an hour-long Tube journey to Heathrow from Kings Cross, St Pancras or Euston, the effect is the same; these inconveniences act as a major deterrent to a journey by rail to Heathrow.

No such impediments exist to an equivalent short-haul air transfer from a regional airport to a hub airport, in order to catch long-haul flight. Regional airports might be located further from a typical traveller's home, but are generally well-sited for road access (generally better than the equivalent intercity rail station) and additionally – with large tracts of available land around the airport perimeter – can accommodate long-stay car parking. They also offer the opportunity for baggage check-in; with no need to reclaim the bags at the hub airport, the traveller is not reunited with his or her luggage until arrival at the final destination.

Possibly the greatest drawback with short-haul 'feeder' flights from regional airports is that they only run at relatively low frequencies, often with many hours between services. Despite the best efforts of airline schedulers, to synchronise timings between inbound feeder flights and outbound long-haul flights (or vice versa), long waits in transit lounges seem to be inevitable in many cases.

F9.3 Capability of Rail to Address Needs of International Travellers

Any model for rail access to Heathrow has to address as many of these issues as possible. Security issues will preclude remote check-in of baggage at a provincial rail station, and instead it will be necessary for the traveller to remain with his or her bags until arrival at Heathrow. This demands appropriate on-train luggage facilities, with changes of train (or of mode) minimised, and (where inevitable) made as 'seamless' as practicable. There is also an absolute imperative for complete elimination of the current cross-London Tube transfers.

It might prove feasible to introduce check-in facilities at a 'perimeter'-located station (ie Heathrow Hub, or HS2 variant thereof), but this would seem certain to require provision of secure baggage tunnels, in addition to all the other airport access infrastructure that will be required. If access to a central Heathrow station can be achieved, that would seem to be better than any perimeter 'hub'.

As noted previously, railway stations generally are more poorly connected to the road network, and even parkway stations lack the capability for long-stay car parking of an airport. But, with an appropriate and fit-for-purpose model of rail access to Heathrow, these drawbacks should be outweighed by the advantages inherent in a high quality integrated network – the achievable frequency of service and geographical spread of the network. These are both of an order of magnitude superior to what is possible with aviation.

F9.4 Models of Rail Access to Heathrow

While it is clearly not practicable to provide direct trains from Heathrow to every single regional centre, two feasible models of operation seem to apply, each requiring just one change of trains (which might reasonably be taken to be the maximum that an interlining traveller would tolerate en route to a long-haul flight). It should be noted that either model demands construction of major infrastructure, to facilitate a level of rail access to Heathrow, that is currently completely impracticable:

- ***High Speed Model : Travel from local station to regional hub, then high speed service direct to airport***
  This places the 'change' at a hub station of a principal regional conurbation, which might merit direct services to Heathrow along the new high speed network. It is a location presumably familiar with the traveller, with all the necessary lift facilities to transfer between platforms. (This transfer could be avoided by drop-off at the regional hub, albeit requiring a longer car journey.) In the absence of any 'regional' model of rail access (see below), the high speed model is only viable if the line is routed close to Heathrow.

- ***Regional Model : Travel from local intercity station to outer-suburban hub, then regional service to airport***
  This model requires the development of a regional network around Heathrow, to connect to the intercity rail network radiating from London. With efficient, hopefully cross-platform interchange at outer-suburban hubs, all major regional centres that enjoy frequent services to London at present would be within a single change of Heathrow. This model would deliver major benefits entirely independent of high speed rail; but when combined with an optimised high speed system (ie 'spine and spur') on which direct services could operate to the principal conurbations, it would still comprise the more comprehensive system accessing the 'second-tier' centres, for which direct services to Heathrow would not be practicable.

F9.5 Comparison between Candidate Schemes

This study has postulated (see Item F8.6) emissions savings of over 1MT of CO_2 per annum, or 47MT over the notional 40 year period of the Climate Change Act, if rail can become the dominant mode in accessing Heathrow's international/ intercontinental connectivity. However, these gains are only achievable with an appropriate and fit-for-purpose model of rail access to Heathrow, that addresses issues of coverage and integration, of speedy implementation, and of efficient operation.

Coverage and Integration
An appreciation of potential airport connectivity can be gained from review of Figures F18 & F19. These illustrate the extent of the airport networks (both direct connectivity, and with single change) achieved with full implementation of HS2 and High Speed North, together with associated enhancements of the local rail network around Heathrow.

It can be seen that achieved connectivity is broadly equivalent to the west, south and east of Heathrow (ie the 'Red Zone'). This assumes (notwithstanding the recent cancellation by British Airports Authority of the 'Airtrack' scheme) that local links to the south and west will be created independent of HS2, and likewise, that the Heathrow 'Compass Point' network will be in place to complement High Speed North.

It is in the 'Green Zone', the Zone of Influence of a high speed line to the north, that the major differences lie – and where, for the purposes of this study, the comparisons need to be drawn. Here, the differences between the two candidate schemes are stark. The airport network created by High Speed North and the associated Compass Point network will connect to all major communities of the Midlands, the North and Scotland, whereas HS2 will only connect to the principal conurbations accessed by the dedicated high speed network.

It is clearly desirable that airport connectivity does extend beyond the principal conurbations, and HS2's deficiency in this respect can be attributed quite simply to the fact that it conforms only to the 'high speed' model of airport access. This has the effect of limiting its effective connectivity to the regional high speed hubs of the proposed system. As previously noted (Section 4.8), the 'exclusive' operational philosophy that underpins the HS2 proposals renders these regional hubs relatively inaccessible to the local public transport system. Moreover, with the need to make a change of trains close to the airport (at either Old Oak Common or Heathrow Hub), any access achieved to local networks would require a second change of trains.

High Speed North's conformance to both high speed and regional models of airport access enables far greater coverage, and integration with the existing network. All regional hubs at the hearts of principal conurbations would enjoy direct 'high speed' services to Heathrow, with the local and regional networks focussed on those hubs also connected; several second-tier cities would also benefit from these direct connections. The links to the classic main lines created by the Compass Point network would provide radically improved 'single-change' Heathrow access for the remainder of the second-tier cities, and for many tertiary centres also.

The economic benefits accruing from such improved connectivity would appear to be self-evident. There would also be major environmental benefits, in the conversion to rail of a much wider scope of journeys that are currently undertaken by private car / taxi, or by air.

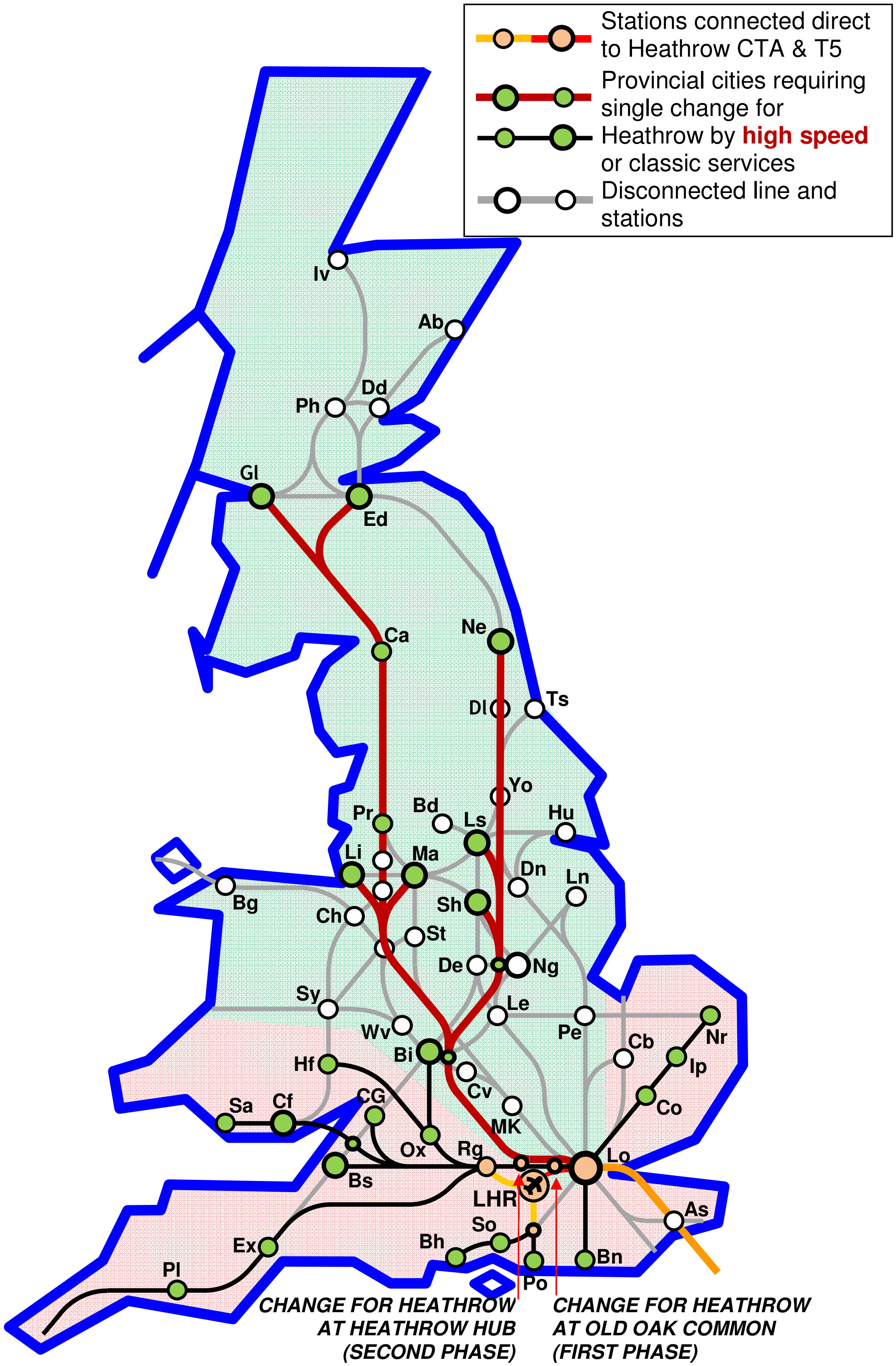


Fig F18: HS2 : Rail Connections from Heathrow

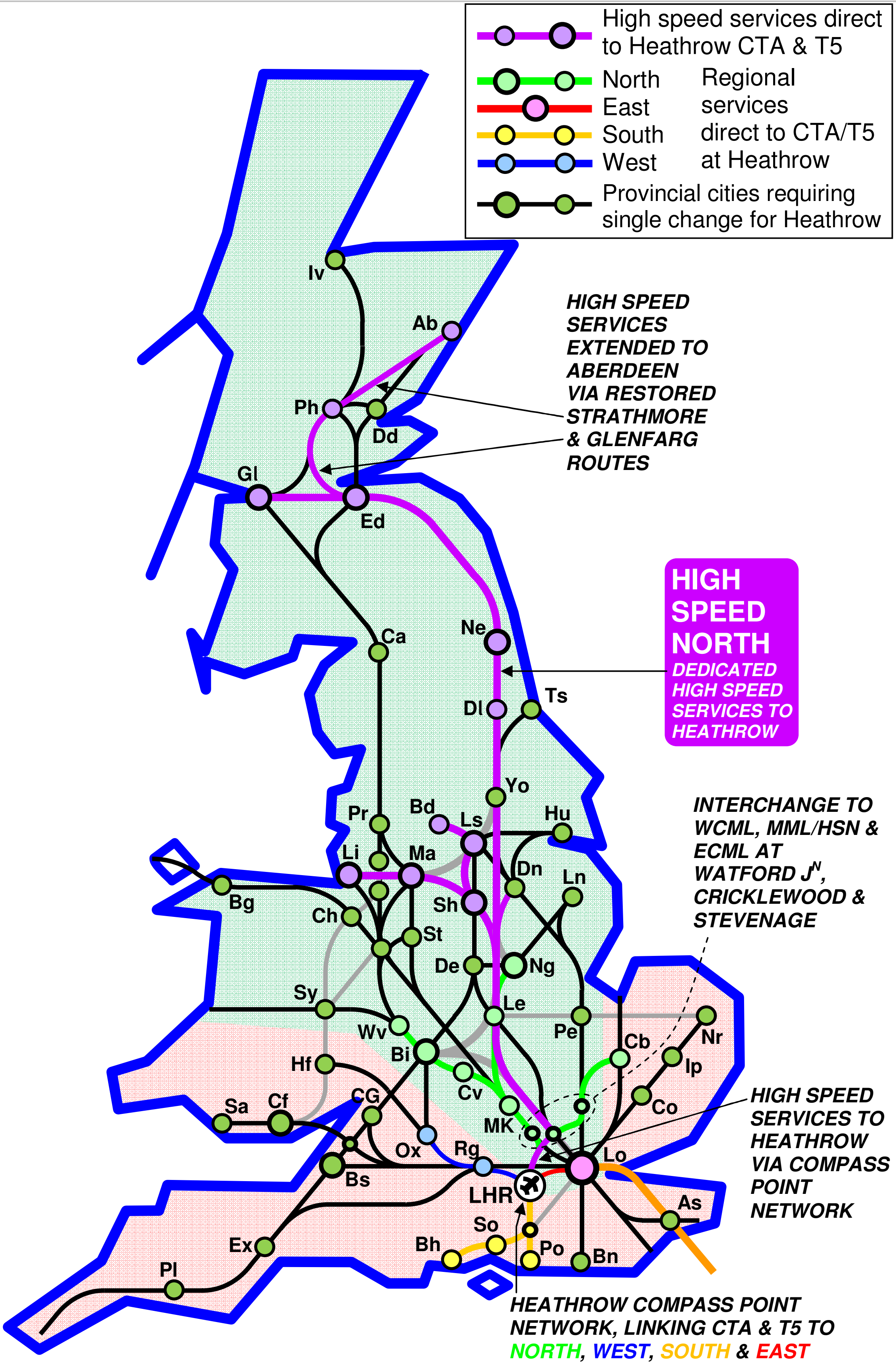


Fig F19: High Speed North : Rail Connections from Heathrow

Table F17 indicates clearly that the major proportion of CO_2 emissions arising from regional access to hub airports is created by short-haul flights, either to Heathrow or a continental hub airport. These flights tend to be concentrated in the outlying areas of the UK – Scotland, the North, the Midlands (and also Wales and the West Country) – which are poorly connected to Heathrow by alternative high quality public transport. If the intervention of high speed rail delivers improved airport connectivity to only a small number of regional hubs (poorly connected to the local public transport system, and no greater in number than the regional airport alternative), then it is unlikely that comprehensive conversion of regional air flows will occur.

It can thus be appreciated that comprehensive and integrated connectivity between Heathrow and its UK hinterland is essential to assure full conversion of airflows, and the resulting major savings in CO_2 emissions.

Timescale for Implementation

There is no doubting the importance of early implementation of improved rail links to Heathrow, that might lead to modal shift and consequent reductions in CO_2 emissions. With even the initial London-Midlands section of a UK high speed rail network requiring circa 200km of new construction, and a timescale of between 7 years (High Speed North) and 14 years (HS2), it is valid to question whether high speed rail is the most effective means of establishing the necessary connectivity to Heathrow – or whether a more local/regional solution would deliver greater benefits.

A solution such as the proposed Compass Point network would only require of the order of 20km of new construction to access all main lines to the north. This could be accomplished far more quickly than even the first section of high speed line, and would still deliver a transformation in connectivity to the UK's national airport; all major regional communities would now be a single change of trains from Heathrow.

Such a step-change improvement, superior by an order of magnitude to Heathrow's rail links (currently reliant on cross-London Tube transfers) would seem certain to deliver major modal shift to rail. Although journey times would not match those achievable through direct, high speed services, it should be borne in mind that journeys to Heathrow from most UK communities, as far north as perhaps Leeds and Manchester, are not especially time-sensitive; frequency of service, and ease of connection from intercity to regional/orbital train, are far more important considerations.

A Compass Point network, offering around 3 trains per hour to the outer-suburban hubs on the radial northern main lines, with interchange to hourly intercity services, would appear to be an appropriate, if not ideal short-term solution. It would not however address the needs of communities further north, particularly in Scotland. To these destinations, intercity journey times from London are too slow to compete with aviation, and the two-leg journey from Heathrow would be even less competitive as an interlining connection.

Effective interlining connections to Scotland (judged on contemporary 'business-as-usual' time-critical criteria) would only be achieved with the implementation of high speed rail. This would bring the London to Glasgow journey time down to below 3 hours, which might translate to a timing of 3½ hours from Heathrow's Central Terminal Area. At such a timing, it would be reasonable to presume full conversion to rail of all flights to Edinburgh and Glasgow, in general conformance with the imperative to adopt a lower-CO_2 transport system.

However, conversion of flights to Aberdeen would only seem feasible if the candidate high speed rail proposal were configured in such a way as to deliver significant improvements north of the Forth-Clyde line, with frequent high speed services extending to Perth, Dundee or Aberdeen.   As already noted (Section 4.9.2), the inherent inefficiencies of the ‘Y’ or ‘fan’ format of HS2 renders such services effectively unviable; no such issues are encountered with the greater efficiency High Speed North’s ‘spine and spur’ configuration.   There would be a natural splitting point at Edinburgh’s Waverley Station, with services proceeding to both Glasgow and to the north of Scotland.

Operational Efficiency
The issue of efficiency, arising from both the speed at which airport trains would operate, and the achieved load factor, would also play a major part in determining the potential emissions reductions from conversion of both road and air access to Heathrow.   Typical Environmental Performance Indicators for airport high speed services can be deduced from Figure 4.24.

For HS2, the relatively small numbers of interlining passengers will not make a fundamental difference to load factor, hence for 360kph operation, an EPI of around $80g_{CO2}$/pass.km might be assumed.   For High Speed North, a lesser ‘high speed’ and better-filled trains would allow an EPI of around $40g_{CO2}$/pass.km to be assumed; this would be the case both for dedicated high speed airport services, and for conventional ‘Compass Point’ and intercity services, running generally slower but with a less favourable load factor.

F9.6 Calculation of Relative CO_2 Emissions Reductions

On the basis of the foregoing commentary, the following simplistic assumptions will be made in the calculation of potential reductions in Heathrow access emissions for both candidate schemes:

HS2 *(for explanation of stages, see Figure 4.11)*

- Restricted extent and connectivity of regional high speed hubs will limit conversion of interlining air flows from English regional airports, and road flows to Heathrow, to around one third.   This will be achieved on completion of Stage 3 in 2031.
- Restricted extent of coverage within Scotland will limit conversion of Scottish interlining airflows to around two thirds.   This will be achieved on completion of Stage 4 in 2041.

High Speed North *(for explanation of stages, see Figure 4.12)*

- Greater extent and connectivity of airport network (high speed and conventional) will achieve effective conversion of interlining air flows from English regional airports, and also road flows to Heathrow.   This will be achieved on completion of Stage 2 in 2021.
- Comprehensive coverage beyond Forth-Clyde line will achieve effective conversion of interlining air flows from Scottish regional airports.   This will be achieved on completion of Stage 4 in 2030.

The calculations are set out in Tables F20 and F21.   These show for HS2 a potential saving of 4.6MT of CO_2 over the 40 year period of the Climate Change Act, whereas for High Speed North, the corresponding figure is 28.9MT.

Mode	Remark		Trips per day				CO_2 emissions per day (T)			
							2011	2031	2041	2050
Air	Interlining via Heathrow	Scotland	4038			2490	914	860	360	360
		North & NE				1548				
		Midlands								
		Wales&West								
Air	Interlining via Euro-hub	Scotland	7680			1560	2091	1621	1240	1240
		North & NE				3060				
		Midlands				1560				
		Wales&West				1080				
	Air flow conversion implies increased surface passenger-km:		Passenger.km(M)							
			4.8	5.5	6.9	6.9				
Bus	$30g_{CO2}$/pass.km, 125km ave. dist, 5000 trips/day		0.6	0.6	0.6	0.6	19	19	19	19
Rail	$40g_{CO2}$/pass.km (conv) $80g_{CO2}$/pass.km (HS)		1.0	2.8	4.2	4.2	40	184	296	296
Car	$110g_{CO2}$/pass.km, 1.5 multiplier for drop-offs		3.2	2.1	2.1	2.1	526	347	347	347
CO_2 saving	Tonnage of CO_2 per day (T)						3590	3031	2262	2262
	Tonnage of CO_2 per year (MT)						1.31	1.11	0.83	0.83
	Tonnage of CO_2 over 40 year period of Climate Change Act								42.2MT	
	Current emissions over 40 year period								46.8MT	
	Potential CO_2 savings over 40 year period								4.6MT	

Table F20: HS2 : Reduced CO_2 emissions of Spoke Flows

Mode	Remark		Trips per day				CO_2 emissions per day (T)			
							2011	2021	2030	2050
Air	Interlining via Heathrow	Scotland	4038			2490	914	751	0	0
		North & NE				1548				
		Midlands								
		Wales&West								
Air	Interlining via Euro-hub	Scotland	7680			1560	2091	823	251	0
		North & NE				3060				
		Midlands				1560				
		Wales&West				1080				
	Air flow conversion implies increased surface passenger-km:		Passenger.km(M)							
			4.8	6.7	8.9	8.9				
Bus	$30g_{CO2}$/pass.km, 125km ave. dist, 5000 trips/day		0.6	0.6	0.6	0.6	19	19	19	19
Rail	$40g_{CO2}$/pass.km (conv) $40g_{CO2}$/pass.km (HS)		1.0	5.8	8.0	8.0	40	232	320	320
Car	$110g_{CO2}$/pass.km, 1.5 multiplier for drop-offs		3.2	0.3	0.3	0.3	526	50	50	50
CO_2 saving	Tonnage of CO_2 per day (T)						3590	1875	640	389
	Tonnage of CO_2 per year (MT)						1.31	0.68	0.23	0.14
	Tonnage of CO_2 over 40 year period of Climate Change Act								17.9MT	
	Current emissions over 40 year period								46.8MT	
	Potential CO_2 savings over 40 year period								28.9MT	

Table F21: High Speed North : Reduced CO_2 emissions of Spoke Flows

Such a disparity in environmental performance between the two candidate schemes is highly significant in itself; but its true impact lies in the more fundamental issue of proportionality. The high speed rail network proposed by HS2 has been predicated upon Heathrow, with the commendable aims of improving regional connectivity to the UK's national airport, and of generating environmental savings through modal shift from domestic aviation to rail. However, it would appear that these gains are only achieved at disproportionate cost.

F9.7 Revised Calculation of Cost Indicators

If HS2 were to convert one third of all current English (Green Zone) spoke flows, and two thirds of all Scottish flows, this would result in approximately 6000 high speed passengers to Heathrow from the Midlands and the North; should the line ever extend to Scotland, a further 2700 'Scottish' users might be anticipated. These figures are considerably in excess of HS2 Ltd's own estimate of 2000 per day, a difference that can probably be explained by the 'business as usual' assumptions implicit in HS2's analysis.

Corresponding figures for High Speed North and associated Compass Point network, assuming 90% of English (Green Zone) spoke flows and 100% of Scottish flows, would be 16000 'English' users and 4000 'Scottish' users.

Using these revised figures, the data in Table F8 has been reevaluated as follows:

	HS2 (March 2010 release)		HS2 (March 2011 consultation)		High Speed North & Compass Point Network	
Network configuration	'Y'		'Y'		Spine & Spur	
Heathrow access model	Shuttle		Loop		Integrated Spur	
Extra length of new railway (km)	0		32		12	
Extra tunnelled length (km)	7		37		0	
Marginal cost of extra infrastructure (£M)	399		2845		276	
Interest charges on capital expended @ 6%pa (£M)	23.9		171		16.6	
Flows from:	England (GZ)	Mainland UK	England (GZ)	Mainland UK	England (GZ)	Mainland UK
Predicted daily passenger flow accessing Heathrow	4200	6100	6000	8700	16000	20000
Predicted annual passenger flow accessing Heathrow (M)	1.51	2.20	2.16	3.13	5.76	7.20
Marginal cost (COBALT) per passenger	£95k	£65k	£474k	£327k	£17k	£14k
Interest charges per return journey (NICKEL)	£15.8	£10.9	£79.2	£54.6	£2.88	£2.31

Table F22: Marginal Cost Impacts of High Speed Access to Heathrow – Passenger Flows recalculated to consistent criteria

The passenger flows set out in Table F22 might be considered to be somewhat optimistic, in terms of contemporary ‘free-market’ travel conditions. They are however more consistent with the fundamental assumption of this study, that the growing environmental crisis will force travel choices to focus on the lowest-CO_2 mode by which a journey can reasonably be accomplished.

As ‘high-sided’ estimates, they represent sound data on which to design infrastructure, in particular terminal facilities at Heathrow. They also allow a more balanced judgement to be made upon the ‘value for money’ assessments, originally set out in Table F8; with a range of airport flows under consideration, ‘optimistic’ and ‘pessimistic’ values can be calculated for the crucial NICKEL indicator.

For HS2, the NICKEL value might vary between £238 (pessimistic) and £55 (optimistic) per return journey. £238, as a cost element to be built into any rail fare to the airport, is clearly unsustainable; even £55 would seem to be excessive, when considered in the context of general market conditions, and the other costs that would be certain to apply.

For High Speed North and the associated Compass Point network, the NICKEL values are of an order of magnitude lower, in the £2 – £3 range. This would not appear to raise any significant issues in ticket pricing.

As noted previously, the disparity between costings can be very simply accounted for, through the much lower infrastructure requirement of the Compass Point proposals, and the much greater number of users. The combination of High Speed North – as an intercity/interconurbation new railway – with the Compass Point network – as a regional system assembled mostly from existing infrastructure – appears to offer a far more cost-effective and fit-for-purpose solution to the requirement for national rail access to Heathrow, than the uniaxial HS2 high speed rail system.

F9.8 Passenger Handling Issues at Heathrow

It is necessary to give brief consideration to the passenger handling issues arising from the increased rail-borne surface flows to Heathrow, as projected in this study.

It can reasonably be assumed that HS2’s projected flows, of up to 8700 passengers per day, would pose no major difficulties in the design of dedicated new station and passenger transfer facilities. Here (as noted previously) the issue centres around how the required large investment could be justified for the relatively low usage (it must be remembered that, whatever the perceived benefits of achieving improved national rail access to Heathrow, there are many other railway development priorities competing for the same funds).

But for High Speed North and the Compass Point network, the projected step-change increase in passenger flows on the existing Heathrow Express system raise major questions of capacity that must be addressed.

At present, such considerations do not apply. The Heathrow Express operating pattern – 4 non-stop services from Paddington to Heathrow’s Central Terminal Area (CTA) and Terminal 5 (T5), and 2 stopping services (to CTA and T4) – amounts to a relatively leisurely regime, with generous station dwell times for the relatively few passengers that use the service.
The low usage (7500 daily passengers) can be attributed to two factors:

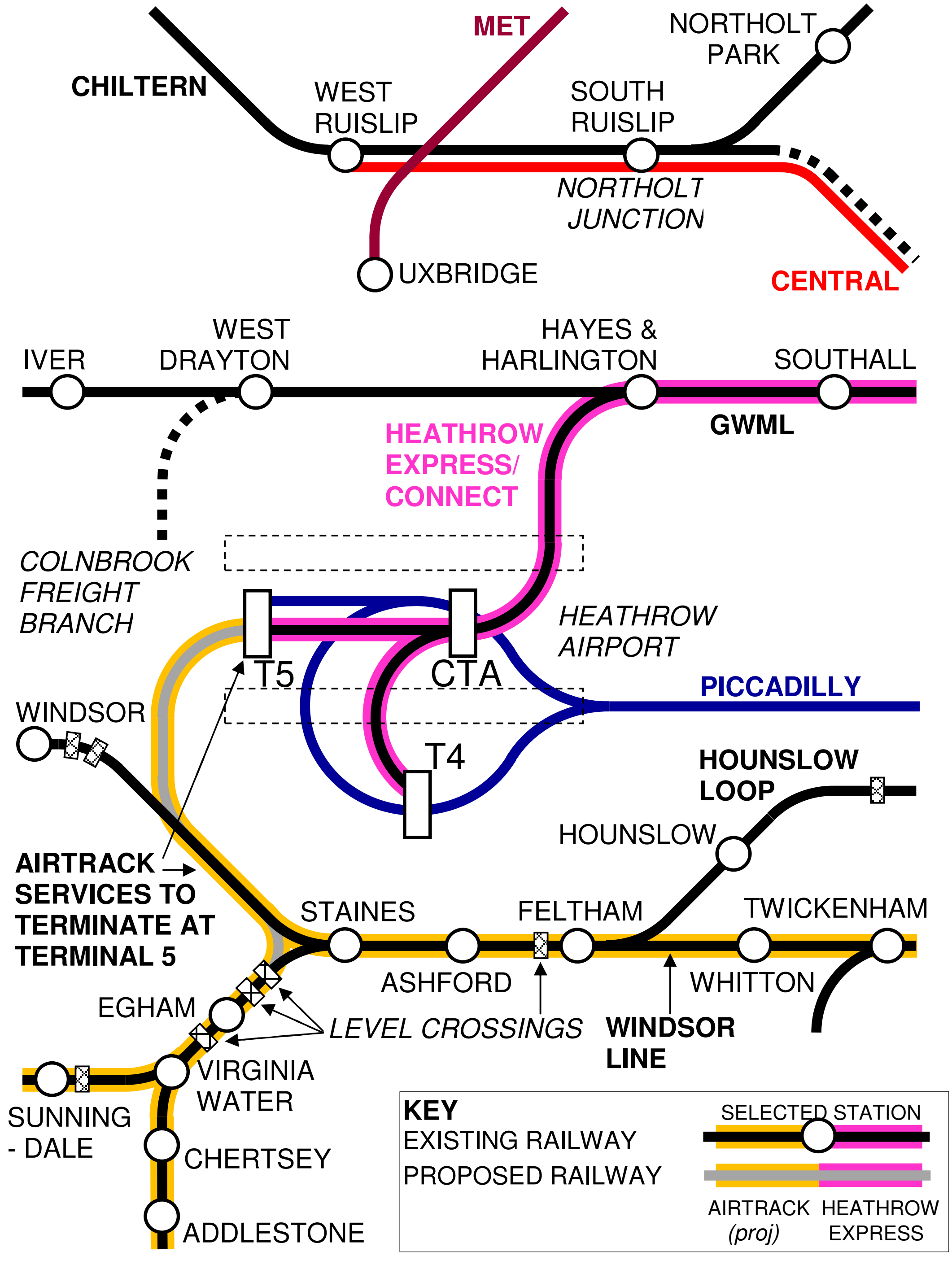


Fig F23: Heathrow Airport : Current Rail Connectivity (incl projected Airtrack)

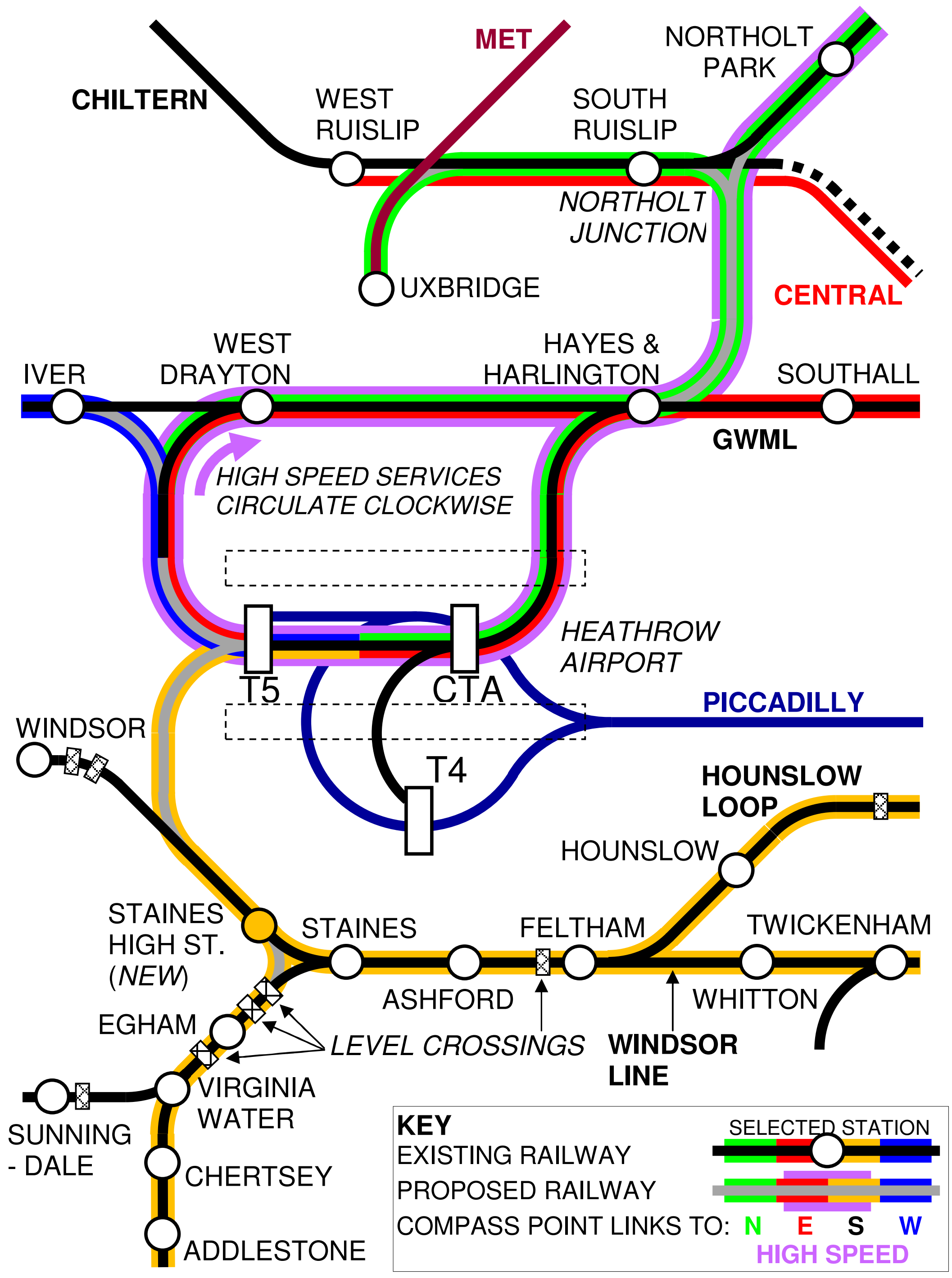


Fig F24: Heathrow Airport : Rail Connectivity with Compass Point network)

- the relative inaccessibility of its London terminal at Paddington, the least central of London's major stations.
- the lower fares applicable on the parallel Piccadilly Line, which therefore takes the dominant market share.

Implementation of the Compass Point network would transform Heathrow Express's current *modus operandi*. It would also transform Heathrow's overall connectivity (see Figures F23 and F24). Instead of a terminating branch line, linking only along the eastward axis towards central London, an intensively-operated through railway, with up to 20 trains per hour in both directions would deliver passengers to north and east, south and west.

Table F16 postulates a total surface access flow to Heathrow (including airport workers) of around 100000 per day. If:

a) all of these passengers were to travel to the airport by rail,
b) all were to use the Compass Point network (assuming perhaps service disruption on the Piccadilly Line), and
c) the 20tph unidirectional service (or 40tph in both directions) were to run throughout the 16 hour 'operating day', implying a total of 640 trains per day,

then each train would carry an average passenger loading of 156. This would appear to be well within the capabilities of the rolling stock that currently operates on the Heathrow Express system (comprising 8-car multiple unit of circa 400 seated capacity).

The above reckoning is admittedly simplistic, but robust; with airport flows relatively constant throughout the operating day (in contrast with highly-peaked commuter flows), and with outflows (eg up to 850 disembarking from an arriving A380 Airbus) 'damped' by Customs control and baggage reclaim, it is unlikely that there would be significant exceedances of the capacity of an 8-car multiple unit at 'peak' periods. As with other railway operations, at 'off-peak' times, it would of course be appropriate to reduce either train length and/or frequency.

It is also necessary to consider whether a 3 minute average headway between trains (implicit in a 20tph operation) is feasible, in the context of delivering massively increased volumes of passengers to an international airport. The simple passenger numbers and train frequencies are not the issues, *per se*; both CrossRail and Thameslink project greater passenger volumes and higher train frequencies (24tph). The concern lies with passengers either burdened with major quantities of luggage, or with insufficient English to fully understand train announcements (or both).

Both considerations indicate station dwell times significantly in excess of what might apply in a more conventional commuter operation. With the assumption made, that radical reconfiguration of the existing underground platform infrastructure is not practicable, it is necessary to undertake such modifications as are feasible, and to develop an optimised mode of operation that maximises the potential of the existing infrastructure.

Key points to consider are as follows:

- The greatest constraint to high-capacity operation is the 'level junction' at the west end of the platforms of the CTA station, where the lines for Terminals 4 and 5 diverge. This would render any 20tph operation unviable. However, with Heathrow now limited in perpetuity to 2 runways, it seems likely that available runway 'slots', rather than terminal capacity, will continue to be the critical determinant upon airport capacity. This being the case, there would appear to be no long-term future for Terminal 4, located to the south of the southern runway, and hence causing this runway to be blocked every time that a plane taxis to or from the northern runway.

Instead, development should logically continue to be focussed upon Terminal 5 and the Central Terminal Area, both located in the optimum position between the runways. Accordingly, the Compass Point proposals have been developed with the core route serving just the CTA and T5.

- If a continued service is required to Terminal 4 (in a presumed reduced role), this could best be achieved through shuttle operation of the existing single-line spur, between T4 and the CTA. This would require construction of a new platform, in a new tunnel at the existing underground CTA station. The usual onerous ground support requirements would be to some extent mitigated by the continued presence of the ring of bored piles, installed to stabilise the ground after the collapse during construction in 1994; this should greatly facilitate the necessary groundworks.
- Assuming that the issues associated with the spur to Terminal 4 can be resolved, as noted above, the existing CTA underground station – comprising 2 platform faces either side of a single island platform – would then become the critical determinant upon capacity. The platforms are constructed at a height to permit level entry/exit, and are generously proportioned, of sufficient width to readily accommodate the entire train load (in the unlikely event that all passengers might wish to disembark at the CTA station, and none at T5).
- Congestion problems would only arise if the platform were already crowded with passengers, wishing to board either the train from which the train load is alighting, or a subsequent train. With direct services to distant locations operating at typical hourly frequencies, it would be necessary to develop a sophisticated passenger handling system, to provide waiting areas (fully equipped with information systems, catering facilities etc) from which passengers would be summoned only shortly before the due departure time of their train.
- With the T5 station comprising 4 platforms (required for separate operation of Heathrow Express and Airtrack services) and located in less confined 'open cut', this would comprise the optimum location to 'hold' passengers awaiting their long-distance train. All train passengers arriving at the CTA would therefore be instructed to make their way (either via Compass Point services or the Piccadilly Line) to the waiting areas at Terminal 5.
- The existing signalling system (presumably specified to match the current leisurely operating pattern) would have to be replaced with a system designed to optimise station dwell times, and at the same time maintain a service frequency of around 20 trains per hour. As noted previously, capacity issues would be critical at the CTA station, with only 2 platforms; an optimised system would be designed with close-spaced signals, enabling (for instance) a train to stand just outside an occupied platform, and to commence its entry to the platform as the departing train clears the midpoint of the platform.
- At T5, the 4-platform layout would pose fewer constraints on capacity, and would permit the critical long-distance services carrying interlining passengers to the North, and to Scotland, to stand for perhaps 5-10 minutes while passengers find their booked seats. This would also allow a degree of 'recovery time'.

Considering all of the foregoing, there would appear to be no fundamental reason, at least at Heathrow Airport, why the Compass Point network should not comprise a fit-for-purpose high capacity transport system, capable of delivering incoming airline passengers either:

- direct (and 'high speed') to key provincial destinations, or
- to outer-suburban hub points, changing to long-distance services on the existing (or high speed) network radiating from London, or
- to local and regional destinations in London and the South-East.

F10 Airtrack Issues

However, there are issues outwith Heathrow that must also be considered. There has been a long-standing strategy on the part of the airport owner ie British Airports Authority, and latterly Ferrovial to increase the proportion of airline passengers using public transport on the surface leg of their journey. This accords with the desire to achieve high speed rail access to Heathrow, and it has also given rise to more local projects, in particular the 'Airtrack' scheme.

In terms of physical works, this would comprise a 4km stretch of new railway, linking from Heathrow Terminal 5 to the Windsor (& Eton Riverside) branch, north-west of Staines. It would allow direct services from Heathrow to much of the Southern rail network, extending to Richmond and Waterloo, to Woking (for interchange with the South-Western Main Line) and to Bracknell and Reading. Despite the apparent opportunity for through running from communities north of Heathrow, Airtrack has always been conceived as a stand-alone service powered by the Southern 'third rail' 750V DC system, and segregated from Heathrow Express (operating to the more widespread 'overhead' 25kV AC system).

Although Airtrack would provide valuable opportunities for public transport access to Heathrow, along axes currently dominated by road transport, its proposed introduction has been attended with controversy. This has centred around the additional trains specified to provide airport services, and the impact that this would have on the 'gates open' time at local level crossings.

The 'Windsor Line', extending westwards from London towards Windsor and Reading across the West Middlesex Plain, has by far the greatest number of level crossings of any commuter or main line railway in the London & South-East region. The concentrations are greatest in two areas:

- between Barnes and Mortlake, within the London Borough of Richmond
- between Staines, Egham and Virginia Water in the Runnymede District

With the intensive rail services that already operate, the level crossing gates can be closed to road traffic for a more minutes in an hour than they are open; and with the level crossings comprising the only means of crossing the railway for several kilometres within a heavily urbanised area, it is not surprising that severe congestion already applies.

There is of course no feasible option, to construct road overbridges (or underbridges) to replace the level crossings; with the proximity of residential development and the need to maintain acceptable road gradients, this is quite simply impracticable.

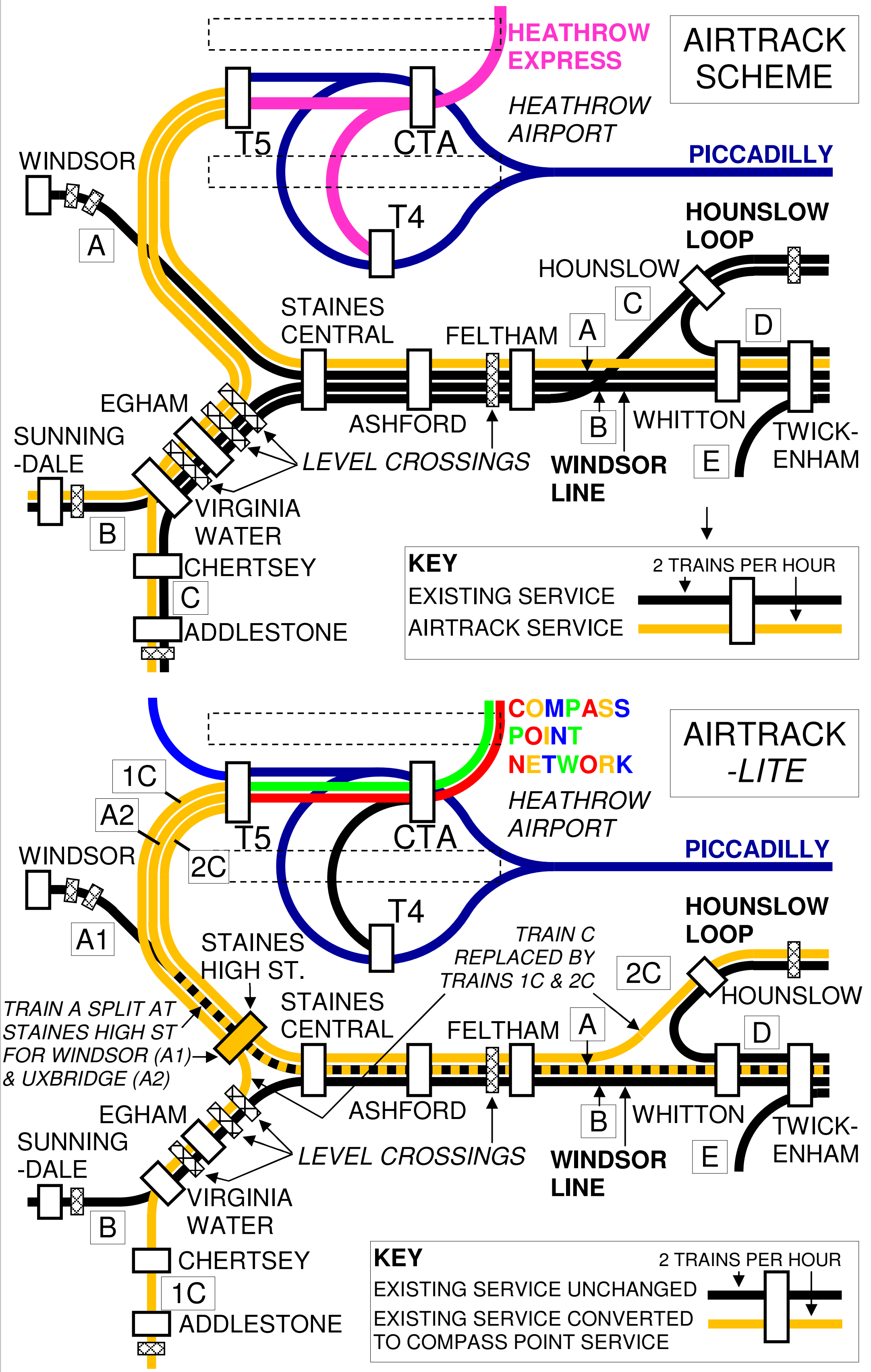


Fig F25: Heathrow Airport : Impact of Rail Access on Local Level Crossings

Under Airtrack proposals – comprising 2 trains per hour from Reading/Bracknell, from Woking and from Waterloo/Richmond – the existing 4tph service in the Runnymede area would double to 8tph, and the existing 8tph in the Mortlake area would increase to 10tph. See Figure F25. With no solution on offer, that could fully mitigate the impacts of the increased train operation (especially in the Runnymede area), local opposition to the Airtrack scheme has hardened, and thishas resulted in the recent decision of BAA Ferrovial, not to proceed with Airtrack. As yet, no other strategy has been put forward by which rail's market share of southward airport access flows might be increased.

It might be tempting, to dismiss the Runnymede (and Mortlake) residents as vociferous and influential 'NIMBYs', putting local issues above the national interest. But however desirable the benefits of a proposal, it remains incumbent upon its promoters to develop it in such a way as to minimise local impacts; and in the case of Airtrack, several clear opportunities for mitigation appear to have been disregarded.

The principal flaw with the Airtrack scheme lies in its basic lack of integration. The new airport services appear to have been superimposed onto the existing commuter services, with little thought given as to how the two service patterns might integrate, to mutual benefit. With two sets of uncoordinated train services operating – see Figure F25 – the following outcomes seem unavoidable:

- More trains running, therefore higher operating costs.
- More trains running, therefore increased CO_2 emissions.
- More trains running, therefore level crossing gates closed for longer, more congestion on road network and generally greater local impacts.
- Higher CO_2 emissions from greater congestion.

It is necessary to examine the existing service pattern against the new requirement for airport access, to determine what opportunities for integration might exist, and indeed, whether it is actually necessary to run any more trains to provide the level of airport connections envisaged in the Airtrack proposals.

The most obvious opportunity lies with the 'Chertsey loop' stopping service. This comprises a twice-hourly service linking Weybridge – Addlestone – Chertsey – Virginia Water – Egham – Staines, continuing to Waterloo (all stations stopping) via the Hounslow Loop. It is intended to provide local connections, rather than a viable commuting service to London; all passengers from Addlestone and Chertsey making such journeys would tend to change at either Weybridge or Staines.

Hence there would seem to be no reason why this service could not be abandoned in its present form, and its 'train path' used to provide two separate services:

- Waterloo – Hounslow Loop local stations – Staines – Heathrow – *points north*
- South Coast – Woking – local stations (Addlestone, Chertsey et al) – Staines – Heathrow – *points north*

This would provide two 'Airtrack' services for Heathrow, without any additional train frequency causing increased road congestion at level crossings. Instead, it would offer major local benefits; it should be noted that without fast and frequent links to London, Addlestone and Chertsey have tended to develop not as commuter towns, but as 'dormitory towns' for airport workers, and the improved links to Heathrow should be of great value. Some opportunities for direct journey would be lost (for instance between Hounslow and Virginia Water) but this could be addressed by a change of trains at Staines, either at the existing 'Central' station, or at the new 'High Street' station.

The third ‘Airtrack’ service to Heathrow would be provided through the expedient of splitting the existing (8-car) Waterloo-Windsor service, probably at the new Staines High Street Station. The two 4-car portions would then be run to Windsor (as existing), and through Heathrow to Uxbridge (Met). This is an unprecedented journey opportunity that would offer huge value to the many residents of the London Borough of Hillingdon who currently have no public transport links to Heathrow, other than by bus. It would be facilitated through the key new-build northward section of the Compass Point network, from Hayes & Harlington (on the GWML) to Northolt Junction (on the Chiltern Line), and would require a further new chord at West Ruislip to access the Metropolitan Line on its approach to Uxbridge. In its apparently undesirable 4-car operation, it is actually making a virtue out of a necessity – longer 8-car trains would not fit into Uxbridge.

The measures listed above have succeeded in generating a 6 trains per hour ‘Airtrack’ level of service – but with no more trains to exacerbate congestion at the level crossings in Runnymede and Mortlake. There is no longer a direct train from Bracknell and Reading, but connection would be provided at Egham or Staines; and it should be noted that Reading would (under wider Compass Point proposals) have a more direct Heathrow service via Slough.

F11 Conclusion

All of the foregoing must cast doubt on the fundamental rationale of high speed rail, as a primary means of achieving rail access to airports. Its basic infrastructure costs (in the vicinity of the airport) appear excessive, its operating standards (ie long and wide-bodied trains) preclude 'adoption' of existing infrastructure, and its fundamental uniaxial nature (compounded, in the case of HS2, by an 'exclusive' operating philosophy) inevitably restricts its coverage.

The 360-degree nature of airport flows is much better suited to a regional rail solution – as exemplified by the Heathrow 'Compass Point' proposals – which is capable of accessing many more population centres, on many more axes. If this can be effectively combined with the high speed rail solution (ie the Compass Point network bringing Heathrow to the high speed line, placed on its ideal intercity alignment), then there is clearly no longer a need to bring the high speed line to Heathrow.

It must be borne in mind that the primary purpose of high speed rail is to facilitate high-volume flows between major conurbations. However desirable the goal of high speed rail access to airports, in proportionate terms this can only be a secondary consideration, only to be addressed in a manner consistent with achievement of the primary goal of linking conurbations. This being the case, the rationale of aligning the high speed line with Heathrow must be questioned.

This point is reinforced by the general findings of this study, which have demonstrated the following:

- The extra infrastructure cost inherent in aligning the high speed line close to Heathrow.
- The extra environmental impact, and consequent controversy, in the onward route through the Chilterns.
- The less efficient, more London-centric Y-network that inevitably develops from a 'Chiltern' route, with Birmingham as the primary 'target' city.
- The low potential of a 'high speed' airport access model to achieve CO_2 reductions through conversion of short-haul aviation.

Overall, it would appear that any small savings in CO_2 emissions, that might be achieved through aligning the high speed line with Heathrow, are hugely outweighed by the negative consequences arising from the onward Chiltern route, and the development of the 'Y'. This routeing strategy has been adopted in the development of the HS2 proposals, in favour of the superior M1-aligned 'spine and spur' for no other (valid) reason than to serve Heathrow. As highlighted in Item F7.2, the marginal CO_2 cost of the Chiltern route (resulting in delayed implementation) and of the 'Y' (resulting in poor network coverage, sub-optimal integration and low operational efficiency) appears to be of the order of 330MT, over a 40 year period.

The complete disparity between the 4.6MT saving in CO_2 emissions (arising from interlining flights et al converted to rail) and the 300MT lost CO_2 savings (arising from adoption of Chiltern route and the 'Y') would appear to demonstrate the present lack of understanding of how the integrated development of new railways (high speed or otherwise) could drive environmental gains compatible with the requirements of the 2008 Climate Change Act, and other wider sustainability concerns. This is to say nothing of the positive economic impacts from optimised high speed rail, and rail links to Heathrow. It is to be hoped that this study will contribute towards advancing knowledge and understanding in these areas.

Appendix G : Supplementary Diagrams

G1 High Speed Rail : Progressive Development of 'Y' and 'Spine & Spur' Network Concepts

G2 Integration of High Speed and Classic Networks

G3 Alternative 'Airtrack' Concepts

G4 Integration of Euston High Speed Terminal with CrossRail, Thameslink and Orbital Rail

Appendix G1 :

High Speed Rail : Progressive Development of ‘Y’ and ‘Spine & Spur’ Network Concepts

The notes and diagrams on the following pages attempt to account for the different logic paths by which the ‘Y’ of HS2, and the ‘Spine & Spur’ of High Speed North have developed. It can be appreciated how the different approach in respect of providing rail access to Heathrow has far-reaching effects on development of the remainder of the high speed network.

Notes re Comparisons of ‘Y-Shape’ and ‘Spine & Spur’ Networks

Figure 1 : *illustrating:*

a) existing main line railway network, showing radial main lines (East Coast, Midland, West Coast and Great Western) extending north and west from London.
b) existing rail links to Heathrow Airport.

Key points:

- WCML is UK’s busiest rail route, extending to Birmingham and Manchester, UK’s 2nd & 3rd cities. WCML is predicted to run out of capacity by circa 2020, before other main lines such as MML & ECML..
- HS1 is UK’s only high speed line.
- Heathrow is linked only to London by rail, and is effectively disconnected from remainder of UK.

Figure 2 : *illustrating the progressive development of the HS2 Y-shaped concept*

Key points:

- HSR intended to provide additional speed & capacity along main line corridors.
- WCML corridor prime candidate for HSR development to B’ham & Manchester.
- With small deviation to west, Heathrow also included in initial HSR concept, for line linking London – Heathrow – Birmingham – Manchester.
- Tunnelled stations under centres of Heathrow and Birmingham not practicable – so both must be placed ‘off-line’.
- Spur link to Heathrow considered – but this would require dedicated airport trains additional to intercity trains to London, and would probably exceed line capacity.
- Instead, links comprising shuttle or loop (to a ‘hub’ on airport periphery) are preferred. This brings HSL close to Heathrow, and the Chiltern route is unavoidable.
- Further change of trains required at hub to access airport terminals.
- To provide greater regional balance, a branch to Yorkshire is also favoured.
- Logical splitting point is north of Birmingham – hence the ‘Y’ is formed.
- Further development of ‘Y’ to access principal conurbations of Midlands, North & Scotland results in ‘fan’ system, with each centre on its own spur.

Figure 3 : *illustrating the progressive development of ‘Spine & Spur’ concept*

Key points:

- Heathrow connectivity addressed (separate to HSR) by developing existing Heathrow Express system into ‘Compass Point’ network extending to south, west & north of airport.
- Not practicable to provide direct connections to all provincial destinations. Instead, main line links provided via connections at outer-suburban hubs (eg Watford, Reading, Stevenage).
- Hence all provincial centres would be one change of trains from Heathrow.
- This principle can be extended to high speed rail. This allows high speed line to be located on optimum route along M1 corridor.
- Realignment of intercity rail onto core spine route encompassing all principal conurbations allows practicable direct connections from Heathrow to key provincial centres.

Figure 4 : *comparing intercity networks created by 'Y' and by 'Spine & Spur'*

Key points re Y-shape:

- Y-shaped 'fan' network entails separate route to each major city.
- With little opportunity for combination of routes, an aspiration for an (average) half-hourly service from London to each of 9 provincial conurbations will result in circa 18 trains per hour on the critical trunk section from London to the Midlands.
- 18tph is stated as the maximum capacity of a 2-track high speed line.
- 'Fan' network is focussed on London, but offers few interregional links.
- There is no necessity for a Y-shaped intercity route to pass through Chilterns – but any route through the Chilterns will preclude the prospect of 4-tracking.

Key points re 'Spine & Spur':

- Spine & Spur format allows several cities to be combined on the same route.
- This permits greater connectivity and greater load factor to be achieved.
- This gives better economic performance from better-filled and more frequent trains, and better environmental performances (with fewer grams of CO_2 per passenger kilometre).
- Fewer trains are required to serve same volume of travellers, resulting in only circa 14 trains per hour on critical southern section.
- A route following the M1 could be configured for 4 tracks, if required.

Figures 5 & 6 : *comparing Heathrow links created by 'Y' and by 'Spine & Spur'*

Key points re Y-shape:

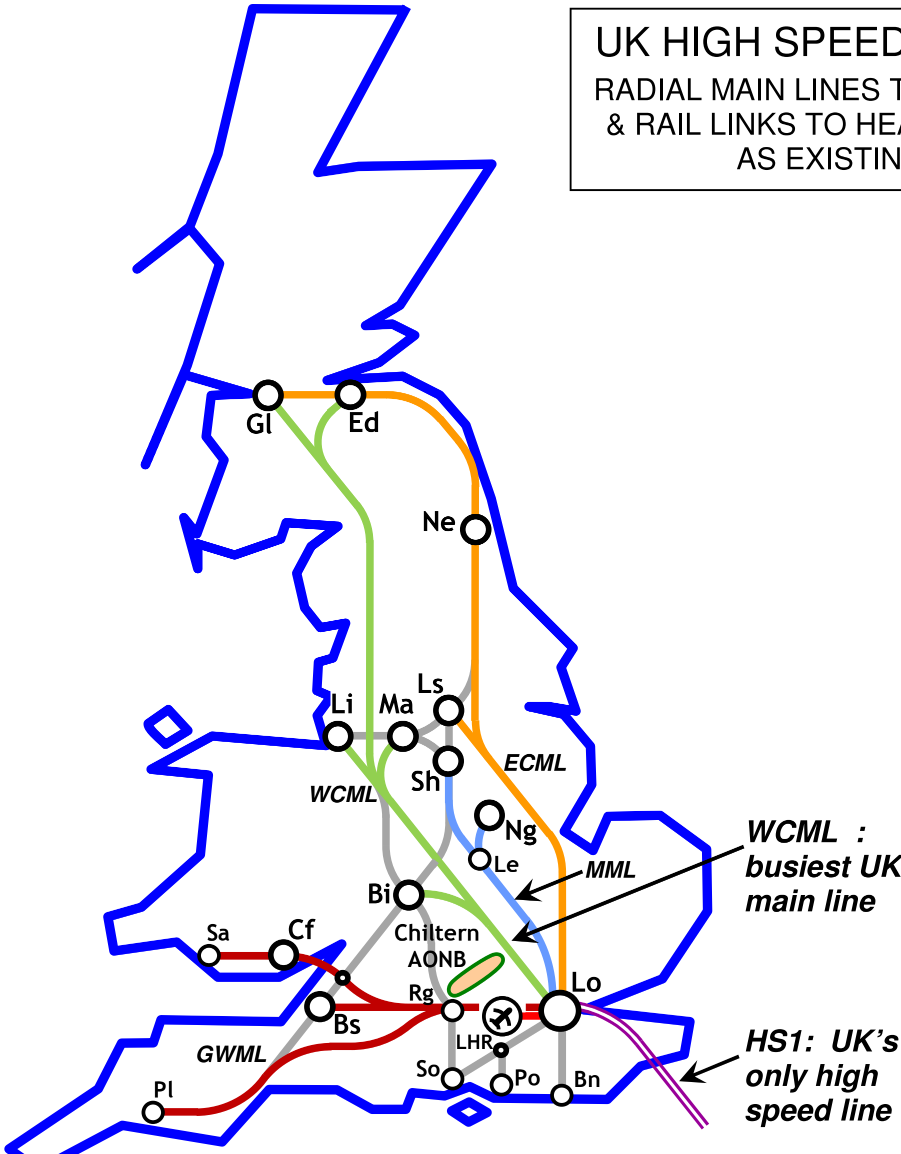
- Assuming a spur link into Heathrow, a Y-shaped 'fan' network would entail a separate route to each major city (assumed to be hourly).
- Such disaggregation would seem unlikely to offer viable train loadings.
- More importantly, this would add another 9 trains per hour to the 18 intercity trains.
- As with the intercity routeings, a spur link into Heathrow does not *per se* dictate a high speed line through the Chilterns.
- However, 27 trains per hour is clearly unsustainable. This requires a mitigation strategy.
- 27tph can be mitigated to 18tph by eliminating a spur in favour of a shuttle or loop link to Heathrow.
- However, this then compels a route through the Chilterns.
- The logical onward route is then to Birmingham, before splitting to west and east of the Pennines, to form the 'Y'.
- The requirement for 'direct' rail access to Heathrow leads to long delays in construction and a fundamentally inefficient network, with poor economic and environmental performance, and offering few interregional links.

Key points re 'Spine & Spur':

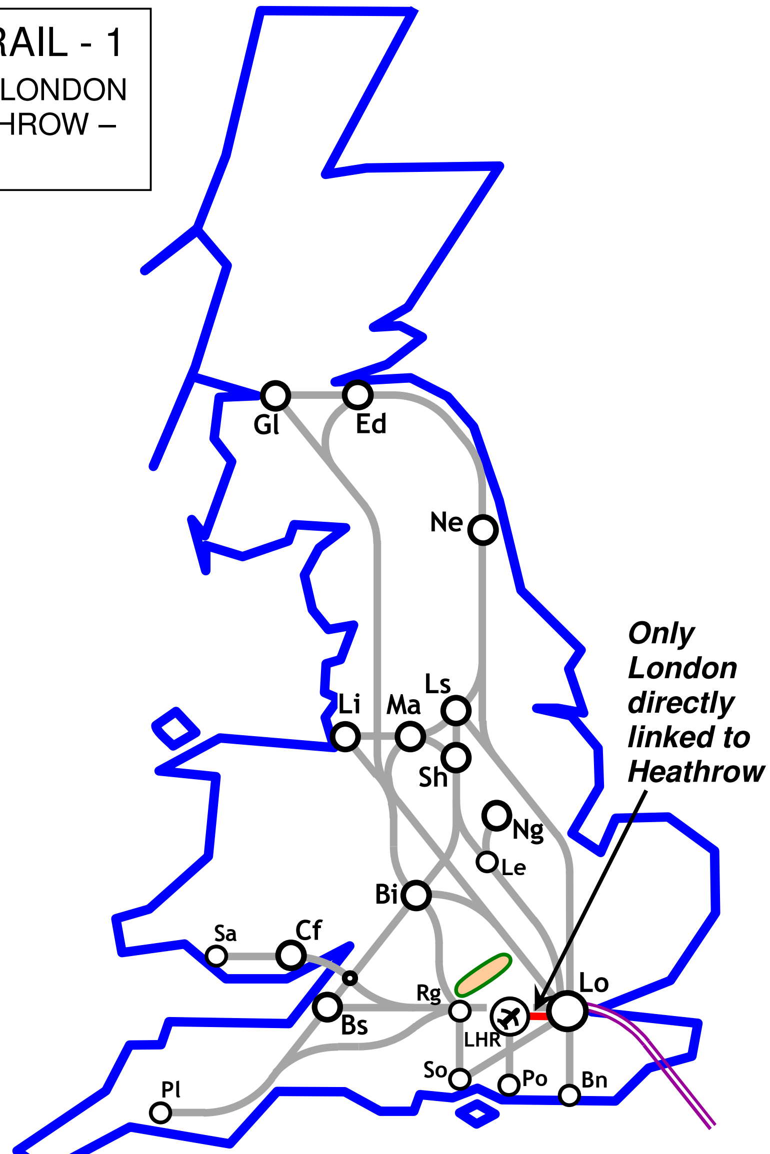
- The combination of routes possible with 'Spine & Spur' requires only 3 airport trains per hour to serve all Midlands, Northern and Scottish destinations.
- All splitting points would be at major traffic-generating centres.
- Such aggregation allows viable train loads.
- With only 3 airport trains per hour added to the 14 intercity trains, the total of 17tph gives rise to much lower pressure on line capacity.
- The airport train to the Midlands would be more usefully routed via the WCML and Milton Keynes. Hence a total of 16tph would operate on the high speed line.

UK HIGH SPEED RAIL - 1

RADIAL MAIN LINES TO LONDON
& RAIL LINKS TO HEATHROW –
AS EXISTING



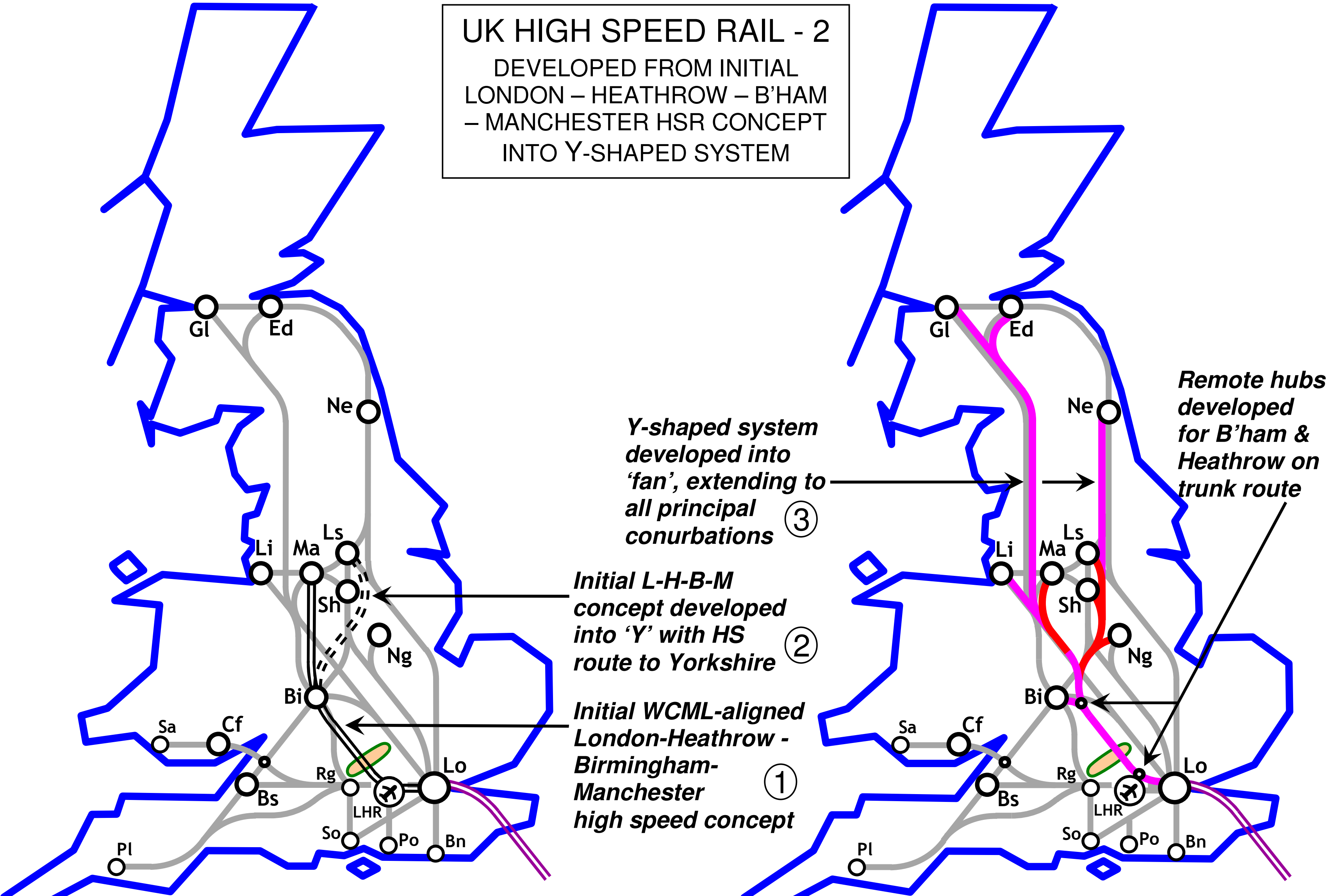
UK RADIAL MAIN LINE NETWORK



EXISTING RAIL CONNECTIONS TO HEATHROW

UK HIGH SPEED RAIL - 2

DEVELOPED FROM INITIAL LONDON – HEATHROW – B'HAM – MANCHESTER HSR CONCEPT INTO Y-SHAPED SYSTEM

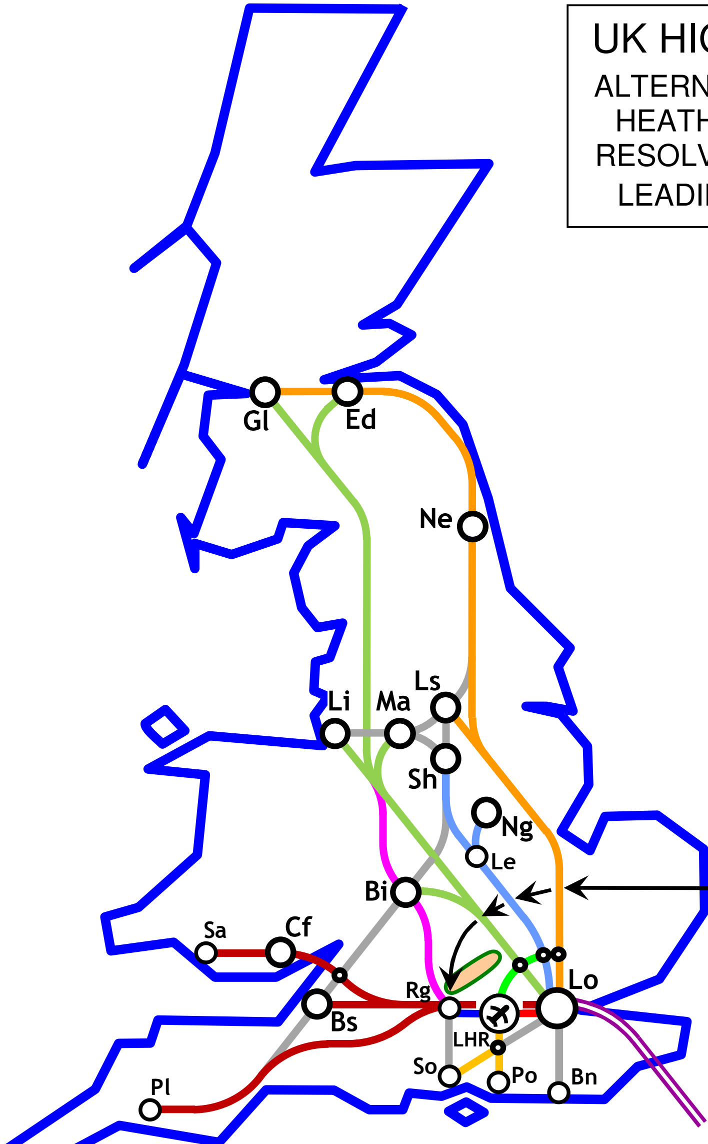


LONDON – HEATHROW – BIRMINGHAM – MANCHESTER HIGH SPEED CONCEPT

L-H-B-M INITIAL CONCEPT DEVELOPED INTO 'Y', EXTENDED TO N.E. & SCOTLAND

UK HIGH SPEED RAIL - 3

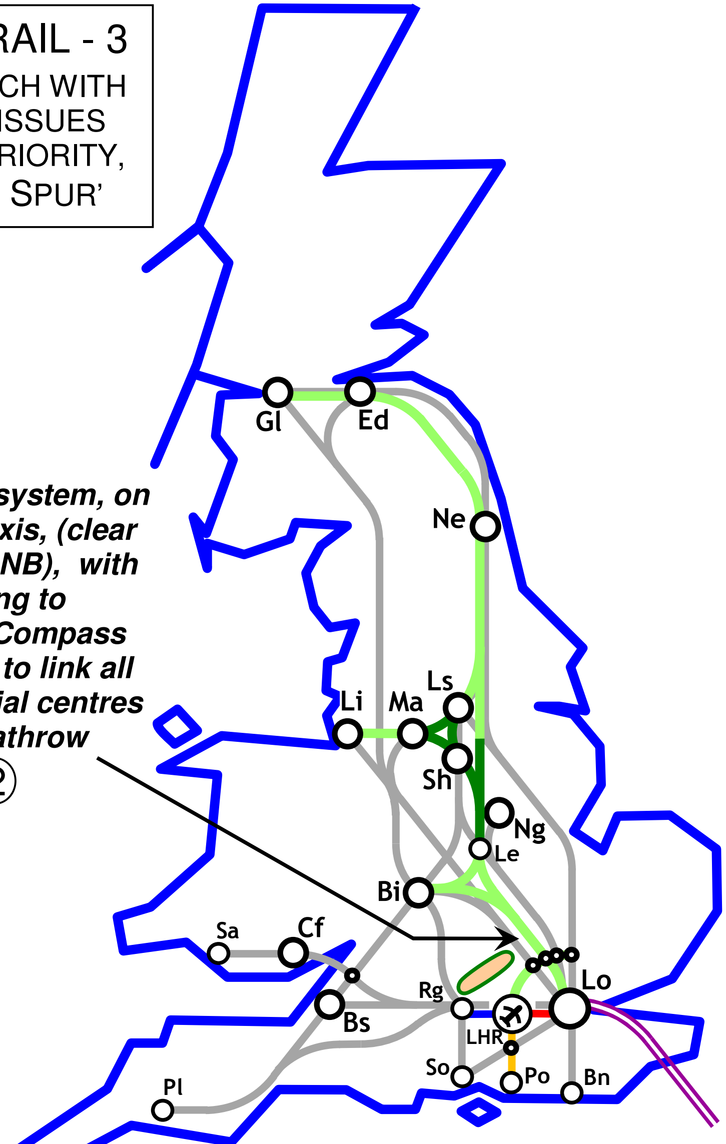
ALTERNATIVE APPROACH WITH HEATHROW ACCESS ISSUES RESOLVED AS FIRST PRIORITY, LEADING TO 'SPINE & SPUR'



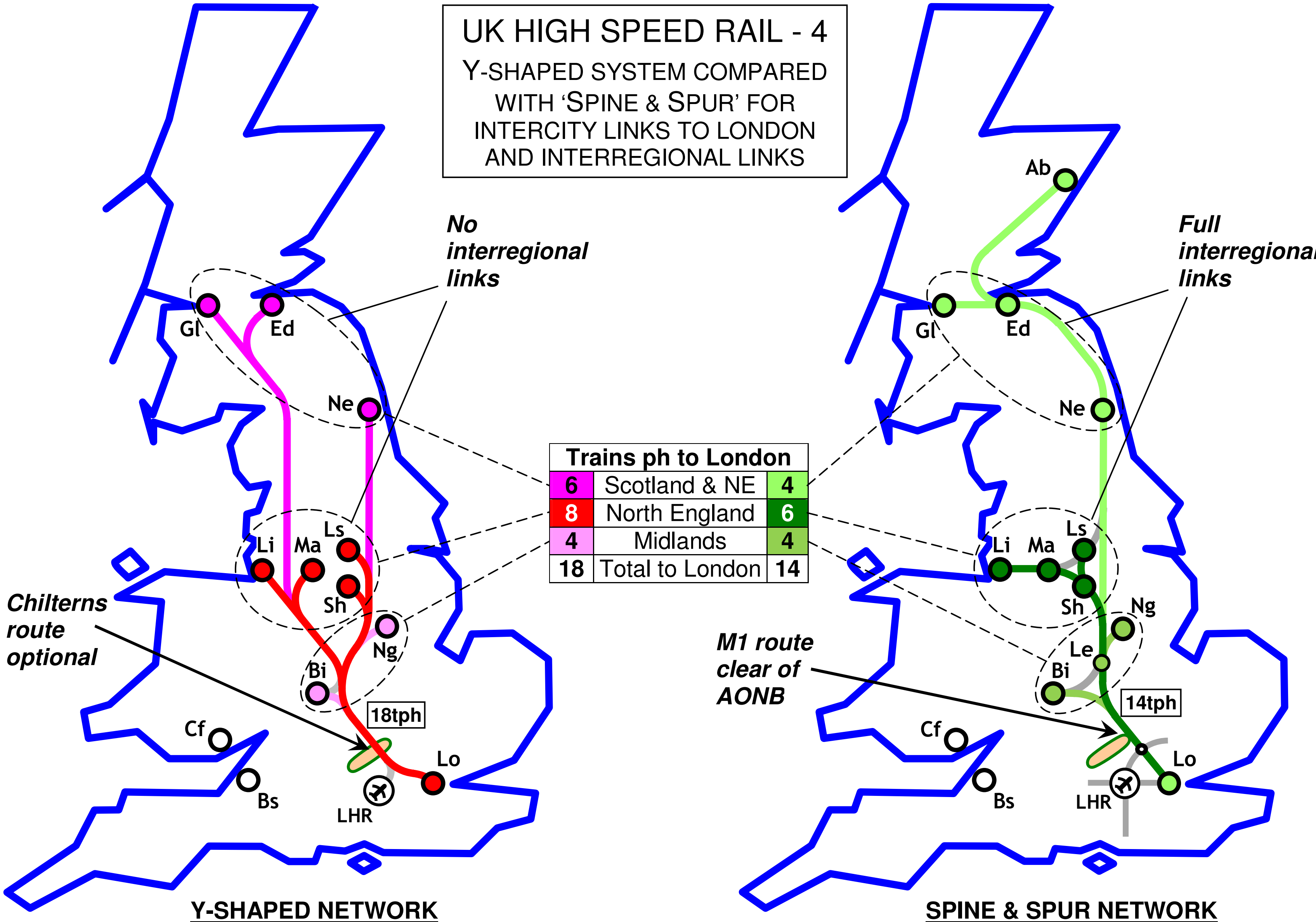
Compass Point network connects to all main line corridors ①

Spine & Spur system, on optimum M1 axis, (clear of Chiltern AONB), with through running to Heathrow via Compass Point network to link all major provincial centres to heart of Heathrow Airport ②

COMPASS POINT NETWORK LINKING TO UK MAIN LINE NETWORK

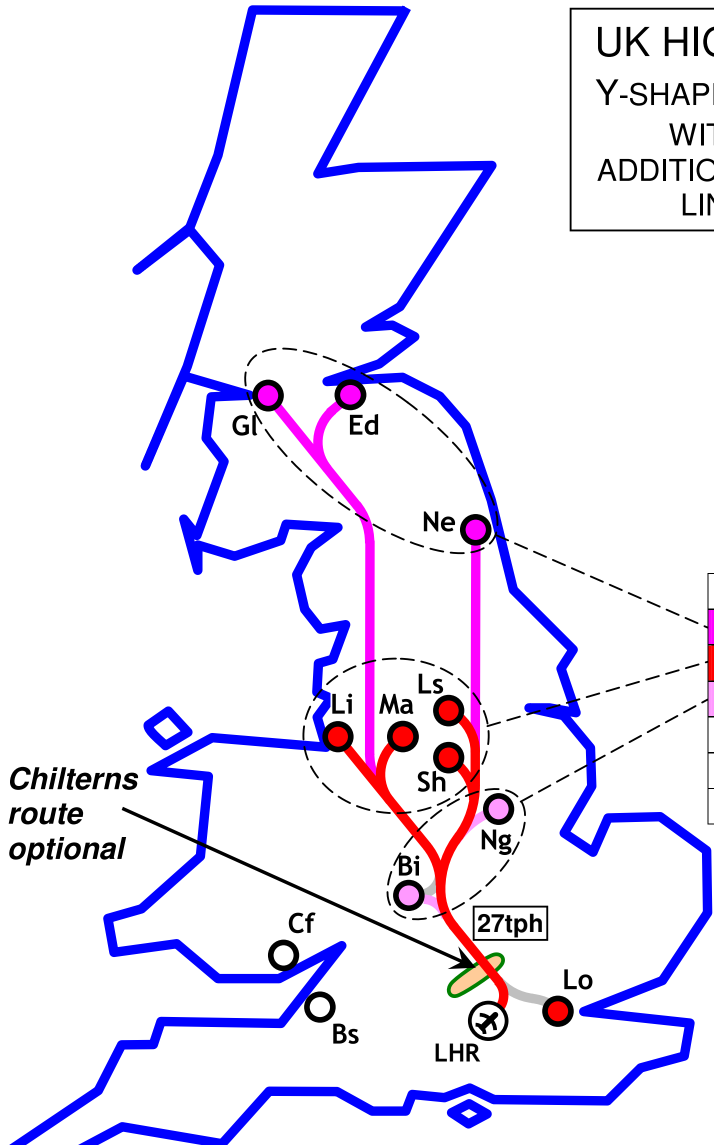


COMPASS POINT NETWORK INTEGRATED WITH SPINE & SPUR


UK HIGH SPEED RAIL - 4
Y-SHAPED SYSTEM COMPARED WITH 'SPINE & SPUR' FOR INTERCITY LINKS TO LONDON AND INTERREGIONAL LINKS
No interregional links
Full interregional links
Chilterns route optional
M1 route clear of AONB
Trains ph to London
6 Scotland & NE 4
8 North England 6
4 Midlands 4
18 Total to London 14
Ab
Gl
Ed
Ne
Li
Ma
Ls
Sh
Ng
Le
Bi
Cf
Bs
LHR
Lo
18tph
14tph
Y-SHAPED NETWORK
SPINE & SPUR NETWORK

UK HIGH SPEED RAIL - 5

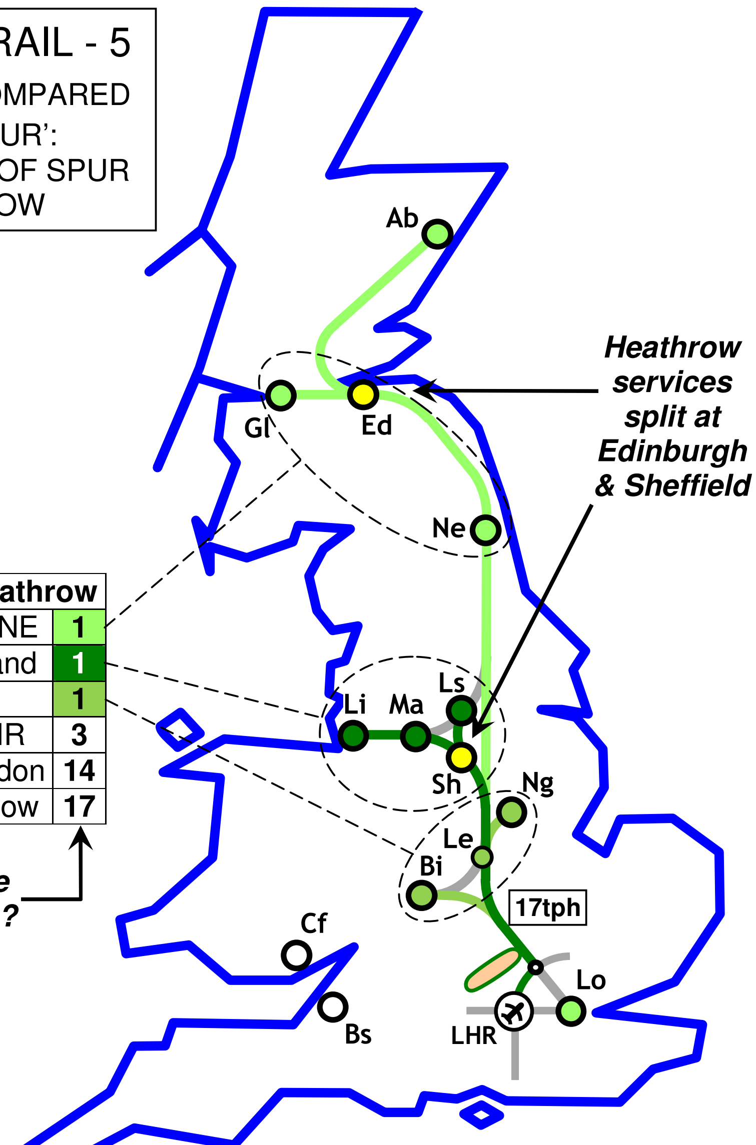
Y-SHAPED SYSTEM COMPARED WITH 'SPINE & SPUR': ADDITIONAL EFFECTS OF SPUR LINK TO HEATHROW



Y-SHAPED NETWORK WITH HEATHROW SPUR

Trains ph to Heathrow		
3	Scotland & NE	1
4	North England	1
2	Midlands	1
9	Total to LHR	3
18	Total to London	14
27	Total HSL flow	17

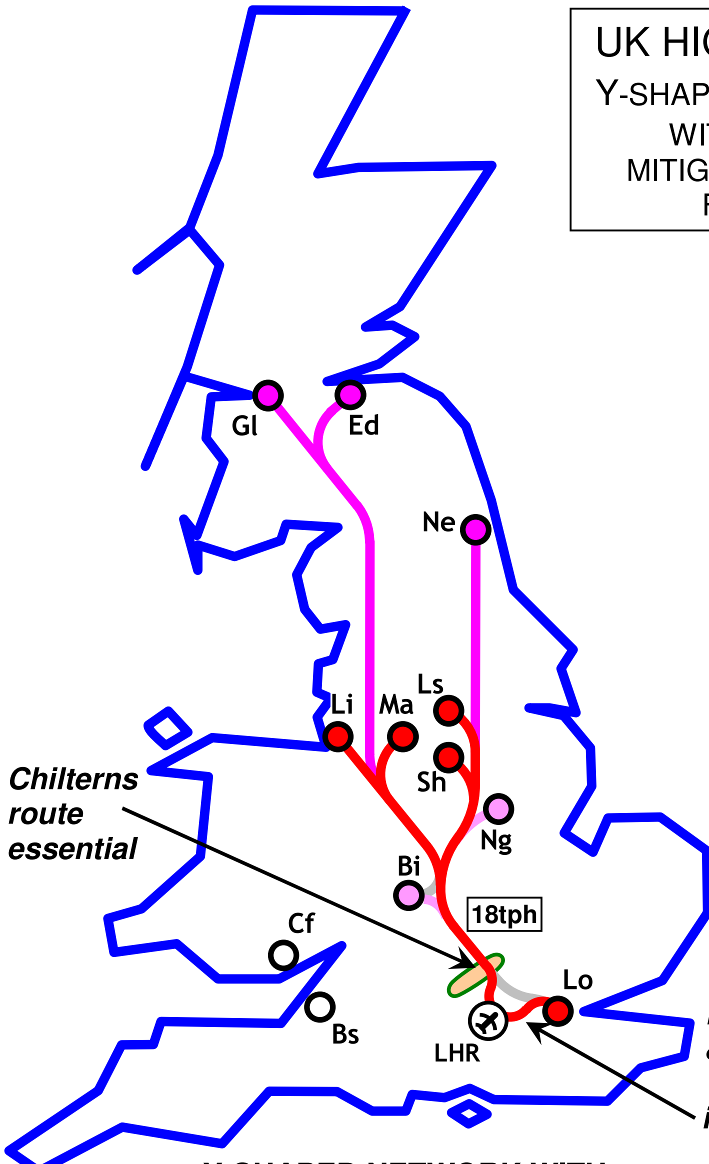
18tph line capacity??



SPINE & SPUR NETWORK WITH COMPASS POINT NETWORK

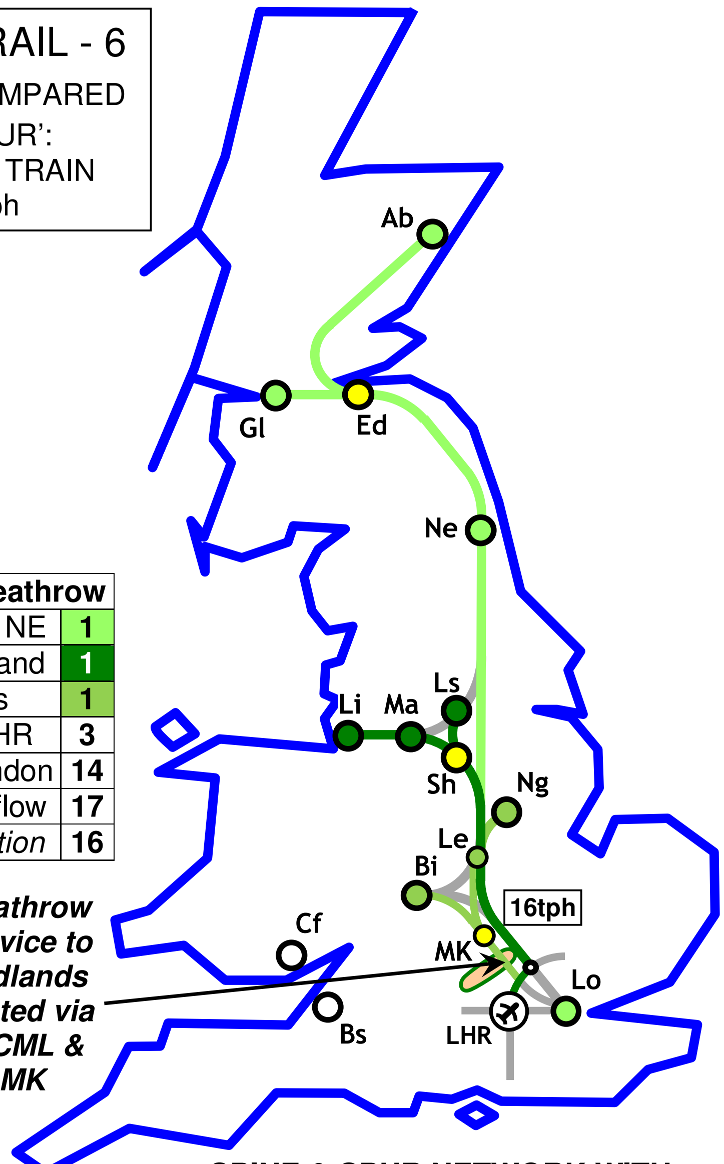
UK HIGH SPEED RAIL - 6

Y-SHAPED SYSTEM COMPARED WITH 'SPINE & SPUR': MITIGATION TO LIMIT TRAIN FLOWS TO ~18tph



Y-SHAPED NETWORK WITH HEATHROW LOOP

Trains ph to Heathrow		
3	Scotland & NE	1
4	North England	1
2	Midlands	1
9	Total to LHR	3
18	Total to London	14
27	Total HSL flow	17
18	*with mitigation*	16



SPINE & SPUR NETWORK WITH COMPASS POINT NETWORK

Appendix G2 :

Integration of High Speed and Classic Networks

The diagrams on the following pages illustrate schematic network diagrams for:

- The existing ‘classic’ rail network.
- HS2
- High Speed North.

The information with regard to HS2 and High Speed North is based on the best data available from the developers of the two candidate schemes.


1
GB RAIL NETWORK:
RADIAL MAIN LINES
TO LONDON
ABERDEEN &
HIGHLANDS
EDINBURGH
GLASGOW
SUNDERLAND
NEWCASTLE
CARLISLE
MIDDLESBROUGH
DARLINGTON
BLACKPOOL
YORK
BRADFORD
LEEDS
PRESTON
HULL
BOLTON
WIGAN
M'CHESTER
LIVERPOOL
W'FIELD
W'TON
S'PORT
DONCASTER
SHEFFIELD
GRIMSBY
CHESTER
NORTH
WALES
C'FIELD
CREWE
STOKE
DERBY
NOTTINGHAM
STAFFORD
PETERBORO'
SHREWSBURY
LEICESTER
WOLVERHAMPTON
BIRMINGHAM
COVENTRY
WORCESTER
RUGBY
MILTON
KEYNES
LUTON
STEVENAGE
CHELTENHAM
LEAMINGTON
WATFORD
JN
GLOUCESTER
OXFORD
KX/
StP
CARDIFF
SWINDON
HEATHROW
AIRPORT
EUSTON
B.P WAY
BATH
READING
PADDINGTON
BRISTOL

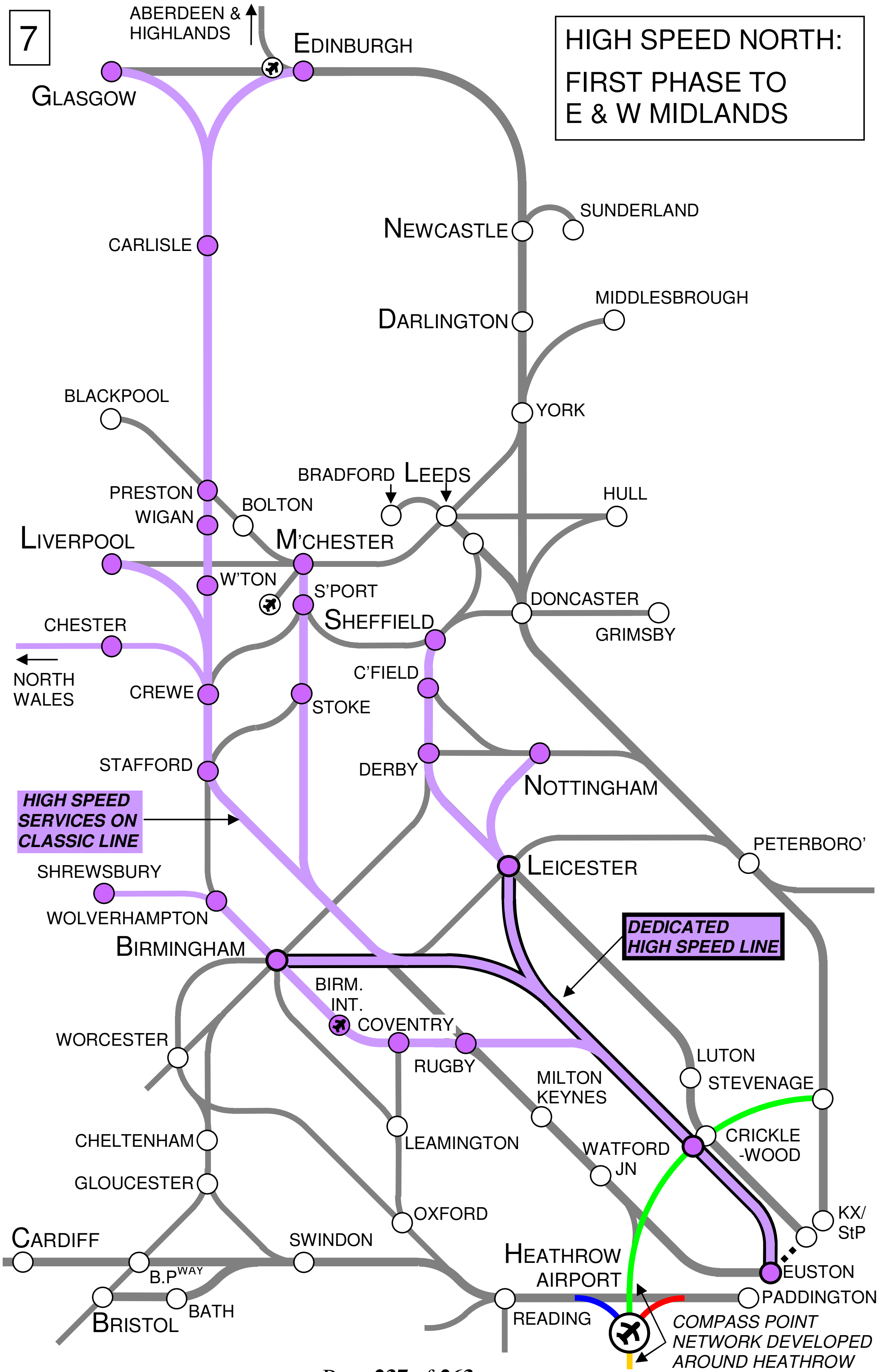

2
GB RAIL NETWORK:
CROSSCOUNTRY ROUTES FOCUSED ON BIRMINGHAM
ABERDEEN & HIGHLANDS
EDINBURGH
GLASGOW
SUNDERLAND
NEWCASTLE
CARLISLE
MIDDLESBROUGH
DARLINGTON
BLACKPOOL
YORK
BRADFORD
LEEDS
PRESTON
BOLTON
HULL
WIGAN
LIVERPOOL
M'CHESTER
W'TON
W'FIELD
S'PORT
DONCASTER
CHESTER
SHEFFIELD
GRIMSBY
NORTH WALES
CREWE
C'FIELD
STOKE
STAFFORD
DERBY
NOTTINGHAM
PETERBORO'
SHREWSBURY
LEICESTER
WOLVERHAMPTON
BIRMINGHAM
COVENTRY
WORCESTER
RUGBY
MILTON KEYNES
LUTON
STEVENAGE
CHELTENHAM
LEAMINGTON
WATFORD JN
GLOUCESTER
OXFORD
KX/ StP
CARDIFF
SWINDON
HEATHROW AIRPORT
EUSTON
B.P WAY
BATH
READING
PADDINGTON
BRISTOL


3
GB RAIL NETWORK:
TRANSPENNINE ROUTES FOCUSED ON MANCHESTER
ABERDEEN & HIGHLANDS
EDINBURGH
GLASGOW
CARLISLE
NEWCASTLE
SUNDERLAND
DARLINGTON
MIDDLESBROUGH
YORK
BLACKPOOL
PRESTON
WIGAN
BOLTON
BRADFORD
LEEDS
HULL
LIVERPOOL
M'CHESTER
W'TON
S'PORT
H'FIELD
DONCASTER
GRIMSBY
CHESTER
NORTH WALES
CREWE
STOKE
C'FIELD
STAFFORD
DERBY
NOTTINGHAM
PETERBORO'
SHREWSBURY
WOLVERHAMPTON
LEICESTER
BIRMINGHAM
COVENTRY
WORCESTER
RUGBY
MILTON KEYNES
LUTON
STEVENAGE
CHELTENHAM
LEAMINGTON
WATFORD JN
GLOUCESTER
OXFORD
KX/ StP
CARDIFF
SWINDON
HEATHROW AIRPORT
EUSTON
B.PWAY
BRISTOL
BATH
READING
PADDINGTON

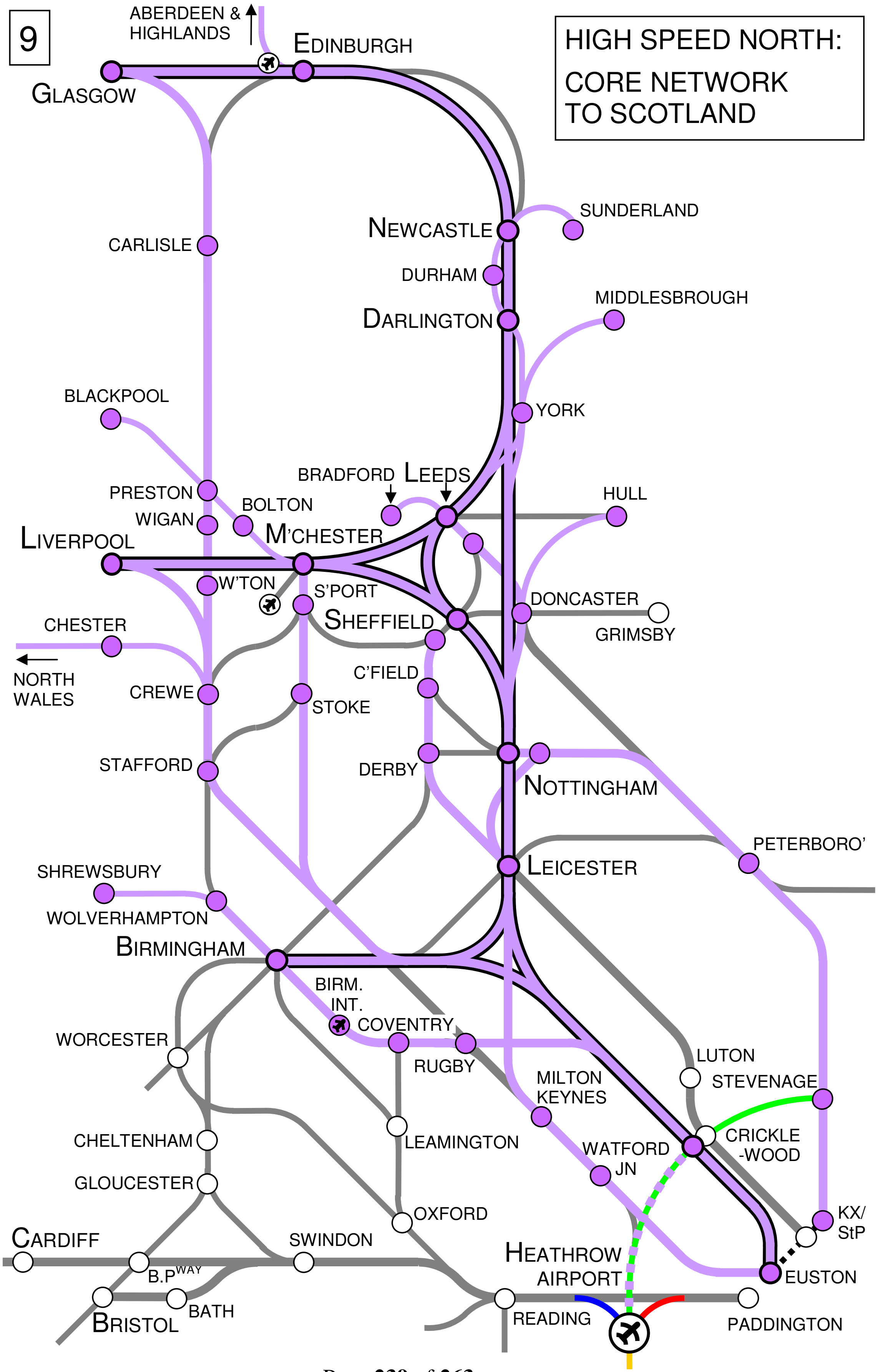

4
HS2:
FIRST PHASE TO WEST MIDLANDS
ABERDEEN & HIGHLANDS
EDINBURGH
GLASGOW
NEWCASTLE
SUNDERLAND
CARLISLE
DARLINGTON
MIDDLESBROUGH
YORK
BLACKPOOL
PRESTON
BRADFORD
LEEDS
HULL
BOLTON
WIGAN
LIVERPOOL
M'CHESTER
W'TON
S'PORT
SHEFFIELD
DONCASTER
GRIMSBY
CHESTER
NORTH WALES
CREWE
C'FIELD
STOKE
STAFFORD
DERBY
NOTTINGHAM
HIGH SPEED SERVICES ON CLASSIC LINE
PETERBORO'
SHREWSBURY
LEICESTER
WOLVERHAMPTON
NEW ST
BIRMINGHAM
BIRMINGHAM INTERCHANGE
FAZELEY ST
COVENTRY
WORCESTER
RUGBY
MILTON KEYNES
LUTON
STEVENAGE
CHELTENHAM
LEAMINGTON
WATFORD JN
GLOUCESTER
OXFORD
KX/ StP
CARDIFF
SWINDON
HEATHROW AIRPORT
EUSTON
B.PWAY
BATH
BRISTOL
DEDICATED HIGH SPEED LINE
READING
OLD OAK COMMON
PADDINGTON

5
ABERDEEN & HIGHLANDS
EDINBURGH
GLASGOW
HS2:
SECOND PHASE OPENED AS 'Y'
SUNDERLAND
NEWCASTLE
CARLISLE
MIDDLESBROUGH
DARLINGTON
POSSIBLE FUTURE EXTENSIONS OF HS2 ALONG WEST COAST CORRIDOR TO SCOTLAND & EAST COAST CORRIDOR TO NEWCASTLE
BLACKPOOL
YORK
BRADFORD
LEEDS
PRESTON
BOLTON
HULL
M'CHESTER
S'PORT
DONCASTER
SHEFFIELD
GRIMSBY
CHESTER
NORTH WALES
CREWE
C'FIELD
STOKE
STAFFORD
DERBY
NOTTINGHAM
PETERBORO'
SHREWSBURY
LEICESTER
WOLVERHAMPTON
BIRMINGHAM
BIRMINGHAM INTERCHANGE
COVENTRY
WORCESTER
LOOP TO HEATHROW HUB CONSTRUCTED IN SECOND PHASE
LUTON
RUGBY
MILTON KEYNES
STEVENAGE
CHELTENHAM
LEAMINGTON
WATFORD JN
GLOUCESTER
OXFORD
KX/ StP
CARDIFF
SWINDON
HEATHROW AIRPORT
EUSTON
B.PWAY
BATH
BRISTOL
READING
OLD OAK COMM
PADDINGTON


6
ABERDEEN &
HIGHLANDS
EDINBURGH
GLASGOW
HS2 VARIANT:
ALTERNATIVE HEATHROW-BIRMINGHAM-MANCHESTER-LEEDS HSR CONCEPT
SUNDERLAND
NEWCASTLE
CARLISLE
MIDDLESBROUGH
DARLINGTON
BLACKPOOL
YORK
BRADFORD
LEEDS
PRESTON
M'CHESTER
HULL
LIVERPOOL
DONCASTER
SHEFFIELD
CHESTER
GRIMSBY
NORTH
WALES
C'FIELD
CREWE
STOKE
STAFFORD
DERBY
NOTTINGHAM
PETERBORO'
SHREWSBURY
LEICESTER
WOLVERHAMPTON
BIRMINGHAM
BIRMINGHAM
INTERCHANGE
COVENTRY
WORCESTER
RUGBY
MILTON
KEYNES
LUTON
STEVENAGE
CHELTENHAM
LEAMINGTON
WATFORD
JN
GLOUCESTER
OXFORD
KX/
StP
CARDIFF
SWINDON
HEATHROW
HUB
B.P WAY
EUSTON
BATH
BRISTOL
READING
PADDINGTON


7
HIGH SPEED NORTH:
FIRST PHASE TO
E & W MIDLANDS
ABERDEEN &
HIGHLANDS
EDINBURGH
GLASGOW
CARLISLE
NEWCASTLE
SUNDERLAND
DARLINGTON
MIDDLESBROUGH
YORK
BLACKPOOL
PRESTON
WIGAN
BOLTON
BRADFORD
LEEDS
HULL
LIVERPOOL
M'CHESTER
W'TON
S'PORT
SHEFFIELD
DONCASTER
GRIMSBY
CHESTER
NORTH
WALES
CREWE
STOKE
C'FIELD
DERBY
NOTTINGHAM
STAFFORD
HIGH SPEED
SERVICES ON
CLASSIC LINE
SHREWSBURY
WOLVERHAMPTON
BIRMINGHAM
LEICESTER
PETERBORO'
DEDICATED
HIGH SPEED LINE
BIRM.
INT.
COVENTRY
RUGBY
WORCESTER
MILTON
KEYNES
LUTON
STEVENAGE
CRICKLE
-WOOD
CHELTENHAM
LEAMINGTON
WATFORD
JN
GLOUCESTER
OXFORD
KX/
StP
CARDIFF
SWINDON
HEATHROW
AIRPORT
EUSTON
B.PWAY
PADDINGTON
BATH
READING
BRISTOL
COMPASS POINT
NETWORK DEVELOPED
AROUND HEATHROW

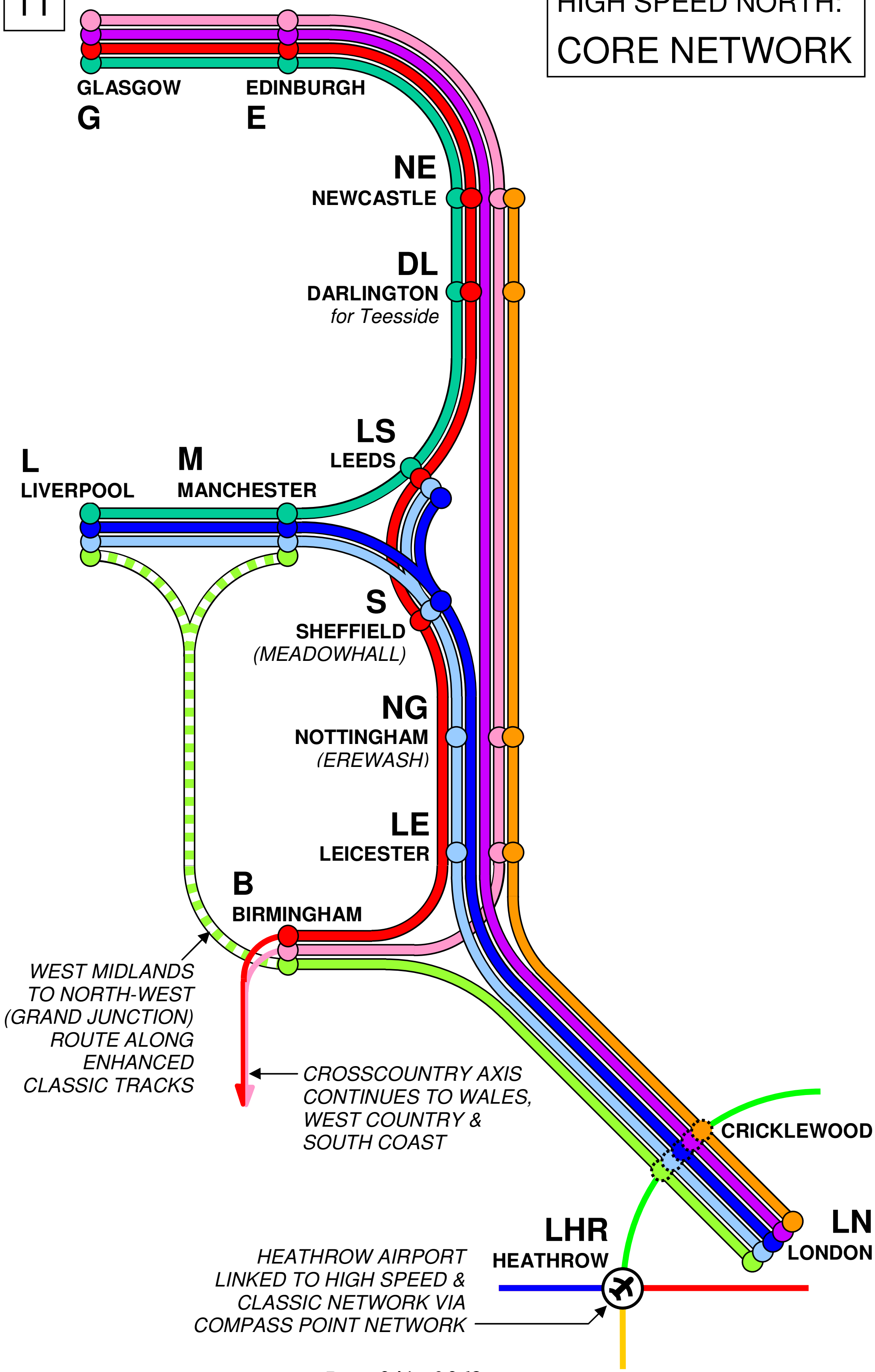

8
HIGH SPEED NORTH:
SECOND PHASE
TO NORTH
ABERDEEN &
HIGHLANDS
EDINBURGH
GLASGOW
CARLISLE
NEWCASTLE
SUNDERLAND
DARLINGTON
MIDDLESBROUGH
YORK
BLACKPOOL
PRESTON
WIGAN
BOLTON
BRADFORD
LEEDS
HULL
LIVERPOOL
M'CHESTER
W'TON
S'PORT
SHEFFIELD
DONCASTER
GRIMSBY
CHESTER
NORTH
WALES
CREWE
C'FIELD
STOKE
STAFFORD
DERBY
NOTTINGHAM
PETERBORO'
SHREWSBURY
WOLVERHAMPTON
LEICESTER
BIRMINGHAM
BIRM.
INT.
COVENTRY
WORCESTER
RUGBY
LUTON
MILTON
KEYNES
STEVENAGE
CRICKLE
-WOOD
CHELTENHAM
LEAMINGTON
WATFORD
JN
GLOUCESTER
OXFORD
KX/
StP
CARDIFF
SWINDON
HEATHROW
AIRPORT
EUSTON
B.PWAY
BATH
BRISTOL
READING
PADDINGTON

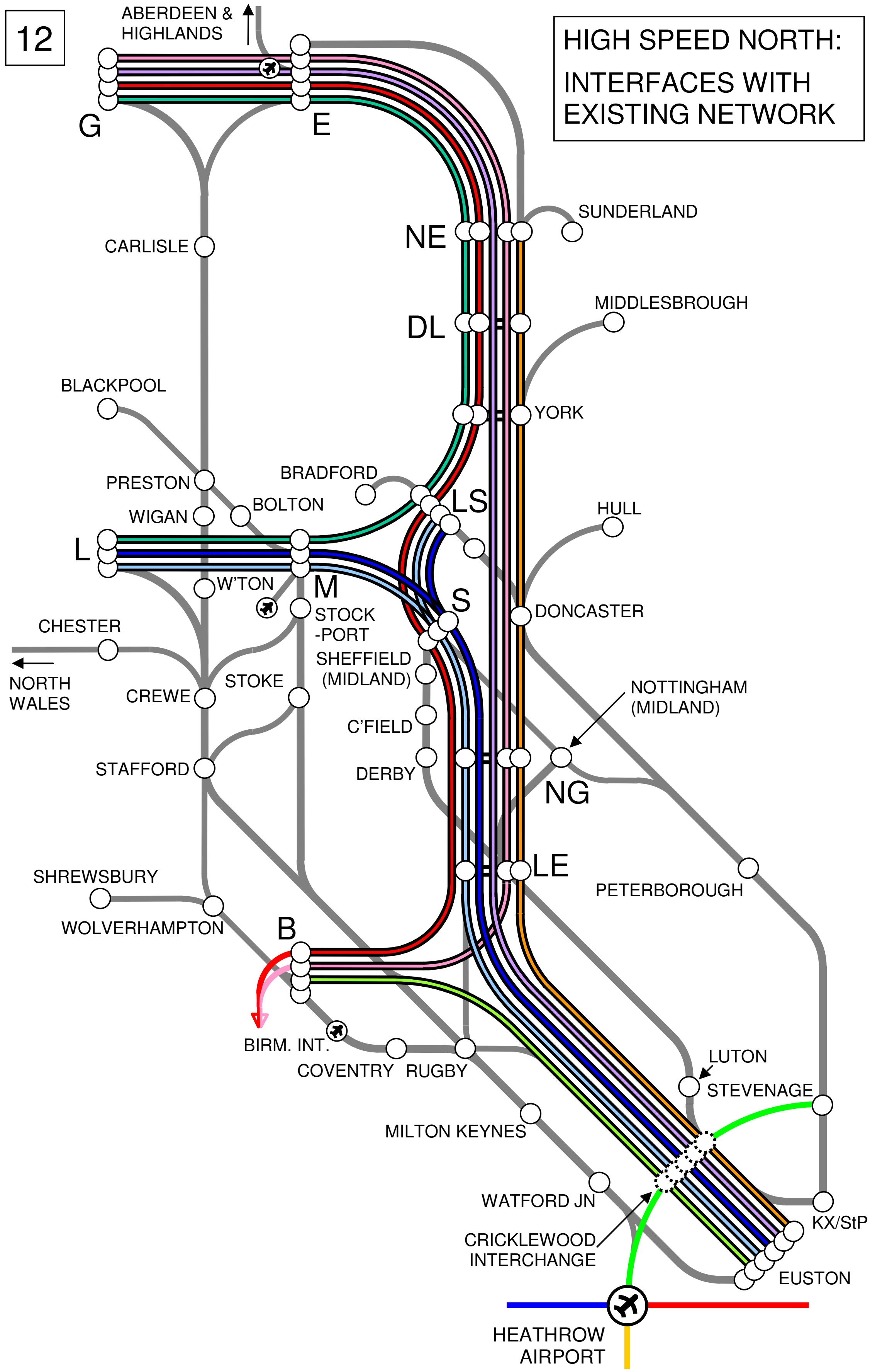

9
HIGH SPEED NORTH:
CORE NETWORK
TO SCOTLAND
ABERDEEN &
HIGHLANDS
EDINBURGH
GLASGOW
CARLISLE
NEWCASTLE
SUNDERLAND
DURHAM
DARLINGTON
MIDDLESBROUGH
YORK
BLACKPOOL
PRESTON
WIGAN
BOLTON
BRADFORD
LEEDS
HULL
LIVERPOOL
M'CHESTER
W'TON
S'PORT
SHEFFIELD
DONCASTER
GRIMSBY
CHESTER
NORTH
WALES
CREWE
C'FIELD
STOKE
STAFFORD
DERBY
NOTTINGHAM
PETERBORO'
SHREWSBURY
LEICESTER
WOLVERHAMPTON
BIRMINGHAM
BIRM.
INT.
COVENTRY
WORCESTER
RUGBY
LUTON
MILTON
KEYNES
STEVENAGE
CHELTENHAM
LEAMINGTON
CRICKLE
-WOOD
WATFORD
JN
GLOUCESTER
OXFORD
KX/
StP
CARDIFF
SWINDON
HEATHROW
AIRPORT
B.PWAY
EUSTON
BRISTOL
BATH
READING
PADDINGTON


10
HIGH SPEED NORTH:
HS GRAND JUNCTION
& HS WEST ADDED
ABERDEEN &
HIGHLANDS
EDINBURGH
GLASGOW
SUNDERLAND
NEWCASTLE
CARLISLE
DURHAM
MIDDLESBROUGH
DARLINGTON
BLACKPOOL
YORK
BRADFORD
LEEDS
HULL
PRESTON
BOLTON
WIGAN
M'CHESTER
LIVERPOOL
W'TON
S'PORT
DONCASTER
GRIMSBY
SHEFFIELD
CHESTER
NORTH
WALES
C'FIELD
CREWE
STOKE
HIGH
SPEED
GRAND
JUNCTION
STAFFORD
DERBY
NOTTINGHAM
PETERBORO'
SHREWSBURY
HIGH
SPEED
NORTH
LEICESTER
WOLVERHAMPTON
DEDICATED NEW
LINE SHOWN
WITH BLACK
BACKING
BIRMINGHAM
BIRM.
INT.
COVENTRY
HSW & HSGJ
GENERALLY
COMPRISE
UPGRADES
OF EXISTING
ROUTES
RUGBY
LUTON
MILTON
KEYNES
STEVENAGE
CHELTENHAM
LEAMINGTON
CRICKLE
-WOOD
HIGH
SPEED
WEST
WATFORD
JN
GLOUCESTER
OXFORD
KX/
StP
CARDIFF
SWINDON
HEATHROW
AIRPORT
EUSTON
B.PWAY
BATH
READING
PADDINGTON
BRISTOL

11

HIGH SPEED NORTH:
CORE NETWORK




12
HIGH SPEED NORTH:
INTERFACES WITH EXISTING NETWORK
ABERDEEN & HIGHLANDS
G
E
NE
DL
LS
L
M
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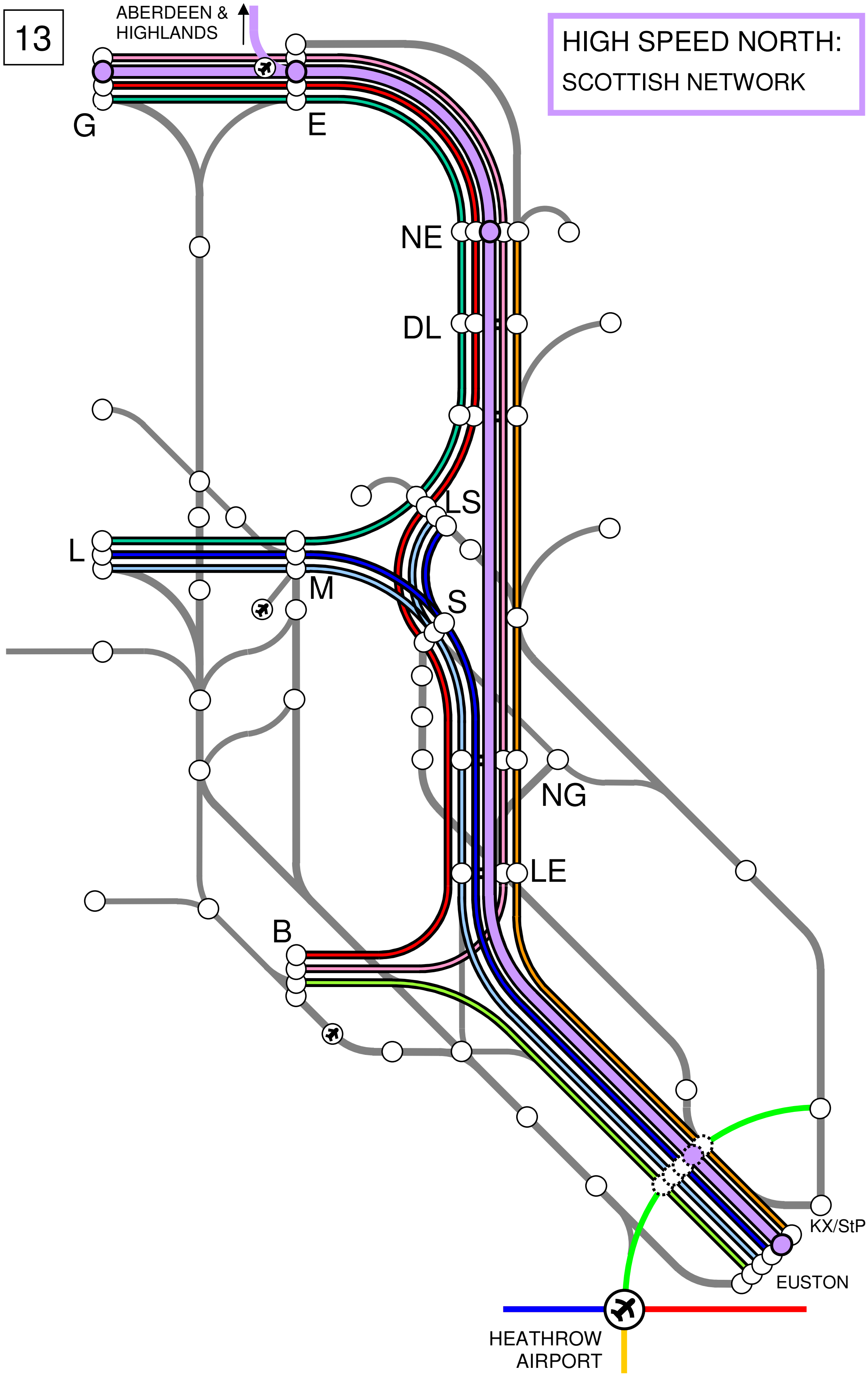
NG
LE
B
SUNDERLAND
CARLISLE
MIDDLESBROUGH
BLACKPOOL
YORK
PRESTON
BRADFORD
BOLTON
WIGAN
HULL
W'TON
STOCK -PORT
DONCASTER
CHESTER
NORTH WALES
SHEFFIELD (MIDLAND)
CREWE
STOKE
NOTTINGHAM (MIDLAND)
C'FIELD
STAFFORD
DERBY
SHREWSBURY
PETERBOROUGH
WOLVERHAMPTON
BIRM. INT.
COVENTRY
RUGBY
LUTON
STEVENAGE
MILTON KEYNES
WATFORD JN
KX/StP
CRICKLEWOOD INTERCHANGE
EUSTON
HEATHROW AIRPORT


13
ABERDEEN &
HIGHLANDS
HIGH SPEED NORTH:
SCOTTISH NETWORK
G
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NE
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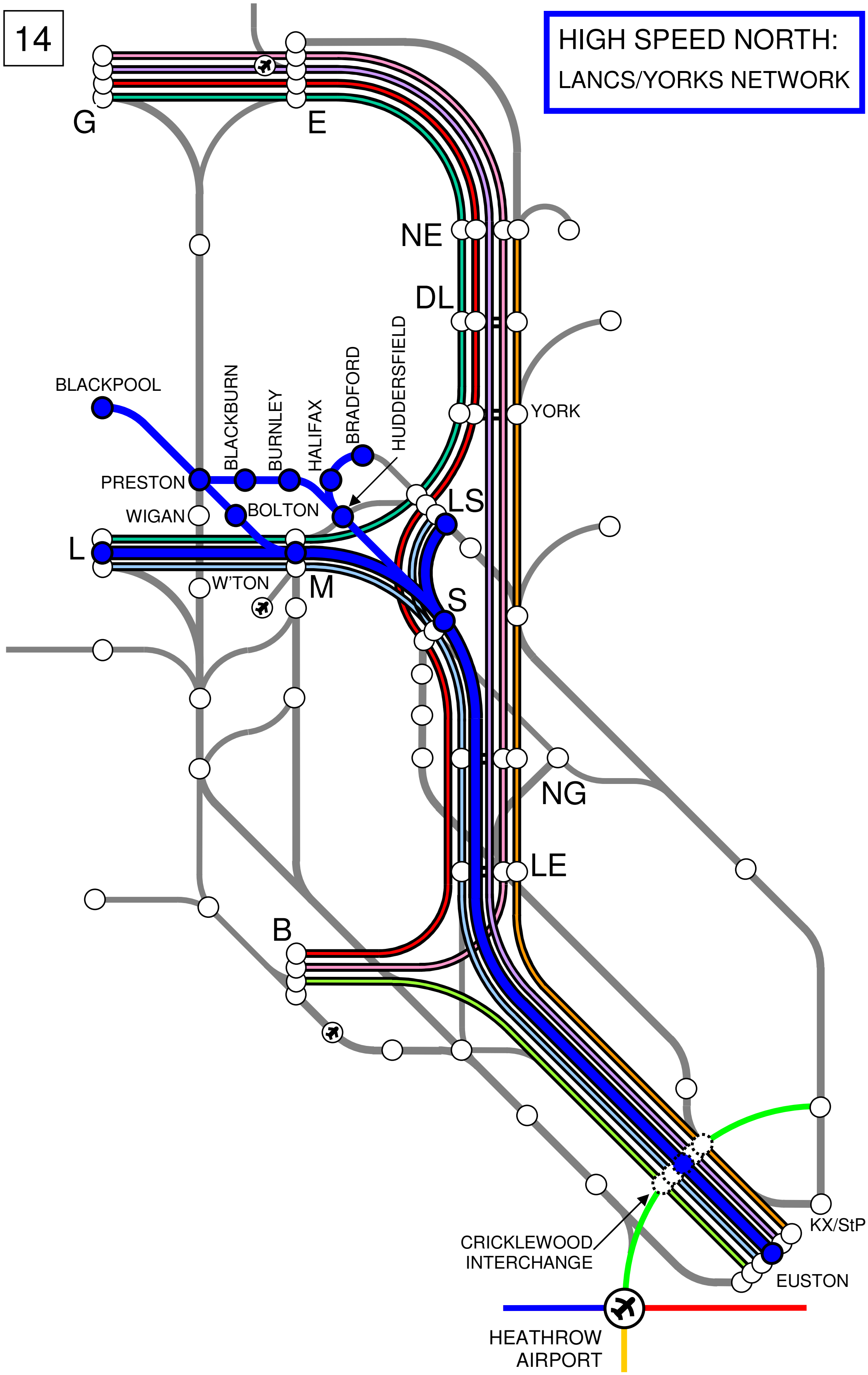
KX/StP
EUSTON
HEATHROW
AIRPORT



14
HIGH SPEED NORTH:
LANCS/YORKS NETWORK
G
E
NE
DL
YORK
BLACKPOOL
BLACKBURN
BURNLEY
HALIFAX
BRADFORD
HUDDERSFIELD
PRESTON
WIGAN
BOLTON
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W'TON
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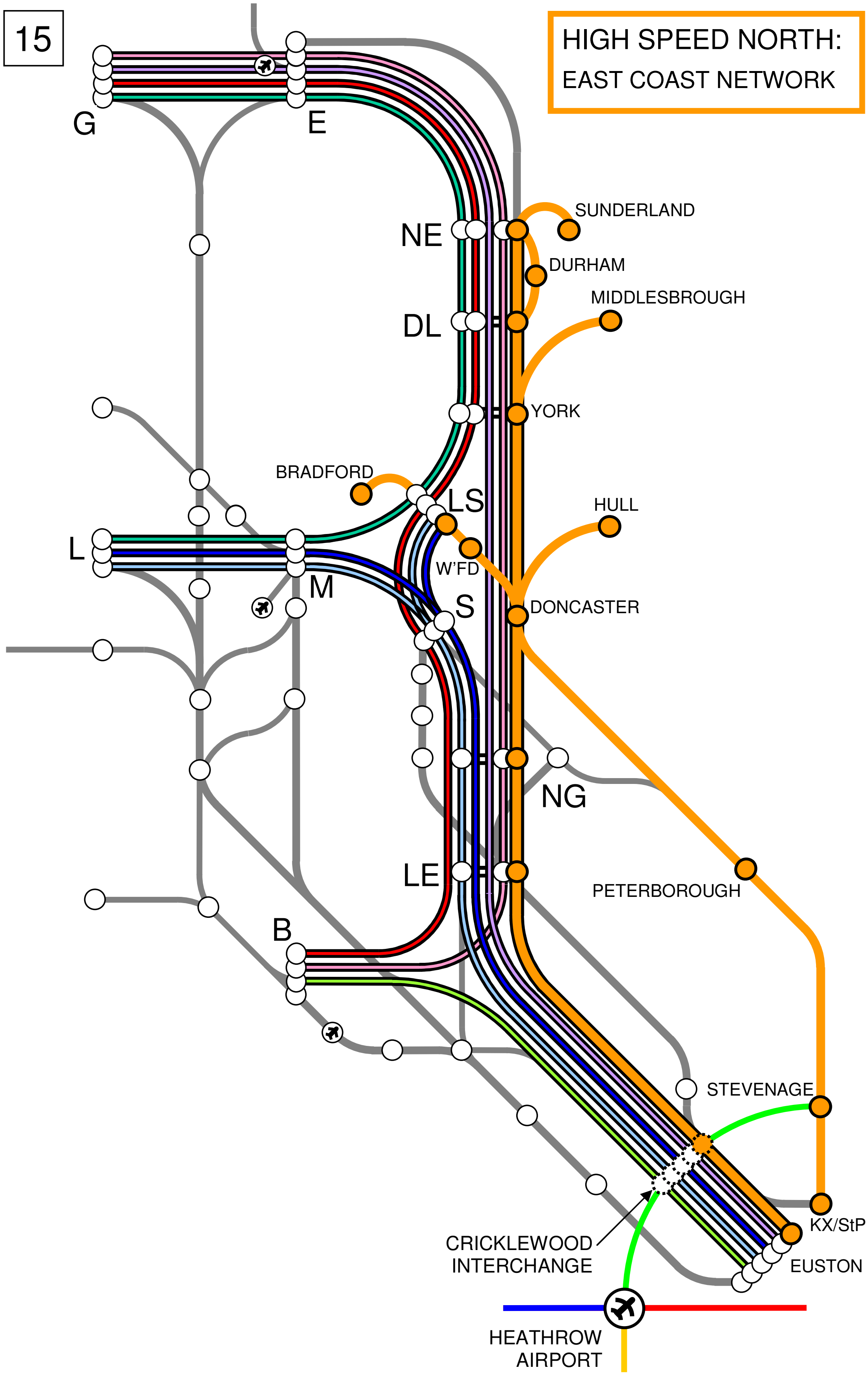
CRICKLEWOOD
INTERCHANGE
KX/StP
EUSTON
HEATHROW
AIRPORT


15
HIGH SPEED NORTH:
EAST COAST NETWORK
G
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W'FD
S
NG
LE
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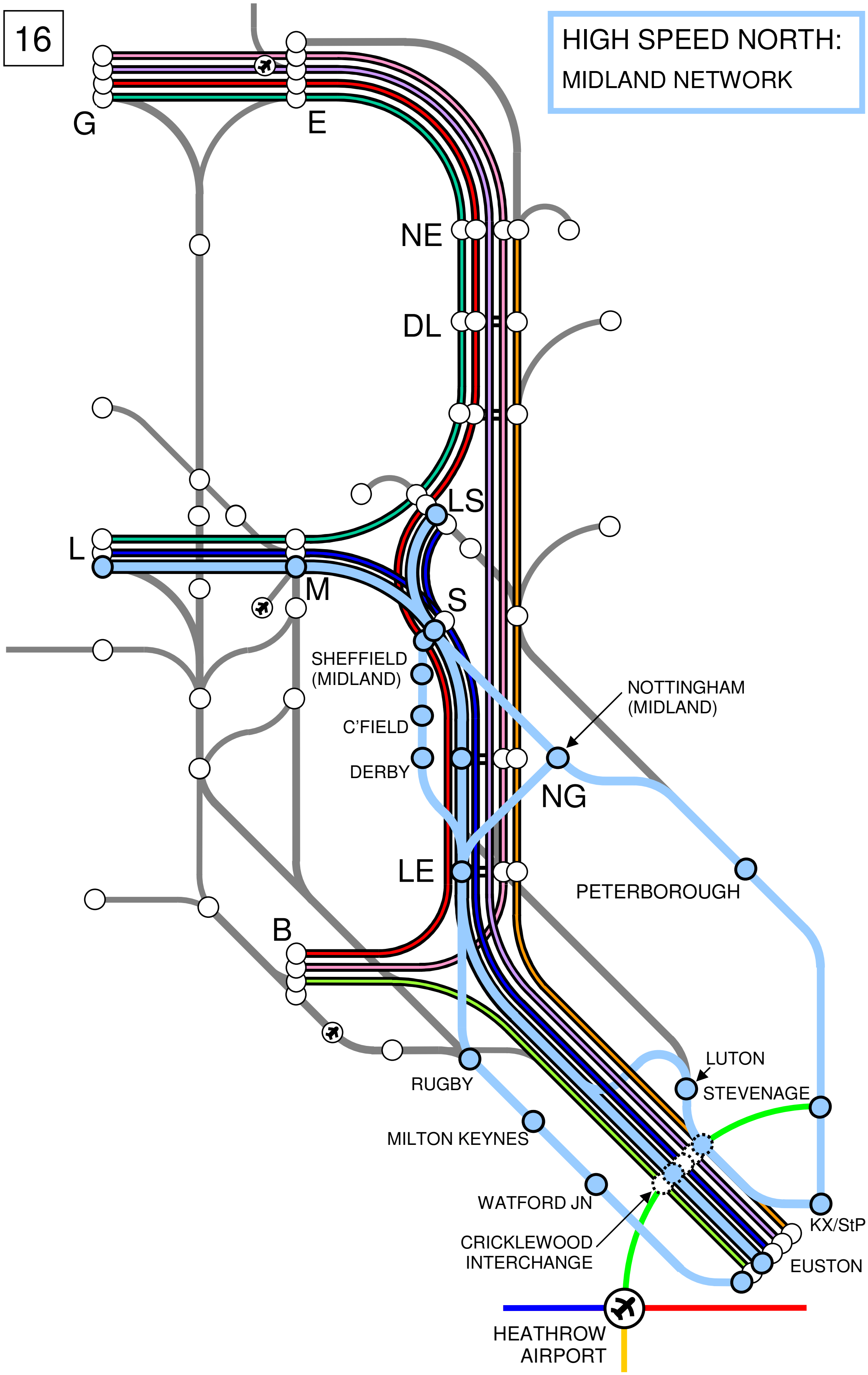
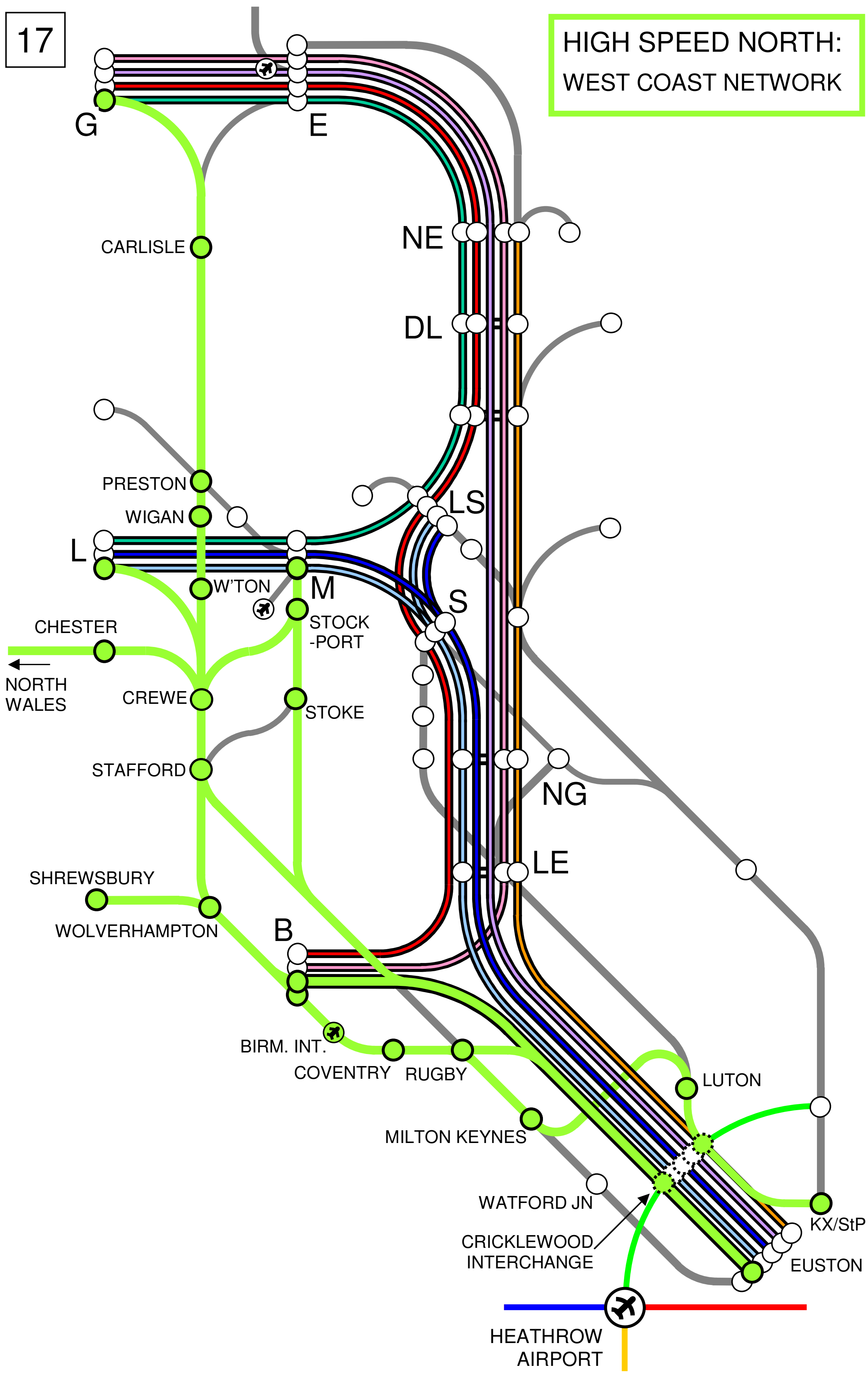
SUNDERLAND
DURHAM
MIDDLESBROUGH
YORK
BRADFORD
HULL
DONCASTER
PETERBOROUGH
STEVENAGE
KX/StP
EUSTON
CRICKLEWOOD
INTERCHANGE
HEATHROW
AIRPORT



16
HIGH SPEED NORTH:
MIDLAND NETWORK
G
E
NE
DL
LS
L
M
S
SHEFFIELD (MIDLAND)
C'FIELD
DERBY
NOTTINGHAM (MIDLAND)
NG
LE
PETERBOROUGH
B
RUGBY
LUTON
STEVENAGE
MILTON KEYNES
WATFORD JN
KX/StP
CRICKLEWOOD INTERCHANGE
EUSTON
HEATHROW AIRPORT



17
HIGH SPEED NORTH:
WEST COAST NETWORK
G
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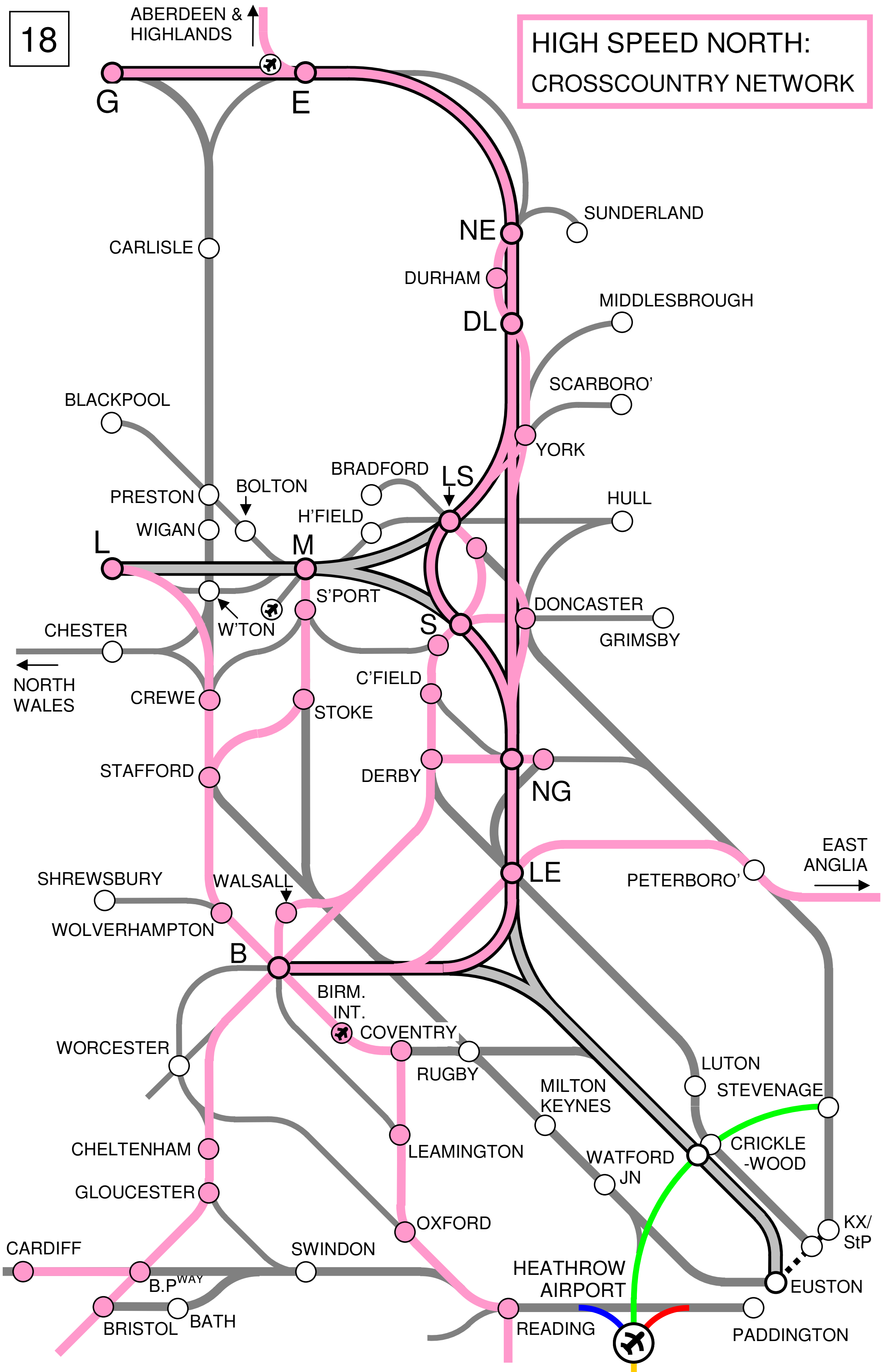
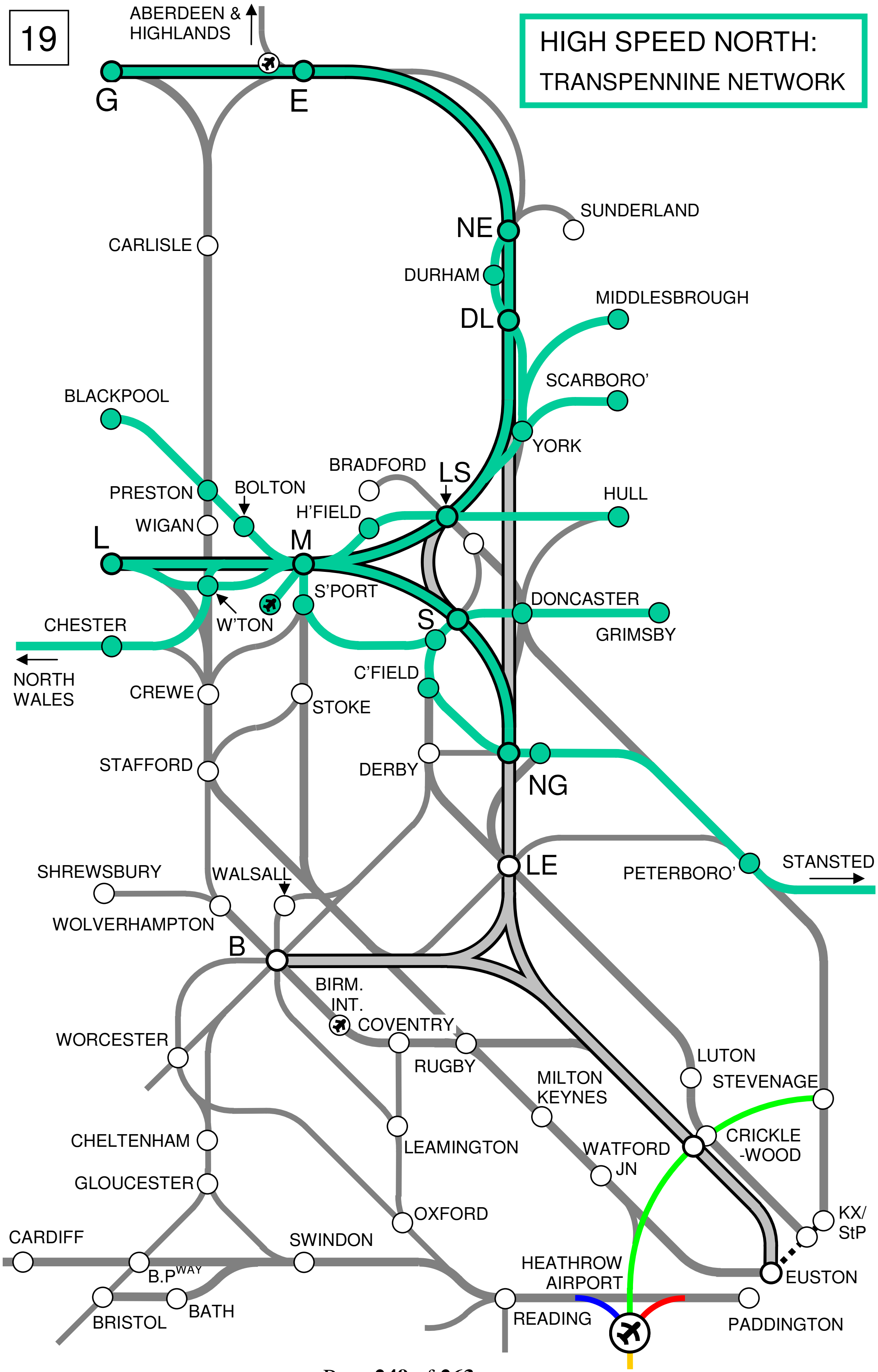
NE
DL
LS
S
NG
LE
L
M
B
CARLISLE
PRESTON
WIGAN
W'TON
STOCK
-PORT
CHESTER
NORTH
WALES
CREWE
STOKE
STAFFORD
SHREWSBURY
WOLVERHAMPTON
BIRM. INT.
COVENTRY
RUGBY
MILTON KEYNES
LUTON
WATFORD JN
CRICKLEWOOD
INTERCHANGE
KX/StP
EUSTON
HEATHROW
AIRPORT



18
ABERDEEN & HIGHLANDS
HIGH SPEED NORTH:
CROSSCOUNTRY NETWORK
G
E
NE
SUNDERLAND
CARLISLE
DURHAM
DL
MIDDLESBROUGH
SCARBORO'
BLACKPOOL
YORK
BRADFORD
LS
PRESTON
BOLTON
H'FIELD
HULL
WIGAN
L
M
S'PORT
DONCASTER
GRIMSBY
W'TON
S
CHESTER
NORTH WALES
C'FIELD
CREWE
STOKE
STAFFORD
DERBY
NG
EAST ANGLIA
SHREWSBURY
WALSALL
LE
PETERBORO'
WOLVERHAMPTON
B
BIRM. INT.
COVENTRY
WORCESTER
RUGBY
LUTON
MILTON KEYNES
STEVENAGE
CRICKLE -WOOD
CHELTENHAM
LEAMINGTON
WATFORD JN
GLOUCESTER
OXFORD
KX/ StP
CARDIFF
SWINDON
HEATHROW AIRPORT
EUSTON
B.PWAY
BRISTOL
BATH
READING
PADDINGTON


19
HIGH SPEED NORTH:
TRANSPENNINE NETWORK
ABERDEEN &
HIGHLANDS
G
E
SUNDERLAND
NE
CARLISLE
DURHAM
MIDDLESBROUGH
DL
SCARBORO'
BLACKPOOL
YORK
BRADFORD
LS
HULL
PRESTON
BOLTON
H'FIELD
WIGAN
L
M
DONCASTER
S'PORT
S
GRIMSBY
CHESTER
W'TON
NORTH
WALES
C'FIELD
CREWE
STOKE
STAFFORD
DERBY
NG
SHREWSBURY
WALSALL
LE
PETERBORO'
STANSTED
WOLVERHAMPTON
B
BIRM.
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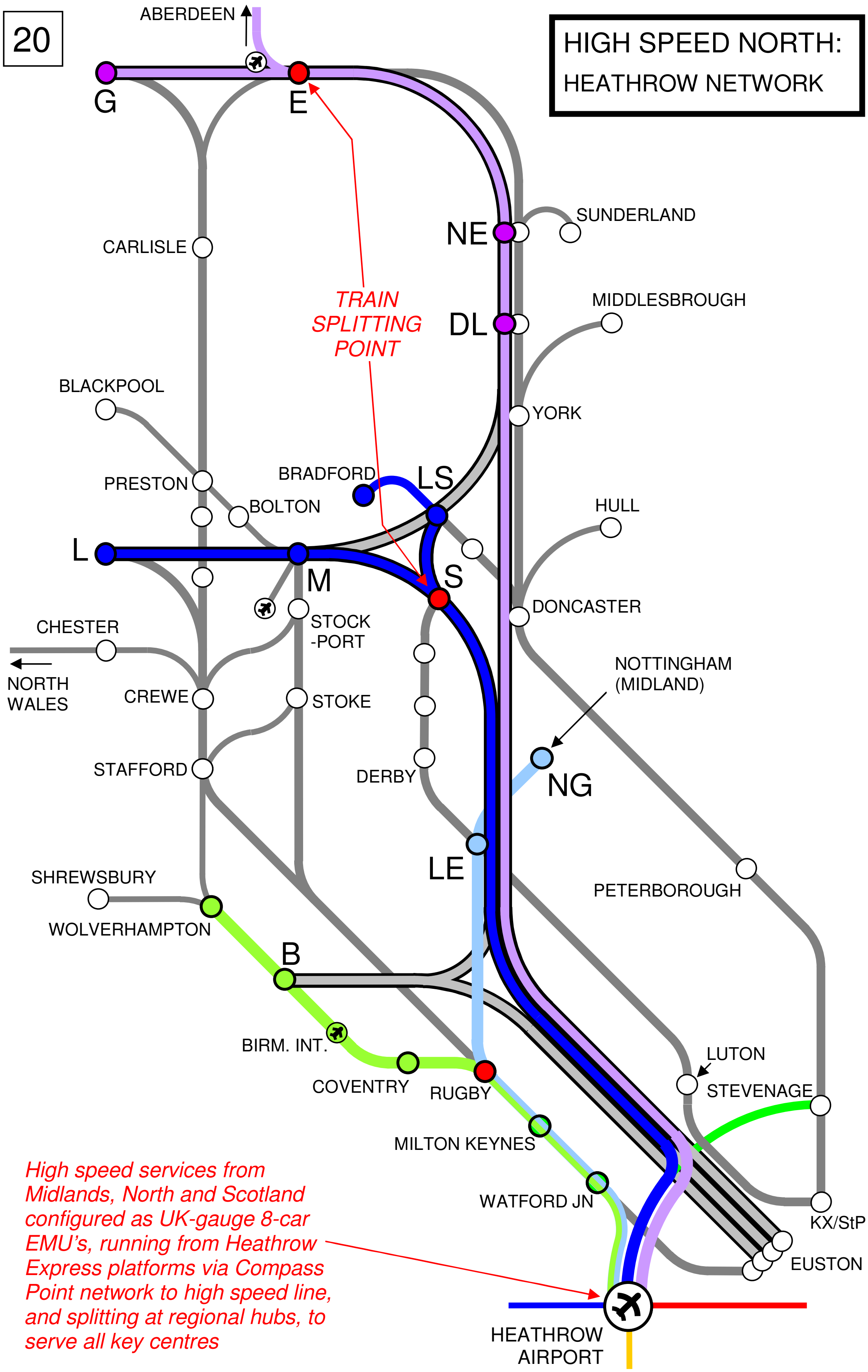
COVENTRY
WORCESTER
RUGBY
LUTON
MILTON
KEYNES
STEVENAGE
CRICKLE
-WOOD
CHELTENHAM
LEAMINGTON
WATFORD
JN
GLOUCESTER
OXFORD
KX/
StP
CARDIFF
SWINDON
HEATHROW
AIRPORT
EUSTON
B.P WAY
BATH
READING
BRISTOL
PADDINGTON

20

HIGH SPEED NORTH: HEATHROW NETWORK

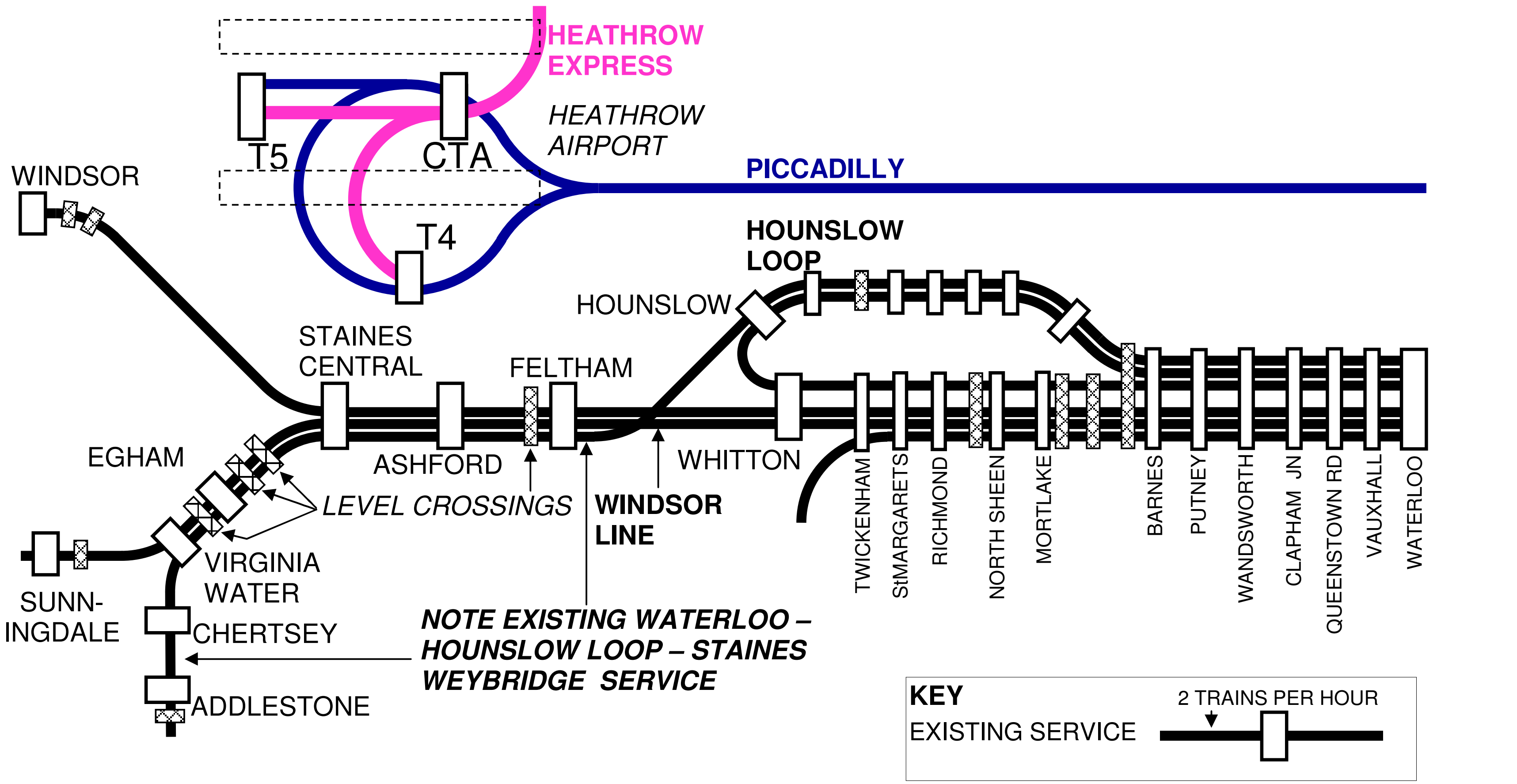


Appendix G3 :

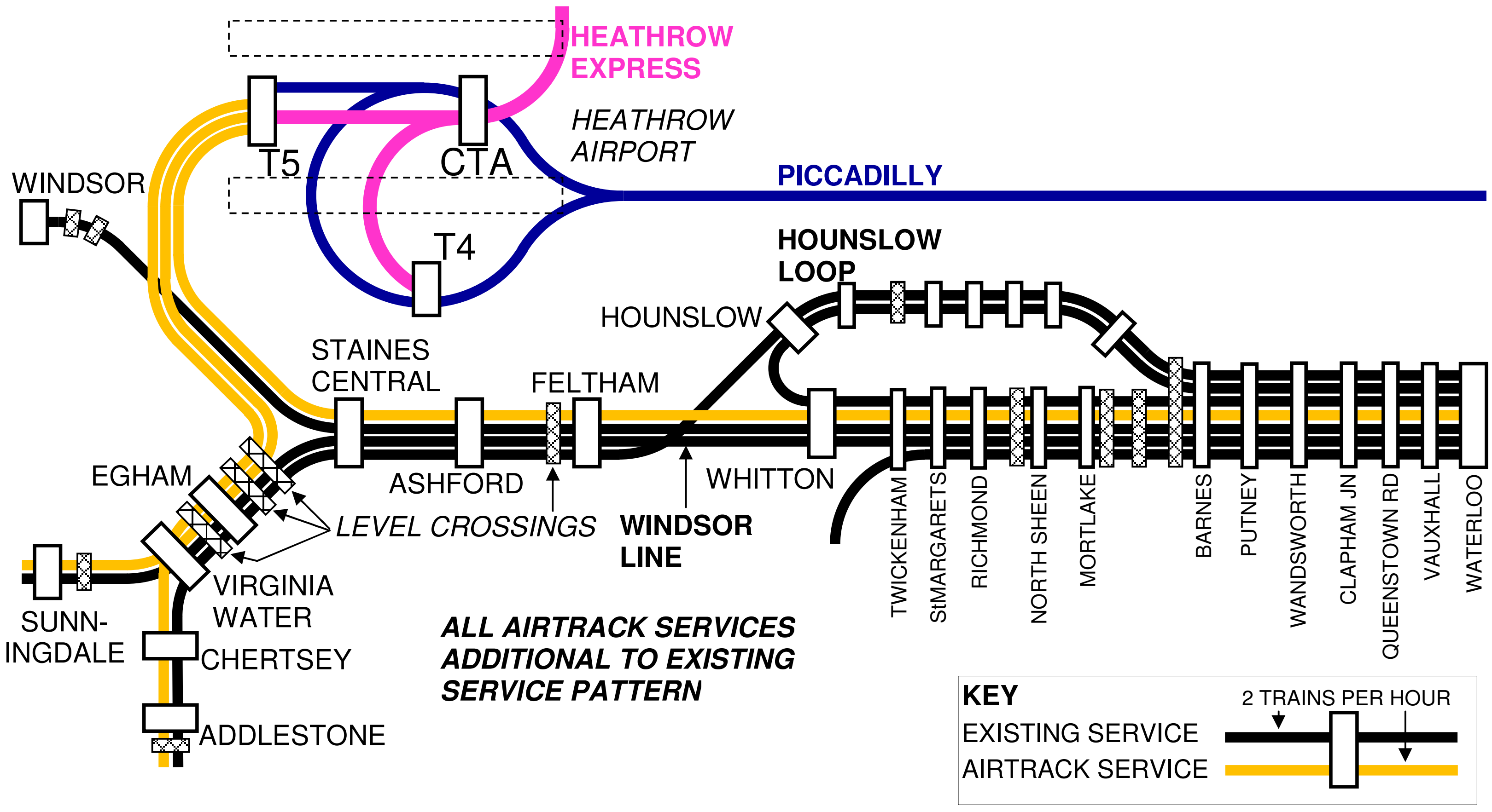
Alternative ‘Airtrack’ Concepts

The diagrams on the following pages are essentially an amplification of Figure F25. They illustrate:

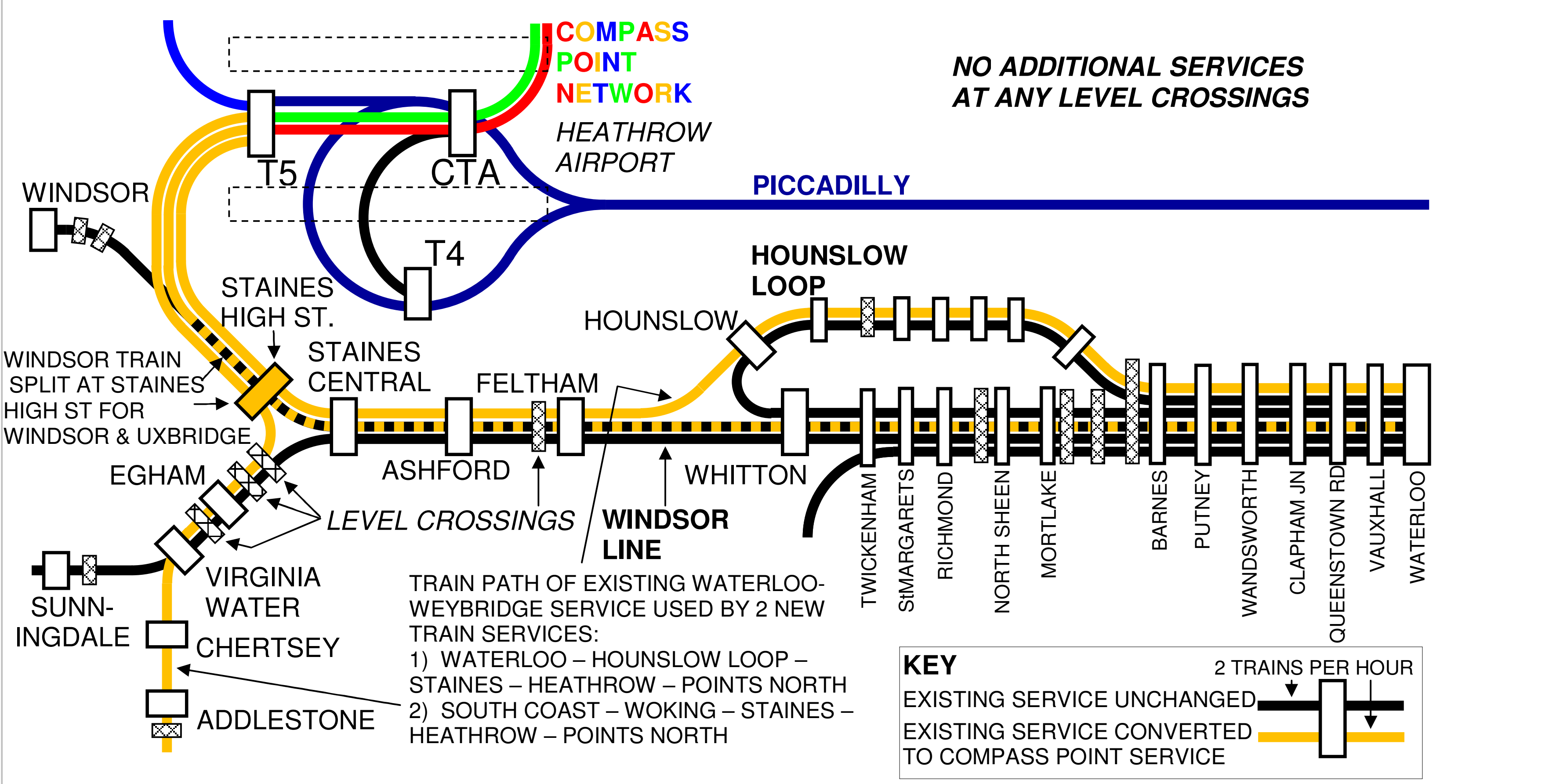
- the existing train service pattern that applies on the London-Staines-Reading/Windsor line (aka the ‘Windsor Line’) at the critical level crossing locations at Mortlake and Runnymede,
- the effects of superimposing extra trains to serve Heathrow on top of the existing service pattern (as per current Airtrack proposals).
- the opportunity to integrate existing services with airport services (as Airtrack-*lite*), and to meet the Airtrack specification of 6 trains per hour to Heathrow, yet avoid increasing train frequencies at any level crossing. This proposal is part of the wider ‘Compass Point’ network, covered at length in this study.



Windsor Line – Existing Service Pattern



Airtrack services, superimposed on existing service pattern



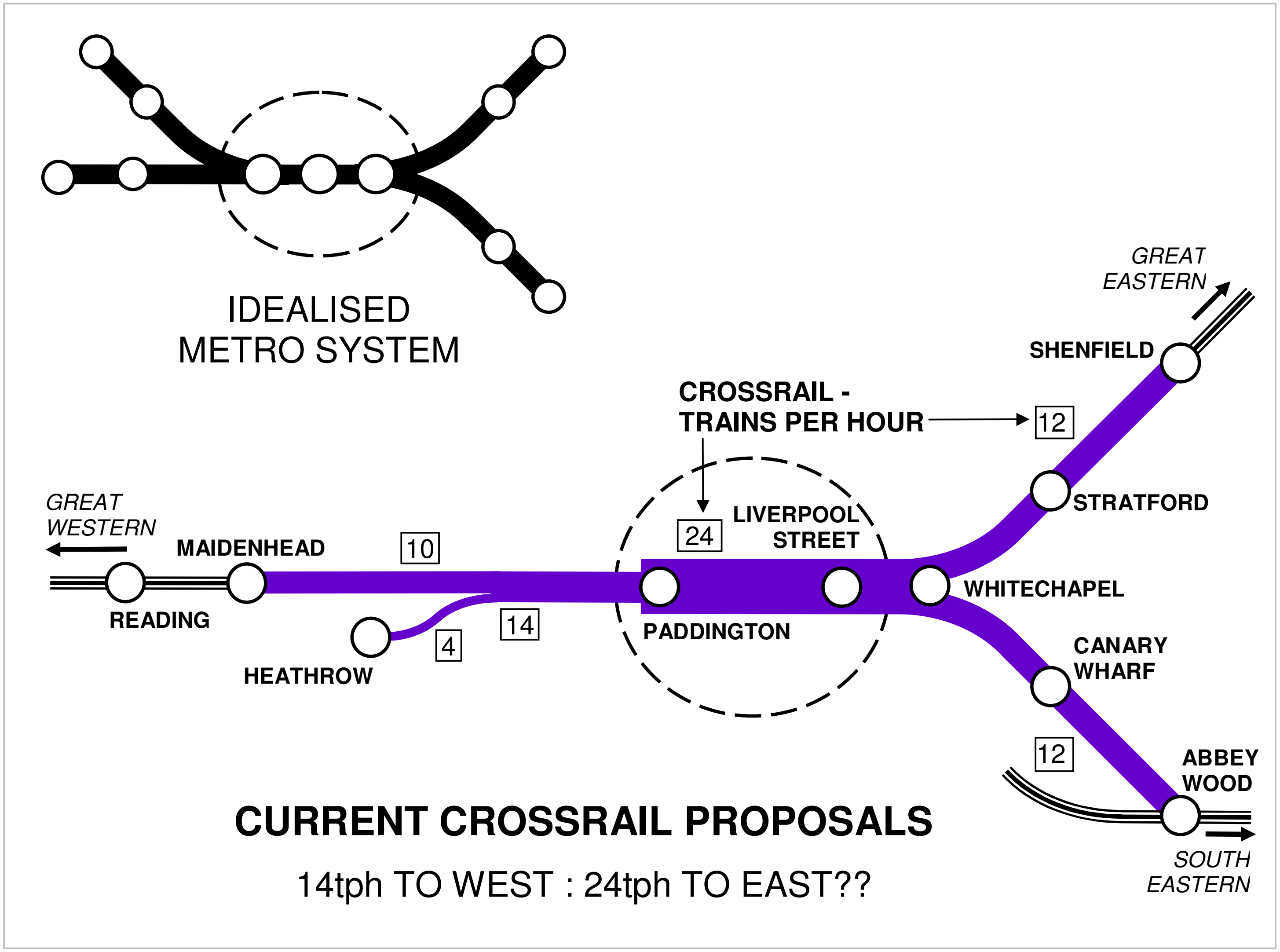
Compass Point Services, integrated with existing service pattern

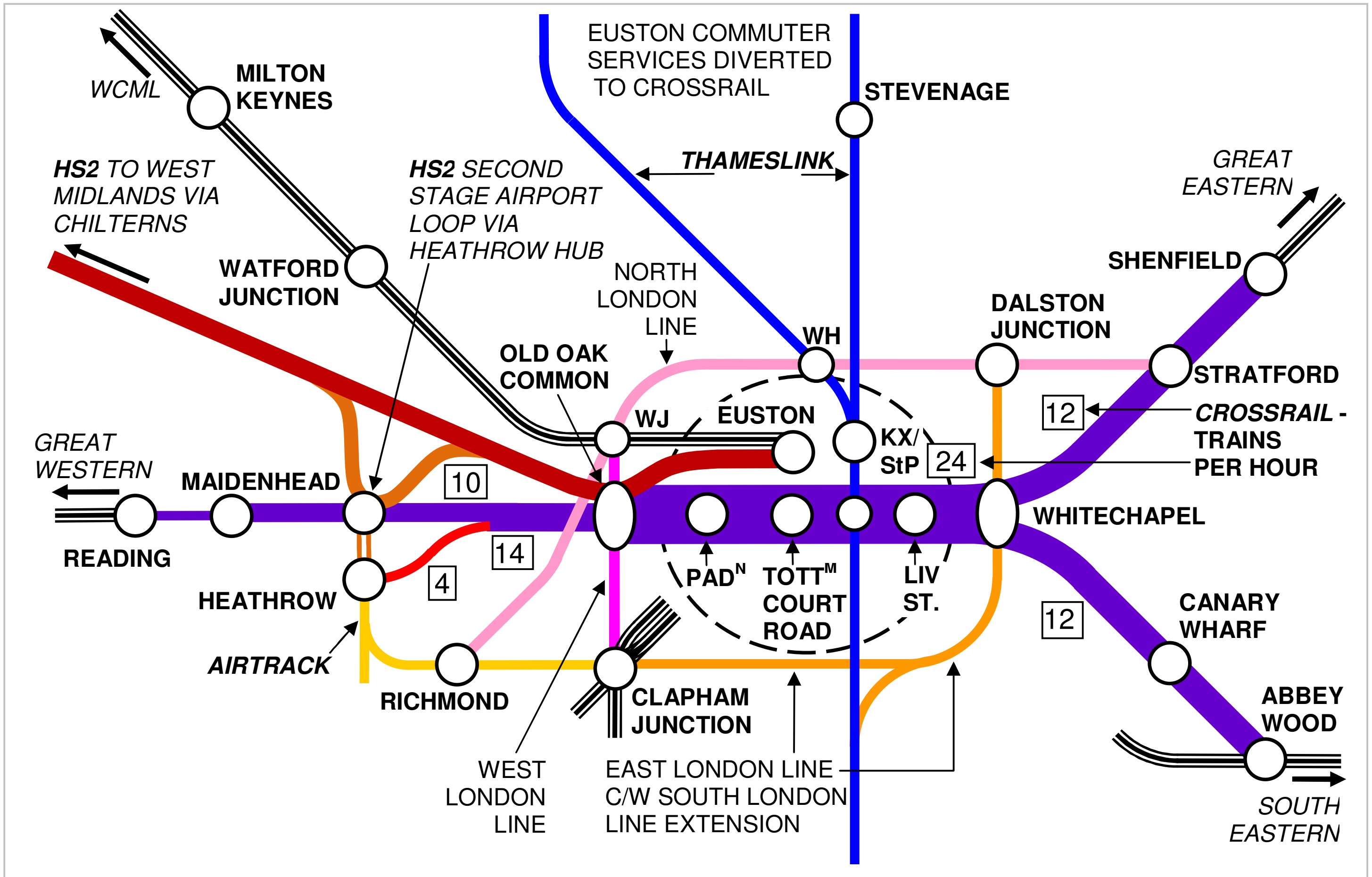
Appendix G4 :

Integration of Euston High Speed Terminal with CrossRail, Thamelink and Orbital Rail

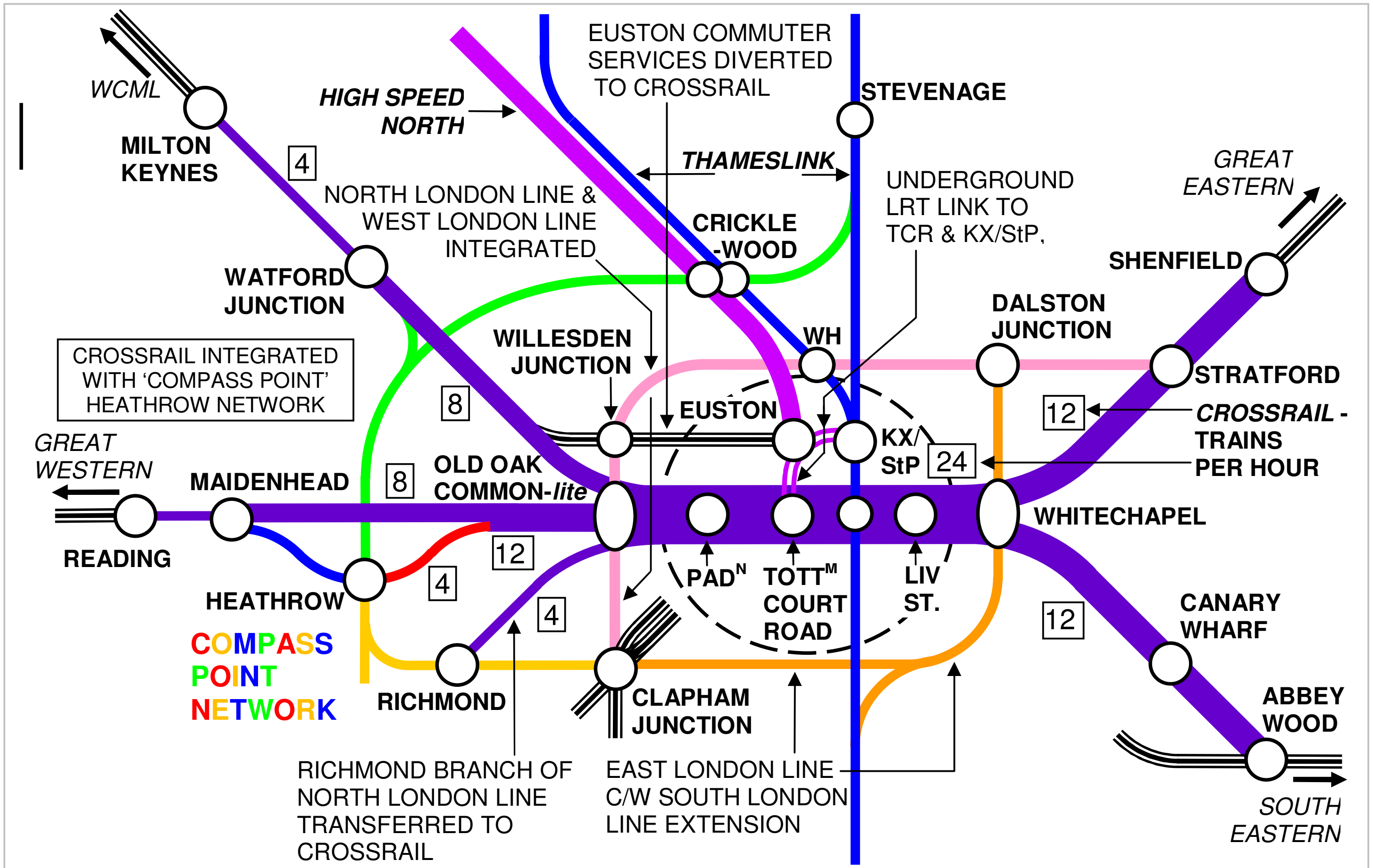
The diagrams on the following pages illustrate:

- existing CrossRail proposals in which 10 trains per hour of proposed 24tph cross-London service will terminate at Paddington, and only 14tph will continue onto the Great Western main line towards Heathrow, Slough and Maidenhead.
- HS2 London terminal solution, with hybrid combination of Old Oak Common and Euston. Note requirement to physically expand station proposal to accommodate high speed and commuter traffic. Meanwhile 24tph CrossRail service from Paddington extended to Old Oak Common.
- High Speed North London terminal solution, with proposed connection from WCML to CrossRail (at surface level Old Oak Common-lite) to balance flows, and to divert WCML commuter flows from Euston, thus easing Tube transfers there and removing need to physically expand station.
- proposed LRT system operating as 'dumbell' between Tottenham Court Road, Euston and Kings Cross / St Pancras. This will deliver incoming high speed passengers from mid-platform at Euston to adjacent Tube/rail hubs at Tottenham Court Road (CrossRail and Central Line) and Kings Cross St Pancras (Thameslink, Piccadilly, Circle/Met plus Northern and Victoria. Overall, this system would connect to both cross-London heavy rail lines, and 7 out of 10 Tube lines. Overlaid lines indicate relative levels at which Tube tunnels intersect.
- HS2 London Connectivity, with accompanying notes.
- High Speed North London Connectivity, with accompanying notes.

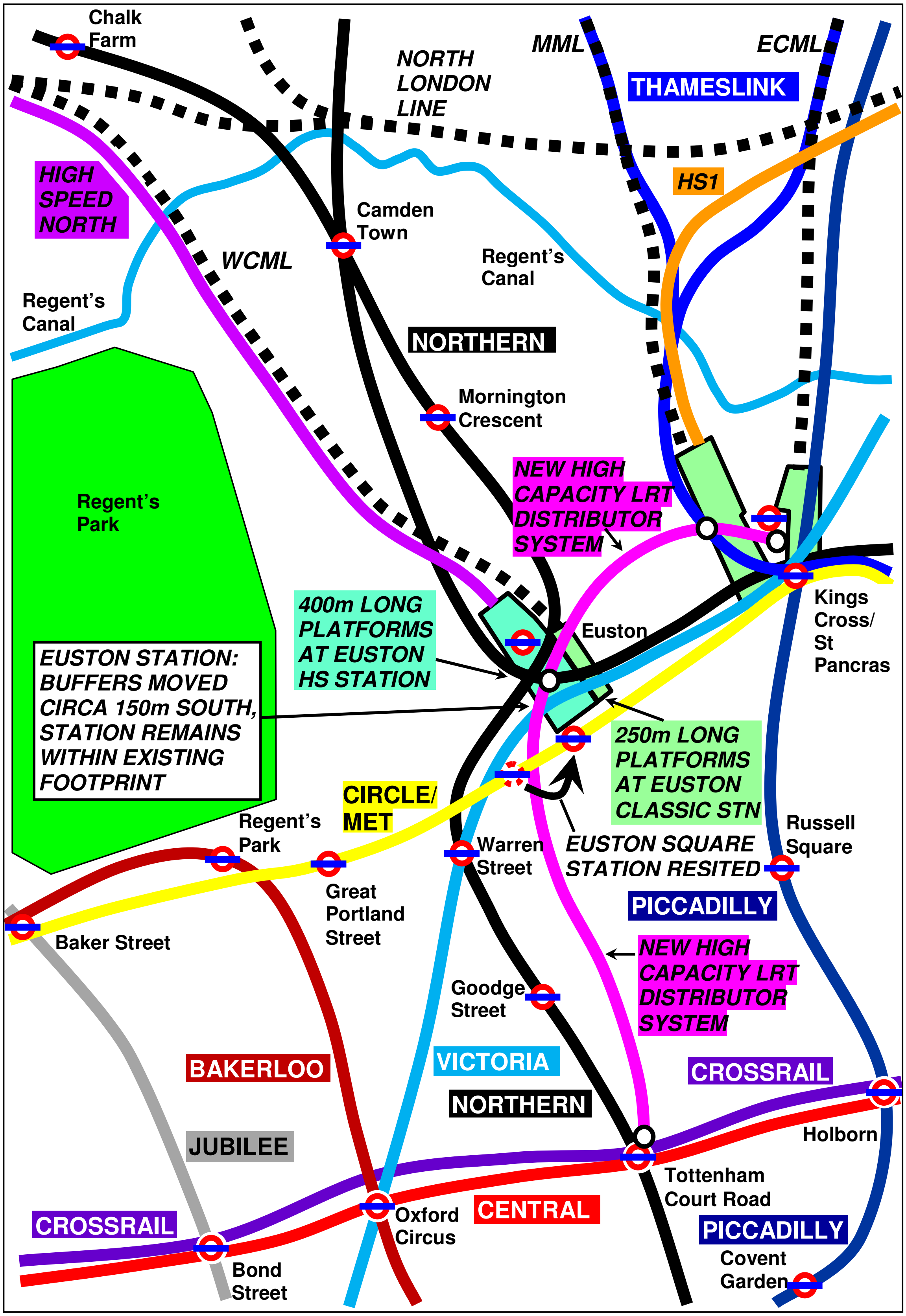

IDEALISED
METRO SYSTEM
GREAT
EASTERN
SHENFIELD
CROSSRAIL -
TRAINS PER HOUR
12
STRATFORD
GREAT
WESTERN
MAIDENHEAD
10
24
LIVERPOOL
STREET
WHITECHAPEL
READING
14
PADDINGTON
CANARY
WHARF
4
HEATHROW
12
ABBEY
WOOD
CURRENT CROSSRAIL PROPOSALS
14tph TO WEST : 24tph TO EAST??
SOUTH
EASTERN



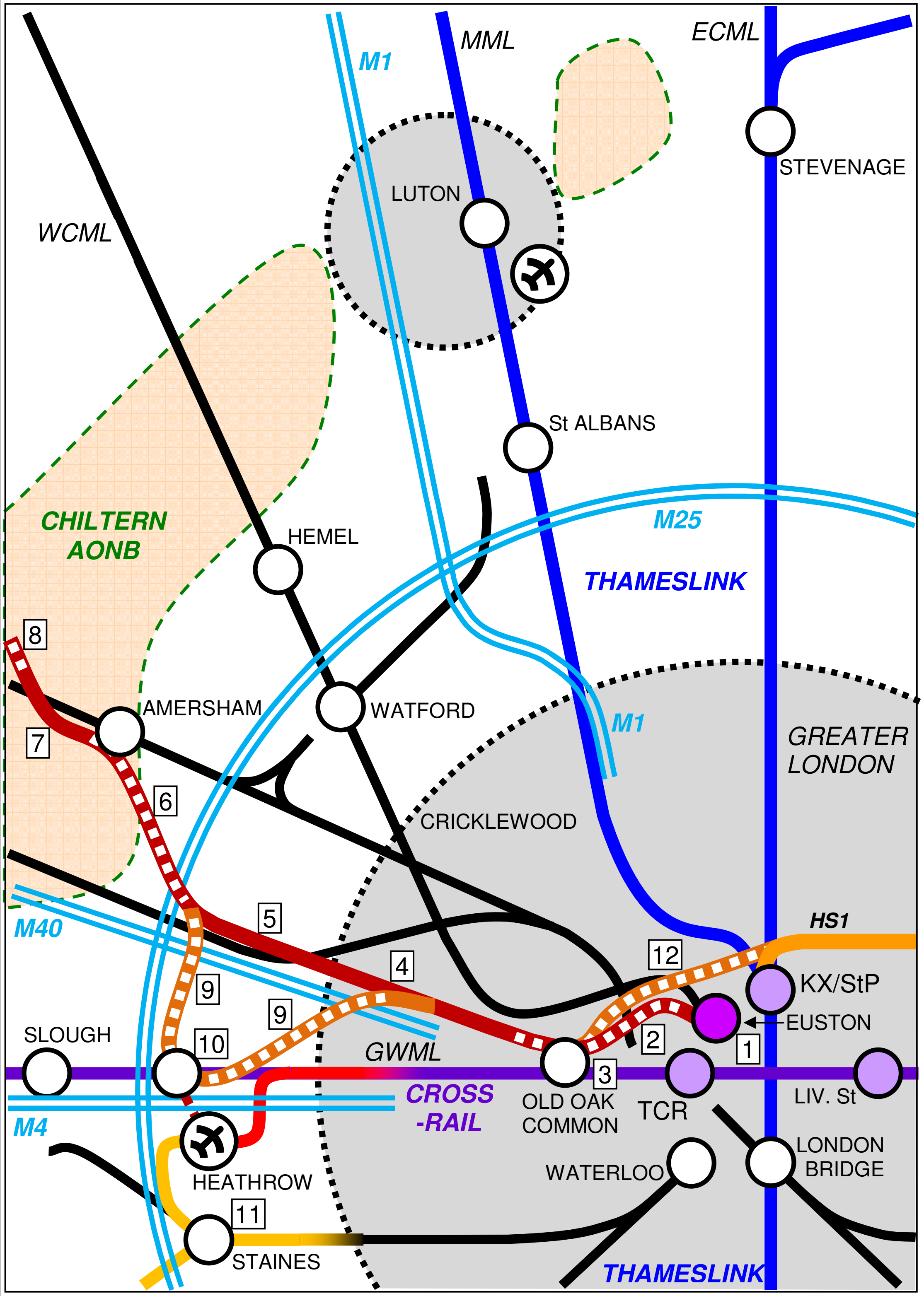
HS2 : CONNECTIONS TO CROSSRAIL, THAMESLINK & ORBITAL RING



HIGH SPEED NORTH : CONNECTIONS TO CROSSRAIL, THAMESLINK & ORBITAL RING

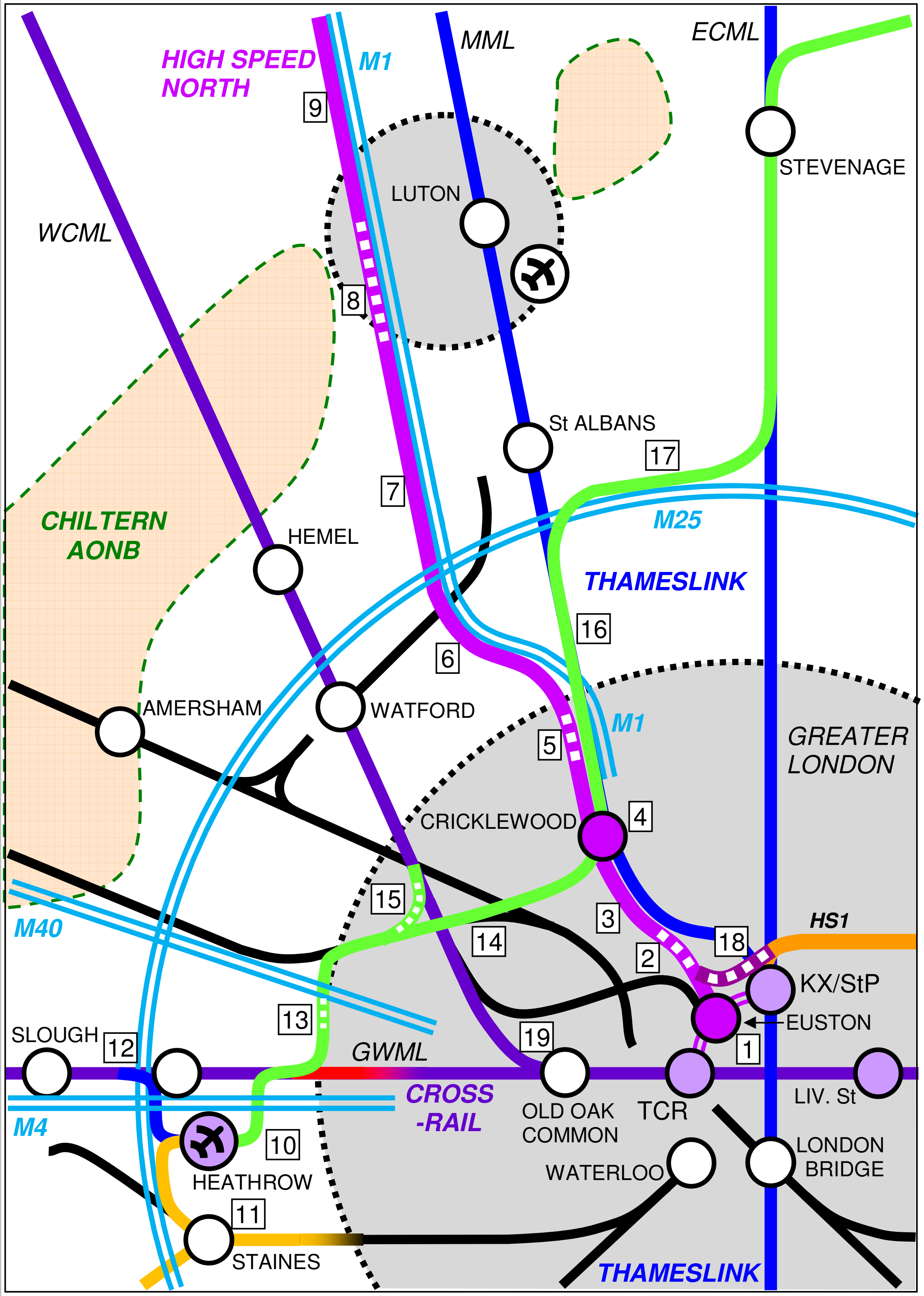


High Speed North Euston Terminal : Proposed LRT Link to Adjacent Tube Hubs



HS2 : London Connectivity

	Notes re HS2	Tunnel length (km)	Land-take reqd??
1	HS2 terminal at Euston, expanded 50m to west to accommodate HS platforms and existing commuter traffic. No improvement proposed to Tube links.		Y
2	HS2 heads west from Euston in tunnel to Park Royal	9	N
3	Interchange station (with CrossRail and Heathrow services) at Old Oak Common, constructed in massive box (similar to Stratford).		N
4	HS2 follows Central Line corridor from Park Royal to Northolt Junction		N
5	HS2 follows Chiltern Line from Northolt Junction to West Ruislip		Y
6	HS2 in tunnel from M25 to west of Amersham	9	N
7	HS2 in deep cutting in Misbourne valley		Y
8	HS2 in tunnel at Hyde Heath	2	N
9	Second stage development of HS2 provides largely tunnelled loop connection to 'hub' station on GWML north of Heathrow. Approx 20km of HSL tunnel required.	20	Y
10	Hub station constructed on GWML, with approx 10km of tunnelled distributors to access airport terminals from hub.	10	Y
11	Link to south via 'Airtrack' (not part of HS2 project) recently cancelled due to excessive impact at level crossings.		N
12	HS2-HS1 link achieved by means of approx 8km tunnel from Old Oak Common to Camden	8	N
	Total tunnelled length (km)	58	
	Total length of new railway (measured to north slope of Chilterns) (km)		95



High Speed North : London Connectivity

	Notes re High Speed North (HSN)	Tunnel length (km)	Land-take reqd??
1	HSN terminal at Euston, dedicated new light rapid transit links to Kings Cross / St Pancras and to Tottenham Court Road, linking to 7 (out of 10) Tube lines and to Thameslink and CrossRail. No requirement for landtake on surrounding property.	2	N
2	HSN routed along reengineered Euston approaches, connection to MML corridor via tunnel under Hampstead ridge	2	N
3	HSN routed along freight tracks of MML from West Hampstead to Mill Hill		N
4	Interchange station with Heathrow Compass Point network at Cricklewood, adjacent to North Circular Road		N
5	Tunnel under main line at Mill Hill	3	N
6	HSN follows M1/A41 Watford bypass to M25, keeping close to motorway for minimum landtake		Y
7	North of M25, HSN follows close to M1		Y
8	Tunnel 4km long required to avoid residential property in Luton	4	N
9	North of Luton, HSN follows close to M1		Y
10	Regional & high speed access to Heathrow by means of 'Compass Point' network, utilising existing Heathrow Express tunnelled station infrastructure at heart of Heathrow.		N
11	Compass Point link to south via 'Airtrack-*lite*', similar to existing Airtrack proposals but integrated with existing network to avoid congestion from additional trains at level crossings.		N
12	Compass Point link to west along existing Colnbrook freight branch, link to GWML at Iver and (facing east) at West Drayton		Y
13	Compass Point link to north (and to HSL) following existing A312 Hayes bypass, with tunnel under residential property to north of White Hart roundabout at Yeading	1	Y
14	Compass Point link to MML & HSL at Cricklewood via Chiltern Line and Dudding Hill freight line. All expansion within existing rail property boundary		N
15	Connection to WCML via tunnelled connection	4	N
16	Compass Point route continues along MML to Radlett		N
17	Compass Point link to ECML following M25		Y
18	Link to HS1 requires tunnel approx 2km long	2	N
19	Connection from WCML to GWML at Old Oak Common, to transfer WCML commuter flows to CrossRail and avoid need to expand Euston station. Note that this will redress present imbalance in CrossRail proposals. Commuter hub to be located at Old Oak Common (no requirement for massive station box), with major rationalisation of West & North London lines to form inner orbital ring (along with South & East London lines).		Y
	Total tunnelled length (km)	14	
	Total length of new railway (measured to north slope of Chilterns) (km)		75