Rail Safety & Standards Board

Research Programme

Engineering

Study on further electrification of Britain's railway network

ATKINS

T633: Study on further electrification of Britain's railway network

Final Report

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Introduction

The Department for Transport (DfT) and the railway industry wish to develop a long-term traction energy strategy for the British rail network, consistent with overall government strategy for sustainability. This study for the Rail Safety and Standards Board (RSSB) aims to inform that strategy by assessing the long term economic case for further electrification of the mainline 25 kV ac rail network. The study has taken into account current best information on whole life costs, long term fuel cost and availability and of EU and UK sustainability policy. The outputs of the study will advise the Government and industry of the material issues that will affect strategic investment decisions on the costs and impacts of further electrification and hence will inform the procurement of long term assets (rolling stock and infrastructure).

Currently, 39% of the UK main line network is electrified. The majority (63%) of this electrified network is on the 25 kV ac overhead system, with the bulk of the remainder on the 750 V dc third rail system. This study considers only the 25 kV ac overhead system, both in terms of extension of electrification and in terms of the possible removal of existing overhead line equipment. The study was not required to consider the third rail system or the replacement of current diesel traction with alternative portable traction energy sources. Beyond the scope of this study, the models are intended for use when assessing particular routes.

In order to identify strategic issues of concern and to test the cost and economic models developed during the study, a set of ‘exemplar routes’ was selected for detailed consideration. These routes provide coverage over a range of criteria, including operational type and extent of existing electrification. The routes tested were:

- Simple un-electrified route with one main user and service style – Chiltern lines;
- Mixed-use route currently electrified for commuter traffic and with limited number of inter-city destinations – Midland Main Line (MML);
- Mixed-use route currently electrified for single service and with a number of commuter and inter-city destinations with potential for staged or limited implementation – Great Western Main Line (GWML);
- Diverse inter-city network with areas of existing electrification – Cross Country;
- Fully electrified main line – East Coast Main Line (ECML).

The models in this study have not been developed to consider small in-fill schemes linking sections of existing electrified lines.

Technical Appraisal

A comprehensive technical appraisal identified key engineering and operational issues and focused on drawing out the cost and risk implications of electrification. The key elements include:

- Overhead line equipment (OLE) – the significant factors that influence costs are the supporting line-side structures, the spacing of structures, the structure foundation type, the specification of contact/catenary dropper wire, materials costs (in particular steel and copper prices), clearances and auto-transformer systems;

- Power supply and distribution equipment to take supply from the National Grid, including transformers and electrical sub-stations;

- The SCADA (supervisory, control and data acquisition) system, including the electrical control room, data transmission network and remote terminal unit. Costs may be shared with other systems and users;

- Civil engineering works – modifications to track, tunnels and bridges may be required to achieve the clearance needed for the electrification equipment;

- Immunisation of signalling and telecommunications, and also resolution of any signal sighting issues;

- Disruption costs to the railway arising from engineering works, which will be affected by the choice of possessions or blockades;

- The provision of access to confined sites.

Electric-powered and diesel-powered trains have significantly different characteristics:

- Electric trains require less maintenance than their diesel equivalents;

- Electric traction usually yields greater reliability, which together with the lower maintenance requirement, results in a lower fleet size requirement;

- For frequently-stopping commuter services, electric trains can accelerate faster than diesel trains;

- For inter-city services, based on the Intercity Express Programme (IEP), electric trains can have a larger passenger carrying capacity;

- Diesel trains are operationally flexible, in terms of operating services on non-electrified route sections, on diversionary routes or when the OLE is out of service.

Ongoing operating costs of the railway will be affected by route electrification. The key elements are:

- Infrastructure operating costs, of which the most significant is the ongoing maintenance of the additional infrastructure;

- Rolling stock operating costs, including the cost of fuel for diesel trains and the train paths required for fuelling transit moves compared with the costs of electric power supply and the comparative maintenance costs of diesel and electric trains.

These factors are taken into account in the cost and economic models.

Environmental Appraisal

The environmental impacts of electrification, in construction and operation, have been assessed through an environmental appraisal.

Any railway infrastructure project will have environmental impacts during the construction phase. The impacts will include:

- Noise and other potential nuisances such as dust, from use of noisy plant and equipment or from handling materials;
- Greenhouse gas emissions, principally carbon dioxide (CO_2), arising from the combustion of petrol and diesel;
- Other emissions that affect air quality, including sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs) and particulate matter (PM);
- Water consumption and the risks of water pollution;
- Waste, hazardous and non-hazardous, arising from the use of construction materials;
- Landscape impacts, where electrification might affect natural or historic resources.

Allowances have been included in the cost model for both general environmental costs arising from construction activities and any site-specific costs where appropriate.

During railway operation, the key factors that distinguish between diesel and electric traction are the consumption of energy and associated greenhouse gas emissions, local air quality and local noise impacts.

Analysis of average energy use and carbon dioxide emissions shows that electric traction currently produces 20% less CO_2 emissions per vehicle-km than diesel traction. Taking into account likely changes in the mix of electricity generation and also the likely increase in use of bio-fuels, this advantage for electric traction could rise to more than 25% by 2020. These effects are quantified and monetised in the economic model. There are a number of uncertainties that will affect these estimates of CO_2 emissions, in particular, any future changes in the relative efficiency of diesel or electric-powered vehicles, the bio-fuel content of transport fuel and the proportion of electricity generated from renewable or nuclear sources.

Diesel-fuelled rail vehicles generate emissions to air (including NO_x, SO_x, CO_2, CO and PM) at the point of use (i.e. from the engines themselves within the locomotives), while emissions from electric vehicles will be generated at the power station where electrical energy is generated. Diesel-related emissions will therefore tend to be more diffuse and hence more easily dispersed, although there may be locations where large numbers of stationary idling diesel engines at stations or depots, or high density well-used rail links, could lead to high pollution in specific confined areas effecting air quality and leaving deposits on structures. Emissions at fossil fuel burning power stations will be significantly greater in concentration than diesel-related emissions but generally these will still be discharged whether or not the railway is electrified.

Railway noise has two principal components: rolling noise from the wheel-rail interface, which is largely independent of the type of motive power, and traction noise from the motive power system. Traction system noise arises from engine and exhaust systems on diesel trains and on control system and motor cooling fans on both diesel and electric trains. A typical modern electric train (a Pendolino) is 3.1 dB quieter than a typical modern diesel train (a Voyager), and in addition a Pendolino has a far greater capacity, so requires fewer train movements to carry the same number of passengers. However, noise modelling carried out for this study suggests that there is not a significant difference in the noise impacts of diesel or electric traction, in large part because relatively few residential properties are sufficiently near to railway lines where trains are accelerating from slow speeds to experience noise above a threshold level.

Costs of Electrification

The factors identified in the technical and environmental appraisals were used as the basis for development of a comprehensive cost model, which is capable of modelling the electrification of the 'exemplar routes' as well as other schemes. Cost data has been obtained from Network Rail and Atkins, using recent projects as data sources.

The model outputs show that the capital costs of electrifying an existing route range from £550k to £650k per single track kilometre. In assessing the economic case an optimism bias has been applied in accordance with DfT guidelines the level of which, considering the detail of the estimates, is considered cautious. Additional infrastructure maintenance costs will also be incurred, and are expected to amount annually to 0.4%-0.5% of the capital costs. Sensitivity analysis demonstrates which input factors have the most impact of costs; the single most significant item is the average span length, particularly in four-track areas with portal structures.

Electrification will also impact on operating costs, because of the switch from diesel to electric-powered rolling stock (which may have to be procured new), with different availability levels, fuel consumption and maintenance costs.

Economic Impacts of Electrification

Electrification is expected to generate benefits to passengers, the rail industry and to wider society:

- Electric trains on inter-city routes can be expected to have greater passenger carrying-capacity than diesel trains, assuming that new rolling stock specifications, such as the Intercity Express Programme, are introduced. This greater capacity arises from the furnishable space in the power cars of electric trains which is not available for passenger use in locomotive-hauled diesel trains;

- Reliability is expected to improve on non-inter-city routes, where trains stop and start regularly. On these types of routes the cyclic loading on diesel engines is not ideal and hence the improvements to rolling stock reliability from introducing electric vehicles outweighs any adverse reliability impacts from OLE;

- Environmental emissions (CO_2) are expected to reduce on the introduction of electric trains, as outlined above;

- On commuter/inter-urban rail services, where trains stop and start frequently, electric trains can provide benefits from their increased acceleration capabilities. Journey times for passengers can therefore be improved. These benefits are not significant for inter-city-type services, where the speed differentials between different types of rolling stock are minor;

- On the disbenefit side, safety impacts are likely to worsen from electrification, because of the increased likelihood of injuries due to presence of the overhead wires.

Key Appraisal Findings

The economic model was used to examine the case for electrification on each of the exemplar routes and from these results, plus a number of sensitivity tests, conclusions can be drawn on the key factors that affect the case for electrification.

The results demonstrate there is potentially a case for electrification on a number of the exemplar routes. On the Great Western Main Line, there is a case for electrification of the route from London Paddington through to Oxford and either to Bristol or Swansea. On the Midland Main Line, there is a case for electrification of the route from Bedford (London St Pancras to Bedford already being electrified) to Nottingham and to Sheffield. On the East Coast Main Line, there is a net economic disbenefit from de-wiring between Newcastle and Drem, hence a case to retain electrification of the whole route. The economic appraisal results suggest there is not a case for electrification of the Chiltern Line or the Cross Country routes.

These results are influenced by the characteristics of the different routes. The key factors are:

- ***The density of demand on a route***. Those routes, such as Midland Main Line, with high levels of demand (and hence likely to experience future crowding problems which can be alleviated by electrification) generate sufficient passenger benefits to justify the infrastructure investment costs;

- ***The density of usage of each route***, in terms of numbers of trains in operation on a route. The section of route between High Wycombe and Birmingham on the Chiltern network, for example, is not as intensively used as the core commuter route from London Marylebone to Aylesbury and so does not generate sufficient benefits to justify the electrification costs;

- ***The extent of existing route electrification***. Midland Main Line is already electrified between London and Bedford and so the incremental costs of electrification are smaller than on other routes;

- ***Operating Limits.*** Electrification of core sections of the Cross Country routes (even taking into account the significant lengths of route already electrified) does not enable significant switch from diesel to electric because of the diverse range of destinations served which are beyond the core section of route considered for electrification. This can also be seen in the GWML tests, where electrification needs to be extended to Swansea in order to allow sufficient trains to switch to justify the capital costs.

The key drivers of the business case for electrification are, in order of importance, crowding relief, operating cost savings and carbon emissions. It is notable that crowding relief, rather than financial cost savings or environmental factors, is critical to the case for electrification and is largely predicated on assumptions on the relative seating capacity of future inter-city trains. On the MML route, for example, crowding benefits account for nearly 60% of the total benefits from electrification, operating cost savings and reliability improvements accounting for the remainder. While electrification will produce a 'greener' railway and will reduce operating costs, these factors alone are unlikely to make the economic case for electrification.

Sensitivity tests have demonstrated that there are a number of factors that influence the case for electrification. One of the most significant factors is future fuel prices. If, for example, gas oil prices increase, affecting the costs of diesel operation, there is a financially positive case for electrifying the GWML and MML, i.e. sufficient operating cost savings will be made to outweigh the capital costs of electrification. On the other hand, even if gas oil prices are low compared with our central scenario, there is still a value for money case for electrification.

The capital costs of electrification have a relatively high impact on the economic return from electrification. On GWML, for example, it has been assumed that around 10% of the capital costs will be covered by the CrossRail scheme. If these costs are attributable instead to the electrification scheme, the benefit: cost ratio falls by around one-third.

Areas for Further Investigation and Study

This study has demonstrated that it is worthwhile examining the case for electrification further and in particular:

- Feasibility studies for electrification on the specific routes examined in this strategic study;
- Investigation of the potential use of dual fuel trains and how this might influence the extent of electrification;
- Using the cost and economic models to examine lines with other characteristics, such as non-London commuter routes;
- Adapting the models to examine other types of route, perhaps including the conversion of dc third rail to 25 kV ac overhead lines or in-fill schemes;
- Investigation of the use of alternative portable fuels and assessing the results of any changes to energy strategy, legislation or prices;
- The impact of new technology including new train control systems.

Conclusions

The costs of further electrification of the railway network are significant: it is estimated to cost approximately £250 million to electrify the Midland Main Line north of Bedford, for example. There are also environmental impacts from any construction project, which must be considered carefully. However, electrification can generate benefits to rail passengers, through improving capacity, journey times or reliability; to the rail industry, by improving reliability and lowering costs; and to wider society – by reducing greenhouse gas emissions.

Where the conditions are right – where a route has a dense pattern of services and is well used, where there are relatively few destinations for the services on the core route – there can be a good case for electrification. Where these conditions do not exist, it will be difficult to generate sufficient benefits to justify the cost of electrification. There are potentially other parts of the network that may benefit from electrification, for example in-fill schemes linking sections of existing electrified lines, although these have not been considered in this study and need further examination before conclusions can be drawn.

It is notable that for the routes modelled a large proportion of the benefits of electrification are derived from increased capacity and crowding relief, particularly for inter-city routes. Operating cost savings and environmental impacts themselves are unlikely to provide a strong economic case where single fleet types operate (i.e. Chiltern). Given there are other means of providing additional capacity, schemes for route electrification should be considered alongside other means of achieving these objectives and in the light of other strategic projects such as the Intercity Express Programme. Other routes not included in this study may have other benefits, particularly where there are existing mixed fleets or significant areas already electrified (i.e. Manchester – Liverpool, Glasgow Suburban).

1. Introduction

This is the Final Report of the study for RSSB on the further electrification of the UK railway network. The study pulls together current information on whole life costs of electrification and takes into account scenarios of long term fuel cost and availability, together with EU and UK sustainability policy.

The study was informed at the outset by a cross-industry workshop which helped identify the main cost drivers of electrification and selected exemplar routes to be modelled. A baselining exercise was then followed by technical and environmental appraisals to assess these main cost and environmental drivers in more depth. Cost and economic models were developed, which have appraised the case for electrification on the exemplar routes, but are also capable of testing other routes and scenarios. This report pulls together the findings from each of these stages.

1.1 Background

The DfT and the railway industry wish to develop a long-term traction energy strategy for the British rail network, consistent with overall government strategy for sustainability and to inform the procurement of long term assets (rolling stock and infrastructure).

A study previously completed by RSSB “T531: Feasibility study into the use of hydrogen fuel” examined one of the alternative fuel sources that may become commercially viable for railway traction. The recommendations supported the need for further consideration to be given to the long-term economics of further electrification of the main line network.

Currently 39% of the UK main line network (Network Rail infrastructure) is electrified of which 63% (25% of network) is on the 25 kV ac overhead system and 37% (14% of network) on the 750 V dc third rail system with a short length of 1,500 V dc overhead for Tyne and Wear metro trains.

In terms of environment, electrification has potential sustainability benefits in the long term because it links railway usage directly to the primary energy network and could reduce dependence on portable fossil fuels through established and mature technology. However it adds to the capital cost of infrastructure and changes the balance of complexity between the trains and other infrastructure and depot fixed assets. In the longer term current fuels may become expensive and in limited supply.

The objective of this study was to assess the long term economic case for further electrification of the mainline 25 kV ac network taking account of best information on whole life costs, long term fuel cost and availability and of EC and UK sustainability policy.

The outputs of the study will advise the Government and industry of the material issues that will affect strategic investment decisions on the costs and impacts of further electrification.

The project has progressed through a number of stages. To start, a workshop was held at which stakeholders including RSSB, DfT, Network Rail, ATOC, ORR and other industry representatives met to agree the main cost drivers for electrification and select exemplar routes to be modelled as part of the study.

A baseline position of the existing railway network was then determined covering electrification infrastructure, rolling stock fleets and train operating franchises. A review of environmental issues has been undertaken and used as input to cost and economic models.

Cost and economic models have been developed taking into account engineering, technical, operational and environmental factors. The models have then been used to develop outline business cases for the chosen exemplar routes.

1.2 Industry Workshop

During the initial stage of the study a review was undertaken to identify the key issues and cost drivers associated with UK rail electrification. A one day workshop was hosted to identify the electrification fundamentals and to select the ‘exemplar routes’ for modelling. To obtain a broad range of inputs, experienced staff including electrification and traction engineers, environmental, asset management and operating specialists, financial experts and economists from within Atkins, RSSB, DfT and other stakeholders were invited.

There were three aims of the workshop:

1. To identify the significant cost drivers for input to the cost model in relation to railway electrification.

2. To identify the criteria for selecting exemplar routes and matching actual routes to the criteria.

3. To obtain stakeholder consensus.

1.2.1 Significant Cost Drivers

The workshop considered the cost drivers under the four headings:

- Engineering;
- Operations;
- Environment; and
- New Technology.

The key cost drivers identified were then organised into a hierarchy to identify the most significant. They were found to be grouped under two main headings:

- Construction (capex); and

- Operations (opex)

These reflect the two key stages in the life-cycle of electrification equipment where construction includes all project planning activities and also includes any end of life-cycle activities for existing equipment which are undertaken as part of a new project (i.e. disposal/renewal/conversion of the existing equipment). A hierarchy of the cost drivers identified was then developed under these two key areas. Environmental issues have a different impact in the construction and operational phases so have been considered separately under each main heading.

The construction cost drivers were subsequently used as the basis for the cost model and the operational costs have been used as an input to the economic model.

1.2.2 Exemplar Routes

The scope of work stated that the study should focus on those types of lines where changes in electrification and electric traction usage are likely to be practical and to make a significant impact. A number of criteria were identified including both operational type (radial inter-city routes from London, cross-country inter-city routes, London commuter routes, regional commuter routes, mixture of London commuter and radial inter-city, and mixed traffic lines) and extent of existing electrification (non-electrified, partly electrified or fully electrified).

During the workshop discussions highlighted that some routes have a range of characteristics that, particularly from a cost point of view, do not fall into a single category. It was noted, for example, that the southern ends of both the Midland Main Line and East Coast Main Line are both electrified inter-city and commuter routes with high traffic density whereas north of Bedford and Peterborough the characteristics are very different.

Subsequently five routes have been selected to test the models based on the original scope of work. These are:

- Simple un-electrified route with one main user and service style:
    - Chiltern Lines (limited to the sections of routes operated by the Chiltern Railways franchise between Marylebone and Birmingham Snow Hill)
- Mixed-Use route currently electrified for commuter traffic and with limited number of inter-city destinations
    - Midland Main Line (limited to the sections of routes operated by the current Midland Mainline franchise between St Pancras and Sheffield via Derby and between Trent Junction and Nottingham)
- Mixed-Use route currently electrified for single service and with a number of commuter and inter-city destinations with potential for staged or limited implementation.
    - Great Western Main Line (limited to the main lines from London Paddington to Cardiff and Bristol via Bath and Bristol Parkway –

    additional modelling has been undertaken to include extensions to Oxford, Bedwyn and Swansea)

- Diverse inter-city network with areas of existing electrification
    - Inter-city Cross country (limited to electrification of the core section between York and Bristol via Leeds and via Doncaster)
- Fully electrified main line
    - East Coast Main Line (limited to the existing electrified route sections from London Kings Cross to Leeds and Edinburgh, considering the replacement or removal of the electrification equipment north of Newcastle)

In order to take into consideration the different route characteristics, sub-sections of routes with common characteristics have been separately identified (i.e. Great Western Main Line has been split into two track and four track sections and branches to Bedwyn and Oxford separately modelled). The cost of each sub-section has then been calculated using the cost model to provide input to the economic model for each exemplar route.

1.3 Baselining

The UK rail network was reviewed to define the current position in terms of electrification, train operating companies and rolling stock. The network has been defined using the Network Rail 26 strategic routes as the basis.

The existing electrified routes are shown in Figure 1.1. Based on Network Rail's 26 strategic routes, Appendix F identifies the year of installation for each section of the 25 kV electrified lines and when the equipment will be 40 years old. The 40 year date should only be used as a guide to indicate when equipment may need to be renewed. Some equipment is already significantly older than 40 years and has been refurbished. This includes the ex 1500 V dc equipment from Fenchurch Street and Liverpool Street which received a heavy refurbishment at the time of conversion to 25 kV ac. Other route sections have been or are currently being refurbished including West Coast Main Line, Bridge Street Junction (Glasgow) to Gourock and Wemyss Bay and sections of the East Coast Main Line. The age of the equipment when renewed and extent of refurbishment will vary from line to line depending on a number of factors including condition and compatibility with proposed operating requirements.

The train operating companies and rolling stock fleets were analysed to identify franchise expiry dates and the train fleets used by each. The ratio of electric/diesel traffic for each franchise was identified to indicate the impact of electrification on franchise operators.

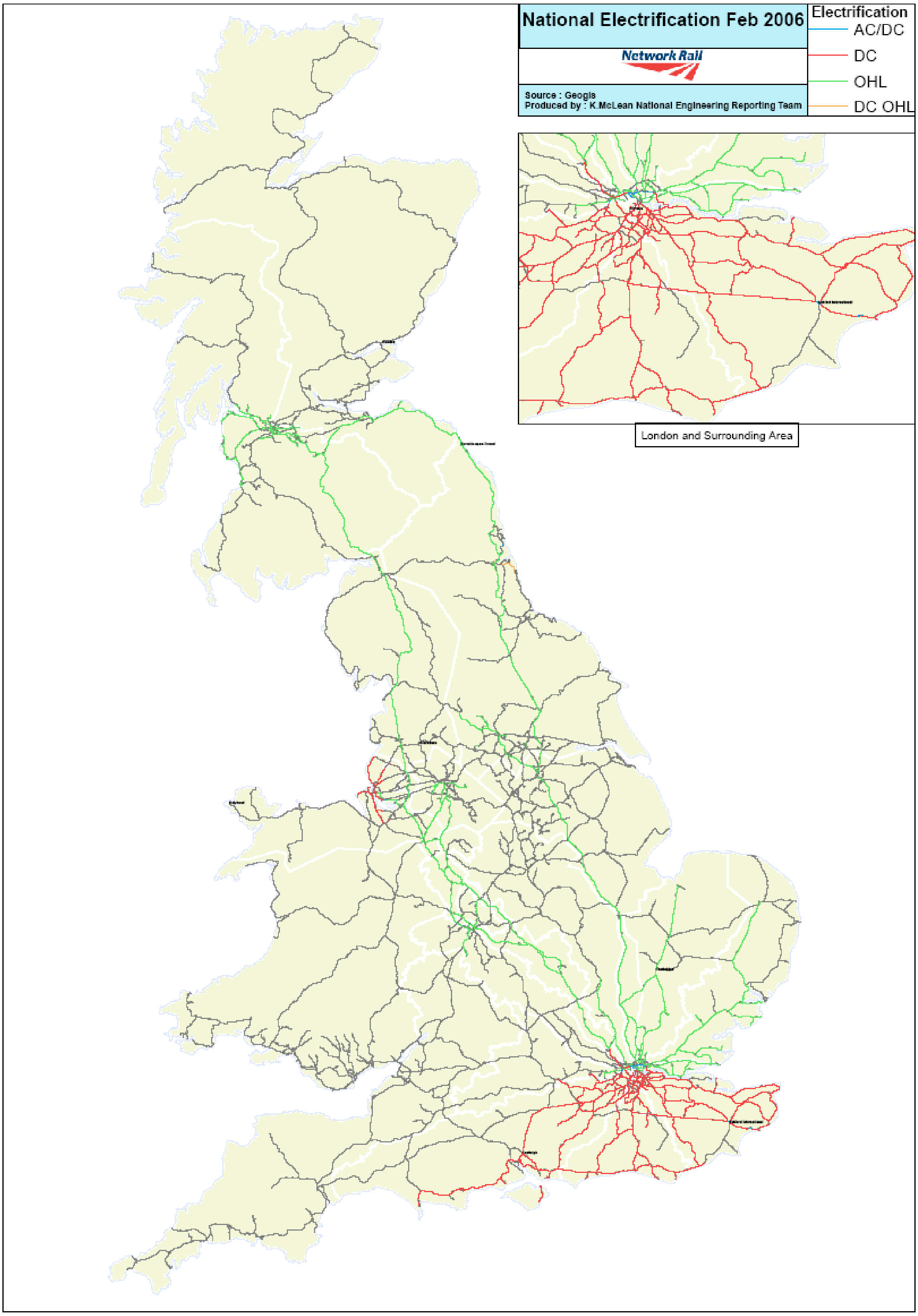


Figure 1.1 – Existing Electrified Lines

1.4 Technical Appraisal

Each of the main cost drivers identified has been defined and significant cost elements identified with, where relevant, examples of where these costs have arisen in the past and where/who may be able to provide cost data.

The analysis has been undertaken for technical, environmental and operational cost drivers to enable the cost model to be developed based on informed assessment. In addition we have investigated the requirements of the Railways (Interoperability) Regulations 2006, particularly with regard to any limitations regarding the removal of existing electrification systems, and future electricity generating scenarios in the UK including diversity of supply.

1.5 Environmental Appraisal

An environmental appraisal has been undertaken to assess the environmental impact of electrified railways. Electrification construction activities have been considered as well as the operation phase, considering the relative benefits of diesel and electric trains.

The range of fuels used for generating electricity, both now and in the future, and consequential power station emissions, have been investigated to assess the environmental impact of electric traction. The current and future emissions from diesel engines, including the impact of legislation to reduce pollutants, have been taken into consideration when assessing diesel traction.

A separate study into the relative noise impacts of diesel and electric trains has been carried out using data from previous studies.

1.6 Cost Model

A cost model has been developed in Excel to provide a tool for undertaking high level estimates for electrification schemes. The model is designed to be used for any route by operators with relatively little technical knowledge. The data in the model can, however, be amended by operators with more technical knowledge to reflect different technical and cost parameters.

1.7 Economic Model

The economic model has been developed in two parts:

- Demand Model Database – This estimates the demand generation impacts of scheme proposals and calculates the scale of demand related impact (journey time, crowding relief, revenue effects)

- Economic Appraisal Spreadsheet – this incorporates the details of the demand model; cost model and environmental assessment to apply monetary values to the attributes estimated: journey time, crowding, revenue, operating costs, capital costs and environmental impacts (air quality).

The model has been designed for use by planners with some operational knowledge of the railway. The key input assumptions relate to the extent of electrification being proposed, and the origin and destination of services involved.

1.8 Exclusions

This study has considered electrification of strategic routes which are currently not electrified and also possible removal of existing overhead line equipment. The following items have been excluded from the scope of work:

- Replacement of current diesel traction with alternative portable traction energy source
- New lines (CrossRail, North – South link)
- Third rail system

In addition the models have not been developed to consider small in-fill schemes to link existing electrified sections.

1.9 Contents of this report

This report provides details of the different stages of the study.

Chapter 2 details the technical appraisal undertaken to assess the relevant engineering and operational issues associated with electrifying a diesel operated railway and comparing operating practices on electrified diesel only railways.

Chapter 3 details the environmental studies that have been undertaken including an assessment of the environmental impact of constructing an electrified railway and comparing electric and diesel traction, particularly in terms of overall emissions and noise.

Chapter 4 details the cost model that has been developed to facilitate estimating the cost of electrifying an existing railway. The outputs from this model are then used as an input to the economic analysis.

Chapter 5 details the economic model including how it has been structured and how each of the elements of the research have fed into the economic appraisal.

Chapter 6 describes each of the exemplar routes examined and the results from the modelling. It details the range of tests undertaken for each route and draws conclusions from the results.

Chapter 7 summarises the findings and considers the wider implications. It identifies the routes that show a positive business case and highlights the key issues that make the case for electrification.

Chapter 8 considers the findings of the study and suggests topics for further debate and study, including enhancing the models and suggesting further types of route that may be suitable for electrification.

2. Technical Appraisal

This section describes the technical appraisal, taking into account all relevant engineering and operational issues. The cost drivers of electrification are described in terms of infrastructure elements, rolling stock issues and railway operations.

The key infrastructure elements of an electrification scheme will include the overhead line equipment, power supply and distribution equipment, the SCADA system, civil engineering works, immunisation of signalling and telecommunications, disruption costs to the railway and the provision of access to sites.

Electric-powered trains can have significantly different characteristics to diesel-powered trains. In general they are more reliable and require less maintenance. On frequently-stopping services, electric trains can provide journey time benefits from their better acceleration, and on intercity services, electric trains may be able to provide more passenger capacity. Diesel trains, on the other hand, have far greater operational flexibility in terms of routes they can operate on, diversionary services or rescue services.

Electrification will affect ongoing railway operating costs, through start-up project costs such as driver training, through infrastructure maintenance costs and rolling stock operating costs, including the costs of power supply. Regenerative braking can provide significant energy and hence operating cost savings. This is more effective on electrified routes though in future hybrid trains are likely to be developed whereby regeneration can supply auxiliary loads or be used to charge energy storage devices (i.e. batteries).

2.1 Infrastructure

2.1.1 General

The base costs for electrifying a route are made up of the elements required for electrification. These costs include the electrification equipment including overhead line equipment (OLE), power supplies, distribution and control equipment (SCADA). In addition, civil engineering work is required to achieve electrical and mechanical clearances and to support the electrification equipment. Signals may need to be moved to ensure they are not unacceptably obscured by the overhead line equipment when viewed from driving cabs.

This study has considered the provision of new OLE infrastructure, OLE infrastructure renewals, maintenance implications and associated cost elements. The actual cost of the overhead line equipment will be dependent on the choice of system to be installed. For any project a system design evaluation will be required to determine the most suitable system to satisfy the operating and environmental requirements. The operating requirements should initially include high level statements such as capacity and journey times which will then be developed to provide line speeds, timetables and train characteristics. The need to comply with technical standards for interoperability (both for high speed and conventional lines) should also be determined at this stage. Power requirements can then be determined and suitable substation spacing and overhead line equipment proposed. If a route is already electrified then suitable replacement proposals for existing equipment should be specified. These will then need to be applied to the geographic features of the route to be electrified before detailed costs can be determined.

For safety reasons and operating flexibility the electrification equipment is divided into electrical sections. Sectioning is provided at feeder stations, auto-transformer sites, and track sectioning cabins with additional sub-sectioning provided, often in junction areas, to increase the operational flexibility. The operational requirements of a particular route determines the sectioning requirements and hence costs including associated section insulators, overhead line isolators and possibly the requirement for additional anchor structures due to an increased number of overlaps and the associated requirement for both additional and more complex supporting structures. Additional land may also be required for trackside equipment. The purchase of land has been excluded from the cost model.

For the purposes of this study a modified Mk3b equipment has been assumed as the basis for the cost analysis. This would include copper catenary, flexible copper droppers, reduced maximum spans and mechanically independent registration (MIR) in multi track areas. Cost data for a number of projects has been analysed but the actual cost for along track equipment varies due to a number of factors (including the price of copper) and hence the value in the model can be adjusted to suit specific route characteristics and availability of more up to date data. Substation separation has been based on typical spacings depending on anticipated intensity of traffic and type of overhead line equipment (i.e. auto-transformers have been considered for the GWML).

Signalling and telecoms works are also generally required to ensure compatibility (immunisation). The costs of immunisation works depends on the type of existing equipment and may be reduced or removed if the intent to electrify a route is defined at the time of a resignalling or telecoms renewals/upgrade project.

Additional costs are also often associated with electrification projects but are not necessarily a direct result of the decision to electrify. Significant layout remodelling may be included in an electrification programme and track circuit/signalling renewals, permanent way remodelling and other civils works that would be required in the longer term may be brought forward to coincide with an electrification project. The cost and economic models currently assume that existing track layouts remain unchanged.

Costs can also be significantly reduced by careful planning to optimise track availability and the use of high output plant. The use of blockades where diversionary routes are available can also significantly reduce costs. The West Coast project has been very successful demonstrating the benefits of high output plant and blockade working. Contractors' costs are also affected by the stop start nature of electrification projects. A long term plan for electrification would enable contractors to recruit, train and retain a more skilled and efficient labour force and more efficient plant and equipment. These issues need to be taken into consideration when assessing the case for electrification of the whole network and will lead to variations in the cost of electrifying a specific route depending on the assessment criteria.

The equipment variables and base costs used in this study are summarised in Appendix E.

2.1.2 Overhead Line Equipment

For the purposes of this section of the report overhead line equipment (OLE) is defined as being the along track elements of the 25 kV overhead traction electrification system and the most significant cost elements contributing to the cost can be defined as supporting structures, structure spacing, structure foundation type, contact/catenary/dropper wire specification, auxiliary conductors (return conductor, earth wire, auxiliary feeder), general material costs, switching and sectioning arrangements, clearances etc.

SUPPORTING STRUCTURES/STRUCTURE SPACING

The overhead line equipment is generally supported from line-side structures. The type of structure is determined by a number of factors including track geometry, clearance requirements, ground conditions and trackside obstructions. Generally for single and two track sections, cantilevers are supported from line-side masts. In multi-track areas headspans and portal structures are used unless the local layout enables cantilevers to be installed between tracks. In some areas two track portal structures may be used to give extra stability on viaducts and in areas with poor ground conditions. Additionally portal structures are considered by some to be more reliable than headspans and in recent years have been preferred by Network Rail. Portal structures have therefore been used in the cost model but headspans could be simulated by simply reducing the value of headspans on the electrification data sheet. Special support arrangements are also used including in tunnels, under overbridges and in station areas.

The spacing of structures is determined by the track geometry and predicted windspeeds to ensure that the equipment remains in tolerance for all expected operating conditions. Higher windspeeds, smaller track radii and junction areas require more frequent structures.

As support structures are installed at frequent intervals (typically 60m on open route sections and reducing in junction areas) they have a significant influence on the cost of an electrification project. Increasing tolerances (i.e. permissible deviation), and hence larger structure spacings, reduces costs but at risk of reducing availability or the need to enforce speed restrictions in high wind conditions. The type, number and size of structures required would also impact upon the programme of works and installation methodology thereby also increasing the costs arising in connection with number of possessions required, type of plant used and labour requirements.

STRUCTURE FOUNDATION TYPE

The type of foundation is dictated primarily by local ground conditions and proposed installation methodology. Poor ground (such as Stilton Fen), unstable embankments, viaducts and hard rock areas need special foundations. In standard open route ground conditions poured concrete or piled foundations may be used depending on preferred installation methodologies (possibly dictated by access restrictions or structure type). The foundation type will therefore need to be considered when undertaking more detailed specific route analysis.

CONTACT/CATENARY/DROPPER WIRE SPECIFICATION

The equipment specification needs to be considered. For many years 107 mm^2 hard drawn copper contact wire with an aluminium/steel (AWAC) catenary and stainless steel droppers have been used in the UK. However, equipment developments, improved current collection, reliability and other considerations may change the specification for a part or whole of a route thereby impacting on cost. For example 120 mm^2 Cu/Ag contact wire and current carrying droppers have been installed as part of the UK1 electrification system on the West Coast Main Line Upgrade Project and replacement of AWAC with copper catenary is ongoing on the East Coast Main Line.

GENERAL MATERIALS COSTS

The main materials used in OLE installations from a cost variation viewpoint are steel and copper. Supply shortages of steel and copper can inflate prices in an unpredictable way. Therefore these commodity prices may vary significantly over time and, as such, are considered to be a sensitivity issue and the price of relevant equipment items can be adjusted in the model.

CLEARANCES

Clearances are considered generally as a civils cost (see 2.1.5). However, some clearance issues may not be capable of removal by additional civils works due to localised constraints e.g. the shortening of a tension length requiring additional structures due to the presence of an overbridge at the optimum tension length end, the additional costs of mounting supporting structures on specially designed brackets due to insufficient space/inability to install a standard foundation (i.e. on viaducts and in cuttings). Further clearance work may include the diverting or raising of utility services crossing the railway, shrub clearance and screens around structures.

AUTO-TRANSFORMER SYSTEMS

Classic electrification systems have used return conductors and booster transformers to reduce the electrical interference caused by traction currents. In future, on some high capacity routes, auto-transformer systems are likely to be used whereby the return conductor and booster transformers are no longer required but auxiliary feeder wires are used to transmit power and also suppress the electrical interference, as currently being installed on the West Coast Main Line. The relative costs between the two types of system primarily relate to the distribution equipment. In the cost model the booster transformers are included as an element of the overhead line equipment and are the significant difference between the two systems when calculating overhead line costs.

RENEWALS

The main costs associated with renewals of existing electrification infrastructure comprise the elements set out above although there are some costs unique to renewals in connection with maintaining the availability of the existing electrification system during the renewals works and in recovering life expired components. Additionally renewals work will include not only the replacement of life expired or substandard OLE components but also the remedial works associated with defective installations, for example the subsiding support structures on the Hertford Loop. Temporary works, which may include temporary anchors and additional structures, required to maintain the availability of the existing system may add to costs.

Where suitable some of the existing equipment is likely to be retained, particularly the support structures. Other elements may be refurbished or sold for scrap therefore reducing the overall costs.

INTERFACES WITH EXISTING EQUIPMENT

Special arrangements may be required, including alterations to the existing equipment, where a new electrification scheme interfaces with existing equipment. The additional costs involved should be considered when estimating the cost of electrification and where relevant is included in the cost model.

2.1.3 Power Supply and Distribution Equipment

In the UK the main line electrified railway uses a 25 kV or 50 kV, 50 Hz single phase supply taken from the National Grid or Distribution Networks at feeder stations located at strategic points along the railway. Transformers are provided to reduce the voltage from the transmission/distribution networks (132 kV, 275 kV or 400 kV) to 25 kV (classic system) or 50 kV (auto-transformer system). Equipment installation costs vary due to size of transformers and logistical factors such as the location (urban/rural), cable routes from the grid site to the railway and the ease of access to the site. Analysis of past projects has shown a wide range of costs reducing the accuracy of initial estimates.

Classic systems distribute the power from the feeder stations at 25 kV with additional electrical substations (track sectioning cabins) installed to provide flexibility and circuit protection. Booster transformers are often installed to suppress the interference caused by the traction system.

For auto-transformer systems, power is distributed along the railway at 50 kV with transformers installed at intervals along the track to give 25 kV between the overhead line equipment and the rails. Electrical substations are installed at these transformer sites to provide circuit protection.

The electrical substations contain the circuit breakers, protection relays and control equipment required to operate and protect the electrified railway infrastructure. A number of factors influence the distances between equipment including location of available connections to the transmission/distribution networks and operational requirements. The spacings used in this study are included in Appendix E.

2.1.4 SCADA

The electrification system is controlled by a SCADA (supervisory, control and data acquisition) system. The main elements of this system are the Electrical Control Room (ECR), data transmission network and the Remote Terminal Unit (RTU) in the substations.

The master control system is contained within the ECR. The costs for the ECR building will normally be shared with other disciplines as the trend is towards integrated control rooms (signalling, operations, and traction power). Existing control rooms will be used for new electrification projects where practical. The cost of the master control system is not directly related to the size of an electrification scheme - the larger the electrified area covered, the lower the relative cost of the control system. Some electrification projects may use existing control systems reducing the overall project costs.

The cost of the data transmission network relates less to the initial capital cost, than to the running costs as data links are normally rented or leased. This is because modern data transmission networks tend to be based around the use of fibre-optic cables which have a very large capacity that is shared between many users and generally are already installed.

At all electrical substations RTUs are installed to provide local control. These are linked to the main control system via the data transmission network.

2.1.5 Civil Engineering

As stated in the Railway Safety Principles and Guidance (Part 2 section A), for existing routes the installation of the OLE requires a minimum of 4.780 m gauge clearance between the rails and the underside of structures i.e. bridges and tunnels (note: new high speed lines will require higher structures to comply with interoperability regulations). This can affect the many bridge and tunnel structures on a route. Where clearances need to be increased to accommodate the electrification equipment there are a number of options that can be considered in developing detailed estimates for a project. Each structure should be assessed to determine the most economic solution for that location. One or more of the following options may be required:

- Demolition of redundant overbridges such as accommodation bridges giving access between farmer's fields which are no longer used. There may be a cost to purchase the rights of access from the land owner if they are amenable.

- The reconstruction of the bridge deck by demolition of the deck and replacing with a new concrete or steel deck to achieve gauge clearance. Raising the level of the existing road may impact on the approach roads to the bridge to achieve acceptable Highways Standards.

- Construction of a new bridge on a new alignment with the consequential costs of additional highway, on a new alignment. The old bridge would be demolished following the construction of the new bridge.

- Steel deck bridges may be raised by jacking the deck upwards, subject to engineering inspection to ensure it is in a satisfactory physical condition.

- Services such as water, electricity cables, telecom cables and gas mains in existing bridges may need temporary support during the reconstruction or temporary diversion. The cost will depend on the size and type of service affected.

- Sluing the track under arched bridges/tunnels may provide the required clearances.

- Lowering the track by reducing the thickness of the ballast below the sleeper, lowering the formation or using slab track. Site investigation of the adjacent bridge foundations could identify the need for expensive underpinning to the bridge abutments. Drainage of low spots in the track alignment may cause local problems particularly between adjacent cuttings. Track lowering is more appropriate on lower speed sections of track as the drop in levels at bridge positions can require significant lengths of lowering either side of the structure to comply with track vertical alignment standards for higher speeds.

- Tunnels with inadequate gauge may prove to be very expensive. Clearances may be provided by track lowering, realignment of the track into the 6 foot or special overhead line solutions such as coasting through the structure with earthed contact/catenary wires.

The cost model calculates a cost for bridge alterations based on the frequency of bridges for the route being assessed and the expected number of bridges needing to be altered, both figures being determined by the user. For tunnels, a more detailed analysis is required by the user with three options available: track slue, track lowering and slab tracking. A cost is also included for diverting or raising utility services. The costs used in this study are listed in Appendix E.

Alterations to station structures, awnings and canopies may be required to support the overhead line equipment and ensure suitable electrical clearances. These alterations are included as a separate cost item in the cost model.

2.1.6 Signalling and Telecoms

Immunisation of signalling and telecommunications equipment can add significant costs to electrification projects. Copper communications cables can be affected by the traction current and may involve extensive additional bonding and other associated works dependant upon equipment type and location. Suitable track circuits are required in electrified areas which may involve the replacement of existing track circuits with traction immune types.

Signal sighting issues to ensure signals are not obstructed by electrification equipment can be complex to resolve and may involve both the re-location of one or more signals or, if this is not possible due to signalling system constraints, significant additional costs could be incurred in the provision of special signal and overhead line structures, e.g. cantilever gantries, special OLE support structures.

2.1.7 Disruption – Rules of the Route Possessions vs. Blockades

There is no definitive solution to the methods of how engineering should be progressed on an operational railway. Decisions on whether to take a possession within the Rules of the Route or a longer blockade depend upon route specific criteria. Generally from an engineering perspective, blockades are preferred to short possessions as productivity is improved and stage works reduced. Operators will also have a clear perspective of the blockade timescales and are able to plan a ‘one off' contingency for the event. However, blockades expose the infrastructure owner to having to pay large compensation costs to the TOCs and potentially significant disruption to customers. In turn, additional costs may be imposed on the TOCs for route learning diversionary routes and for re-training over the blockaded route before commissioning.

Significant amounts of electrification work are possible using discrete possessions rather than blockades because of the nature of the engineering work. In open route sections much of the overhead line installation work can be undertaken with only one track blocked and special vehicles/trains have been developed for this purpose reducing the impact on train operators. Where headspan or portal structures are used and in junction areas multiple track possessions are required but with careful planning work can be broken down into packages with relatively little abortive work required. Where more invasive civils work is required (e.g. to raise overbridges to increase clearances, work in tunnels, etc.) then longer possessions may be required. However unrestricted access to site leads to more efficient delivery as the blockade for the electrification of the Crewe to Kidsgrove route demonstrated

The cost model has been developed to calculate the most cost efficient possession regime based on user inputs regarding disruption to passenger and freight operators.

2.1.8 Site Access

Access to confined sites can incur additional costs. Access roads, temporary bridges and scaffolding to bridges over rivers may have to be considered and included in the project costs. Access to sites where residential properties and gardens are adjacent to the railway may require alternative methods of working with additional programme times resulting in additional costs as a consequence. A facility exists within the cost model for the end user to add one off costs to take account of such issues.

2.2 Rail Vehicles

2.2.1 Train Characteristics

Electric trains require less maintenance than diesel equivalents resulting in lower vehicle depot downtimes hence fewer vehicles are required to deliver a given service. In addition, electric traction usually yields greater reliability also resulting in less rolling stock required to deliver a given service.

For stopping services electric trains are able to accelerate faster than diesels resulting in reduced journey times giving passenger benefits and may allow fewer vehicles to be used for any given service.

Diesel traction is more flexible as it can operate without OLE therefore, unless the complete service route is electrified, train operators will continue to utilise diesel traction for non-electrified routes thus making the money spent on electrification less beneficial.

When comparing inter-city trains, the characteristics of the proposed Intercity Express Programme (IEP) trains have been used. These vehicles are proposed to have similar top speed and acceleration characteristics with the main difference being a larger passenger carrying area on electric trains.

Back up diesel locomotives are usually required on electrified routes in order to provide rescue services when the OLE is out of service. Diesel locomotives may also be hired to pull electric trains on diversionary services or through isolated overhead line sections.

2.2.2 Depots

Installation of 25 kV electrification infrastructure in depots will involve ensuring that there is suitable supply capacity, possible installation of additional transformers/sub-stations, installation of the OLE and installation of new depot protection/isolation systems.

This may result in significant depot disruption during the change over. The construction of new purpose built depots for electric trains allows existing diesel fleets to continue to operate from existing depots while work progresses. New depots and the addition of this infrastructure to existing depots will involve high capital expenditure and will include local control and protection systems.

Specific depot plant is required for AC Traction including:

- Transformer oil recirculation plant.
- Insulation High Voltage Testing Facility.
- Pantograph overhaul facility.
- Other dedicated facilities required for the maintenance and overhaul of AC traction equipment such as an electronics room.
- Shore supplies.
- Different lifting facility requirements.
- Different ladders and access platforms.

Decommissioning and decontamination of existing diesel traction infrastructure may be required. This includes fuel point, oil separators/interceptors, fuel / lube oil storage facilities, coolant storage and interceptors, general decontamination and sanitisation of depot, pits and roads.

It is becoming increasingly common for rolling stock manufacturers to build and operate dedicated maintenance depots under design, build and maintain contracts. This is applicable for both electric and diesel traction and hence the cost differential between the two is predominantly the need for overhead line equipment.

Other facilities along the line of route may also require upgrading / improvement where vehicles are stabled overnight.

2.2.3 Compensation/Lease issues

Change over to an electric fleet may involve the purchase of new rolling stock. This will require high capital expenditure which will be reflected in the lease rates of Rolling Stock Leasing Companies. However, the benefits offered to the TOCs from operating newer stock may justify increased leasing charges.

The introduction of new electric stock should ideally be timed to coincide with the diesel stock needing to be replaced. Additional costs may be incurred if existing diesel stock is released early or Rolling Stock Leasing Companies (ROSCO's) are unable to re-lease stock.

The increased leasing costs for new electric stock compared to leasing older diesel trains may be offset against the lower maintenance and overhaul costs associated with modern electric traction maintenance regime.

Modification costs usually associated with issues arising from the introduction of new rolling stock may be incurred by the ROSCOs and therefore TOCs. Some of these issues may be covered by warranty agreements.

2.3 Operating Costs

2.3.1 Project Costs

The introduction of new electrification equipment and trains will result in operational costs being incurred. These will include:

- production and introduction of a new life cycle maintenance regimes for both infrastructure and rolling stock
- Safety Case to reflect electric traction operation which will need to reflect both Maintenance (Depot Safety Case) and Operations (Operational Safety Case)
- Retraining and Competence Assessment of staff for Maintenance and Safety Issues.
- Driver training
- Operator training (Electrical Control Room operators and signallers).
- Publicity and general staff briefings

2.3.2 Infrastructure Operating Costs

ELECTRIFICATION EQUIPMENT

The most significant additional cost associated with electrification of a route is the ongoing maintenance of the additional infrastructure. The significant cost element under this heading is the cost associated with the planned preventative maintenance requirement arising from the availability implications of the mean time before overhaul/replacement and the requirement for periodic adjustment, e.g. height and stagger adjustment, of the OLE system components and, to a lesser extent, the risk of reactive maintenance following a system failure.

This is a trade off between the capital cost and maintenance cost of the OLE system whole life cost and will need to be considered in conjunction with the Network Rail current capital/maintenance cost trade off philosophy and any changes anticipated in connection therewith during the lifetime of this study.

The cost of this maintenance used in the study has been based on the Network Rail annual maintenance budget. The budget figures have been analysed to give a cost per route km for 25 kV electrification taking into account the various electrified systems in use on the network.

ELECTRICAL CONTROL ROOM

Depending upon the design of the scheme, the system requirement may opt to incorporate the control and monitoring equipment into an existing Electrical Control Room. The scheme may alternatively opt for a new Electrical Control Room which will incur ongoing operating costs.

POSSESSIONS AND ENGINEERING WORK

Possession management is more complex on an electrified railway since the traction supply is generally required to be isolated during any work that is undertaken. This means it takes time before the possession is imposed and time when the possession is given back for the traction current to be isolated or restored. In some cases extra time must also be planned to allow for the de-wiring and re-wiring of the catenary to allow engineering work to take place. These factors may mean more possessions for the same work; it may also adversely affect performance and incur delay penalties.

DIVERSIONS

When essential engineering work is undertaken, the traction power supply will be isolated. In these circumstances, electric trains are often diverted over non electrified routes hauled by diesel traction. An increase in the electrified lines will require additional diesel traction for haulage over diversionary routes. However as the electrified network expands, more diversionary routes will become available for electric traction.

ADVERSE WEATHER

Adverse weather can affect AC traction in ways that do not affect diesel, e.g. High winds, icing of the contact wire, causing speed restrictions to be imposed which adversely affects performance and incurs delay penalties. Train paths may also be required to de-ice the contact wire on a precautionary basis. Including higher wind speeds in the requirements specification should reduce/remove the need for speed restrictions.

TRACTION AND BRAKING CHARACTERISTICS

The traction supply to electric trains is limited (not from an infinite busbar). Within each electrical feeding area the total capacity is limited by the electrification equipment rating. This can affect train performance and reduce capacity which needs to be assessed when specifying the supply requirements.

Regenerative braking offers the potential for some cost saving but is only effective if the energy can be used, stored or returned to the grid.

DEGRADED WORKING

Traction supply failures have a greater disruption potential and therefore a higher cost associated with them than would be the case for a failure of diesel traction. All electric trains in an isolated section will be affected making it much harder to recover the situation.

Adjacent tracks may also be affected which precludes the transfer of passengers to other trains. There is also a greater safety risk associated with the catenary coming down which requires specialist plant to restore it. Consideration of the operating and electrical sectioning requirements, including for degraded mode operation, at the planning stage of a project can significantly reduce the impact of failures.

SAFETY COST

All incidents and accidents ultimately result in a capital cost which in some cases may be significant. Emergencies are more complex on electrified railways, even if the traction supply is not directly involved. For example, a train fire may require the OLE to be isolated (in an unplanned manner) before the fire can be tackled – leading to delay and increased disruption.

OLE stanchions have significantly increased the damage to derailed trains as was evident at the Ladbroke Grove and Hatfield rail crashes. RSSB report T177: ‘Overhead line structure design to cater for collision’ concludes that there are methods that can be incorporated in the design of line-side structures that can reduce the damage caused to passenger coaches when in collision with a mast. However the containing effect of the line-side masts may also be beneficial in some accident situations. The report recommends further study to determine if any additional measures are required in relation to either the design of vehicles and/or the design of overhead line support structures.

FREIGHT TERMINALS

OLE can be a hazard at freight terminals, either because of the risk of a spark, obstructing the loading/unloading process, or restricting the use of plant such as forklifts, mobile cranes and particularly gantry cranes. If the scheme included electrifying an existing terminal within the route, costs may be incurred redesigning assets.

2.3.3 Rolling Stock Operating Costs

Electric traction maintenance frequency is driven by pan head and brake pad wear with depot visits at A Exam, typically 15,000 miles/28 days whereas diesel traction maintenance is driven by fuelling – every other day (extra time / transportation / storage / environmental cost), service checks – fuel, lube oil, coolant – 1 to 3 days and brake pad wear – A exam. It should be noted however, that both electric and diesel passenger services both require toilet emptying and water refilling on a two / three day regime.

Electric traction has the potential for lower brake pad wear with the use of regenerative / rheostatic braking. This will reduce material cost/service time and potential for longer service intervals and, where regenerative braking is used, traction energy savings of 10 to 15% may be realised. Rheostatic braking can also be used on diesel trains with electric motors and in future hybrid trains are likely to be developed whereby regeneration can supply auxiliary loads or be used to charge energy storage devices (i.e. batteries).

In addition to train maintenance, the cost of operating electric traction from the operator's perspective lies primarily in the cost of train paths that include for both traction energy used and the additional cost of provision and maintenance of the supply infrastructure. The cost of traction energy supply is currently calculated by modelling for a particular train type and route and with an allowance for regenerative braking where implemented. However, there is a project, being led by ATOC, looking at fitting energy meters on trains which would enable the operator to benefit from energy saving driving techniques.

The cost of operating diesel traction from the operator’s perspective lies primarily in the cost of the fuel and in the use of train paths for trains/locomotives to return to maintenance depots for re-fuelling and coolant top ups.

Fuel is an additional load that non-electric trains have to carry. The power to weight ratio generally improves the performance of electric traction. This has the potential to improve operating performance and increase capacity. In addition, the lighter electric vehicles result in reduced track damage.

Compared to electric traction, the main additional cost drivers for diesel from the operator’s perspective are:

- Train paths for fuelling transit moves.
- Provision of fuel storage and fuelling equipment on depots.
- Arranging to keep fuel storage supplied (by road).
- Provision of staff to carry out fuelling.
- Planning staff and traction diagrams to allow for fuelling.
- Shore supplies.
- Monitoring fuel consumption to avoid trains running out of fuel, etc.

Water coolant is always associated with any fuelling facility and should also be identified with diesel train operating costs.

The handling and management of diesel fuel carries the risk of polluting the environment. Punitive fines have been imposed on some operators where fuel spillages have occurred amounting to many thousands of pounds.

3. Environmental Appraisal

This section details the environmental work undertaken to assess the benefits and disbenefits of electrifying a route. The work has focused on the environmental impact of electrification construction activities and on the impact of diesel or electric traction, particularly with regard to emissions and noise. The impact on the environment of the proportion of different fuels used to generate electricity in the future is examined.

During the construction phase, an electrification scheme is likely to generate environmental impacts in terms of noise, dust, greenhouse gas and other emissions, water consumption, waste issues and landscape impacts. Some of these impacts are general, others are site-specific.

Analysis has been carried out for this study on greenhouse gas emissions, based on fuel consumption and emission levels. This demonstrates that electric trains produce 20% to 36% less carbon dioxide emissions than diesel trains, although these projections are affected by uncertainty over long term energy policy and fuel availability (see Tables 3.1 and 3.2).

Local air quality impacts are difficult to quantify – diesel-fuelled trains generate emissions at point of use, and these tend to be relatively diffuse and easily dispersed, except at confined locations such as depots and large stations. Electric trains indirectly generate emissions at power stations, which tend to be much greater in concentration but only a small proportion is as a result of railway electrification. If future policy adopts nuclear generation then power station emissions will be significantly reduced.

Noise impacts are also not clear-cut. While modern electric trains will tend to be less noisy than modern diesel trains, noise modelling carried out for this study suggests that neither type of train produces significant levels of noise in residential areas. Noise is not therefore a significant factor in choosing between diesel and electric traction.

3.1 Electrification Construction

Construction activities (i.e. handling materials; use of noisy plant and equipment; vehicular use; unsocial working hours, etc) generate noise and other potential nuisances (e.g. dust). Electrification construction will generate some additional noise and there may be some costs associated with limiting the noise generated.

3.1.1 Greenhouse Gas (GHG) Emissions and Air Quality

Petrol and diesel, the most conventionally used fossil fuels in construction projects, are finite resources and therefore limited in supply. Whilst current availability of fuel is high, this may not be the case in the future and fuel scarcity, together with oil price, may rise. Alternative fuels are likely to be developed reducing the environmental impact.

The combustion of petrol and diesel generates greenhouse gases (GHG) that are increasingly being subject to regulatory instruments (i.e. EU Emissions Trading Scheme). Carbon Dioxide is the principal GHG emitted from fossil fuel combustion which contributes to climate change.

Vehicles and equipment used in construction burn fossil fuels that generate emissions to air (including NO_x, SO_x, CO, VOCs and Particulate Matter (PM)).

Sulphur Dioxide (SO_2): Is an acidic gas which combines with water vapour in the atmosphere to produce acid rain. Both wet and dry deposition have been implicated in the damage and destruction of vegetation and in the degradation of soils, building materials and watercourses. SO_2 emissions arise from the direct combustion of fossil fuels by mobile plant and machinery used in the construction of both electrified and diesel traction rail networks.

Nitrogen Oxides (NO_x): are formed during combustion of fossil fuel which leads to the oxidation of nitrogen contained within it. NO_x can irritate the lungs and lower resistance to respiratory infections such as influenza. Continued or frequent exposure to concentrations that are typically higher than those found in ambient air may cause increased incidence of acute respiratory illness. NO_x emissions will arise as a result of the combustion of fossil fuels in construction vehicles, plant and equipment.

Carbon Monoxide (CO): is a toxic gas which is emitted from the combustion of fossil fuels. In Europe, most CO is produced from road traffic emissions. However, all forms of fossil fuel combustion produce CO, including construction machinery, plant and equipment. Carbon monoxide prevents the normal transport of oxygen by the blood.

Volatile Organic Compounds (VOCs): are released from vehicles and plant either as unburned fuels or as combustion products. In addition to contributing to the depletion of the ozone layer, certain VOCs can pose chronic health risks including cancer, central nervous system disorders, liver and kidney damage, reproductive disorders and birth defects.

Particulate Matter (PM): varies in terms of its physical and chemical composition, source and particle size. Small particles are of the greatest concern as they are small enough to penetrate deep into the lungs, potentially causing serious health risks. Emissions of PM will arise from the combustion of fossil fuels in construction machinery, plant and equipment. High levels of PM release are typically associated with diesel engines.

Whilst the above impacts can be significant, the extent of their significance depends upon the scale of the construction operation and its geographical setting. Clearly, the impacts are likely to be greater where the construction activity is carried out within built-up or urban areas and where humans could to be impacted.

3.1.2 Water

Water is consumed for batching/mixing cement; vehicle washing and domestic purposes (construction workers etc). There are pollution risks associated with the bulk storage and handling of fuel oil and chemicals at construction sites. Where the railway passes protected sites (i.e. Sites of Special Scientific Interest, Areas of Outstanding Natural Beauty) special precautions may be necessary to protect the environment from construction activities. Additionally protective measures may need to be included in the design resulting in additional costs.

3.1.3 Construction Materials

Materials used in the construction of railway infrastructure include concrete, masonry, timber and steel in varying quantities. Consumables may include paints, adhesives, resins etc.

Non-hazardous wastes generated during construction include spoil, timber, packaging (cardboard, plastic and polythene etc). Hazardous wastes generated during construction include used oils, oil and chemical containers, contaminated fill material.

The costs of handling and disposal of redundant material when equipment is replaced needs to be taken into consideration though some equipment (particularly copper based products) will be suitable for re-cycling and can make a positive contribution to the cost of a renewals project.

3.1.4 Landscape

The construction of railway infrastructure can have a negative impact upon the landscape, particularly when new equipment is installed in sensitive areas. This is important where the new equipment entails the removal or alteration of landscape features that are of value (i.e. trees, hedgerows, buildings etc) or where additional features are added that do not necessarily compliment the existing value of landscape (i.e. the visual impact of electrification equipment).

Modification or ‘like for like’ replacement of the existing electric network infrastructure is unlikely to have any additional impact on landscape character as it is unlikely to involve any additions to the network that would impede landscape character.

The electrification of a route could potentially involve damage/alterations to structures/buildings of historical interest (i.e. listed buildings, scheduled ancient monuments, previously unidentified archaeological finds etc). Construction may also involve a need to carry out works on or near to protected historical resources.

Careful planning and design can limit the impact and reduce the objections with examples including alterations to St Pancras Station and specially designed overhead line structures used on the Royal Border Bridge at Berwick and Durham viaduct.

3.1.5 Summary

Some of the above are general and apply to any electrification project whilst others are site specific. An allowance has been included in the cost model for general installation activities including noise abatement, disposal of spoil, protecting sites of special scientific interest (SSSI) etc. There is also a facility for adding costs to cover specific environmental measures under the heading “cost for specific route features”.

3.2 Energy and Greenhouse Gas Emissions

3.2.1 Diesel Fuel

There is pressure (backed up by legislation) to reduce emissions, including both ‘cleaner’ engines and reducing CO_2. A2 gas oil is currently used in the UK diesel fleet that includes locomotives for freight and passenger traction, and passenger diesel multiple units (DMUs). Approximately 450 million litres are used annually by the passenger fleet and 190 million litres by the freight fleet.

Diesel is a fossil fuel which is a finite resource and therefore ultimately limited in supply. The combustion of diesel in railway engines generates greenhouse gases that are increasingly being subject to regulatory instruments to curb usage (e.g. emissions trading scheme). Whilst there has been little emphasis to date on fuel oil use in rail vehicles, in future the price of diesel is likely to rise as result of scarcity and also possible fiscal/regulatory measures as a result of pressures to curb GHG emissions. These will affect oil producers/suppliers as well as users/consumers. The use of bio-diesel may reduce CO_2 emissions from portable fuel engines. Current research is ongoing to determine the overall benefits including performance, efficiency, emissions and engine service life.

3.2.2 Electricity Generation

Whilst not directly involved in the combustion of fossil fuels, electric traction is indirectly related to GHG emissions as electrical power is obtained from the National Grid which (in 2005) was dependent on a variety of sources (Gas 40%, Nuclear 19%, Coal 33%, Hydro 1%, Oil 1%, Imports 2.5% and Others 3.5%). With some 70% of CO_2 emissions arising from the way we produce electricity, if the UK is to achieve its goal of reducing CO_2 emissions by 60%, the electricity generation mix will have to be much different in the future, favouring renewable energy sources and nuclear generation.

According to current government policy, renewable energy will play a significant part in the future energy mix, with targets of 10% in 2010 and 20% by 2020 being set. Currently, renewable electrical energy generation is more expensive than conventional electricity generation technology. This is because the technologies are still relative immature with limited opportunity to achieve economies of scale. However, it is envisaged that as the cost of fossil fuels rise, the relative expense of renewable energy will diminish.

Diesel fuel is a finite fossil fuel resource which, by definition, is limited in supply. Similarly, the bulk of electricity generation is reliant upon fossil fuel sources. The continued consumption of fossil fuels is contributing to the depletion of this non-renewable resource. The proportion of nuclear energy in the generating mix will have a significant impact on emissions and is a proven technology to replace fossil fuels.

3.2.3 Carbon Dioxide

The combustion of fossil fuels either by rail vehicles in operation or power stations that supply electricity for powering trains produces carbon dioxide (CO_2) which contributes to global warming. To understand the extent to which each form of transport contributes to global warming, CO_2 emissions emitted by each have been compared:

DIESEL	ELECTRIC
Average Energy Use per vehicle km (kWh/vehkm) = 5.22 Source: The Energy Consumption of Rail Vehicles in Britain, section 7.1 (ATOC, Bombardier Transportation & National Express Group, November 2006)	Average Energy Use per vehicle km (kWh/vehkm) = 2.00 Source: The Energy Consumption of Rail Vehicles in Britain, section 7.1 (ATOC, Bombardier Transportation & National Express Group, November 2006)
Carbon dioxide emissions per unit of energy consumed (kgCO$_2$/kWh) = 0.25 Source: Energy & Carbon Emissions (Carbon Trust, 2006) Assuming 5% is from bio-diesel by 2010 (as detailed in current government policy – Renewable Transport Fuel Obligation RTFO), and then conversion factor may fall to 0.2375.	Carbon dioxide emissions per unit of energy consumed (kgCO$_2$/kWh) = 0.517 2005 = 528 2006 = 522 2007 = 517 2008 = 511 2009 = 506 2010 = 500 2011 = 502 2012 = 505 2013 = 507 2014 = 509 2015 = 512 2016 = 503 2017 = 494 2018 = 486 2019 = 477 2020 = 468 Source: Data provided by AEA Energy & Environment, (e-mail January 2007) ***Note****: there are other values stated for this in the public domain, the most widely quoted by DEFRA is 0.43, although the above figure has been reported by AEA in related research so we have used this for consistency in approach.*
Carbon Dioxide Emissions per vehicle km (kgCO$_2$/vehkm) = 2007 = 1.305 2010 = 1.23975 (with RTFO taken into account)	Carbon Dioxide Emissions per vehicle km (kgCO$_2$/vehkm) 2005 = 1.056 2006 = 1.044 2007 = 1.034 2008 = 1.022 2009 = 1.012 2010 = 1.000 2011 = 1.012 2012 = 1.010 2013 = 1.014 2014 = 1.018 2015 = 1.024 2016 = 1.006 2017 = 0.988 2018 = 0.972 2019 = 0.954 2020 = 0.936 ***Note:*** *if conversion factor of 0.43kgCO$_2$/kWh as published by DEFRA is used, the difference between diesel and electric traction related emissions widens (i.e. 2 x 0.43 = 0.86 kgCO$_2$/vehkm).*
Assumptions: Diesel energy consumption based upon total volumes of diesel fuel supplied by wholesalers to train companies. These numbers were then divided by vehicle kilometres reported to ATOC in connection with the national reliability monitoring programme and by the total passenger kilometres recorded from the Rail Settlement Plan, the system that records and attributes passenger revenues across the country. Accuracy is estimated to be with ± 10% for each train company. Excludes 'well to tank' emissions (estimated at 14% above the figures quoted) 2007 value excludes bio fuel content which, by 2010, is likely to be 5% of transport fuel if the RTFO is successful.	Assumptions Electrical energy consumption based on the total amount of electricity billed to train companies. These numbers were then divided by vehicle kilometres reported to ATOC in connection with the national reliability monitoring programme and by the total passenger kilometres recorded from the Rail Settlement Plan, the system that records and attributes passenger revenues across the country. Accuracy is estimated to be with ± 10% for each train company. Excludes 'fuel extraction point' to power station emissions (no quoted figures exist for emissions in relation to this) Excludes distribution losses (estimated at 5% from the public grid and 2% from the rail network).

Table 3.1 – CO$_2$ Emissions for Diesel and Electric Traction

On the basis of the above comparison, electrification is the more advantageous in terms of energy consumption and CO_2 emissions when normalised against the energy required to propel a rail vehicle; there being a net difference of approximately 270grams (20% saving) CO_2/vehkm in 2007, 305grams (23%) CO_2/vehkm in 2010 and 370grams (28%) CO_2/vehkm in 2020 between electric and diesel rail vehicles (excluding RTFO). However there is expected to be a greater proportion of fuels derived from bio-fuel sources (up to 5% by 2010) which are considered CO_2 neutral (i.e. CO_2 released is then 'off-set' by the bio fuel crops in rotation). This would result in a net difference of approximately 240grams (19%) CO_2/vehkm by the year 2010. Any change in the generating mix will have a net change on these figures. If the current debate on future generation results in the existing nuclear capacity being replaced with a new generation of nuclear power stations then the benefits of electric traction associated with CO_2 emissions will increase.

We have reviewed the draft Interfleet report (T618 – Traction Energy Metrics). Both this study and the Interfleet study have referred to the Energy Consumption of Rail Vehicles in Britain report (Phillip Hinde and Christina Larsson, published by ATOC, Bombardier Transportation and National Express Group) for energy use data on train services. Interfleet have calculated CO_2 emissions per seat.km whereas the Atkins calculations are per vehicle.km for comparing diesel and electric traction. The results from Figure 18 of the Interfleet report and Table 3.1 above have been compared:

Study	Date/type	Diesel	Electric	Benefit
Interfleet	interurban	24 g CO_2/seat.km	16 g CO_2/seat.km	33%
Interfleet	inter-city	28 g CO_2/seat.km	18 g CO_2/seat.km	36%
Atkins	2007	1305 g CO_2/veh.km	1034 g CO_2/veh.km	20%
Atkins	2010 (RTFO)	1240 g CO_2/veh.km	1000 g CO_2/veh.km	19%
Atkins	2020 (RTFO)	1240 g CO_2/veh.km	936 g CO_2/veh.km	24%

Table 3.2 – Comparison of CO_2 Emissions

The figures used in the Atkins study are therefore relatively less favourable to electrification than Interfleet's. Using the Interfleet figures would strengthen the calculated BCR.

Although current knowledge demonstrates a CO_2 case in favour of electrification, there are a number of issues that may affect this in the future.

1. Both diesel and electric powered vehicles will become more efficient to varying degrees, making the comparisons different with time.

2. Government policy may change, affecting the bio fuel content of transport fuel, thus further changing the figures that are currently presented.

3. It is also possible (and arguably quite likely, given the current government policy on climate change), that as the drive for greater proportions of energy generation

from renewable sources increases, that the fuel mix will adjust and that the CO_2 emissions from electricity generated power per kWh will fall even further post 2020. The amount by which this will fall is impossible to predict as much will depend upon market forces and the effectiveness of government policy.

3.3 Sulphur in Diesel

Today A2 Gas Oil is used which allows a maximum of 2000 parts per million (ppm) of sulphur, although the actual sulphur level may in practice be lower. By way of comparison fuels used by diesel road vehicles have different particulate content; Ultra Low Sulphur Diesel (ULSD) has a maximum of 50 ppm of sulphur; Sulphur Free Diesel (SFD) will contain a maximum of 10 ppm of sulphur. The sulphur content of Gas Oil will reduce to within a maximum of 1000 ppm of sulphur, in 2008 to achieve compliance with EU Sulphur in Fuels Directive.

Further legislative change will affect fuels available for diesel traction. EU Directive 2003/30/EC promotes the use of biofuels or other renewable fuels for transport and required member states to enact its provisions into national legislation by the end of 2004. In advance of a Renewable Transport Fuel Obligation (RTFO) the UK 2006 budget set targets for bio content in fuel by volume of:

- 2.5% in 2008/9
- 3.75% in 2009/10
- 5% in 2010/11.

Reduced sulphur fuels have lower density than Gas Oil resulting in a lower thermal energy; tests have shown consequent power output reduction of up to 3% and fuel consumption increase of up to 2%.

Manufacture of low sulphur Gas Oil, ULSD or SFD will increase the commodity cost over that of A2 Gas Oil of today, and introduction of bio will raise the commodity cost further.

Taxation levied on A2 Gas Oil is 6.44 pence per litre while currently ULSD or SFD for road use is taxed at over 40 pence more. For ULSD or SFD to become viable alternatives we must assume similar tax exemptions for rail use would be agreed by government.

Changing the choice of rail fuel will change the emissions generated. Clearly lowered sulphur Gas Oil will reduce SO_X emission; the sulphur content will be required to reduce to 1000 ppm, but reduction below this level possibly approaching 50 ppm (as may result if pressure increases to reduce European heating oil emissions), would greatly reduce SO_X. If the density of reduced sulphur Gas Oil is unaffected the adverse power and economy effects may not be present. Introduction of bio into Gas Oil may however reduce the density, and hence available power per litre of fuel.

Despite the adverse power and economy effects of lowered ULSD or SFD density, tests have shown NO_X, SO_X and PM10 emissions will reduce. Initial tests have shown changes to CO_2, resulting from ULSD or SFD including increasing bio content, can vary relative to A2 Gas Oil; further engine tests are being undertaken by industry to provide data that can be regarded with confidence.

3.3.1 Local Air Quality

Diesel fuelled rail vehicles generate emissions to air (including NO_x, SO_x, CO_2, CO and PM) at the point of use (i.e. from the engines themselves within the locomotives). The development of new engines and new fuels, including hybrid engines, is likely to reduce emissions to air from diesel engines. Air emissions from electric vehicles will not be generated by the locomotive, but at the power station where electrical energy is generated.

Diesel related emissions are more diffuse and hence more easily dispersed when compared to large power stations. The overall impact on local air quality will depend ultimately upon background air quality and the extent to which the operation of the rail route will contribute/add to this. High density, well-used rail links within a small area could lead to occasional episodes of high pollution whereas less dense and less used routes will have lesser episodes of high pollution and hence contribute less. As a result of the infrequent and non-continuous nature of rail vehicle emissions, very little has been done to physically model the precise impacts resulting from them.

When considering NO_x emissions, DEFRA states that these are unlikely to have any significant impact alongside railway tracks, but there is the potential for problems to occur in close proximity to large numbers of stationary, idling engines, for example at depots or in stations. The impact is unlikely to extend beyond a distance of about 50 metres.

Similarly, in terms of sulphur dioxide (SO_2), diesel trains may give rise to elevated sulphur dioxide concentrations. This, however, is only likely to occur when locomotives are regularly stationary with their engines running for periods of around 15-minutes or longer close to sensitive locations. It should also be noted that the current maximum allowable sulphur content of rail diesel (2000 ppm) is expected to reduce to 1000 ppm by 2008 as a result of forthcoming EU legislation (still under discussion). Current emissions of sulphur dioxide from rail vehicles are therefore expected to decline in future years.

Whilst emissions at the power station are similar in terms of type, the quantity at the point source will be significant, having potentially greater effects upon local air quality though only a small proportion is attributable to railway electrification. Whilst a power station is likely to have a greater impact in terms of local air quality, there remains the potential to abate these emissions as required under Integrated Pollution Prevention and Control (IPPC) legislation.

There are very different characteristics to local air pollution issues when comparing a diesel network with an electrified network. Although the impact on local air quality will be greater at power stations, with emissions from diesel trains more evenly distributed, pollution from diesel trains in enclosed stations has a direct impact on passengers and staff. The absence of accurate air pollution modelling data from diesel related rail traffic prevents any reliable comparison from being made.

3.4 Noise

3.4.1 The Characterisation Of Railway Noise

Railway noise has two principal components, at least at speeds relevant to most of the UK rail network. These are noise from the motive power system (traction noise) and noise from the wheel-rail interface (called 'rolling noise' in this report).

ROLLING NOISE

Rolling noise is largely independent of the type of motive power. It depends mainly on the number and size of wheels, the wheel construction, the train braking system, (disc or tread braked) the type of track, the roughness of the track and the type of track support system.

Modern multiple-unit trains have similar wheel configurations and disc braking systems so this is not a particular distinguishing feature between diesel and electric traction.

Rolling noise increases rapidly with train speed, with the average sound level increasing at about the square of the speed, and the maximum sound level increasing at about the cube of the speed.

TRACTION SYSTEM NOISE

There are many sources of traction system noise on modern trains. Engine and exhaust systems are the obvious sources of noise on diesel and diesel-electric traction system. Less obvious sources are pantograph, engine and control system cooling fan noise. Developments in pantograph noise and aerodynamic drag are currently being investigated in Germany and Japan.

Control-system and motor cooling fans are a major source of noise on both diesel-electric and electric traction systems.

Whilst it is obvious that diesel engines will be running when the train is travelling at low speed or when stationary, it is less obvious that the cooling fans on electric trains will also produce noise at low speed and when stationary.

ANCILLARY SYSTEMS

All types of trains also have ancillary units associated with braking systems, lighting systems, door control systems and air conditioning systems which tend to produce the same sort of noise levels irrespective of whether the train is stationary or travelling.

3.4.2 Noise Measurement And Assessment

Noise calculations were made using the standard UK assessment procedure 'Calculation of Railway Noise' produced by the Department of Transport in 1995 (and as subsequently amended). This procedure requires knowledge of the 'Noise Correction Factor' for the type of train under consideration. Atkins has obtained correction factors based on information in their possession on various past projects, and believe the following factors to be appropriate.

- Pendolino – CRN correction factor = +10.7 dB
- Voyager – CRN correction factor = +13.8 dB

The correction factors suggest that Voyagers are about 3.1 dB noisier than Pendolinos at reference distance and speed. However, Pendolinos carry 9 cars and have 439 seats per train, whilst Voyagers carry 4 cars (at least in original configuration) and 186 seats per train. Thus two Voyagers carry about the same number of passengers as one Pendolino.

The Department of Transport advises that the multi-modal TAG assessment methodology should be used for comparing strategies, but that noise is a local impact which depends on the precise geometrical relationship between source and receiver. TAG warns that for strategies, monetary evaluation is not meaningful in the absence of initial values of noise exposure.

The TAG methodology assesses environmental noise impact in terms of numbers of people affected. The noise exposure is first calculated, and then converted into numbers of people annoyed or ‘bothered’ by noise. This is then converted into monetary values, using a procedure set out in TAG. A threshold of 45 dB LAeq (18-hour) is used for both annoyance and monetary evaluation.

For monetary evaluation, the cost of a change in noise level is given by TAG in a cost per decibel change. The cost per dB change ranges from £8.40 at a starting point of 45 dB, rising to £98 at a starting point of 80 dB.

As noted above, noise assessments for strategies are difficult to undertake, because of their dependency on local effects. It was agreed that to provide a basis for comparison, two exemplar train types (Pendolino and Voyager) would be assessed for two exemplar stations on the Midland Main Line, namely Derby and Sheffield.

At both locations, the train flow rate was assumed to be an average of 2 Pendolinos per hour and 4 Voyager trains per hour, as these would give about the same passenger-carrying capacity.

Noise contours were generated in 1 dB steps, starting from 45 dB, which is the minimum level that Transport Analysis Guidance (TAG) requires to be assessed and overlaid on the 1:10000 scale Ordnance Survey map of the area. The property immediately adjacent to the tracks is of industrial and commercial appearance, and large buildings act as an effective screen to noise, which results in noise levels at residential property being below the 45 dB threshold.

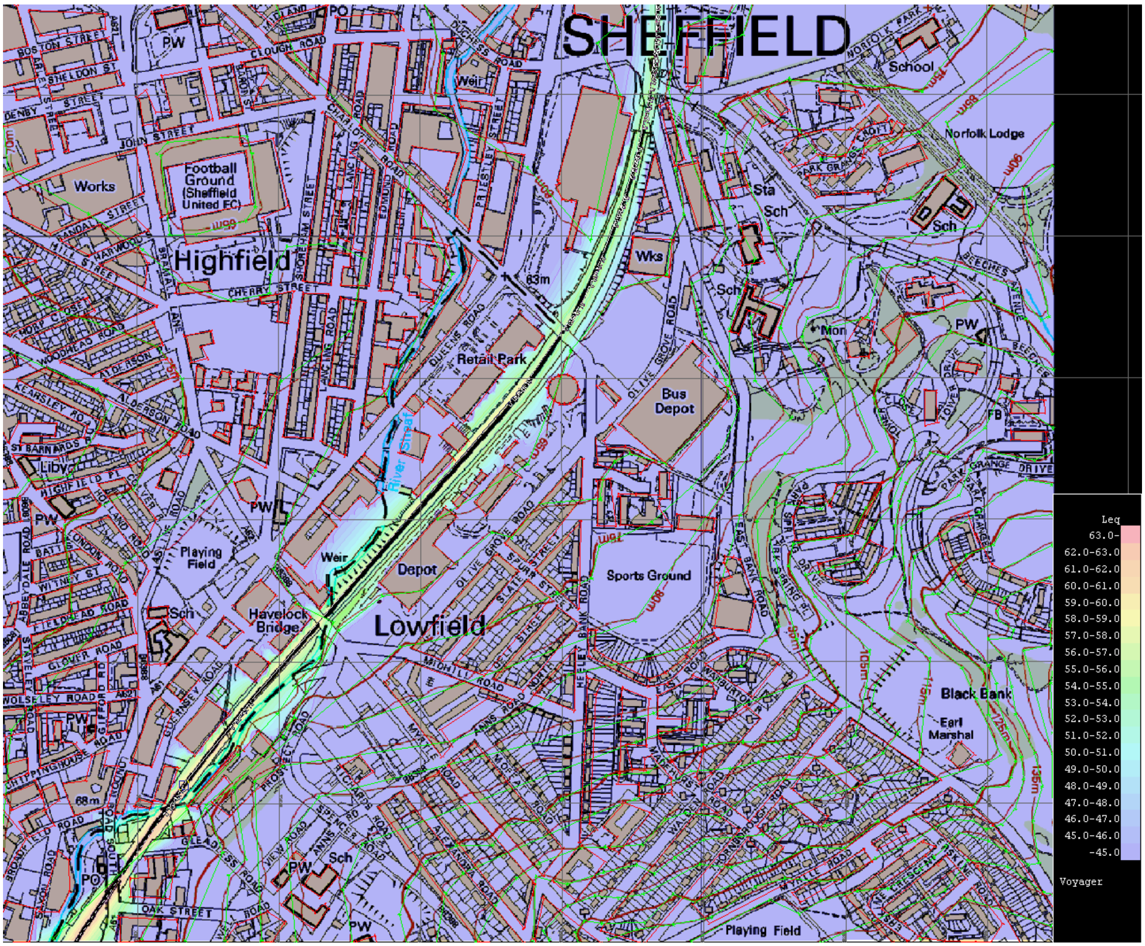


Figure 3.1 – Voyager noise contours – Sheffield

Based on these exemplar cases, noise is not a significant factor in choosing between diesel and electric traction, using modern train types. It must, of course, be recognised that this analysis does not include all traffic at these stations, as this information is not known. If noise from all trains is included, the area affected by noise would be greater, but this analysis cannot be undertaken without a detailed knowledge of trains types and numbers, and would be entirely location-specific.

For the two types of train compared here, diesel-electric multiple units are up to 6 dB noisier than electric multiple units, in these exemplar areas, for the train types and traffic flows assumed, noise levels do not meet the threshold level at which either the annoyance or monetary values can be assessed.

Indeed, government guidance note PPG 24 ‘Planning and Noise’ points out that ‘a change of 3 dB is the minimum perceptible under normal conditions.

Accordingly, it is unlikely that a choice between diesel and electric traction will have any significant noise impact, either in terms of annoyance or monetary value. However, it should be noted that this comparison is between two of the newest types of multiple unit trains. It does not mean that a replacement of older rolling stock or motive power would have no noise benefit: indeed the benefit could be significant for some types of locomotive or older diesel multiple units.

Moreover, given that there are no current general noise limits on railway vehicles (or on noise from most existing railways), it should not be assumed that the comparison between Pendolinos and Voyagers would necessarily hold true for all possible future trains types.

The study undertaken has not considered the local effects of noise on passengers and staff, particularly in enclosed stations where the design of trains and the location of noise generators will be a key factor (i.e. platforms will provide a level of screening for low level/under slung equipment).

4. Cost Model

This section describes the electrification cost model, how it has been developed and outlines how it should be used. The model produces estimates of the infrastructure costs of electrification, for both capital and maintenance costs. It is designed to be capable of being applied to any user-specified route or scenario.

The cost model has been used to estimate the costs of electrification on each of the exemplar routes. The costs per single track kilometre range from £550,000 to £650,000. Sensitivity analyses have identified the input factors that have the greatest impact upon costs.

4.1 Model Development

The cost model has been developed to provide a simple method of calculating the costs for electrification schemes requiring minimal detailed technical or route knowledge. To simplify operation a single screen is used for inputting route specific data and showing the calculated costs. These costs are calculated using cost and system data embedded in the model and the route specific inputs.

The cost model has been developed in excel based on the key cost drivers identified in the industry workshop. A baseline cost item database has been developed based on a range of data sources and construction techniques. Each item in the database is accessible to the end user and hence can be amended if, for example, base costs change, technology changes or more accurate costs are identified. More significant technological developments can either be modelled by changing the unit rates to suit (i.e. reducing the rate for portal structures to represent headspans) or by more significant changes to the model to reflect the new technology.

Data sheets have been included for the following cost items:

- Electrification equipment
- Interfaces with existing overhead line equipment
- Immunisation costs
- Overbridges
- Platform canopies
- Tunnels
- Depots
- On costs
- Environment

- Possessions/disruptions
- Electrification operational costs (maintenance)

The costs are unit costs based on the most efficient installation techniques. Any allowance for contractor and client on-costs or cost allowance for inefficient working due to access restrictions are added separately.

A cost for the inefficiency of having to work with restricted access is separately calculated. It is based on a balance between the impact on train operators and the increased costs for contractors having to work with access restrictions. The baseline compensation values and inefficiency on-cost percentages have been developed to give a range of general possession types depending on the impact on operators. The relative compensation values between operators are more significant than the actual values which have been calculated based on typical compensation costs and to give a range of possession types that would be expected based on impact to operators specified on the User Interface Screen.

Contractor and client on-costs, including non-contractor design, testing and commissioning are variables within the model and can be set at different percentages for different activities.

The model calculates the costs based on the base costs, user input route characteristics and electrification equipment characteristics. These characteristics are embedded in the model but can be changed by the user. They include:

- Average tension length. Mid point to mid point distance (not anchor to anchor i.e. length of parallel running at overlaps counted once)
- Average span length (new)
- Average span length (existing cantilevers)
- Average span length (existing portals)
- Average span length (existing headspans)
- Overlap span length
- Anchor span length
- Neutral Sections spacing
- Average switching equipment spacing (excluding substations)
- Booster transformers spacing
- Track to track bond spacing
- Feeder Stations spacing (for classic Booster Transformer (BT) & Return Conductor (RC))

- Auto transformer (AT) spacing
- Feeder Stations spacing (AT)

4.2 Sources of Cost Data

Cost data with regard to new and renewed infrastructure has been obtained from Network Rail project and engineering teams. Additional data has been sourced from within Atkins. Projects used as a data source include Leeds to Hambleton Junction studies, Airdrie to Bathgate studies, Crewe to Kidsgrove, Larkhall, Trent Valley 4 Tracking, Shields to Gourock, Hertford Loop Structures, West Coast Route Modernisation and East Coast span wire and conductor replacement. Civil engineering data has been based on projects including Ipswich Tunnel, track slues in Stoke tunnel (ECML) and W10 gauge enhancements projects. The cost model has been reviewed in detail by Network Rail and data updated following feedback. The data used in this study is included in Appendix E.

4.3 Model Structure

The model has been developed in excel with a front page used to navigate around the model by ‘point and click’ buttons. When opening the model this page automatically shows.

Figure 4.1 – Cost Model Navigation Page with 'Point and Click' Buttons

For general use the User Interface and Cost Summary screens are all that are required. The user interface screen enables the user to load route specific details. The Cost Summary screen shows the same output data as on user interface screen (blue boxes shown in Figure 4.2). The remaining screens are for changing the base data and to calculate the cost values.

ELECTRIFICATION CALCULATION SCREENS

These screens, titled 'Single Track OLE' (new, re-wire & de-wire), 'Four Track OLE' (new, re-wire & de-wire), 'Classic RC & BT 1 or 2 track', 'Classic RC & BT 4 track' and 'Auto Transformers', have no user input facility and calculate the electrification costs based on the route and electrification data. The relevant outputs for the route being modelled are then transferred to the User Interface screen and the Cost Summary screen.

Where new electrification interfaces with existing, an additional cost for each interface is added. The user can change the values for base price and contractors' on costs if required.

IMMUNISATION COSTS

This screen calculates the cost of immunising telecoms and signalling equipment where required. The base rates, per route km for telecoms and per single track km for signalling, and contractors' on costs may be changed by the user. The cost for moving signals (e.g. for signal sighting purposes) is not included here but covered in the electrification costs. It should be noted that the costs for immunisation included in the model are based on the assumption that the telecoms and signalling equipment will need to be replaced at some stage. Therefore the costs included in the business case as to whether to electrify a route or not reflect the early replacement costs of non life-expired equipment.

CIVIL ENGINEERING COSTS

These screens, titled 'Over Bridges', 'Platform Canopies' and 'Tunnels' (Track Slue, Track Lower (Ballast) and Track Lower (Slab Track)), calculate the civil engineering costs based on the route data and base costs.

The cost for overbridges includes providing adequate clearances for electrification equipment and alterations to parapets.

The cost for platform canopies recognises the need for alterations to canopies to accommodate overhead line equipment. The extent of modification is difficult to assess without a detailed knowledge of each platform. Local knowledge may require the base cost to be changed.

The costs for tunnels are based on the length of alterations required as input on the User Interface screen with options for track slue, track lower on ballast track and more extreme measures to reduce track levels using slab track. It is assumed that no drainage work is required for a track slue and that in multiple track areas the length of track to be slued is the same for each track. For track lowering of ballast track it has been assumed that drainage work is required and that in multiple track areas the length of track to be lowered is the same for each track. Where slab track is required it is assumed that drainage work is incorporated in the slab and that in multiple track areas the length of track to be lowered is the same for each track.

DEPOT COSTS

These screens calculate the cost of provision of new depots or converting existing depots for electric trains (including provision of specific facilities for electric trains and wiring stabling sidings, sheds etc.). These are based on an 'average' depot as the costs are wide ranging with the location and number of vehicles to be maintained having a significant impact.

ON COSTS

This screen calculates the non-contractor on costs for a project including:

- Testing & Commissioning
- Non Contractor Design

    - Scheme Design/OPS
    - Detail Design
    - Site Investigation / Correlation
    - Handover Package
    - Planning consents/Third Party Consultation
- Other On-Costs
    - Network Rail Project Management
    - Possession/isolation Management.

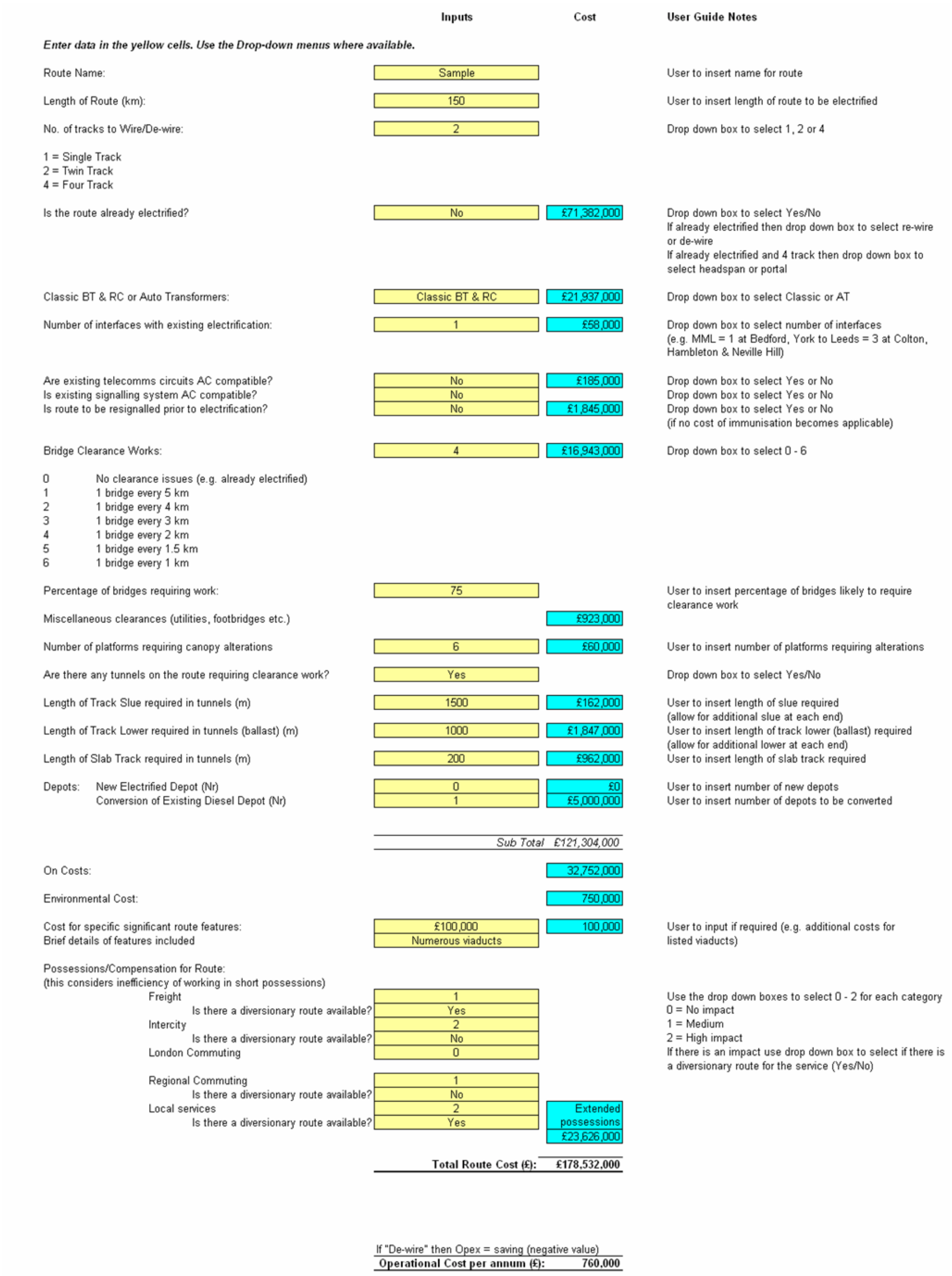
The percentage values may be changed by the user.

ENVIRONMENTAL COSTS

The environmental costs are those associated with the electrification installation activities and include noise abatement, disposal of spoil, protecting sites of special scientific interest (SSSI) etc.

OPERATIONAL COSTS

The annual cost for maintaining the electrification infrastructure is based on the Network Rail maintenance budget and the length of railway electrified with overhead line equipment. These figures can be changed by the user.

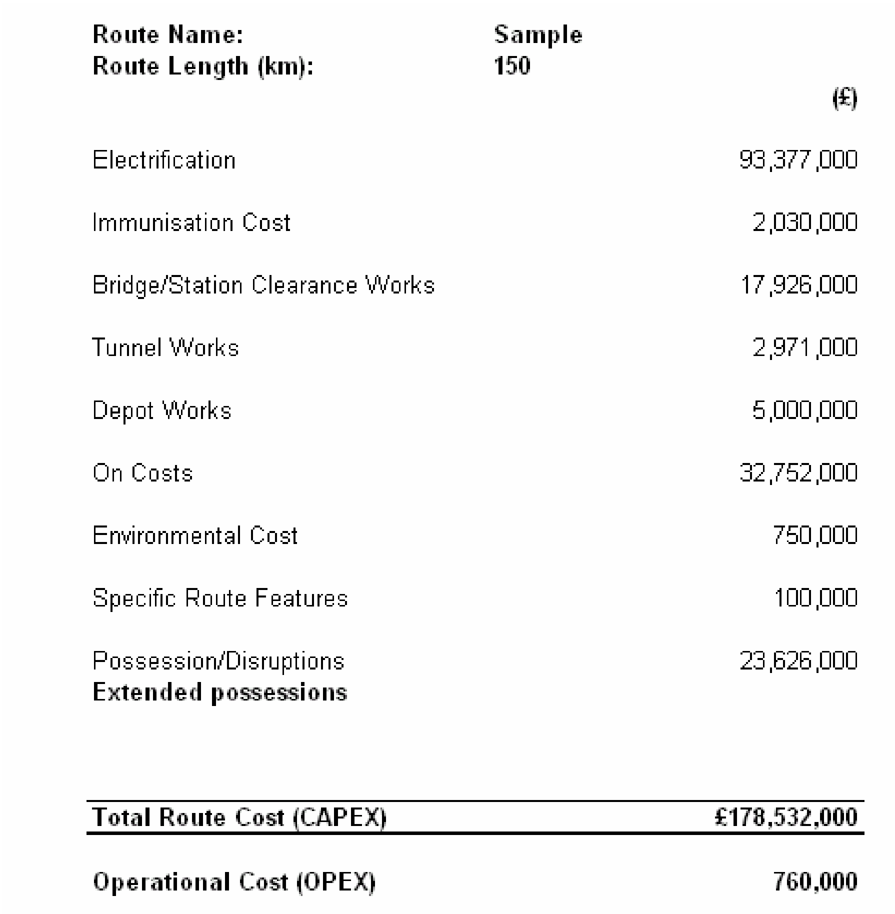


	Inputs	Cost	User Guide Notes
Enter data in the yellow cells. Use the Drop-down menus where available.			
Route Name:	Sample		User to insert name for route
Length of Route (km):	150		User to insert length of route to be electrified
No. of tracks to Wire/De-wire:	2		Drop down box to select 1, 2 or 4
1 = Single Track 2 = Twin Track 4 = Four Track			
Is the route already electrified?	No	£71,382,000	Drop down box to select Yes/No If already electrified then drop down box to select re-wire or de-wire If already electrified and 4 track then drop down box to select headspan or portal
Classic BT & RC or Auto Transformers:	Classic BT & RC	£21,937,000	Drop down box to select Classic or AT
Number of interfaces with existing electrification:	1	£58,000	Drop down box to select number of interfaces (e.g. MML = 1 at Bedford, York to Leeds = 3 at Colton, Hambleton & Neville Hill)
Are existing telecomms circuits AC compatible?	No	£185,000	Drop down box to select Yes or No
Is existing signalling system AC compatible?	No		Drop down box to select Yes or No
Is route to be resignalled prior to electrification?	No	£1,845,000	Drop down box to select Yes or No (if no cost of immunisation becomes applicable)
Bridge Clearance Works:	4	£16,943,000	Drop down box to select 0 - 6
0 No clearance issues (e.g. already electrified) 1 1 bridge every 5 km 2 1 bridge every 4 km 3 1 bridge every 3 km 4 1 bridge every 2 km 5 1 bridge every 1.5 km 6 1 bridge every 1 km			
Percentage of bridges requiring work:	75		User to insert percentage of bridges likely to require clearance work
Miscellaneous clearances (utilities, footbridges etc.)		£923,000	
Number of platforms requiring canopy alterations	6	£60,000	User to insert number of platforms requiring alterations
Are there any tunnels on the route requiring clearance work?	Yes		Drop down box to select Yes/No
Length of Track Slue required in tunnels (m)	1500	£162,000	User to insert length of slue required (allow for additional slue at each end)
Length of Track Lower required in tunnels (ballast) (m)	1000	£1,847,000	User to insert length of track lower (ballast) required (allow for additional lower at each end)
Length of Slab Track required in tunnels (m)	200	£962,000	User to insert length of slab track required
Depots: New Electrified Depot (Nr)	0	£0	User to insert number of new depots
Conversion of Existing Diesel Depot (Nr)	1	£5,000,000	User to insert number of depots to be converted
	Sub Total	*£121,304,000*	
On Costs:		32,752,000	
Environmental Cost:		750,000	
Cost for specific significant route features:	£100,000	100,000	User to input if required (e.g. additional costs for listed viaducts)
Brief details of features included	Numerous viaducts		
Possessions/Compensation for Route: (this considers inefficiency of working in short possessions)			
Freight	1		Use the drop down boxes to select 0 - 2 for each category 0 = No impact 1 = Medium 2 = High impact If there is an impact use drop down box to select if there is a diversionary route for the service (Yes/No)
Is there a diversionary route available?	Yes		
Intercity	2		
Is there a diversionary route available?	No		
London Commuting	0		
Regional Commuting	1		
Is there a diversionary route available?	No		
Local services	2	Extended possessions	
Is there a diversionary route available?	Yes		
		£23,626,000	
	Total Route Cost (£):	**£178,532,000**	
	If "De-wire" then Opex = saving (negative value)		
	Operational Cost per annum (£):	**760,000**	

Figure 4.2 – Cost Model User Interface Screen showing a Sample Route

4.4 Outputs

The outputs from the model are summarised on the Cost Summary screen. These values are then used in the economic model.



Route Name: **Sample**
Route Length (km): **150**

	(£)
Electrification	93,377,000
Immunisation Cost	2,030,000
Bridge/Station Clearance Works	17,926,000
Tunnel Works	2,971,000
Depot Works	5,000,000
On Costs	32,752,000
Environmental Cost	750,000
Specific Route Features	100,000
Possession/Disruptions	23,626,000
Extended possessions	
Total Route Cost (CAPEX)	**£178,532,000**
Operational Cost (OPEX)	**760,000**

Table 4.1 – Cost Model Cost Summary Screen showing costs for a Sample Route

The total costs for the exemplar routes modelled have been collated to enable ease of use and to compare rates. This table also shows costs/single track kilometre (STK) with a range of approximately £500k to £650k for new electrification.

Summary of Costs For Exemplar Routes

Route	Sub-route	Capital Cost	Cost/STK	Total Route Capital Cost	Total Route Cost/STK	Operational Cost/annum	Total Route Operational Cost/annum
MML	MML	£252,140,000	£649,845	£252,140,000	£649,845	£983,000	£983,000
Chiltern	Marylebone - Snow Hill	£192,390,000	£531,464	£252,571,000	£529,499	£917,000	£1,237,000
	Neasdon - Aylesbury	£53,911,000	£518,375			£264,000	
	Princes Risborough - Aylesbury	£6,270,000	£570,000			£56,000	
	Marylebone- Aylesbury	£66,697,000	£537,879			£314,000	
Cross Country	York - Leeds	£42,967,000	£565,355	£354,157,000	£600,266	£193,000	£1,495,000
	Leeds/Doncaster - Sheffield	£47,483,000	£608,756			£198,000	
	Sheffield - Birmingham	£155,116,000	£625,468			£628,000	
	Birmingham - Bristol	£108,591,000	£577,612			£476,000	
	Derby - Birmingham	£75,562,000	£572,439			£334,000	
ECML	Newcastle - Drem de-wire	£35,107,000	£102,652	£35,107,000		-£867,000	-£867,000
	Newcastle - Drem re-wire	£121,977,000	£356,658	£121,977,000		£867,000	£867,000
	Newcastle - Edinburgh	£142,638,000	£356,595	£142,638,000		£1,014,000	£1,014,000
GWML	Maidenhead - Didcot	£113,304,000	£590,125			£243,000	
	Heathrow - Didcot	£155,562,000	£580,455	£576,867,000	£635,316	£340,000	£2,129,000
	Didcot - Bristol TM	£116,039,000	£557,880			£527,000	
	Severn Tunnel Jn - Cardiff	£86,483,000	£568,967			£193,000	
	Cardiff - Swansea	£73,355,000	£516,585			£360,000	
	Wootton Bassett - Severn Tunnel Jn	£74,199,000	£515,271			£365,000	
	Didcot - Oxford	£19,914,000	£524,053			£96,000	
	Reading - Bedwyn	£51,315,000	£523,622			£248,000	
	Reading - Newbury	£28,288,000	£523,852			£137,000	

Table 4.2 – Summary of Costs for Exemplar Routes

4.5 Sensitivity Analysis

A sensitivity analysis of the input technical and cost data has been undertaken whereby a change in base data values for the 32 items most likely to impact on the total have been changed by ±10% and the resultant change in total cost reviewed.

The most sensitive items are:

OLE average span length (distance between support structures)
Foundation, mast, single track cantilever (multiple)
Foundations (2 off), 4 track portal, 4 off single track cantilevers (multiple)
Remove along track equipment including catenary, contact, droppers, return conductor
Supply & Install along track equipment including catenary, contact, droppers, return conductor
Auto transformers
ESI grid connection @ Feeder stations for AT system including civil site works
Contractor's Preliminaries
Over bridges
On-costs – both Client and Contractors

Table 4.3 – Most sensitive cost drivers

The most sensitive item is the average span length, particularly in four-track areas with portal structures, where a 10% decrease led to a 4% increase in costs for the Heathrow to Didcot section. It should also be noted that Client on-costs used in the study are significant.

5. Economic Model

This section describes the economic model. It highlights the basic structure of the economic model and describes how each of the elements of the research have fed into the economic appraisal.

Key features of the discussion are the development of the crowding benefit effects from the new stock of inter-city services, a discussion of the operating cost impacts of a move to diesel operation, and a discussion around the environmental assessments carried out in the appraisal work. An Important assumption has been the level of Optimism Bias assumed in the economics, the default highest level being chosen on the basis of schemes developed without design work. In reality the rigour of the cost model itself is much higher than would normally sit alongside such high levels of Optimism Bias.

The section highlights key economic assumptions. More details of the models are contained within the appendices.

5.1 Model Development

The model has been developed to incorporate the "monetary" impacts of electrification. The basic structure sees the Cost Model, Environmental impacts and the Demand Model feed the Economic Model. A full description of the Demand Model is included at Appendix A.

Within the Economic Model there is also an Operating Cost Model. It is held here as a number of the features of both the Cost Model (such as route length) and the Demand Model (such as train km) are required to run the Operating Cost Model. Full details of the Operating Cost Model itself are included in Appendix B.

The Economic Model has captured the main differences between the costs and impacts of operating an electric railway over those of a diesel or gas oil powered system. To this end the model identifies the main differences between the two systems.

For the majority of tests the economic model is set up such that the do-minimum scenario is one with diesel powered vehicles and the do-something has electric vehicles. The exception being where de-wiring of existing electrified lines is considered where a comparison has been made between the removal or replacement of the overhead line.

A key assumption in setting up the tests is the form and specification of future diesel and electric trains. For the purposes of the modelling it has been assumed that a future case with diesel inter-city vehicles as operational today (either Voyager of HST) is not likely. We have therefore taken vehicle specifications from the current Intercity Express Programme (IEP), where possible, for our future inter-city trains. Future commuter/inter-urban trains are not assumed to change to the same degree, and the assumptions for rolling stock on such lines have been based around the newest stock currently available. A comparison of the IEP characteristics used in this study and the recently issued IEP Functional Specification is included in Appendix H.

Given the basic assumptions around vehicle specifications the main differences between operations of the vehicles can be assessed and the impacts, in terms of economics, determined for the modelling. The key areas of difference identified have been:

- On train passenger capacity – leading to relief of train crowding;
- Vehicle and infrastructure reliability;
- Safety
- Environmental emissions.
- Journey time – primarily acceleration differentials;
- Operating costs;

5.1.1 Calculation of Capacity Benefits

The key driver behind the calculation of crowding benefits is the emerging information from the Intercity Express Programme (IEP) which suggests that electric trains have a greater area available for passengers due to the fact that no seating or facilities can be placed in the power cars of diesel trains.

Although it could be argued that some diesel trains recently introduced such as the Class 221/222s built by Bombardier and operated by Virgin Cross Country, Midland Mainline and Hull Trains have furnishable power cars due to the location of the engines under the vehicles, the IEP programme will result in HSTs reverting back to locomotive based engines, and there would be capacity benefits of running electric high speed trains over diesel.

The IEP diesel train has 8 coaches with 22 metres of furnishable space with no furnishable space in the two power cars. In addition to the furnishable space in the 8 coaches, the electric train has furnishable space of 21 metres in the two power cars. This has formed the basis of any train capacity uplifts and Table 5.1 shows the derived capacity uplifts.

Power Cars	Trailer Cars	Furnishable Space – Electric	Furnishable Space – Diesel	Seating Adjustment Factor
2	8	218	176	23.86%
2	9	240	198	21.21%
2	10	262	220	19.09%
1	4	109	88	23.86%
1	5	131	110	19.09%

Table 5.1 – IEP Capacity Assumptions

These uplifts (or reductions in de-wiring tests) have been applied to the existing number of seats on inter-city trains to derive a comparative capacity of switching between diesel and electricity based on the IEP assumption as opposed to any specified seating capacities on future intercity trains. This method will solely appraise the impact of switching between diesel and electric on the studied routes and not encompass any impacts on capacity due to changes in rolling stock when switching between current rolling stock and the proposed Intercity Express services. A more detailed explanation of how the capacity assumptions have been taken forward into the analysis is included in Appendix A – Demand Model Database

5.1.2 Calculation of Reliability Benefits

In order to apply a common approach to each of the 5 case study electrification schemes, a simple model was developed.

The data employed within the model are:

- Miles per casualty (MPC) by type of train from the National Fleet Reliability Improvement Programme (NFRIP) – as presented in Modern Railways (January 2006);
- TOC level delay minutes per fleet incident and total train miles (from the same article in Modern Railways);
- Network Rail (NR) data for OLE related incidents and delay minutes, by NR region;
- Electrified track mileage by NR region (from ORR's Annual assessment of Network Rail 2005-06);
- MOIRA for: (a) peak versus off-peak train miles - used to calculate the share of incidents in the weekday Peak; (b) average peak and off-peak train loads (weighted by train-arc miles), and (c) estimated track mileages for the 5 case studies; and
- LATS 2001 for peak vs. off-peak journey purpose (Business/Commuter/ Other)

The model compares the reliability disbenefits suffered per track mile on routes electrified with 25 kV overhead electrification against those on routes operated by diesel traction (DMU or HST). In the case of diesel operation, disbenefits were confined to those associated with train failure rates, whilst on electrified routes disbenefits were summed across overhead line equipment (OLE) incidents and failures of electric traction.

In order to compare the two types of train operation, it was necessary to identify a ring-fenced part of the network where rates of OLE failure could be compared to rates of electric traction failure. The NFRIP data could then be used to estimate the (additional) train failures that would have occurred, had the electric services been run as diesels. Thus, data on OLE failures and electric traction failures showed their relative incidence, whilst the NFRIP data showed the rate of diesel traction failure, relative to electric traction failure.

In addition to the causes of differential delay per incident noted in the previous section, the delay minutes from a given incident can vary according to its location. In general, an incident on a remote section of an inter-city route will result in fewer delay minutes than a comparable incident on a busy commuter route – simply because fewer trains will be affected. Reactionary delays (due to out-of-course running and the lateness of subsequent workings in a train's daily diagram) will also tend to be worse where the incident occurs at an urban location.

It is also the case that train failure rates (both in terms of miles per casualty, and failures per track mile per year) will differ between inter-city operations and urban routes. Fleet incidents will tend to occur more regularly on services and route sections where trains stop-and-start frequently as greater strain is placed on traction (and braking) equipment and on doors.

In order to capture the differences between inter-city and urban train operations, two exemplar NR regions were used:

- Non-IC - NR's Anglia Region (plus Heathrow-Paddington)
- IC LNE Region

Both of these regions host services that fall in the converse category. However, the electrified services within Anglia Region are heavily skewed towards high frequency (c2c, WA and GE) services serving the commuter belt. Although LNE includes FCC services (on both the MML and ECML), the region's AC-powered train miles are dominated by GNER[1].

The difference between the IC and non-IC inputs made a significant difference in the benefits of electrification per track mille. Non-IC electrification showed significant net reliability benefits, whilst IC electrification showed a broadly neutral effect.

The main underlying cause of this finding is that train failures are far more prevalent on non-IC services where trains are 'working hard' i.e. stopping and starting regularly. This means that the ratio of electric traction failures to OLE failures (both measured per track mile) is relatively high, which in turn inflates the ratio of diesel failures to the sum of OLE and electric traction failures. The higher delay minutes associated with (non-IC) DMU failures is another complementary contributor. A fuller explanation of how the reliability impacts have been taken forward into the modelling is included in Appendix A.

5.1.3 Calculation Of Safety Benefits

Electrification will result in some safety disbenefits as a result of an increased likelihood of injuries and fatalities due to the presence of the overhead wires. Incidents per annum per track kilometre were provided by RSSB and these were converted into annual monetised costs in line with the methodology outlined in TAG Unit 3.13.1.

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[1] LNE WAS PREFERRED OVER LNW BECAUSE THE LATTER INCLUDES A SIGNIFICANT ELEMENT OF 3RD RAIL ELECTRIFICATION, AND NR DATA DID NOT DIFFERENTIATE BETWEEN OLE AND 3RD RAIL INCIDENTS.

5.1.4 Calculation of Monetised Greenhouse Gas Emissions

The estimated reduction in Carbon emissions as a result of operating electric trains is based on the methodology outlined in Chapter 3 – Environmental Section. This has been converted into monetary values using the methodology outlined in WebTAG Unit 3.3.5. The central scenario has been used for the central cases although a sensitivity test has been conducted and details are included in Appendix I.

5.1.5 Journey Times

The experiences of the existing “modern” inter-city rolling stock has been that speed differentials between the stock types is minor, primarily because the maximum speeds of trains is typically governed by line speed rather than speed capability of the rolling stock.

Where there is a difference is with the acceleration capability of commuter/inter-urban trains, in which the acceleration potential of electric trains is faster than that of diesel. A wider analysis of these issues is included in Appendix B on operating costs.

5.1.6 Operating Costs

One of the key differentials between diesel and electric traction is the operating costs of the train types. A fuller explanation of the differences in contained within Appendix B.

A key factor for future decision making is the future price of diesel and electricity. Whilst it is difficult to predict with any certainty how the future balance will sit here, we have explored the principles around which the prices of fuel would need to alter to affect the conclusions being drawn.

5.2 Appraisal Assumptions

General appraisal assumptions are consistent with those outlined in the DfT’s Transport Appraisal Guidance. In summary these are:

- 60 year appraisal period;
- 2002 price and discounting base;
- Discount rate of 3.5% for first 30 years, with 3.0% thereafter;
- Unit of account is market prices and therefore any factor prices are uplifted by 20.9% which is the average rate of indirect taxation in the economy.

5.2.1 Optimism Bias

As per DfT Guidance optimism bias has been applied to the costs. Given that the costs are based upon a generic model as opposed to a detailed analysis of the specific characteristics of each scheme, a level of optimism bias of 66% has been adopted for capital costs. This level of bias is recognised as being cautious. The level of detail within the cost model is beyond that which would be expected for a GRIP 1 estimate for Network Rail and thus the level of bias could arguably be lower.

However DfT guidance has been applied and any reduction in the value would increase the Benefits: Cost Ration (BCR).

5.3 Outputs

The prime output from the Economic Model is a Transport Economic Efficiency Table (TEE). This is the standard means of reporting the economic effects of a project. Table 1 indicates the impact on the transport system, broken down by consumer, business user and private sector. Table 2 shows the impact on public sector accounts and Table 3 pulls in the environmental factors and provides a summary of the scheme costs and benefits in general.

Table 1: Economic Efficiency of Transport System

	Total	Rail	
	Total	Rail	
Consumers user benefits			
- travel time saving			
- Vehicle opcost			
- user charges			
- during construction & maintenance			
Net (1)	**£0**	£0	
Business			
User benefits			
- Travel time			
- Vehicle opcost			
- user charges			
- during construction & maintenance			
Net (2)	**£0**	£0	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue			
- opcost			
- investment cost			
- grant/subsidy			
- revenue clawback			
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£0**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£0**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes Total	Rail
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue		
- Op costs		
- Investment costs*		
- Developer and other contributions		
- Grant/Subsidy (k)*		
- Indirect Tax Revenues		
- Revenue clawback		
Net (8)		
Total PV of costs (9 =7+8)		

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)		
Local air quality (s)		
Greenhouse gases (s)		
Journey ambience (incl. rolling stock quality, station quality and crowding)		
Accidents (incl. safety)		
Consumer users (sub-total 1, Table 1)		
Business users and providers (sub-total 5, Table 1)		
Reliability (incl. performance & reliability) (s)		
Option values (s)		
Interchange (s)		
Central PVB, (c = sum of above, excluding sensitivity (s) items)		
Sensitivity PV of Benefits (a = sum of all benefits)		
PVC (b = sub-total 9, Table 2)		
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)		
- BCR (a/b)		

Table 5.2 – Standard TEE Tables for reporting Economic Effects of a Project

6. Application to Exemplar Routes

This section describes the exemplar routes modelled and the results of the economic appraisals of each of these. Details of each route and how different scenarios have been considered are included.

There is potentially a case for electrification on the Great Western Main Line and the Midland Main Line. The results for the GWML tests show the progression made in developing a solution that was more optimal than the starting point and also highlights the key drivers in the electrification case. There is also a case for retaining electrification on the northern sections of the East Coast Main Line.

Using the criteria modelled, the benefits generated by electrifying the Chiltern lines and the Cross Country routes do not justify the considerable capital costs required.

Sensitivity tests highlight the impact of fuel price changes and capital costs on the economic appraisal results. Dual fuel trains do not appear to significantly improve the case on the GWML and higher values of carbon savings have a relatively modest effect.

Full TEE tables of each route and the tests within it are included in Appendix C.

6.1 Great Western Main Line

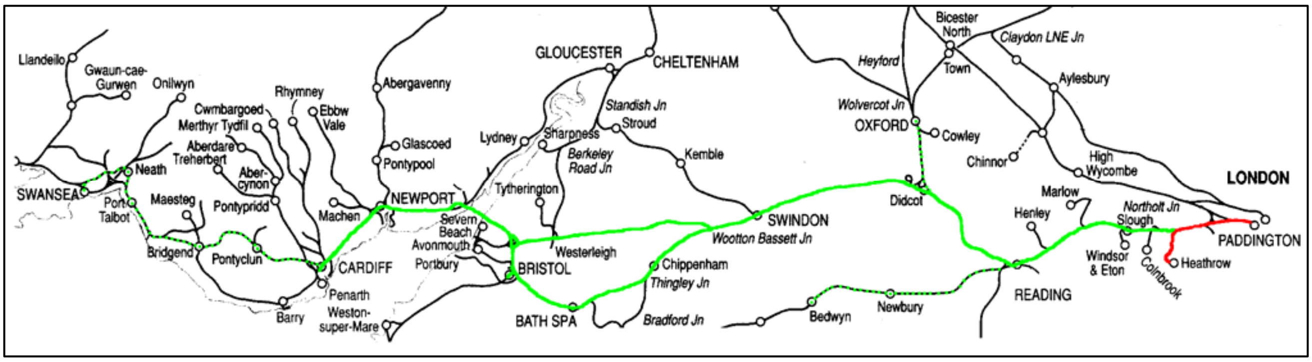

Figure 6.1 – GWML Route Sections Modelled

6.1.1 Route Summary

The Great Western route links London's Paddington station with Plymouth and Penzance in the south-west, Bristol, Cardiff and Swansea to the west and Oxford, Worcester and Hereford to the north-west. There are numerous branch lines off this main network. Longer distance services on this network are worked by High Speed Train (HST) sets and newer Alstom built class 180 'Adelantes'. The shorter, First Great Western Link services, are worked by class 165 and 166 'Network Turbo' Units.

For the HST inter-city services First Great Western presently operate a fleet of 43 HSTs with 2 locomotives and 8 passenger cars First Great Western are in the process of a £63m refurbishment of the HST coaching stock.

Local and regional commuter services to the West of London operated formerly as First Great Western Link are operated by 57 Class 165/166 Units. In addition there are 14 Class 180 Adelantes operating primarily on the Cotswold Line to Hereford, Worcester and Great Malvern but also operate on some of the services from Oxford and some inter-city services to the South West.

The Class 165/166 Network Turbo units operate services on the following routes:

- Reading/Twyford/Maidenhead to London Paddington;
- Banbury/Oxford to London Paddington;
- Newbury/Bedwyn to Reading/London Paddington;
- Greenford to London Paddington;
- Great Malvern/Worcester to London Paddington
- Reading to Basingstoke;
- Reading to Guildford, Redhill and Gatwick Airport;
- Oxford to Bicester Town;
- Slough to Windsor and Eton Central;
- Maidenhead to Marlow.

6.1.2 Test Descriptions

For the intercity route diesel train capacity based on the current fleet of HSTs is 472. Based on the IEP assumptions, a 10 car locomotive electric train would have 24% more furnishable space than its diesel counterpart therefore it is assumed that the capacity of electric trains on this route is 585.

An important characteristic of the peak timetable is that the majority of the HSTs and Class 180s extend to a large number of destinations outside the core corridor. Out of 27 HST services entering London between 07:00 and 10:00 only 8 start at Oxford, Bristol or Didcot with 5 out of 21 HST and Class 180 services between 16:00 and 19:00 terminating at Bristol or Oxford. This enables a wider geographical coverage for peak commuter and business trips into London before the services reverts to the off peak service which has a greater proportion of trains terminating at Bristol which operate at a 30 minute frequency, with one train per hour terminating at Cardiff. As a result, electrification does not result in capacity enhancements on a large proportion of peak trains due the large variation in destinations which are off the core network resulting in diesel trains having to be retained to fulfil this service pattern.

Journey time benefits through improved acceleration would be delivered on commuter services currently operated by Class 165 and Class 166 Units and there would also be reliability benefits to commuter services.

TEST 1 – ELECTRIFICATION OF LINE FROM MAIDENHEAD TO OXFORD, BRISTOL AND CARDIFF

The core test involves the electrification of the lines from London Paddington to Wootton Bassett Junction, with both sections of lines electrified from Wootton Bassett Junction to Cardiff Central and Bristol Temple Meads.

This will enable First Great Western to operate electric trains to be operated on:

- Inter-city network between Bristol, Bath Spa, Chippenham and London Paddington which has 47 services per day;
- Inter-city network between Cardiff, Newport, Bristol Parkway and London Paddington which has 18 services per day;
- Commuter services between Reading, Twyford, Maidenhead and London Paddington.

This test showed a BCR of 0.89, with one of the key issues being that, using the current timetable, less than 10% of trains would switch from diesel to electric as their starting point is beyond the proposed electrified route, yet the Bristol-Cardiff link accounts for nearly one third of the costs. Additionally no peak trains start and terminate at Cardiff thus there are almost no crowding benefits of electrifying trains which terminate at Cardiff.

TEST 2 – ELECTRIFICATION OF LINE FROM MAIDENHEAD TO OXFORD AND BRISTOL

By only electrifying as far as Bristol, the inter-city network between Cardiff, Newport, Bristol Parkway and London Paddington, which has 18 services per day, will remain diesel operated. This test has a BCR of 2.53, with the increase on Test 1 due to the fact that extending to Cardiff adds a significant amount to the capital costs and only benefits 18 services per day, which generally operate off peak and will not be overcrowded.

TEST 3 – ELECTRIFICATION OF LINE FROM MAIDENHEAD TO OXFORD, BRISTOL AND SWANSEA

This is an extension of Test 1 through to Swansea, which gives a BCR of 2.20 indicating that any electrification west of Bristol should be extended to Swansea. The main reason for the increase in BCR, over electrification just to Cardiff, is the fact that there are more trains per day which serve Swansea than terminate at Cardiff and the peak trains into London from Wales all start and terminate at Swansea, thus generating extra crowding benefits by being able to run these trains through to Swansea. Cash flow/benefits profile for this test are shown in Appendix G.

One issue that needs to be considered which is not captured in the modelling is any increase in fleet sizes required to operate the existing timetable due to the fact that diagramming limitations would be incurred as a result of having to operate both diesel and electric trains. A simple diagramming exercise conducted for this test based on the existing timetable indicated that 25 sets would be required to operate the electric services with another 23 diesel sets required to operate the remaining services which served non-electrified sections of the route, which indicates 5 additional units, not including any provisions required for spares.

TEST 4 – ELECTRIFICATION OF LINE FROM MAIDENHEAD TO OXFORD, BRISTOL AND SWANSEA WITH EXTENSION TO BEDWYN

This is an extension of Test 3 through to Bedwyn enabling the electrification of Network Turbo services to Bedwyn and Newbury which will enable a further 39 services per day to be electrified. The impact of electrifying this additional section of the network results in a BCR of 1.57, which when compared to the BCR of 2.20 for Test 3 which is the equivalent test without this additional section, indicates that the additional costs of electrifying to Bedwyn outweighs the journey time, operating cost and reliability benefits of electrifying these services.

TEST 5 - ELECTRIFICATION OF LINE FROM HEATHROW AIRPORT JUNCTION TO OXFORD, BRISTOL AND SWANSEA

One of the assumptions underlying Tests 1 to 4 is that the section of track between Maidenhead and Heathrow would be electrified as part of the CrossRail scheme. This test assesses the impact on the BCR should this not be the case and this section would need to be included in any electrification programme. Electrification of the section is estimated at £42.3M with an incremental operation cost of £97,000 per annum. A comparison with Test 3 which shows the same set of services electrified but assuming the line is electrified to Maidenhead shows a reduction BCR from 2.20 to 1.63 if this section is included.

6.1.3 Summary

The series of test described above show the progression of scheme results in our attempts to provide a more optimal solution for the Great Western Main Line. The starting point in Test 1 was the core exemplar route outlined in the industry workshop. This produced a BCR of 0.89, but failed to capture the most crowded trains into Paddington in the morning peak, which tended to start beyond Bristol or Cardiff, and significantly it was noted that the majority of the morning peak trains from Wales to London do not start from Cardiff.

Thus Test 2 cut the Cardiff electrification from the tests, and increased the BCR to 2.5, due to the removal of what had essentially been poorly utilised infrastructure. The alternative to cutting back was to extend the electrification to Swansea, thus making more use of the electrification, particularly for the morning peak services. This Test 3 produced a BCR of 2.2.

A further option considered was to explore the impacts of route extension for the most crowded services even further. In Test 4 therefore, electrification was extended to Bedwyn (the starting point of most of the Newbury services). The test carried out on a base with extensions to Swansea saw a worsening of the economic case to 1.6.

Finally, the costs of electrification of CrossRail have been considered. The basic assumption in tests 1 to 4 is that CrossRail would electrify the section between Maidenhead and Heathrow Junction. Test 5 considers the case if CrossRail does not bear these costs. The impact would be to reduce the BCR by a third to 1.6.

A further test of the GWML has been undertaken on the basis of the impact of diversionary routes. The results are reported in section 6.6.4, and have been developed on the basis of an example across all schemes of the diversionary route impacts.

6.2 Midland Main Line

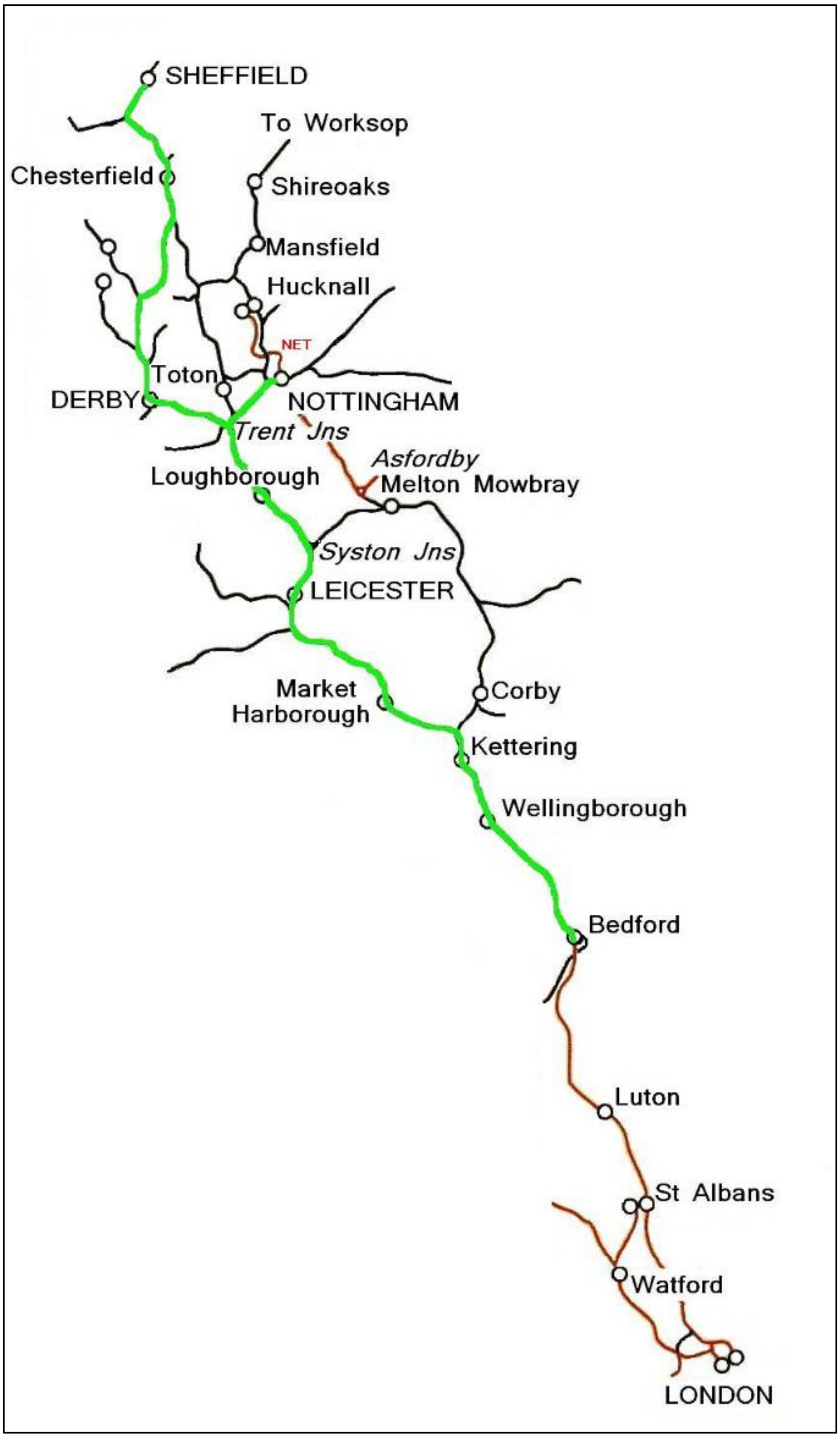

Figure 6.2 – MML Route Section Modelled

6.2.1 Route Summary

The Midland Main Line links London's St Pancras Station with Sheffield and Leeds to the north. The line splits in the East Midlands to serve both Derby and Nottingham, before rejoining to the south to Chesterfield. Additional services serve Burton-Upon-Trent (via Derby) and Barnsley (via Sheffield). Services on this route are worked by a combination of HST sets, and newer Bombardier built class 222 'Meridian' Units.

6.2.2 Description

As the section between Bedford and London St Pancras utilised by First Capital Connect Thameslink services is already electrified, extending the electrification to Nottingham and Sheffield would enable the vast majority of current Midland Mainline services to be operated using electric trains.

The only exceptions which would still require trains to be operated by diesel would be:

- Services to Sheffield via Nottingham, which utilise the line between Lenton Junction and Clay Cross South Junction, some of which call at Alfreton and Langley Mill;
- Services extending from Sheffield to Leeds which operate via Doncaster and Wakefield Westgate;
- Services extending from Sheffield to York and Scarborough through Doncaster via Colton Junction;
- Services extending from Sheffield to Barnsley;
- Services extending from Derby to Burton-on-Trent.

It should be noted that due to the way local stations are allocated to larger surrounding stations within the model, Burton-on-Trent is allocated with Derby and as a result the 2 services per day in each direction starting and terminating at Burton-on-Trent will be included in the test as being electrified, although as mentioned above these would not in fact be able to operate to Burton. Should trains no longer operate under an electrified network, based on an analysis from MOIRA, the associated journey time disbenefits would be £51,000 per annum and revenue loss £25,000 per annum which is small in relation to the other costs and benefits of the scheme.

6.2.3 Fleet Assumptions

Midland Mainline currently operate a fleet of 17 Class 43 HSTs each with 2 power cars and 8 passenger coaches and 23 Class 222s which consist of 7 eight car sets, 7 five car sets and 9 four car sets. The HSTs primarily serve the route from London to Sheffield, with the Class 222s serving the route from Nottingham to London.

In order to fulfil the existing timetable and service pattern, this would require diesel trains to be operated on 13 weekday services, 19 Saturday services and 11 Sunday services. It is envisage that based on a simple diagramming exercise using the modelled timetable that this would require 7 trains to remain diesel.

6.2.4 Crowding Assumptions

There are two caveats to the crowding benefits calculated for the Midland Mainline tests, which are discussed further below.

- The MOIRA dataset appears to be inaccurately allocating passengers between trains around Bedford and Luton, resulting in over allocation of passengers into St Pancras on Midland Mainline and under allocation of passengers on First Capital Connect services into Moorgate;

- As the model is based on average inter-city capacities and loading information calculated per train, it is not feasible to base capacity on average fleet size given the range in capacities of the Class 222 units.

Some of the loadings on Midland Mainline based on the National MOIRA are in excess of double the train capacities with large numbers of passengers boarding at Luton and Bedford. Validation of this data with the East Midlands version of MOIRA suggests lower loadings and further analysis of National MOIRA indicates that some First Capital Connect services into Moorgate are in fact being under allocated. In order to prevent this resulting in the overestimation of crowding benefits, loadings of Midland Mainline trains have been capped at 150%.

The assumed capacity for the crowding benefits is based on the average capacity derived from the fleet composition of the 10 car Class 43 HSTs and the 9 car Class 222s which have total train capacities of 465 and 485 respectively. It is acknowledged that Midland Mainline as discussed above operate 8 car units, as rolling stock has been reconfigured from the original 9 car units. As demand is based on 9 car units being operated, applying the recent capacity changes to demand profiles based on the original configurations would over estimate crowding benefits, therefore train configurations which fit the demand profiles have been used.

Although some of the five and four car sets will be in operation during the peak times and operating inter-city services, these have not been included because it is not possible to allocate capacities per individual trains. By including these shorter units in deriving the average capacity based upon overall fleet composition for intercity services, it is likely to result in significant overestimation of crowding benefits particularly if this average capacity is applied to the loading on 10 and 9 car units, and additionally if the loadings are overestimated as a result of the issue with the over allocation of passengers to MML services. As a result the model will not estimate any crowding benefits to passengers using the four and five car units.

6.2.5 Journey Time Benefits

The test does not include any journey time benefits as it assumed that no commuter services switch to electric. In theory the scheme would enable Central trains to operate some of its services between Derby, Leicester and Nottingham using electric trains, and the presence of a depot at Nottingham would suggest that this would be operationally feasible. Given the level of service patterns between these stations, which in total is only 13 per weekday, any fuel operating cost saving is unlikely to exceed the incremental costs due the loss of interoperability of the rolling stock with other routes served by Central Trains.

6.2.6 Results

The MML test produces a very strong case for electrification with a BCR of 3.22. The size of the BCR is a function of a number of factors: the extent of existing crowding on the MML services, the fact that MML services can be fully electrified on the core route without the need to consider extensions to differing destinations and the fact that around a third of the core route is already electrified. Cash flow/benefits profile is included in Appendix G.

6.3 Chiltern Line

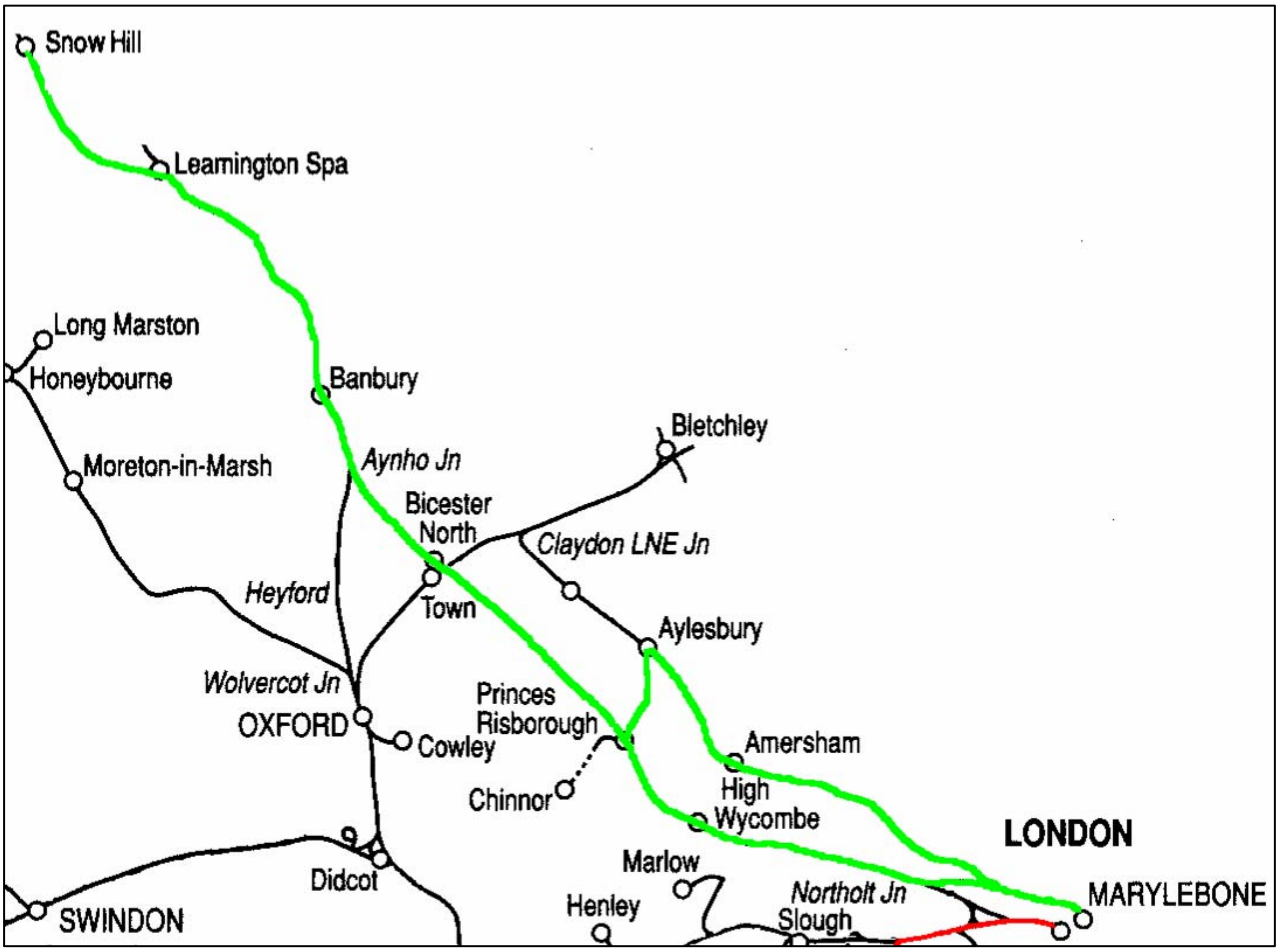

Figure 6.3 – Chiltern Route Sections Modelled

6.3.1 Route Summary

The Chiltern network links London Marylebone Station with Aylesbury and Birmingham Snow Hill in the West Midlands. There are also services on the branch line to Stratford-Upon-Avon. A limited number of services originate in the morning at Kidderminster and return to Kidderminster following the evening peak period. Shorter distance services on this route are worked by class 165 'Network Turbo' Units, whilst the longer distance services linking London with Birmingham are generally worked by class 168 'Clubman' Units.

6.3.2 Test Descriptions

As Chiltern do not presently operate HSTs and in the future it is assumed that services on this route will continue to be operated by DMUs there will be no crowding benefits as a result of the electrification of this line. The only source of passenger benefits will be as a result of faster acceleration of electric trains and the reliability benefits of electric compared to diesel commuter services.

TEST 1 – ELECTRIFICATION OF LINE FROM LONDON MARYLEBONE TO BIRMINGHAM SNOW HILL AND AYLESBURY, AND AYLESBURY TO PRINCES RISBOROUGH

Test 1 encompasses the majority of the Chiltern Network enabling electric trains to be run on longer distance services starting or terminating between Birmingham Snow Hill and High Wycombe. Although this electrifies the core Chiltern Network, the following services would still require operating using diesel trains:

- Services extending to Kidderminster from Birmingham;
- Services to Stratford upon Avon.

This test showed a BCR of 0.25 indicating poor value for money with the journey time, reliability, operating cost and greenhouse gas benefits not outweighing additional cost of electrification.

TEST 2 – ELECTRIFICATION OF LINE FROM LONDON MARYLEBONE TO AYLESBURY

In Test 1, a large proportion of the cost which would be incurred between High Wycombe and Birmingham is not on a particularly intensively used section of track. This test compared the impacts of just electrifying the core commuter route from Aylesbury into London Marylebone. This results in an increase in BCR to 0.44 due to the electrification being focused on the more intensively used Chiltern routes but still poor value for money, primarily due to the lack of crowding benefits and the lower differential in operating costs between diesel and electric trains on commuter trains compared to intercity trains.

6.3.3 Results

The Chiltern tests show poor BCRs. The key reasons behind this are that the assumed vehicle specification is an inter-urban/commuter vehicle, thus the assumed crowding impacts of the previous tests are not apparent here. The main positive effects for such services are limited journey time impacts due to greater vehicle acceleration, improved reliability of electric stock over diesel stock and minor impacts in terms of fuel efficiency.

Further studies have been undertaken to investigate the impact of higher costs for carbon. Based on existing diesel traction and the emissions from the current mix of primary energy sources used for generating electricity, with all other parameters unchanged, there would need to be significant increases in the value of carbon to increase the BCR significantly (see Appendix I).

6.4 Cross Country

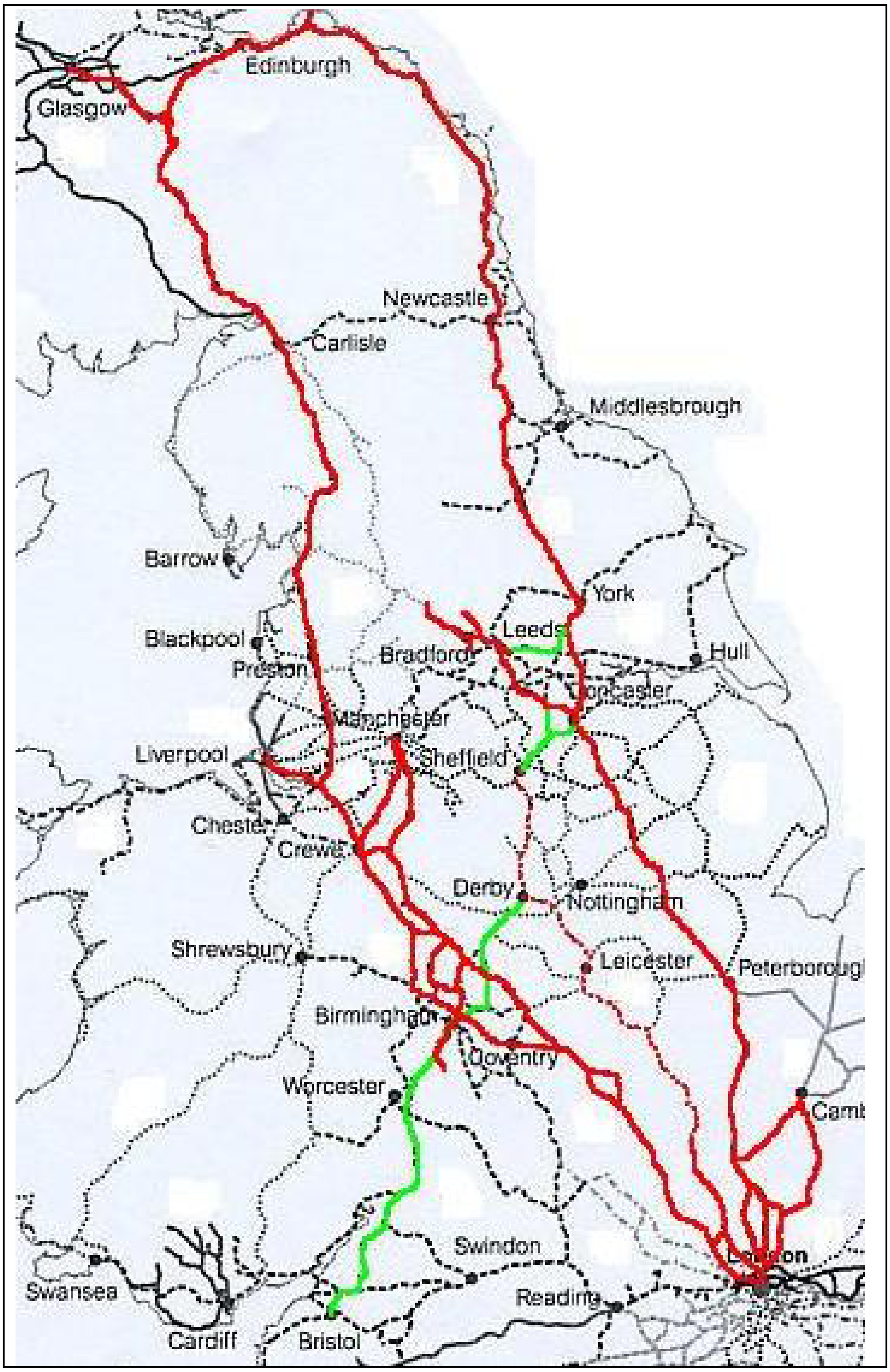

Figure 6.4 – Cross Country Route Sections Modelled

6.4.1 Route Summary

Virgin Cross Country operate an extensive network which extends to Penzance in the south-west, Bournemouth to the south, and Glasgow, Edinburgh and Aberdeen in the north. The network is broadly 'X' shaped, with Birmingham New Street forming the centre point of the Cross Country network. Services between the South, Midlands and Scotland travel both via the West Coast Main Line (i.e. via Crewe) and the East Coast Main Line (i.e. via York). The Cross Country network also includes services to Cardiff Central (via Bristol) and services Brighton via Guildford and Gatwick Airport. All services on this extensive network are served by Bombardier built class 220 Voyager and 221 Super Voyager Diesel Multiple Units, the latter of which have a tilting capability.

Late in 2007, a new Franchise to run the Cross Country network will be awarded. A number of changes will be made to the route structure as part of this change. Cross Country will no longer serve stations between Preston and Glasgow Central via the West Coast Main Line. All Cross Country services to Scotland will run via the East Coast Main Line. The new Cross Country Franchise will be expanded however to accommodate Cardiff Central and services between Birmingham New Street and Stansted Airport, via Leicester. Both of these routes are currently run by National Express owned Central Trains.

6.4.2 Test description

For Cross Country, one scenario has been tested which is the electrification of the line between Bristol Temple Meads and York.

The assumed capacity for the crowding benefits is based on the average capacity derived from the 4 and 5 car sets which gives an average capacity of 197 which is assumed to increase to 234 if electric trains were operated.

The test showed poor value for money with a BCR of 0.08. The reason for this is due to the diverse range of destinations served by Cross Country trains resulting in only a small proportion of trains in the existing timetable being able to switch to electric (58 out of 181). This figure also includes services between Manchester and Birmingham which currently run using diesel trains under the wires. Out of these 58 trains which could switch to electric, only 3 were over 100% loaded thus the level of crowding benefits were very small from the trains which did switch.

In addition the impacts of running a split fleet on a franchise of this nature are likely to result in increased fleet requirements due to the lack of interoperability between different sections of the network.

6.4.3 Results

The results on cross country are clearly poor and largely a reflection of the structure of the timetables over the route. The majority of services start or end outside of the proposed electrified sections. There may be scope to alter future timetables to accommodate better use of the electrified network, but as service patterns revolve around Birmingham New Street, the degree of flexibility is likely to be limited.

A further question on the validity of electrifying cross country is that the majority of diagrams operate as 4 or 5 car units. Given the key benefit from inter-city electrification is increased capacity, a similar effect could be achieved by lengthening the existing rolling stock which could be accommodated without significant infrastructure changes.

As the electrified network expands (i.e. the cross country section between Sheffield and Derby would be electrified as part of the Midland Main Line leaving only a short section between Sheffield and Doncaster not electrified between Derby and Edinburgh), the extent of operating ‘under the wires’ will increase which may justify a revised timetable, the use of dual fuelled trains and/or further in-fill electrification to make better use of the electrification infrastructure.

6.5 East Coast Main Line

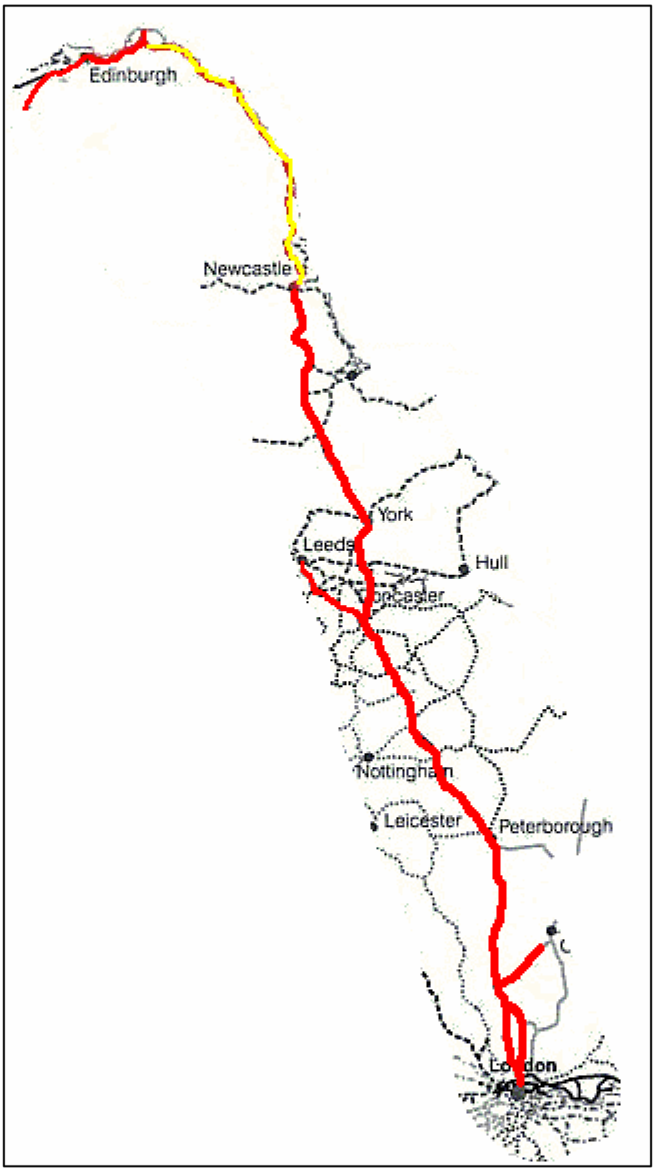

Figure 6.5 – ECML Route Section Modelled

6.5.1 Route Summary

GNER operate core inter-city services to Leeds, Newcastle, York, Edinburgh and Glasgow along an electrified network with some electric services extending to Bradford. In addition some services are operated by diesel trains off the core network which include services to Inverness, Aberdeen, Hull and Skipton. On electric routes GNER operate Class 91 locomotives with 10 cars plus DVT whilst on diesel routes Class 43 HST units are used with two power cars and eight carriages.

6.5.2 Test description

This test examined the impacts of de-wiring between Newcastle and Drem which would effectively result in all of GNER's services to Scotland having to run using diesel trains.

This test generated a revenue case due to the loss in revenue that would result from increases in crowding, and the increase in train operating cost of operating diesel trains, these exceed any maintenance cost savings of not having the electrification infrastructure and also the incremental capex of re-wiring over de-wiring.

Although there is not a crowding problem on GNER services within Scotland, a number of trains which start or terminate in Scotland actually form peak trains into and out of Kings Cross and therefore the benefits are due to crowding increases on the diesel trains on the southern section of the route.

6.5.3 Results

In summary the potential cost savings from retaining the electrified network as far as Edinburgh are such that they outweigh the capex from the re-wiring operation. So from the results shown here, re-wiring should be seriously considered.

6.6 Sensitivity Tests

A number of sensitivity tests have been undertaken around the core assumptions. These relate to:

- Fuel Price
- Running of Dual Fuel IEP trains
- Rate of Carbon valuation
- Impact of diversionary routes
- Renewal costs
- Capex - The capex tests have effectively been included as test 5 of the GWML results where the capex has been increased by including the route section from Heathrow Junction to Maidenhead.

6.6.1 Fuel Price Sensitivity

It has been assumed for all tests on the exemplar routes that energy prices move in line with the DTI's central case scenarios. Table 6.1 shows the impact of assuming the low and high scenarios for both Oil and Electricity. More details of the fuel price assumptions are included in appendix B.

Fuel Price Scenario	Great Western Test 3 BCR	Midland Mainline BCR
Central Scenario	2.20	3.21
Low Gas Oil, Low Fossil Fuel Price	1.78	1.96
High Gas Oil, High Fossil Fuel	6.2	Revenue Case

Table 6.1 – Fuel Price Scenarios

These tests show that under the High Scenarios the Great Western case increases from 2.2 to 6.2 whereas for the Midland Mainline the increased operating cost savings result in net revenue and cost savings exceeding the additional costs of electrification – in other words the cost savings and farebox revenue gains are greater than the capital cost over the appraisal period. In the low scenarios BCRs for both schemes drop to a similar level. The reason for the higher impact of fuel price changes on the MML business case is due to the fact that a higher proportion of the benefits on Midland Mainline are due to operating cost reductions than on Great Western which has a significant amount of journey time benefits in addition to crowding and operating cost savings.

6.6.2 Dual Fuel

One element of the IEP is the development of a 'Dual Fuel' train which consists of a diesel locomotive at one end and an electric locomotive at the other enabling trains to run on electric along electrified sections of line and continue on diesel to destinations not served by electrified routes.

A simple test was conducted on Great Western to ascertain the impacts of this dual fuel train. The main source of benefits would be capacity increases on a large number of trains, due the additional furnishable space in the electric locomotive which would equate to an 11% capacity increase over a diesel train.

Based on Test 3 which has electrification to Oxford, Bristol and Swansea approximately 9 out of the 10 most loaded trains still remain diesel due to the timetabling enabling maximum geographical coverage for peak services into and out of London. Therefore by assuming that all diesel trains could be operated using dual fuel trains crowding benefits would almost treble resulting in a revenue case.

One major caveat to this analysis though is the fact that the dual fuel trains specified in the IEP only have a maximum speed of 95 mph when operated under diesel. Therefore these crowding benefits would be offset to a large degree by journey time disbenefits and lost revenue through increased journey times.

More detailed analysis has been carried out and is included in Appendix J.

6.6.3 Carbon Emissions

As mentioned in 5.1.4, the Central Case scenario was used for the social cost of carbon emissions. Using the upper bound in TAG Unit 3.3.5 with the Great Western Test 3 resulted in Greenhouse Gas benefits increasing from £64M to £107M increasing the BCR from 2.2 to 2.5. Additional tests have been undertaken using higher values for carbon which increase the BCR. The results of these tests are detailed in Appendix I.

6.6.4 Diversionary Routes

A test has been undertaken to determine the likely impact on scheme BCR of the fact that non-electrified diversionary routes will require the use of diesel traction for planned and unplanned closures of the electrified route.

Accurately modelling the impacts is hampered due to the uncertainty of the incidents that may happen and also due to a lack of detail in terms of train loadings during such incidents and journey time effects.

We have undertaken an assessment using a series of assumptions on the key factors including:

- Delay per diversion
- Average load per diverted train
- Frequency of the event – planned and unplanned

A test has been carried out on the GWML test 3 – which includes Bristol, and Swansea. The following assumptions have been made against the headings set out above:

- Delay per diversion: Bristol – Reading (via Berks and Hants) 10 minutes; Swansea – Paddington (via Gloucester) 60 minutes.
- Average load per train – 50%.
- Frequency of event – Planned – 6 weekends pa, for 12 hours (8 hours with trains). Unplanned – 6 times a year for 4 hours.

Based on these assumptions the present value of the impact is just over £12m over a 60 year appraisal reducing the scheme BCR by 0.1.

6.6.5 Renewal Costs

No additional allowance for renewals has been included in the appraisal except in as much as the incremental system maintenance costs cover some elements of renewal. Further analysis of the cost model shows that the renewals elements would account for typically 25% of the capex. Running the test on MML, and assuming 25% of capex at year 40, would result in around a 5% uplift in the scheme present value of scheme capital costs.

We therefore conclude that whilst renewals costs could have been included in the analysis undertaken to date, they would not make a material difference to the results. Moreover the models have been demonstrated to be flexible and it is relatively simple to include renewals costs in future analysis.

6.7 Summary

Test	BCR
Great Western Main Line	
Test 1 – Maidenhead – Oxford – Bristol and Cardiff	0.89
Test 2 – Maidenhead – Oxford – Bristol only	2.53
Test 3 – Maidenhead – Oxford – Bristol and Swansea	2.20
Test 4 – Maidenhead – Oxford and Bedwyn – Bristol and Swansea	1.57
Test 5 – as Test 3 with CrossRail electrification omitted	1.63
Midland Mainline – Kings Cross – Nottingham and Sheffield	**3.21**
Chiltern Line	
Test 1 Marylebone – High Wycombe and Aylesbury – Birmingham	0.25
Test 2 Marylebone – Aylesbury Only	0.44
Cross Country – Bristol – Birmingham – York	**0.08**
East Coast Mainline – de-wire between Newcastle and Drem	**N/A – there is a Revenue Case to retain the existing electrified lines and to re-wire when life-expired**

Table 6.2 – Overview Of The Results

7. Implications of Study Findings

This section provides a discussion of the findings from the research. It identifies the exemplar routes that show positive cases and those that do not. It draws inferences from these and various sensitivity tests undertaken to highlight the conditions in which electrification makes sense, highlighting key drivers in making the case, and goes on to question these drivers and considers whether similar results could be achieved through other rail improvements.

Key conclusions here lie with the emphasis on crowding impacts of the economic case, the significance of operating cost savings and a discussion on the potential scale of environmental impacts to the case for electrification.

7.1 Which Schemes Work

The results clearly show that under the assumptions made here there is a case for electrification of the Great Western Main Line, the Midland Main Line and for retaining the wiring on the East Coast Main Line north of Newcastle.

The main issue for the ECML scheme is that the operating cost savings of operating electric trains over the London – Edinburgh journey itself is sufficient to cover the net additional capex of re-wire over de-wire.

The results of the GWML and MML schemes, with associated sensitivity tests, has allowed us to understand a deal more about the key points in making the case for electrification, moreover, the very poor case presented by the cross country test emphasises these points. The following section explores some of these issues and draws tentative conclusions.

7.2 Necessary Conditions for Successful Electrification

There are a number of factors which would appear central to making the successful case for electrification:

- Passenger demand – a core route, heavily used and at or above loading capacity now or in the near future allows the basic assumption of extra capacity on future inter-city trains to maximise crowding relief benefits. A key additional feature must be that the train is at the maximum length within the capacity of the infrastructure – so for example additional capacity could be provided on cross country by running longer trains OR using IEP electric trains.

- Density of service provision – the ability of the route to allow maximum usage of the infrastructure for electric trains is crucial. MML for example has virtually all services running over the electrified lines on electric operation, thus obtaining the maximum operating cost benefits.

  The GWML series of tests highlighted the importance of this. The central case which ran only to Bristol and Cardiff showed much poorer results because only around 1 in 3 services could be electrified as a result. Expanding the network to include particularly crowded services, such as to Oxford, and to include services arriving in the peak into London, such as Swansea, significantly enhanced the case. Moreover, the limited extent of electrification offered by cross country tests given the diversity of origins south of Bristol has had a seriously detrimental impact on that case, and without wholesale timetable adjustments to fit the electrified network, the cross country case is unlikely to be proven.

- Extent of existing electrification – the MML service provides particularly strong results partly because around a third of the route north from London is already electrified. Thus the additional electrification is gaining from this sunk investment. This issue is pertinent in that the ability to find suitable sections of in-fill electrification that allow “bigger bangs per buck” would seem on this limited evidence to be important. However, the other conditions in terms of density of passenger and service demand will still be important.

7.3 Drivers of the Business Case

7.3.1 Crowding Relief

The main driver in the electrification case has been the extent of crowding relief offered by the IEP assumptions on the specification of future inter-city trains.

7.3.2 Operating Cost Savings

The second most important feature has been the scale of potential operating cost savings that can be achieved through operation of electric trains over diesel stock. The scale of this impact is highly reliant on the future assumptions with respect to fossil fuel prices and the operating mix of the electricity industry.

Under central DTI operating assumptions, the prices of diesel and electricity would effectively be moving in the same direction, thus the scale of operating cost saving should not materially differ. However, if one were to take more radical assumptions – say more nuclear generation or hydrogen fuel cell technology making significant advances - then the situation could change to be more in favour of electrification (cheaper electricity with nuclear generation) or against – through the use of alternative fuel sources altogether.

7.3.3 Environmental Factors

The study demonstrates that electrification provides environmental benefits however the economic benefits, based on the current appraisal guidance and assumptions on valuation of carbon emissions, are less significant than other factors. It is unclear what the future mix of electricity generation will be and the valuation of carbon emissions has the potential to rise significantly, thus increasing the economic benefits of electrification. Additionally low sulphur and bio-diesel fuels are at an early stage of development as a replacement for A2 gas oil.

We have captured these impacts through sensitivity testing, though the uncertainty of future values makes this more an exercise in determining the tipping point of decision making than one of accurate forecasting. Taking the high end WebTAG figures for carbon valuation increases the case for electrification by about 10% on BCR.

7.3.4 Capital Cost

The capex assumption is clearly one of the central planks of the electrification argument. This is apparent given the strong case for MML – which has considerable sunk investment in electric infrastructure thus reduces the net capex of the scheme – and also in the GWML test where the exclusion of the electrification costs of the CrossRail section has a marked impact on scheme BCR.

The GWML test is interesting given the make-up of the economics. CrossRail savings are only around 10% of the scheme capex, but the impact on BCR is around a third. This is a result of the special case of electrification schemes which have such significant potential to give opex savings that are then netted off the capex in the BCR equation, thus exaggerating the impact of capex variability on BCR.

7.3.5 Other Means to Achieve the Same Result

In developing any business case one needs to consider what problem needs to be solved and what overall constraints apply in solving the problem.

Thus in developing the case for electrification, perhaps the primary concerns are financial costs and environmental impacts. What has become clear is that the case for electrifying core routes is largely predicated on the assumptions about relative seating capacity of future inter-city trains.

This study demonstrates that electrification supports the case for a greener railway. The extent of the benefits depends on the environmental impact of electricity generation and the development of greener fuels for traction purposes. If, however, providing additional passenger capacity is the prime aim, then clearly electrification can provide this, but then so may other methods such as in cab signalling/automatic train control and longer trains.

7.4 Other Factors Considered

In developing the various models for assessment of electrification a large range of factors have been considered. Thus far we have focussed on those that have driven the conclusions being drawn from the analysis. There are a number of additional issues that impact on the results but that are not central to making the case.

- Reliability of rolling stock/infrastructure – research was undertaken to determine the impacts of existing vehicle and infrastructure reliability on the economics for electrification. These showed that whilst it was conclusive that electric trains are more reliable than diesel, once the impact of infrastructure reliability is taken into account the impact is less marked. The conclusions from the results are that inter-city operations had no discernable differences in the overall reliability rates between the two traction types. However, commuter/inter-urban electric traction is more reliable than diesel. This is a function of the relatively poorer reliability of diesel vehicles probably resulting from the increased stop-start nature of commuter/inter-urban services over inter-city ones. This was tested by running the model with the electrification infrastructure having no impact on the reliability and the increased BCR was minimal.

- Regenerative Braking – RSSB are in the middle of a detailed study of the potential for the wider application of regenerative braking for electric vehicles for the railway industry. The emerging conclusions suggest that 10 to 20% energy savings may be developed. This is clearly significant, but unlikely in itself to make the case for electrification.

8. Issues for Further Consideration and Study

This section identifies some key areas that this study has shown to be worth further consideration. Most of these issues will need to be considered before any firm case for electrification can be put forward on the exemplar routes; other workstreams would be required to extend the scope of this work to other routes.

8.1 Feasibility Studies

This study has shown that using the criteria proposed there is a business case for electrifying the Midland Main Line and Great Western Main Line. It is recommended that these routes are analysed in more detail looking at more route specific issues including more technical analysis to enable the cost estimates to be refined. The business case should also be reviewed as further details of the IEP characteristics are confirmed.

8.2 Dual Fuel Trains

The effects of using dual fuel trains have been considered when reviewing the outputs for the exemplar routes and the economic model updated to include dual fuel train characteristics. It is recommended that further tests are undertaken using different combinations of the extent of electrified lines and dual fuel services to give an optimised solution to the balance between user costs and benefits, operating cost savings and benefits and possible electrification cost savings to support or revise the conclusions and to influence the extent of electrification, particularly with regard to the GWML.

8.3 Additional Routes, DC Electrified Lines and In-fill Electrification

This study has applied the models developed to the exemplar routes identified. There may be benefits in widening the scope of work to include lines with different characteristics (i.e. non-London commuter routes). The models have not been developed to assess the conversion of dc third rail to 25 kV ac overhead lines. Development work would be needed to compare the different types of train and the infrastructure costs associated with replacing the third rail equipment. New route characteristics may also need to be included in the models as there may be the potential to increase line speeds when converting from third rail (i.e. on the Brighton or SW main lines) whereas the models to date have assumed no speed enhancements.

Relatively short sections of route between existing electrified areas may provide benefits not directly related to those modelled including use as diversionary routes, easing capacity constraints and improving existing fleet utilisation. Short sections are also likely to require a more detailed assessment when using the cost model as individual items can have a more significant impact on the cost (i.e. tunnels). Such schemes may include Liverpool to Manchester and Leeds to Selby/York.

8.4 Diesel and Electricity

A number of studies have looked at the use of alternative portable fuels including low sulphur and bio-diesel and hydrogen. As more details emerge and taking into account future availability, further study may be required. Future legislation/taxation changes (i.e. environmental restrictions, road pricing etc.) may also impact on the business case for electrification as will changes to electricity generating strategies.

8.5 New Technology

This study has identified that one of the main benefits of electrification is increased capacity on busy inter-city routes. Electrification should be considered as an element of the capacity debate and needs to be reviewed as new technology emerges including the consequences of future train control systems. Removing current line side signalling equipment may have a cost benefit with regards to electrification (immunisation and signal sighting costs avoided) though additional trains may need larger and hence more expensive power supplies.

Development in electrification equipment may reduce the capital costs of electrification projects and further study into different electrification systems for different types of route is recommended (such as light weight systems with larger tolerances for lightly used lines). Additionally control equipment developments may facilitate avoiding the need for significant civils works as overhead line equipment may not be required in tunnels and under bridges.

Appendix A – Demand Model Database

Introduction

A demand forecasting model has been developed as an element of the RSSB Rail Electrification Study. The model estimates the demand generation impacts of specified electrification and de-electrification schemes and calculates the scale of demand related impacts (journey time and crowding savings and revenue increases).

The demand related calculations are undertaken in an Access database with the necessary outputs exported directly to the economic assessment spreadsheet which attributes a monetary valuation to the estimated benefits.

This note sets out the data used in the database and the calculations undertaken within it, consisting of four further sections:

- **Cost and demand data**: Outlining the source and form of input base cost and demand data along with the approaches used to forecast future background demand growth and the changes in demand associated with schemes;
- **Train service data**: Providing details on the source and nature of input information related to specific train services and loadings;
- **Estimated benefits**: Outlining the source of benefits associated with schemes and the methods used to estimate their scale;
- **Summary:** Providing an overview of the scope and contents of the model.

Cost and Demand Data

The cost data used in the database is based on information extracted directly from the national MOIRA model. The demand data is also based on information from MOIRA along with parameters and approaches set out in the Passenger Demand Forecasting Handbook (PDFH)[2]. The calculations require estimates of three categories of costs and demand:

- Base Costs and Demand (i.e. 2006 levels);
- Reference Case Future Year Demand (i.e. demand in forecast years including an allowance for background growth but assuming no change in the extent of the electrification of the rail network);
- Generated Demand (i.e. change in demand resulting from the scenario tested).

The following sections provide further detail on the data sources and approaches used in deriving the data for each category.

Base Cost and Demand

The base cost and demand datasets used in the database were largely taken directly from the national MOIRA model. However, modifications to the demand data were required to address the recognised underestimation of demand in PTE areas served by travelcards or equivalent ticketing arrangements[3].

MOIRA Model Data

MOIRA is a timetable based model of rail market and passenger choice maintained and developed by AEA Rail on behalf of the Association of Train Operating Companies (ATOC). It includes detailed information on:

- Rail demand and revenue by origin and destination station, extracted annually from LENNON, a database recording virtually all national ticket sales;
- Train service details including stopping patterns and times, extracted from the national Train Service Database

Due to the number of stations network wide (over 2600), the national version of MOIRA (used in this study) aggregates them into 430 groups centred around key points on the network. Information on demand by origin and destination is provided in terms of these station groups as are the details of train services.

The demand forecasting database uses information directly from MOIRA, retaining its disaggregate form to make maximum use of the available detail. The source used is the June 2006 MOIRA dataset which provides matrices of annual demand (accounting for weekdays and weekends), average generalised journey time (by day of the week) and fare. All the matrices are by origin and destination station group and are disaggregated into the three ticket type categories of:

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[2] PDFH: Passenger Demand and Forecasting Handbook

[3] i.e. Birmingham, London, Manchester, Merseyside, South Yorkshire, Strathclyde, Tyne and Wear and West Yorkshire

- Full fare;
- Reduced fare; and
- Season ticket.

AEA also provided the study with further information from the datasets underlying MOIRA, identifying the proportion of annual demand between each origin and destination pair by ticket type that relate to weekdays, Saturdays and Sundays

Modifications for PTE/Travel card demand

As the MOIRA demand data is based on information from the LENNON database it does not include details of tickets sold at outlets such as newsagents, travel shops and TfL stations. This is a significant issue in PTE areas where these sales account for a significant proportion of the total for travelcard type tickets. Such area based ticket types also present a further complication in the estimation of local intra-PTE demand. Even where ticket sales are captured, they do not provide sufficient information to allocate the journey to a station to station flow. Whilst these difficulties are overcome to a large extent in London (through the use of additional information), the MOIRA user guide states that they result in the majority of journeys using PTE Travelcards being excluded from MOIRA data.

To address this issue, the database includes the capability to input factors for each of the 7 affected urban areas. The factor is applied to MOIRA demand for trips with both an origin and destination within the PTE area to account for the additional trips made using travelcards and therefore not captured in the MOIRA data.[4] The model currently includes a factor based on analysis of local ticketing data for Birmingham (for use in the exemplar routes). All other PTE factors are set to 1.

Future year reference case demand

The database uses forecast demand growth factors from the ‘Growth Forecasting Tool’ developed for the PLANET suite of models. This tool uses the latest methodology recommended by the DfT (based on PDFH), taking into account a wide variety of spatially variable factors including GDP, employment and population growth and car ownership levels.

The outputs are separate growth forecasts for each combination of origin and destination zones in PLANET and for each of the three purposes of business, commuting and leisure. These factors have been converted into the format required for the demand forecasting database (i.e. factors by origin/destination station and ticket type) through the following steps:

- Identification of the PLANET Strategic Model zone that each MOIRA station falls within;
- Identification of the relevant growth factor for each purpose for each station pair (on the basis of the zone each station falls within);

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[4] Train load information is not factored up because its primary use within the database is for estimating crowding levels on intercity trains. It was judged that the impact of additional PTE demand on crowding levels would be relatively minor and that it would therefore be disproportionate to carry out the multi -staged calculations required to factor up loading levels to account for this additional demand

- Estimation (for each movement) of a weighted average growth factor for each ticket type (full, reduced and season) on the basis of the estimated proportion of trips using each ticket type that are made for business, commuting and leisure purposes. The proportions used were derived from the LATS 2001[5] surveys.

The database applies the resultant factors to base year demand to produce estimated demand in two forecast years selected by the database user (from the options of 2016, 2021 and 2026).

Generated Demand

Sources of Additional Scheme Related Demand

The database demand generation calculations involve the assumption that electrification schemes would reduce generalised travel costs and therefore increase passenger demand through two effects:

- *Reductions in* generalised journey times. The greater acceleration/deceleration rates associated with some electric trains (compared with the equivalent diesel train) would bring modest time savings for each stop served by any train services switching from diesel to electric rolling stock as a result of the scheme.
- Reductions in crowding penalties: Crowding effects are assumed to be restricted to high speed inter-city trains. Planned future diesel and electric inter-city trains would be identical in size but whilst diesel versions would need an engine in each of the end carriages, the use of electric power would allow this space to be used for seating, considerably adding to the train's capacity.

PDFH Elasticity Approach

The database uses the PDFH elasticity based approach to estimate the impact on demand of each of the travel cost effects outlined above.

PDFH provides elasticities that estimate the change in demand associated with a given percentage change in travel cost using the following formula:

$$\mathbf{I = (C_T/C_R)^{el}}$$

Where I = Test Demand/ Reference Case Demand

CT/CR = Test Cost/ Reference Cost

El = elasticity

The impacts of changes in generalised journey times (GJT) are estimated through comparison of Test Case GJT with Reference Case GJT (extracted directly from MOIRA). Crowding savings are however treated as 'Non Timetable Related Service Quality Improvements' and the PDFH specifies that their impact on demand should be estimated through a comparison with Reference Case fares (again available directly from MOIRA).

The elasticities provided in PDFH vary by ticket type, purpose and geographical area. The database therefore includes information on the allocation of each station to the relevant PDFH area. The elasticities allocated to each journey (between a given

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[5] London Area Transport Survey (LATS) 2001 was a large scale survey of transport and travel in London including household and on-mode public transport surveys

origin/destination pair) are therefore determined on the basis of the areas that the origin and destination stations fall within and the application of PDFH values as set out in the tables overleaf (which are consistent with those used in MOIRA)[6].

Ideally, the impact of crowding changes would be estimated through an iterative process. Crowding reduction results in a negative feedback process whereby reduced crowding penalties encourage more passengers onto the trains causing an increase in crowding levels with a resultant reduction in benefits experienced. In turn this reduced benefit would cause a slight reduction in demand, increasing the crowding benefits again. This adjustment would repeat until equilibrium was achieved.

Modelling such equilibrium would involve assignment of trips to routes, trains and time periods and so is considerably beyond the scope of the database. However, the simplest alternative, to undertake only one iteration of the process, would inevitably overestimate benefits. The full value of both the benefit of reduced crowding and of the increased demand attracted by the full reduction in crowding would be included in the benefits calculated, causing double counting (i.e. by taking no account of the negative feedback loop).

To prevent this overestimation, the database incorporates an assumption that the final crowding benefits are a fixed percentage of the value estimated in the initial iteration and then calculates demand changes accordingly. The default percentage is 50% (i.e. effectively assuming that the iterative process described above would stabilise at a point where crowding savings were 50% of the initial estimate). However it is recognised that this is likely to be a conservative assumption and so the database includes the scope to change this percentage if required.

Flow Origin	Flow Destination	PDFH Table	Elas (Full & Reduced)	Elas (Season)
Central London	Central London	B3.2	-0.8	-0.7
Central London	Travelcard Area	B3.2	-0.8	-0.7
Central London	South East	B3.3 (L)	-0.85	-0.75
Central London	Rest of Country	B3.4	-0.9	-0.9
Travelcard Area	Central London	B3.2	-0.8	-0.7
Travelcard Area	Travelcard Area	B3.2	-0.8	-0.7
Travelcard Area	South East	B3.3 (N)	-1.0	-0.9
Travelcard Area	Rest of Country	B3.4	-0.9	-0.9
South East	Central London	B3.3 (L)	-0.85	-0.75
South East	Travelcard Area	B3.3 (N)	-1.0	-0.9
South East	South East	B3.5	-0.9	-0.9
South East	Rest of Country	B3.5	-0.9	-0.9
Rest of Country	Central London	B3.4	-0.9	-0.9
Rest of Country	Travelcard Area	B3.4	-0.9	-0.9
Rest of Country	South East	B3.5	-0.9	-0.9
Rest of Country	Rest of Country	B3.5	-0.9	-0.9

Key: Central London: Travelcard Zone 1, Travelcard Area: Travelcard Zones 2-6, South East: Former Network South East area outside Travelcard Zone 6, Rest of Country: Everywhere outside the former NSE area

Table A.1 – GJT Elasticities

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6 The simple forecasting approach identified in PDFH is used i.e. using single elasticities for each ticket type independently and not accounting for cross elasticities.

ORIGIN AREA	DESTination AREA	Orig PTE	Dest PTE	Trip DIST	Commuting	Business	Leisure
Travelcard Area	Travelcard Area	Lon	Lon	<20	-0.6	-0.55	-1.05
Travelcard Area	Travelcard Area	Lon	Lon	>20	-0.6	-0.55	-1.05
Travelcard Area	South East	Lon	Non	<20	-0.6	-0.8	-1.45
Travelcard Area	South East	Lon	Non	>20	-0.6	-0.8	-1.45
Travelcard Area	Rest of Country	Lon	Non	>20	-1	-0.65	-1.25
Travelcard Area	Rest of Country	Lon	PTE	>20	-1	-0.65	-1.25
Travelcard Area	Rest of Country	Lon	PTE	<20	-1	-0.65	-1.25
Travelcard Area	Rest of Country	Lon	Non	<20	-1	-0.65	-1.25
South East	Travelcard Area	Non	Lon	<20	-0.6	-0.8	-1.45
South East	Travelcard Area	Non	Lon	>20	-0.6	-0.8	-1.45
South East	South East	Non	Non	>20	-0.6	-0.8	-1.45
South East	South East	Non	Non	<20	-0.6	-0.8	-1.45
South East	Rest of Country	Non	Non	>20	-0.9	-0.6	-1.1
South East	Rest of Country	Non	PTE	>20	-0.9	-0.6	-1.1
South East	Rest of Country	Non	PTE	<20	-0.6	-0.5	-0.9
South East	Rest of Country	Non	Non	<20	-0.7	-0.6	-1.05
Rest of Country	Travelcard Area	Non	Lon	<20	-1	-0.65	-1.25
Rest of Country	Travelcard Area	PTE	Lon	>20	-1	-0.65	-1.25
Rest of Country	Travelcard Area	Non	Lon	>20	-1	-0.65	-1.25
Rest of Country	Travelcard Area	PTE	Lon	<20	-1	-0.65	-1.25
Rest of Country	South East	Non	Non	>20	-0.9	-0.6	-1.1
Rest of Country	South East	Non	Non	<20	-0.7	-0.6	-1.05
Rest of Country	South East	PTE	Non	>20	-0.9	-0.6	-1.1
Rest of Country	South East	PTE	Non	<20	-0.6	-0.5	-0.9
Rest of Country	Rest of Country	PTE	PTE	>20	-0.9	-0.6	-1.1
Rest of Country	Rest of Country	PTE	PTE	<20	-0.6	-0.5	-0.9
Rest of Country	Rest of Country	Non	PTE	<20	-0.6	-0.5	-0.9
Rest of Country	Rest of Country	Non	PTE	>20	-0.9	-0.6	-1.1
Rest of Country	Rest of Country	PTE	Non	<20	-0.6	-0.5	-0.9
Rest of Country	Rest of Country	PTE	Non	>20	-0.9	-0.6	-1.1
Rest of Country	Rest of Country	Non	Non	<20	-0.7	-0.6	-1.05
Rest of Country	Rest of Country	Non	Non	>20	-0.9	-0.6	-1.1

Key: Areas as previous table except Travelcard Area includes Central London.
PTE: Lon = London, PTE = PTE area, Non - All other areas
Dist: < 20 miles or > 20 miles

Table A.2 – Crowding Elasticities

Train Service Information

In addition to the matrix data described, the database makes use of detailed datasets relating to train services and passenger routings (provided directly by AEA from the datasets underlying national MOIRA), estimates of future growth in train loadings and additional datasets allocating arcs and stations to descriptive categories.

Moira Datasets

The following two train service related datasets were provided directly by AEA from the data underlying national MOIRA for use in the study.

- Service information[7] for each of the 17666 weekday trains included in national MOIRA, including details of:
  - Stops served (defined in terms of MOIRA station group);
  - Arrival and departure times at each stop;
  - Passengers alighting and boarding at each stop;
  - Stock type: a broad categorisation identifying maximum speed and diesel or electric power source;
  - Service code: a code allocating the train to a group of trains run by a given operator and serving similar routes.
- Details of routes taken between each origin and destination defined in terms of the percentage of journeys using given services on given arcs (where an arc is the section of network between two adjacent MOIRA 'stops').

Loading Growth

Estimates of future year train loadings are required to allow estimates of future crowding levels in the model. The database uses estimates derived from future growth in train loadings in 'Business as Usual' scenarios forecast using the PLANET Strategic Model (PSM) for the Inter Urban Rail Forecast Study for the DfT[8]. The forecasts are consistent with those applied to the demand matrices in the database (described above) as the matrices used in the PSM runs were based on the same input growth assumptions, derived from the PLANET 'Growth Forecasting Tool'.

PSM produces estimates of passenger loads on each link of the rail network for services run by each TOC. These forecasts were used directly to derive the growth factors used in the database for 2016 and 2026 by comparing the forecast loads on each relevant arc with the modelled loads for 2006. The factors for 2021 (not a PSM forecast year) were then derived by interpolation, assuming constant annual growth rates.

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[7] The train related data remains largely in the form in which it is held in MOIRA but some additional processing was required to calculate on board loadings from boarding and alighting data, identify the full routes covered by split and joined trains and identify all of the MOIRA national stops passed through by some fast services

[8] Interurban Rail Forecasts, Final Report, Atkins on behalf of DfT, July 2006

As the following section describes, crowding benefits are assumed to occur only on inter-city trains. Consequently the input PSM loading growth forecasts were restricted to those TOC and rail arc combinations relating to inter-city train services. For completeness, a default growth factor (entered via the user input form) is applied to all other links. However, it will have no impact on results as long as the definition of inter-city trains remains the same as (or more restricted than) the current definition.

It is noted that this approach is intended to provide indicative future passenger numbers only and involves some recognised limitations. PSM is an all day model and therefore the growth forecasts generated refer to the growth in loads on given TOC/arc combinations over a full day. In the database these factors are applied to trains running at all times of the day. To prevent this causing unreasonable levels of loading on already busy trains, a maximum possible value of 150% is assumed for the ratio of passengers/seats on all trains[9]. However, there is no allowance for a corresponding increase on other trains (possibly in shoulder hours) to offset the demand capped from the busiest trains. Therefore effectively any time or route shifting occurring in response to demand increases is excluded. The result is likely to be a conservative estimate of crowding levels over the day.

Additional Datasets

Two key further datasets related to characteristics of the rail network were also used in the database as follows:

- Categorisation of MOIRA arcs (i.e. links between adjacent stations groups) in terms of their current electrification status;
- Categorisation of MOIRA station groups in terms of their geographical area (Central London, Travelcard area, South East or Rest of Country) in line with the categories used in PDFH.

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[9] 150% was used for consistency with PDFH crowding penalty, maximum crowding penalties are allocated at 140% for Business and Leisure purposes and 160% for Commuting.

Benefit estimates

As outlined in the previous section, there are two key potential sources of user benefits from electrification schemes:

- Reduced generalised journey time; and
- Reduced crowding penalty.

These changes will affect demand levels (as discussed above) and so will also impact on:

- Revenue income from the rail network.

The database uses the demand data and other detailed input information outlined above to calculate the scale of the demand related benefits. It then exports suitable outputs to the economic appraisal spreadsheet to allow economic values to be attributed to the benefits.

The following sections outline the benefits calculated and the outputs exported to the appraisal spreadsheet.

It is noted that the model has been developed to forecast the impact of both electrification and de-electrification schemes. However, for simplicity, this note refers throughout to ‘electrification’ schemes only. The processes and calculations described apply equally for de-electrification schemes (usually representing the opposite effect) unless otherwise stated.

Estimation of benefits

Reduced Generalised Journey Time

Source of Benefit

Generalised journey time refers to the time spent waiting for, changing between and travelling on train services. As discussed, an electrification scheme could cause time savings by reducing the time spent slowing down for and speeding up after each stop (through improved acceleration and deceleration rates).

Benefits would be experienced at all stops served by trains able to use electric rolling stock in the Test scenario but not in the Reference Case. This would include stops on any sections of route that were already electrified in the Reference Case (but served by a diesel train because the route extended onto the then non-electrified network).

Calculation of Benefit

The calculation of user benefits is complicated by the fact that they are most readily identified at the level of the individual train whilst the demand generation calculations require estimates of benefits experienced on individual journeys (as represented by the origin/destination pairs in the demand matrix) over an average day and for each of the three ticket types.

The benefit calculation process therefore involves the following key stages:

- Identification of benefits experienced on individual trains, involving:
    - Identification of train services experiencing reduced journey times as a result of the scheme; and
    - Estimation of the time savings experienced on each arc of the route served by the identified services.
- Identification of benefits experienced on individual journeys, involving:
    - Identification of any affected trains used by passengers travelling between each origin and destination; and
    - Estimation of the average saving experienced by all passengers (for each ticket type) travelling between each identified origin and destination pair over the course of a day

Each stage is discussed in more detail below.

i) Benefits Experienced on Individual Trains

The train services affected by a scheme are identified as those which are able to transfer from using diesel rolling stock in the Reference Case to electric stock in the Test Case because the scheme provides (or completes) electrification of the route served by the train[10].

The database identifies the affected trains using information on:

- the sections of the network (route arcs) to be electrified (defined as part of the input Test specification);
- the Reference Case electrification status of all route arcs (part of the base information included in the database) ; and
- the routes followed by each train (part of the base information included in the database);
- the TOCs assumed to be affected by the scheme (defined as part of the input Test specification). Trains with routes electrified by the scheme but run by unidentified TOCs are assumed to run diesel stock ‘under the wires’ to make best use of their stock.

The affected trains identified are assumed to transfer to using electric rolling stock in the Test Case and therefore to experience reduced journey times resulting from acceleration and deceleration benefits at each stop made.

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[10] The few examples of ‘Under the Wire’ trains are also identified by the model. These are trains which are currently run on wholly electrified routes but using diesel stock because of fleet logistical considerations for the TOC concerned. In cases where the electrification allows a large-scale switch to electric stock for a given TOC, it is assumed that any ‘under the wire’ trains that they operate will also transfer to electric stock. It is noted that there is no equivalent reverse assumption for de-electrification schemes.

The total time saving experienced on a given train service therefore depends on the number of stops served. However, this information is not directly available from the MOIRA data because train stopping patterns are specified in terms of the 430 station groups rather than the 2600 individual stations. The number of stops identified for some services is therefore considerably smaller than the actual number made, particularly on local and commuting services (where trains may stop at several of the individual stations grouped in a single MOIRA 'stop'/station group). Benefits for such trains would be underestimated if calculated on the basis of the stops represented in national MOIRA alone.

To address this issue, the database incorporates a mechanism to estimate the number of actual stops on each arc (defined as the route section between adjacent MOIRA 'stops'). The calculation makes use of details on the maximum operating speed of the train (assumed on the basis of stock category), the distance between MOIRA 'stops' and assumptions on acceleration and deceleration rates. This detail provides sufficient information to identify the travel time between the MOIRA 'stops' at the start and end of the arc, assuming no intermediate stops.

The actual travel time for the journey is then calculated from the timetabled arrival and departure times at the start and end MOIRA 'stop' (provided in the input data). The difference between the actual journey time and potential minimum 'non-stop' time is assumed to be the result of additional stops made. The implied number of stops made is then estimated on the basis of assumed acceleration and deceleration rates and an average at-station dwell time.

The resultant estimated number of stops is used to calculate the total journey time reductions experienced on the train service (resulting from acceleration and deceleration savings at each stop).

ii) Benefits Experienced on Individual Origin/Destination Pairs

iia) Average GJT Change

The ultimate journey origins and destinations of passengers using the affected trains are identified by matching the information on train routings with the information on passenger routings between each origin/destination pair. In some cases passengers use more than one route between a given origin and destination, therefore the process of calculating the daily average benefit experienced by all passengers making the journey between a given origin and destination involves the following stages:

- Identification of the routes or sections of routes[11] between the origin and destination that are served by affected trains (i.e. those with a changed power source as a result of the scheme);
- For each affected route between the origin and destination:
    - Identification of the trains serving the route throughout the day;

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[11] 'Routes' are restricted to sections of journeys possible on one train service. In the relatively rare cases where a journey would involve travelling on more than one affected train, the portion travelled on each train is treated as a separate route, resulting in a slight underestimate of impacts.

- Calculation of the benefit experienced by passengers using each train to travel between the selected origin and destination on the basis of the stops at which they would join and leave the service and the benefits experienced on the intervening arcs. The savings experienced on the identified route may vary between trains because of differing stopping patterns. More significantly, some trains may experience no savings because they serve longer (or different) routes which still include some non-electrified sections;

- Calculation of the weighted average benefits experienced by all passengers using the given route throughout the day on the basis of the benefit experienced on each relevant train and an estimate of the relative number of passengers using each one[12].

The overall benefit calculations require separate estimates of average GJT savings for trips for each purpose and using each ticket type. The proportion of trips in each purpose/ticket type category travelling at various times of day varies (for instance a higher proportion of commuting than leisure travel occurs in the peak). Consequently the weighted average GJT saving would vary between categories (assuming GJT savings vary through the day). Separate weighted average savings are therefore calculated for each category on the basis of estimates of the relative numbers of passengers in each category travelling on each train, derived by disaggregating the overall estimate of relative passenger numbers using average proportions derived from the LATS 2001 survey.

As the relevant proportions of passengers in each purpose/ticket category vary between time periods, each train is allocated to a time period on the basis of the estimated time at which a passenger would arrive at the ultimate journey destination if using that service. (For arrival times between 7 and 10 am, morning peak proportions are used, for those between 10 am and 4pm, inter peak proportions used and for those between 4 and 7 pm evening peak proportions are used. In all other cases ‘non peak’ proportions are used).

- For all routes between the origin/destination pair combined:

- Calculation of an overall weighted average benefit for all passengers using all routes between the origin and destination throughout the day. This is derived by multiplying the average benefit estimated for each route by the proportion of trips forecast to use that route (available from MOIRA routing data).

The overall average GJT saving for each origin/destination pair in the matrix is therefore a weighted average of the daily saving experienced on all possible

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[12] Ideally, the relative loadings used would be the number of passengers using each train to travel between the given origin and destination. As this information is not available, the closest approximation is used, i.e. the minimum loading occurring along the affected routes. This reflects the theoretical maximum number of passengers who could be using the service to travel between the origin and destination and should provide a reasonable basis for comparing the relative numbers using each train (removing the potential for bias by for instance heavy local peak movements that might be caused in weighting long distance journeys using the alternative measure of average loadings over the route).

passenger routes between the origin and destination[13]. In turn, the savings on each route are the weighted average of the savings on all trains serving the route throughout the day.

iib) Average Demand Change

A weighted average change in demand levels[14] throughout the day is calculated for each journey through a similar process. For a given origin/destination pair, this involves the following stages:

- For each possible route between the selected origin and destination:
    - Identification of the trains that serve the route throughout the day;
    - Calculation of an estimated change in the forecast numbers of passengers using each identified train service to travel between the given origin and destination using the selected route due to the forecast change in GJT. (As described above, this is achieved using the PDFH elasticity approach based on a comparison of the Test GJT and Reference Case GJT. Test GJT is calculated by subtracting the estimated time saving experienced on the relevant route from the Reference Case average GJT for the complete journey between the origin and destination). Separate estimates are made for changes in demand for journeys using each ticket type, reflecting the differences in PDFH elasticities.
    - Calculation of an approximate weighted average change in demand between the origin and destination for each ticket type and purpose combination. This is based on the changes forecast for each relevant train service and the relative numbers of passengers on each, estimated, as described above, on the basis of minimum loadings along the route and average purpose and ticket proportions associated with time of day.
- For all routes between the origin/destination combined:
    - Calculation of an overall weighted average change in demand (for each purpose/ ticket type passenger category) between the origin/destination pair through weighting the change associated with demand on each route by the proportion of all passengers (between the origin and destination) estimated to use that route.

The estimated daily average change in demand between each origin and destination is then applied to the Reference Case demand to provide an estimate of Test Case demand for each journey, by ticket type.

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[13] This approach assumes in the absence of other information that the proportion of journeys using each potential route remains constant throughout the day

[14] A weighted average demand change is used in preference to simply calculating the demand change implied by the average daily saving because the relationship between GJT and demand change is not linear and therefore the result produced by the two approaches might vary considerably. This is particularly relevant for crowding savings which vary significantly throughout the day.

Finally, the overall value of GJT user benefits is estimated by using the matrices of demand (Reference Case and Test Case) and change in GJT in the standard Rule of Half approach detailed in DfT appraisal guidance[15].

It is noted that the Test Case demand used in the calculation includes the allowance for demand generated by both the GJT savings as described and crowding savings (described below)[16].

Crowding Savings

Source of Benefit

The database only considers crowding benefits resulting from the increased amount of seating capacity available in electrically powered high-speed/inter-city trains.

As with GJT benefits, crowding benefits would be experienced by passengers travelling on any (in this case crowded) train that the Test scheme enables to use electric rather than diesel rolling stock.

Calculation of Benefit

Again, the crowding benefits are most readily identified at an individual train level but are required at an average daily trip level for use in the demand and benefit value calculations.

The key stages involved in the calculation process are therefore identical to those described above for estimated GJT benefits; involving identifying affected trains and the benefits associated with them and then identifying affected journeys and the weighted average benefit experienced by passengers making those journeys and the associated change in demand levels. The main differences for calculations of crowding benefits are that the number of trains experiencing the savings is potentially considerably smaller (being constrained to high-speed, inter-city trains) and benefits on a given route may vary more significantly between affected trains (according to time of service and associated crowding levels).

i) Benefits by Individual Train

The PDFH provides estimates of the value of crowding disbenefits expressed in pence per minute spent in crowded conditions. Values vary according to whether passengers are seated or standing, their purpose of travel, crowding levels and whether or not the train originates or terminates in London[17].

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[15] i.e. Benefits = 0.5(Ref Demand + Test Demand)*(Ref Cost - Test cost) on the assumption that existing trips experience the full value of any benefits whilst new (or transferred) trips on average experience half the value

[16] Test demand = Ref Demand + Ref Demand * (Change due to GJT savings) + Ref Demand * (Change due to crowding savings)

[17] PDFH presents values in terms of 2000 prices and values. Income and inflation factors are applied to convert these to 2006 prices and values for comparison with fares, also in 2006 prices. The economic spreadsheet provides further income factors to reflect increases in real values of crowding penalties through time but converts prices back to 2002 levels for use in the final appraisal.

The key element of the calculation of savings experienced on relevant individual trains is therefore the estimation of changes in crowding levels on each one. This is dependant on the scale of passenger demand as a ratio of available seating capacity and therefore requires the identification of:

- Relevant trains
- Seating capacity and
- Passenger volume.

Relevant trains are identified as those that are:

- high speed inter-city trains (currently defined as those services on which current trains have a maximum speed of 110 mph or greater, although this assumption can be changed); are
- operated by one of the TOCS identified as affected by the scheme (on the User Input Form); and are
- enabled to convert from diesel to electric rolling stock by the Test scheme (largely identified on the basis of train routing and the Reference Case electrification status of each route arc as discussed above).

The seating capacity of each relevant train is input to the Test specification as the number of seats per electric and diesel inter-city train on the relevant route in each time period. Each train is allocated to a time period (and therefore allocated an assumed seating capacity) on the basis of the time of its maximum load. Those with a maximum load occurring between 7 and 10 am are allocated to the morning peak and those with a maximum between 4 and 7 pm to the evening peak. All others are defined as 'non peak'.

The volume of passengers on each train is estimated on the basis of the input MOIRA train related information which includes details on passengers boarding and alighting at each station. For the forecast years, volumes are estimated by factoring base year levels by the PSM growth factors described above.

These inputs provide sufficient information to estimate a crowding level for the Reference Case (assuming the seating capacity for diesel trains) and Test Case (assuming seating capacity for electric trains). This in turn allows the estimation of associated average crowding penalties in each case (calculated as the weighted average of penalties experienced by seated and standing passengers). Separate penalties are calculated for each arc served by the train and for each purpose of passenger travel. As discussed above this value is then multiplied by a fixed percentage (default value 50%) to represent the final result of the iterative interaction between demand levels and crowding levels.

As described above, the method for estimating passenger loadings in future years is necessarily approximate. In this context, the calculation process incorporates measures to ensure crowding benefits estimates are conservative. The key measure is to assume a maximum possible ratio of passengers/seating (V/C) of 150%. In cases where this cap is applied, the full benefit of increased capacity available in electric trains is assumed to be experienced but to reduce the V/C value from a starting point of 150% (rather than the value calculated using forecast loading and seats).

ii) Benefits by Individual Origin Destination Pair

The process of using the crowding savings identified for individual trains to estimate savings experienced by passengers on journeys between given origins and destinations is identical to that described above for the GJT benefits. In summary:

- the origins and destinations of journeys using the affected trains are identified, along with the routes used;
- for each route for each affected origin/destination pair:
  - the trains serving the route are identified;
  - the benefits experienced on each train serving the route are identified on the basis of the stops at which passengers would board and alight and the savings on intermediate arcs;
  - the forecast increase in passengers using each train to travel between the given origin and destination is estimated. (This is undertaken using the PDFH elasticity approach as before but in this case based on comparing the saving experienced with Reference Case fares levels and calculated separately for each purpose type[18]).
  - the weighted average benefit experienced by passengers using all trains serving the route throughout the day is calculated, along with the associated average demand change. (As for the GJT calculations, weighting is undertaken using minimum loads on the affected route, disaggregated by ticket type and purpose.)
- At the overall origin/destination level:
  - the crowding savings and associated demand change percentages calculated for each route are multiplied by the estimated proportion of passengers using that route between the origin and destination. This provides overall average figures for the origin/destination pair.

As with GJT savings, the overall scale of benefits is calculated using the Reference Case and Test Case demand matrices and cost change matrices in the standard Rule of Half approach.

Revenue

The changes in demand associated with the GJT and crowding benefits described above would also result in a change in the revenue generated by the rail network.

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[18] As mentioned above, estimates of future crowding levels are recognised to be approximate therefore a conservative approach is adopted in evaluating the benefits brought by electrification. This includes capping V/C at 150% and assuming the demand/crowding iteration stabilises at 50% of initial benefit estimate as discussed above. Finally, future year crowding related demand change is forecast by considering the value of crowding penalties in base values, rather than applying future year income related value increases which would increase the value of crowding relative to fares and so increase forecast change.

The Reference Case fare between each origin/destination pair is included in the MOIRA data for each ticket type. Reference Case revenue is therefore calculated by multiplying demand for each origin/ destination pair by the average fare. The Test Case revenue is calculated on the same basis and the revenue impact of the scheme is calculated as the difference between the two values.

Database Outputs

The database produces a series of outputs that are exported directly to the appraisal spreadsheet for conversion to monetary values:

- Value of GJT benefits calculated using the Rule of Half approach and disaggregated by PDFH area category, ticket type and purpose.
- Value of crowding benefits calculated using the Rule of Half approach and disaggregated by PDFH area category, ticket type and purpose.
- Value of revenue benefits disaggregated by PDFH area category, ticket type and purpose.
- Change in passenger kilometres disaggregated by PDFH area category, ticket type and purpose.
- Change in diesel and electric train kilometres (disaggregated by stock type)

Summary

The demand forecasting element of the RSSB electrification study is undertaken in an Access database (with relevant outputs fed directly into an Excel appraisal spreadsheet). The input data is primarily detailed demand, routing and train service information from the national MOIRA model but also includes some additional geographical detail and assumptions about stock, station and arc characteristics.

The future year demand forecasts used are based on background demand growth assumptions and are consistent with DfT guidance as represented in the ‘PLANET demand forecasting tool’. The additional estimated demand changes associated with electrification schemes and related benefits are calculated on the assumption that such schemes would generate user benefits and increased demand through reductions in generalised journey time (due to improved acceleration and deceleration) and crowding penalties (due to increased seating capacity on inter-city trains). The impact of these effects on demand levels are forecast using the elasticity based approach advised in PDFH. The associated impacts on revenue are also calculated.

The database is generally structured to enable tests to be specified with limited input and to enable underlying assumptions to be changed easily.

Appendix B – Operating Cost Model

Introduction

This technical note outlines the assumptions used to derive the operating and capital costs of the rolling stock used in the economic model. This is split into 7 sections:

- Rolling Stock Classification
- Electricity consumption for rolling stock and cost of electricity;
- Fuel consumption for rolling stock and cost of fuel;
- Future Fuel Price Scenario
- Variable Track Access Charges
- Rolling Stock Capital & Lease Costs;
- Maintenance Costs

The fixed charge and capacity charge have not been included in the model. The cost of the fixed charge it is assumed would included in the capital costs derived from the cost model. These costs would be paid for by Network Rail and transmitted to TOCs through access charges so to include them within operating costs to TOCs would be double counting. Given the study is considering the incremental cost solely of switching between electricity and diesel powered trains, there would be no impacts on the capacity charge as the levels of service provided between both scenarios would be the same.

Rolling Stock Classification

Within the model, all rolling stock is classified into three categories:

- Inter-city
- Regional Commuting
- Local Commuting

The variable costs within the model which are linked to the number of train kilometres run which are electricity cost, diesel cost and maintenance costs are based upon train kilometre figures from the Access database. MOIRA which forms the basis of the inputs into the models classifies services based upon type (diesel or electric, multiple unit or hauled) and speed. Table B.1 shows the MOIRA classifications and the categorisation based on the three route types defined in the model.

Stock Type	Classification	Examples of Existing Rolling Stock
DLH090	Inter-city	
DLH095	Inter-city	
DMU075	Local Commuting	Pacers
DMU090	Regional Commuting	Sprinters
DMU100	Regional Commuting	Class 170/171 'Turbostar' Class 165/166 'Network Turbo' Class 175 'Coradia' – Arriva Trains Wales Class 185 'Desiro' – Transpennine Express
DMU125	Inter-city	Class 180 'Adelantes' - First Great Western Class 221/222 – Virgin Cross Country, Midland Mainline, Hull Trains
ELH090	Regional Commuting	
ELH100	Regional Commuting	
ELH110	Inter-city	
ELH125	Inter-city	Class 90 - One Class 91 – GNER
EML095	Inter-city	Class 47 – Virgin West Coast
EMU050	Local Commuting	
EMU075	Local Commuting	
EMU090	Regional Commuting	
EMU100	Regional Commuting	
EMU110	Inter-city	
EMU125	Inter-city	
HST110	Inter-city	
HST125	Inter-city	Class 43 – Midland Mainline, First Great Western, GNER

Table B.1 – Operating Cost Model Rolling Stock Classification

Electricity Consumption for Rolling Stock and Cost of Electricity

Background

In November 2004 the Office of Rail Regulation (ORR) started a review of the structure of costs and charges. This included a review of the traction electricity charge which is designed to enable Network Rail to recover the costs incurred in procuring electricity for train operators for traction purpose. The three main elements which make up this charge are:

- The modelled consumption rate per kilowatt hour which is differentiated by vehicle and route;
- The number of miles operated; and
- The price of electricity.

The conclusions of this review were published in October 2005[19] and it was decided that no changes will be made to the traction electricity price list at this time. Although it was acknowledged that whilst prices and actual costs have differed over time both upwards and downwards any alteration would need to be considered at the same time as the overall level of Network Rails required revenue.

In parallel a review of vehicle consumption rates was also conducted which identified some possible changes to the modelled consumption rates. The existing consumption rates were produced at the periodic review in 2000 with further vehicle and route combinations added since, all of which have been derived from the TRATIM model. The findings of the review of charge rates were primarily based on the addition some new vehicles and route combinations and of the removal of obsolete vehicles. [20]

The existing traction election price list was derived at the period review in 2000 which provided consumption in kilowatt hours per mile for EMU's and watt hours per tonne mile for locomotive.

Electricity is priced differently depending based on the following characteristics: [21]

- Area with the country being split into 9 different tariff zones;
- Time of year split between Winter (November to March inclusive) and Summer (April to October inclusive);
- Weekday and weekend;
- Time period with differing tariffs between 07:30-15:59, 16:00-18:59 and 19:00-07:29.

In order to derive the cost of electricity based on changes in price since the periodic review in 2000, the price is set by applying an index published by the DTI for moderately large users. It is acknowledged in the review that the established price using this index does not consistently reflect the costs incurred by Network Rail. One suggested solution which will carried forward as part of PR2008 is to look at alternative indices or consider an alternative approach which would result in charges following Network Rails actual costs of procurement.

Impact of Regenerative Braking

A discount of 16.5% is allowed on the modelled consumption rates for any trains which utilise generative braking and this was specified in the 2000PR. A review of this discount as part of the structure of costs and charges was conducted in 2005. This recommended that although a set of relationships have been developed to estimate regenerative savings they should not been seen as applicable to every route or train service but the results are not sufficiently comprehensive to recommend changing the discount and therefore the 16.5% discount should be maintained until further studies had been conducted.

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[19] STRUCTURE OF COSTS AND CHARGES REVIEW: CONCLUSIONS, OCTOBER 2005, ORR

[20] REVIEW OF ELECTRICITY CONSUMPTION OF RAILWAY VEHICLES : STAGE 2 REPORT, MAY 2005, AEA TECHNOLOGY

[21] APPENDIX Q – PERIOD REVIEW OF RAILTRACKS ACCESS CHARGES; FINAL CONCLUSIONS VOLUME 2, OCTOBER 2000, ORR

Model Assumptions

Electricity Consumption

In order to derive the default electricity consumption of the three route types it was necessary to examine existing rolling stock based on the published modelled TRATIM consumption rates for 25Kv AC powered vehicles and supplement it with additional data which was available.

For the commuter and mixed use scenarios the electricity consumption per vehicle for a Class 357 Bombardier Electrostar was chosen as being a general representative electric unit used to operate this type of routes. This had a consumption of 15.471 kilowatt hours per mile per unit based on the modelled fuel consumption for those operating in the C2C franchise. This equates to a consumption of 2.40 kW hours per vehicle kilometre. In addition a further study which examined the fuel use of the Class 357 using on-board sensors observed a consumption level of 2.36 kW hours per vehicle kilometre indicating that the selected value is robust.

Given the likelihood in the future that electric powered trains would use regenerative braking the 16.5% reduction was applied to this modelled consumption rate as the rates modelled in TRATIM do not include the electricity redistributed to the network through regenerative braking.

For inter-city services the current modelled consumption rates lacked information on modern inter-city trains. Consumption for existing inter-city services such as those hauled by Class 87,90 and 91 locomotive hauled trains were deemed as unsuitable proxies for future inter-city services, yet a key issue is the fact that the Class 390 Pendolinos operated by Virgin on the West Coast Mainline are the only current example of a new high capacity electric inter-city train. Therefore electricity consumption information available on the Class 390 was used for inter-city services based upon the observed electricity from 14 trips from London to Manchester,[22] although it could be argued that other inter-city routes on the rail network are unlikely to be upgraded to the level required to cater for 140mph tilting trains. The default value for inter-city is based on the electricity consumption for a Pendolino which is 29 kW hours per mile for a 9 car train.

Cost of EC4T

There is no default value for the tariff used given the variations depending on the area served by the route and time period. The model provides the ability to select from the ORR specified tariff zones plus a national average based on these tariff zones weighted by the train miles run through the respective tariff zones. Given that tariffs have only been determined for existing electrified routes there is a lack of data for large areas which currently have no electrification, particularly in the West of England. To determine tariffs for sections of route not electrified though would require a detailed analysis of the drivers of electricity prices in the area based on the factors which influence electricity prices in existing tariff zones.

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[22] RAIL EMISSIONS MODEL, NOVEMBER 2001, AEA TECHNOLOGY

The existing tariff prices are in 2001/02 prices. These have been uprated to 2006 prices based on the methodology in Appendix O of the 2000 Review of Access charges using the DTI index of electricity prices for Moderately Large Users.

Fuel Consumption for Rolling Stock and Cost of Gas Oil

Fuel Consumption

The basis of fuel consumption is consumption rates outlined in the report, ‘The Energy Consumption of Rail Vehicles in Britain’ by ATOC, Bombardier and National Express published in November 2006.

For commuter and mixed use, the default value is based on the fuel consumption of a Class 170 from which will provide generally a similar comparison with the Class 357 chosen for the electric train on these route types as they are both made by the same manufacturer. Studies were conducted on both 3 and 4 vehicle units which when averaged out per vehicle resulted in a fuel consumption of 0.462 litres per kilometre.

For inter-city services, observed fuel consumption values for the 9 car Class 222 trains were used which equate to a fuel consumption of 0.512 litres per vehicle kilometre.

Cost of Gas Oil

The cost of gas oil per litre was derived from the DTI publication ‘Quarterly Energy Trends’ published in November 2006 which provided the price per litre of gas oil in May 2006. In addition, the level of Hydrocarbon Tax on Gas Oil was raised from 5.2 pence per litre to 6.44 pence per litre on the 3rd December and this incremental change has also been added to the price giving a price of £0.37 per litre.

Future Fuel Price Scenarios

The development of future fuel prices for Gas Oil (Diesel) and electricity has been undertaken through reference and discussion with DTi economists. The central plank of the research has been two reports titled “UK Energy & CO_2 Emissions Projections”, one in Feb 2006 and the other in July 2006.

The basis for the DTi research has been the development of a model to predict the future mix of electricity generation in the UK energy market. To do this the model takes assumptions on future predictions of fossil fuel prices and uses these to determine the future electricity generation mix.

For the purposes of this study we are looking for predictions on the future price of diesel and electricity and so the DTi research provides a useful starting point. It provides an index for future fossil fuel prices (ffp) which we have used to infer forecasts for diesel price directly and also predicts the future mix of electricity generation. Whilst there is no direct forecast made of future electricity price, this has been inferred from the changes to input costs (fuel) and the forecast mix of generation types.

Electricity Mix	2005	2010	2015	2020	2030	2040	2050
High FFP	1	1.04	1.09	1.14	1.20	1.20	1.20
Low FFP	1	0.85	0.72	0.61	0.52	0.52	0.52
Central	1	0.95	0.89	0.81	0.75	0.75	0.75

Table B.2 – Future Electricity Price Indices

Gas Oil Assumptions	2005	2010	2015	2020	2030	2040	2050
High FFP	1	1.094	1.197	1.309	1.309	1.309	1.309
Low FFP	1	0.364	0.364	0.364	0.364	0.364	0.364
Central	1	0.935	0.875	0.818	0.818	0.818	0.818

Table B.3 - Future Gas Oil Price Indices

Variable Track Access Charge

The variable track access charge incurred by TOCs is determined based on a series of characteristics related to the rolling stock they use including weight. Given that diesel trains are generally heavier due to the additional weight of the trains due to addition engine weight, they generally result in increased maintenance costs to Network Rail thus resulting in increased costs charged to the TOCS

In determining the incremental track access charges, consideration needs to be given to the availability of VTAC for existing vehicles combined with the IEP assumption used in the economic model in relation to capacity benefits. At present although the Class 222 has been used as a proxy for the characteristics of diesel trains, their impacts on maintenance is likely to be different to having two loco hauled diesel engines at each end of the train. Therefore VTAC information for Class 43 has been used for diesel trains and Class 390 for electric inter-city trains as based on existing rolling stock, these are the closest fitting units to the proposed IEP trains.

Two caveats which should be highlighted with the use of these units are:

- The existing Class 43 units are unlikely to capture any recent or future developments which enable to reduction in weight of diesel hauled engine or any changes in weight due to the need for improved crashworthiness;
- Using the Class 390 will capture increases in weight due to the improved crashworthiness and also the weight of the tilting mechanism contained in the bogies.

For regional commuting and local commuting, Class 170 'Turbostars' have been used for diesel units and Class 357 'Electrostars' for electric units.

Rolling Stock Capital and Leasing Costs

In order the differentiate whether there is any cost differential between the capital costs of electric and diesel train, the model has based the default values on available data within Atkins and externally on the actual capital cost at point of production as opposed to the leasing cost.

Although the TOCs face the costs stipulated by the 3 rolling stock leasing companies, using lease prices is likely to insert significant distortions into the analysis based on the market faced by TOCs and differences between leasing costs of electric and diesel units are unlikely to be due to whether they are electric or diesel units. The main issues are:

- The market is still heavily influenced by the presence of the rolling stock transferred after privatisation and therefore lease prices are heavily driven by the demand for this existing stock which can vary significantly based on availability and operational requirements thus leading to a supply driven price structure.
- Although, through the procurement of new rolling stock some of the issues relating to the distortions relating to existing rolling stock would start to be removed and a more competitive market opened up, any price differential between leasing costs of diesel and electric trains is unlikely to be due to their power supply. Examples of potential distortions would be due to the buying power of specific operators, the range of alternative options open to TOCs depending on their requirements for the route that they operate, and the risks perceived by the leasing companies relating to their ability redistribute the rolling stock to other sections of the network at the end of franchise agreements.

Based on evidence from past studies within Atkins there is little difference in the capital cost between diesel and electric trains. Examples in the cost differential from examples of purchase prices of Electrostars and Turbostars small differences in the purchase prices between electric and diesel trains with electric trains being 2% cheaper although in this particular case, the order for the electric trains was significantly larger therefore the difference may be due to economies of scale.

Also the costs estimated for the IEP study assume the same cost of a train when comparing electric and diesel trains with the same number of cars. Therefore the default value assumes that there is no differential between the capital cost of diesel and electric trains.

Maintenance Costs

Information on the difference in maintenance costs between diesel and electric trains was based upon information from past studies in Atkins. A maintenance cost of 38 pence per vehicle mile for electric trains and 43 pence per vehicle mile for diesel trains was assumed. These rates were used for Inter-city, Regional Commuting and Local Commuting.

Appendix C – TEE Tables

Midland Main Line

Table 1: Economic Efficiency of Transport System

	Total	Rail	
Consumers user benefits			
- travel time saving	£0	£0	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£0**	£0	
Business			
User benefits			
- Travel time	£0	£0	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£0**	£0	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	£180,463,362		£180,463,362
- opcost	£114,188,117	-£32,995,939	£147,184,056
- investment cost	-£301,248,549	-£301,248,549	
- grant/subsidy	£334,244,488	£334,244,488	
- revenue clawback	-£327,647,418		-£327,647,418
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£0**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£0**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes Total	Rail
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	£334,244,488	£334,244,488
- Indirect Tax Revenues	£30,987,228	£30,987,228
- Revenue clawback	-£327,647,418	-£327,647,418
Net (8)	**£37,584,298**	£37,584,298
Total PV of costs (9 =7+8)	**£37,584,298**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	£38,421,372	£38,421,372
Journey ambience (incl. rolling stock quality, station quality and crowding)	£86,559,681	£86,559,681
Accidents (incl. safety)	-£4,163,354	-£4,163,354
Consumer users (sub-total 1, Table 1)	£0	£0
Business users and providers (sub-total 5, Table 1)	£0	£0
Reliability (incl. performance & reliability) (s)	£0	£0
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	82,396,327	
Sensitivity PV of Benefits (a = sum of all benefits)	**120,817,699**	
PVC (b = sub-total 9, Table 2)	**37,584,298**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	83,233,401	
- BCR (a/b)	**3.21**	

Great Western Main Line – Test 1 London to Oxford, Bristol and Cardiff

Table 1: Economic Efficiency of Transport System

	Total	Rail	
Consumers user benefits			
- travel time saving	£50,351,086	£50,351,086	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£50,351,086**	£50,351,086	
Business			
User benefits			
- Travel time	£105,096,685	£105,096,685	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£105,096,685**	£105,096,685	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	£142,505,668		£142,505,668
- opcost	£95,922,676	-£43,757,952	£139,680,629
- investment cost	-£473,218,922	-£473,218,922	
- grant/subsidy	£516,976,875	£516,976,875	
- revenue clawback	-£282,186,297		-£282,186,297
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£105,096,685**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£155,447,771**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes	Rail
	Total	
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	£516,976,875	£516,976,875
- Indirect Tax Revenues	£31,459,054	£31,459,054
- Revenue clawback	-£282,186,297	-£282,186,297
Net (8)	**£266,249,632**	£266,249,632
Total PV of costs (9 =7+8)	**£266,249,632**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	£40,368,805	£40,368,805
Journey ambience (incl. rolling stock quality, station quality and crowding)	£42,787,010	£42,787,010
Accidents (incl. safety)	-£5,951,860	-£5,951,860
Consumer users (sub-total 1, Table 1)	£50,351,086	£50,351,086
Business users and providers (sub-total 5, Table 1)	£105,096,685	£105,096,685
Reliability (incl. performance & reliability) (s)	£5,525,068	£5,525,068
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	192,282,920	
Sensitivity PV of Benefits (a = sum of all benefits)	**238,176,793**	
PVC (b = sub-total 9, Table 2)	**266,249,632**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	-28,072,839	
- BCR (a/b)	**0.89**	

Great Western Main Line – Test 2 London to Oxford and Bristol

Table 1: Economic Efficiency of Transport System

	Total	Rail	
	Total	Rail	
Consumers user benefits			
- travel time saving	£50,220,768	£50,220,768	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£50,220,768**	£50,220,768	
Business			
User benefits			
- Travel time	£104,808,179	£104,808,179	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£104,808,179**	£104,808,179	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	£141,894,543		£141,894,543
- opcost	£79,312,590	-£28,136,642	£107,449,232
- investment cost	-£287,733,367	-£287,733,367	
- grant/subsidy	£315,870,009	£315,870,009	
- revenue clawback	-£249,343,775		-£249,343,775
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£104,808,179**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£155,028,947**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes Total	Rail
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	£315,870,009	£315,870,009
- Indirect Tax Revenues	£24,966,624	£24,966,624
- Revenue clawback	-£249,343,775	-£249,343,775
Net (8)	**£91,492,858**	£91,492,858
Total PV of costs (9 =7+8)	**£91,492,858**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	£31,642,263	£31,642,263
Journey ambience (incl. rolling stock quality, station quality and crowding)	£42,627,012	£42,627,012
Accidents (incl. safety)	-£3,621,950	-£3,621,950
Consumer users (sub-total 1, Table 1)	£50,220,768	£50,220,768
Business users and providers (sub-total 5, Table 1)	£104,808,179	£104,808,179
Reliability (incl. performance & reliability) (s)	£5,525,068	£5,525,068
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	194,034,008	
Sensitivity PV of Benefits (a = sum of all benefits)	**231,201,339**	
PVC (b = sub-total 9, Table 2)	**91,492,858**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	139,708,481	
- BCR (a/b)	**2.53**	

Great Western Main Line – Test 3 London to Oxford, Bristol, and Swansea

Table 1: Economic Efficiency of Transport System

	Total	Rail	
Consumers user benefits			
- travel time saving	£50,375,891	£50,375,891	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£50,375,891**	£50,375,891	
Business			
User benefits			
- Travel time	£105,310,132	£105,310,132	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£105,310,132**	£105,310,132	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	£291,352,744		£291,352,744
- opcost	£170,280,668	-£57,424,065	£227,704,733
- investment cost	-£557,897,311	-£557,897,311	
- grant/subsidy	£615,321,376	£615,321,376	
- revenue clawback	-£519,057,477		-£519,057,477
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£105,310,132**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£155,686,023**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes Total	Rail
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	£615,321,376	£615,321,376
- Indirect Tax Revenues	£50,612,119	£50,612,119
- Revenue clawback	-£519,057,477	-£519,057,477
Net (8)	**£146,876,018**	£146,876,018
Total PV of costs (9 =7+8)	**£146,876,018**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	£64,118,681	£64,118,681
Journey ambience (incl. rolling stock quality, station quality and crowding)	£105,019,726	£105,019,726
Accidents (incl. safety)	-£7,455,711	-£7,455,711
Consumer users (sub-total 1, Table 1)	£50,375,891	£50,375,891
Business users and providers (sub-total 5, Table 1)	£105,310,132	£105,310,132
Reliability (incl. performance & reliability) (s)	£5,525,068	£5,525,068
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	253,250,039	
Sensitivity PV of Benefits (a = sum of all benefits)	**322,893,787**	
PVC (b = sub-total 9, Table 2)	**146,876,018**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	176,017,769	
- BCR (a/b)	**2.20**	

Great Western Main Line – Test 4 London to Oxford, Bristol, Swansea and Bedwyn

Table 1: Economic Efficiency of Transport System

	Total	Rail	
Consumers user benefits			
- travel time saving	£64,468,140	£64,468,140	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£64,468,140**	£64,468,140	
Business			
User benefits			
- Travel time	£131,685,730	£131,685,730	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£131,685,730**	£131,685,730	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	£303,391,494		£303,391,494
- opcost	£165,578,501	-£67,529,724	£233,108,225
- investment cost	-£649,788,168	-£649,788,168	
- grant/subsidy	£717,317,891	£717,317,891	
- revenue clawback	-£536,499,719		-£536,499,719
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£131,685,730**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£196,153,870**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes Total	Rail
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	£717,317,891	£717,317,891
- Indirect Tax Revenues	£52,328,389	£52,328,389
- Revenue clawback	-£536,499,719	-£536,499,719
Net (8)	**£233,146,562**	£233,146,562
Total PV of costs (9 =7+8)	**£233,146,562**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	£66,317,449	£66,317,449
Journey ambience (incl. rolling stock quality, station quality and crowding)	£105,165,159	£105,165,159
Accidents (incl. safety)	-£8,493,579	-£8,493,579
Consumer users (sub-total 1, Table 1)	£64,468,140	£64,468,140
Business users and providers (sub-total 5, Table 1)	£131,685,730	£131,685,730
Reliability (incl. performance & reliability) (s)	£7,168,823	£7,168,823
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	292,825,449	
Sensitivity PV of Benefits (a = sum of all benefits)	**366,311,721**	
PVC (b = sub-total 9, Table 2)	**233,146,562**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	133,165,159	
- BCR (a/b)	**1.57**	

Great Western Main Line – Test 5 London to Oxford, Bristol and Swansea (without CrossRail)

Table 1: Economic Efficiency of Transport System

	Total	Rail	
Consumers user benefits			
- travel time saving	£50,375,891	£50,375,891	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£50,375,891**	£50,375,891	
Business			
User benefits			
- Travel time	£105,310,132	£105,310,132	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£105,310,132**	£105,310,132	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	£291,352,744		£291,352,744
- opcost	£167,866,317	-£59,838,416	£227,704,733
- investment cost	-£606,678,435	-£606,678,435	
- grant/subsidy	£666,516,851	£666,516,851	
- revenue clawback	-£519,057,477		-£519,057,477
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£105,310,132**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£155,686,023**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes Total	Rail
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	£666,516,851	£666,516,851
- Indirect Tax Revenues	£50,612,119	£50,612,119
- Revenue clawback	-£519,057,477	-£519,057,477
Net (8)	**£198,071,494**	£198,071,494
Total PV of costs (9 =7+8)	**£198,071,494**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	£64,118,681	£64,118,681
Journey ambience (incl. rolling stock quality, station quality and crowding)	£105,019,726	£105,019,726
Accidents (incl. safety)	-£7,455,711	-£7,455,711
Consumer users (sub-total 1, Table 1)	£50,375,891	£50,375,891
Business users and providers (sub-total 5, Table 1)	£105,310,132	£105,310,132
Reliability (incl. performance & reliability) (s)	£5,525,068	£5,525,068
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	253,250,039	
Sensitivity PV of Benefits (a = sum of all benefits)	**322,893,787**	
PVC (b = sub-total 9, Table 2)	**198,071,494**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	124,822,294	
- BCR (a/b)	**1.63**	

Chiltern – Test 1 Marylebone to Birmingham and Aylesbury

Table 1: Economic Efficiency of Transport System

	Total	Rail	
Consumers user benefits			
- travel time saving	£15,041,153	£15,041,153	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£15,041,153**	£15,041,153	
Business			
User benefits			
- Travel time	£29,064,710	£29,064,710	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£29,064,710**	£29,064,710	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	£10,915,109		£10,915,109
- opcost	£2,044,105	-£28,068,545	£30,112,650
- investment cost	-£237,183,378	-£237,183,378	
- grant/subsidy	£265,251,923	£265,251,923	
- revenue clawback	-£41,027,759		-£41,027,759
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£29,064,710**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£44,105,862**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes	Rail
	Total	
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	£265,251,923	£265,251,923
- Indirect Tax Revenues	£7,735,542	£7,735,542
- Revenue clawback	-£41,027,759	-£41,027,759
Net (8)	**£231,959,706**	£231,959,706
Total PV of costs (9 =7+8)	**£231,959,706**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	£11,930,820	£11,930,820
Journey ambience (incl. rolling stock quality, station quality and crowding)	£0	£0
Accidents (incl. safety)	-£4,786,753	-£4,786,753
Consumer users (sub-total 1, Table 1)	£15,041,153	£15,041,153
Business users and providers (sub-total 5, Table 1)	£29,064,710	£29,064,710
Reliability (incl. performance & reliability) (s)	£6,636,295	£6,636,295
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	39,319,110	
Sensitivity PV of Benefits (a = sum of all benefits)	**57,886,225**	
PVC (b = sub-total 9, Table 2)	**231,959,706**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	-174,073,482	
- BCR (a/b)	**0.25**	

Chiltern – Test 2 Marylebone to Aylesbury only

Table 1: Economic Efficiency of Transport System

	Total	Rail	
Consumers user benefits			
- travel time saving	£7,685,728	£7,685,728	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£7,685,728**	£7,685,728	
Business			
User benefits			
- Travel time	£13,723,954	£13,723,954	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£13,723,954**	£13,723,954	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	£4,958,358		£4,958,358
- opcost	£2,947,124	-£7,118,381	£10,065,505
- investment cost	-£62,633,556	-£62,633,556	
- grant/subsidy	£69,751,936	£69,751,936	
- revenue clawback	-£15,023,863		-£15,023,863
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£13,723,954**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£21,409,682**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes Total	Rail
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	£69,751,936	£69,751,936
- Indirect Tax Revenues	£1,995,435	£1,995,435
- Revenue clawback	-£15,023,863	-£15,023,863
Net (8)	**£56,723,508**	£56,723,508
Total PV of costs (9 =7+8)	**£56,723,508**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	£2,998,926	£2,998,926
Journey ambience (incl. rolling stock quality, station quality and crowding)	£0	£0
Accidents (incl. safety)	-£1,216,306	-£1,216,306
Consumer users (sub-total 1, Table 1)	£7,685,728	£7,685,728
Business users and providers (sub-total 5, Table 1)	£13,723,954	£13,723,954
Reliability (incl. performance & reliability) (s)	£2,045,175	£2,045,175
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	20,193,376	
Sensitivity PV of Benefits (a = sum of all benefits)	**25,237,476**	
PVC (b = sub-total 9, Table 2)	**56,723,508**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	-31,486,032	
- BCR (a/b)	**0.44**	

Cross Country

Table 1: Economic Efficiency of Transport System

	Total	Rail	
Consumers user benefits			
- travel time saving	£0	£0	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£0**	£0	
Business			
User benefits			
- Travel time	£0	£0	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£0**	£0	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	£20,834,257		£20,834,257
- opcost	£45,692,212	-£41,436,857	£87,129,069
- investment cost	-£408,826,176	-£408,826,176	
- grant/subsidy	£450,263,033	£450,263,033	
- revenue clawback	-£107,963,326		-£107,963,326
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£0**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£0**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes Total	Rail
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	£450,263,033	£450,263,033
- Indirect Tax Revenues	£16,228,822	£16,228,822
- Revenue clawback	-£107,963,326	-£107,963,326
Net (8)	**£358,528,529**	£358,528,529
Total PV of costs (9 =7+8)	**£358,528,529**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	£21,329,002	£21,329,002
Journey ambience (incl. rolling stock quality, station quality and crowding)	£12,373,841	£12,373,841
Accidents (incl. safety)	-£6,227,213	-£6,227,213
Consumer users (sub-total 1, Table 1)	£0	£0
Business users and providers (sub-total 5, Table 1)	£0	£0
Reliability (incl. performance & reliability) (s)	£0	£0
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	6,146,628	
Sensitivity PV of Benefits (a = sum of all benefits)	**27,475,630**	
PVC (b = sub-total 9, Table 2)	**358,528,529**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	-331,052,899	
- BCR (a/b)	**0.08**	

East Coast Main Line

Table 1: Economic Efficiency of Transport System

	Total	Rail	
Consumers user benefits			
- travel time saving	£0	£0	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (1)	**£0**	£0	
Business			
User benefits			
- Travel time	£0	£0	
- Vehicle opcost	£0	£0	
- user charges	£0	£0	
- during construction & maintenance	£0	£0	
Net (2)	**£0**	£0	
		Rail	
Private sector provider impact		Network Rail	TOC
- revenue	-£335,174,096		-£335,174,096
- opcost	-£141,787,163	£14,053,017	-£155,840,181
- investment cost	£103,789,408	£103,789,408	
- grant/subsidy	-£117,842,426	-£117,842,426	
- revenue clawback	£491,014,277		£491,014,277
Sub total (3)	**£0**	£0	£0
Other impacts			
- Developer contribution (4)	**£0**	£0	
Net business impact (5 = 2+3+4)	**£0**		
Total, PV of transport econ eff. Benefits (6 = 1+5)	**£0**		

Note that subtotals (1) and (5) flow into the AMCB table. Subtotal (6) does not.

Table 2 Public Accounts (costs should be recorded as a positive number, surpluses as a negative one)

	All Modes Total	Rail
Local Government funding		
- Direct Revenue	-	
- Op costs	-	
- Investment costs	-	
- Developer and other contributions	-	
- Grant/Subsidy (k)*	-	
- Revenue clawback	-	
Net (7)	**-**	-
General Government funding		
- Direct Revenue	£0	
- Op costs	£0	
- Investment costs*	£0	
- Developer and other contributions	£0	
- Grant/Subsidy (k)*	-£117,842,426	-£117,842,426
- Indirect Tax Revenues	-£35,753,592	-£35,753,592
- Revenue clawback	£491,014,277	£491,014,277
Net (8)	**£337,418,259**	£337,418,259
Total PV of costs (9 =7+8)	**£337,418,259**	

*The public sector costs in these boxes should exclude developer contribution e.g. developer contribution is subtracted from these figures to give Net (8)

Table 3: Analysis of Monetised Costs and Benefits (AMCB)

	Total	Rail
Noise (s)	£0	
Local air quality (s)	£0	
Greenhouse gases (s)	-£41,878,140	-£41,878,140
Journey ambience (incl. rolling stock quality, station quality and crowding)	-£190,528,374	-£190,528,374
Accidents (incl. safety)	£4,292,117	£4,292,117
Consumer users (sub-total 1, Table 1)	£0	£0
Business users and providers (sub-total 5, Table 1)	£0	£0
Reliability (incl. performance & reliability) (s)	£0	£0
Option values (s)	£0	
Interchange (s)	£0	
Central PVB, (c = sum of above, excluding sensitivity (s) items)	-186,236,257	
Sensitivity PV of Benefits (a = sum of all benefits)	**-228,114,397**	
PVC (b = sub-total 9, Table 2)	**337,418,259**	
Overall impact, total (includes all monetised benefits)		
- NPV (a-b)	-565,532,656	
- BCR (a/b)	**-0.68**	

Appendix D – Assumptions

Data/Assumption		Source	Description	Further Comments/Explanation
1) Demand Data				
a)	Base Demand	MOIRA Data	Annual passenger demand by Origin/Destination station pair, ticket type and day of week	
b)	PTE Demand Factors	Estimate/ Assumptions	Factors to apply to intra-urban demand to account for the travel card style ticketing not captured in LENNON and therefore MOIRA (*in Manchester, Merseyside, South Yorkshire, Strathclyde, Tyne and Wear and West Yorkshire*).	Factor of 3 entered for Birmingham for use in the exemplar routes (based on analysis of local ticketing data). Factors for other areas are user inputs.
c)	Reference Demand Growth	PLANET 'Growth Forecasting Tool'	Forecasts by O/D and ticket type for 2016,2021 and 2026	Generated from forecasts by PLANET origin and destination zone and purpose type
d)	Elasticities of demand to change in travel cost	PDFH Part B. Tables B3.2 to 3.5 (GJT elasticities) and B2.1 to 2.4 (Fares Elasticities)	Elasticities to identify the proportional change in demand associated with a given proportional change in travel cost using the following formula: $I = (CT/CR)^{el}$ *Where I = Test Demand/ Reference Case Demand* *CT/CR = Test Cost/ Reference Cost,El = elasticity* Overall generated demand is estimated through separate calculations for GJT and crowding change. Total GJT is used as the reference cost for GJT change is total GJT and reference fare is used for crowding change. GJT elasticities vary by origin/destination area and ticket type and crowding elasticities vary by origin/destination area, PTE area, trip length and purpose.	Test Case demand is calculated as: $Ref\ Case + Ref\ Case * (I_{GJT}-1) + Ref\ Case * (I_{crowd}-1)$ The simple single fares elasticity approach identified in PDFH is used i.e. excluding cross elasticities.
e)	Loading Growth	PLANET Strategic Model forecasts for 'Business As Usual' (from Inter Urban Rail Forecast Study) for 2016 and 2026	Factors derived through comparison of forecast passenger loadings on services run by relevant TOCs on relevant arcs in future years against modelled loadings in the base year (2006).	Factors produced relate to growth in passenger loading over the whole day and are applied to all trains throughout the day. Factors are calculated for those TOC and arc combinations that relate to inter-city services only as PSM focuses on strategic movements and the growth factors are required for crowding calculations only which are restricted to inter-city trains.
f)	Default loading growth	Assumption	Factor applied to base year passenger loads to estimate future year loading growth for all those TOC/Arc combinations not included in the PSM based TOC/arc specific forecasts.	Factors included for completeness only and are not required with the current definition of inter-city trains experiencing crowding savings (i.e. those with a top speed of 110 mph and above).
2) Travel costs				

Data/Assumption		Source	Description	Further Comments/Explanation
a)	Fares	MOIRA June 2006 Data	Average fare (in £) paid to travel between each origin and destination station pair, varying by ticket type	Derived using revenue and demand data supplied by MOIRA.
b)	GJT (Generalised Journey Time)	MOIRA June 2006 Data	Average generalised journey time in minutes (including wait, interchange and in-train time) for journeys between each origin and destination pair. Provided separately for each ticket type and for weekdays, Saturdays and Sundays.	
c)	JT (Journey Time)	MOIRA June 2006 Data	Average in-train journey time in minutes between each origin and destination pair, separately for each ticket type.	
d)	Crowding Penalty	PDFH Table B5.1	Values are provided in pence per minute of crowded travel and vary by purpose, whether or not train starts or ends in inner or outer London, level of V/C for the train and whether passengers are sitting or standing.	PDFH provides penalties in 2000 prices and values. These have been converted to 2006 prices and values for use in the demand modelling using inflation and income adjustments in line with the PDFH guidance. NB Penalties in 2006 values are used to calculate demand change in future years to provide a conservative estimate (but future year values are used in the economic evaluation).
3) Train Services & Operations				
a)	Train service stops and times	MOIRA Data (underlying data supplied by AEA)	Detail of each MOIRA stop (i.e. one of 430 station groups) served by the train including the time of arrival and departure.	
b)	Train loadings	Calculation from MOIRA data	Average loading on each section of the train route.	Calculated from information on numbers of passengers boarding and alighting.
c)	Passenger Journey Routings	MOIRA Data (underlying data supplied by AEA)	Detail of the services and route arcs used by passengers between each origin and destination and the proportion of passengers using each combination.	
d)	Services by TOC	MOIRA Data	List of all service codes identified in MOIRA and their operating TOCS	
e)	TOC List	MOIRA Data	List of all 25 TOCs represented in MOIRA data	
4) Rail Network				

Data/Assumption		Source	Description	Further Comments/Explanation
a)	Station groups	MOIRA Data	Identification of which of the 2300 individual stations on the rail network falls in each of the 430 station groups used in National MOIRA.	
b)	Route Arcs	MOIRA Data	Identification of representative route sections used in national MOIRA (i.e. sections joining adjacent station groups).	
c)	Electrification status	Knowledge of the current extent of electrification	Identification of whether each rail arc (i.e. section between 2 MOIRA 'station groups') is currently electrified..	In a few cases the grouping of stations in MOIRA groups means that arcs could be identified as either electrified and not (depending on the individual stations chosen to represent the station groups). In these cases, individual judgements have been made on the basis of the dominant usage of the line and tests likely to be run.
d)	Station locations	MOIRA Data (underlying data supplied by AEA) and further information on rail network	Allocation of stations to geographic areas, primarily for use with PDFH parameters and equations. e.g. allocation to PTE areas	
5) Train Stock Details				
a)	Maximum Possible Speed	MOIRA Data	MOIRA stock categories are identified according to maximum speed in mph	
b)	Maximum Operating Speed	Assumption	Assumed to be 75% of top possible speed	
c)	Acceleration/Deceleration Rates	Assumption	0.65m/s^2 for diesel commuting trains 1m/s^2 for all electric and inter-city diesel trains Based on industry information.	
d)	Average Station Dwell Time	Assumption	1 minute	
e)	Equivalent train types	Assumption	Stock type that services using a given initial stock type would be assumed to use if a scheme allows it to change power source (e.g. EMU125 identified as equivalent for a service currently using DMU125)	Used to calculate GJT savings caused by changes in stock
6) Year. Time and Purpose Assumptions				

Data/Assumption		Source	Description	Further Comments/Explanation
a)	Base Year	MOIRA Data	2006 for consistency with base MOIRA data	
b)	Forecast Years	Assumption	Choice of 2016,2021 and 2026 based on reasonable forecasting horizons and available growth forecasting data	
c)	Time Periods	Assumption	AM Peak = weekday 7 am to 10 am, PM Peak = weekday 4 pm to 7 pm and Non Peak = all other time (consistent with PLANET)	Individual trains are allocated to time periods (for identification of seat numbers for use in crowding calculations) on the basis of the period in which the maximum loading occurs. Passengers are allocated to time periods (for identification of appropriate purpose split factors) on the basis of the period in which they would arrive at their ultimate destination.
d)	Purpose/ticket type splits	Assumption based on LATS data	Analysis of LATS data provided overall average estimates of the proportion of passengers travelling using each ticket type for each purpose in each time period.	Generic proportions are used on all routes and trains
7) Calculation of Scheme Benefits Experienced on Individual Trains				
7i) General				
a)	Affected Trains	Assumptions	Trains are assumed to be affected (i.e. to change power source) if they are: a) operated by TOCs identified as affected by the scheme and either: b1) use a route that is fully electrified after the scheme but was previously partially or fully non-electric; or b2) previously used diesel stock despite being on a route that was fully electric (i.e. an 'under the wire' train).	The database provides the opportunity to identify specific TOCS affected by the scheme. If all TOCs are selected, 'under the wire trains' (i.e. b2) are only assumed to be affected if they are run by TOCs for which the scheme allows at least 5 trains to change due to electrification of their route (i.e. b1) i.e. if there is likely to be sufficient fleet requirement to make electric trains worthwhile.
7ii) Crowding Benefits				
a)	Source of benefit	PDFH Approach	Change in crowding penalty (in pence) experienced per minute of travel on each arc of the rail journey- calculated based on levels of V/C and associated PDFH crowding penalties (described above).	

Data/Assumption		Source	Description	Further Comments/Explanation
b)	Trains experiencing crowding impacts	Assumption	Crowding benefits assumed to be experienced on affected weekday inter-city trains only.	The main impact of electrification schemes is expected to be through allowing additional space in electric inter-city trains (relative to the equivalent diesel trains). Minor crowding effects resulting from demand generation due to GJT change are not directly accounted for. Crowding is assumed not to occur on weekend trains
c)	Definition of Inter-city trains	Assumption	Trains with a maximum speed of at least 110 mph. Based on industry knowledge.	
d)	Seating Levels	Assumption	Estimates based on details of current seating patterns and future train layout designs.	Estimates made for inter-city trains on affected routes only.
e)	Maximum likely value of V/C (passengers/ seating)	Assumption	150% assumed for consistency with PDFH which provides crowding penalties up to 140% for leisure and business trips and 160% for commuting trips.	The percentage is used to cap crowding levels (and associated benefits), particularly in future years
f)	Level of benefit	Assumption	The crowding saving achieved (after iterative feedbacks between crowding benefits and demand levels) is assumed to be 50% of the saving calculated using V/C values calculated using the Ref Case loading and a) Ref Case and b) Test Case seating (i.e. assuming no feedback onto loading levels).	Used as a proxy for the crowding penalty/demand feedback loop (whereby crowding savings encourage increased demand and therefore decreases crowding savings which in turn slightly decreases demand etc). 50% is likely to be a conservative assumption.
7iii) GJT Benefits				
a)	Source of benefit	Assumption	Time saving per stop made by affected trains due to the improvement in acceleration and deceleration rates associated with the change in stock type between the Ref and Test Case	Savings are assumed to occur at all stops made, not just the indicative station group 'stops' included in National MOIRA.
b)	No. of non Moira stops	Assumption/ Calculation	Calculation based on an estimate of minimum 'non stop' journey time between MOIRA 'stops' (using acceleration and deceleration rates and operating speeds). The difference between non stop and actual timetabled time then assumed to be accounted for by additional stops with the number involved calculated using acceleration/deceleration rate, operating speed and dwell time estimates.	Calculations use maximum operating speed rather than maximum possible speed.
c)	Weekend benefits	Assumption	Weekend daily average GJT saving is assumed to equal the daily average weekday saving for each OD pair.	Savings are due to the average number of stops experienced per passenger and are therefore likely to be relatively consistent between days.

Data/Assumption		Source	Description	Further Comments/Explanation
8) Benefits by Passenger Journey				
a)	Affected journeys	Assumption (using MOIRA train and passenger routing information)	Journeys are assumed to be affected where some or all of the passengers use a train affected by the scheme (according to the MOIRA routing data)	
b)	Excluded affected journeys	Assumption	Origin/destination pairs are excluded if the total number of annual trips (all ticket types) is less than 15,000 (i.e. max 40 per day) and/or if less than 2% of trips use affected trains.	The filters are used to reduce processing time by excluding those origin/destination pairs contributing negligible amounts to overall benefits. Sensitivity tests show removing the filters more than doubles processing time but adds less than 1% to benefits.
c)	Average benefit by origin/destination pair	Assumption/Calculation	Weighted average of benefits experienced on each affected route between the origin/destination.	
d)	Affected route sections between origin/destination pair	Assumption/Calculation	Affected route sections are identified as a combination of rail arcs that: - are affected by the scheme (i.e. changed power source), - carry a constant proportion of total passengers between the given origin and destination; and - fall on the route of a single train service (i.e. assuming no interchange on the affected section of the network).	The assumption of no interchange generally has no impact as schemes largely focus on one stretch of the network and one TOC meaning that each journey is likely to use one affected train only. In those cases where more than one affected train would be used, the section of journey on each train is treated as a separate route, resulting in a slight underestimate of benefits.
e)	Average benefit by route section between origin/destination pair	Assumption/Calculation	Weighted average of benefits experienced (by journey purpose) on each train serving the route. Benefits are weighted according to the minimum load on each train over the affected route, disaggregated by ticket type and journey purpose using the LATS based proportions (described above).	The benefits experienced on each train would ideally be weighted on the basis of the number of passengers using the train to travel between the given origin/destination pair. As this information is not available, the minimum loading approach is used as the best available method of identifying the relative usage of each train, avoiding potential distortions. (e.g. peak local commuting loads might distort weightings for longer distance journeys if average train loadings were used to weight benefits.)

Data/Assumption		Source	Description	Further Comments/Explanation
9) Overall Demand Related Benefits				
a)	Revenue	Calculation	(Test Demand * Av Fare)-(Ref Demand * Av Fare)	
b)	User Benefits	Calculation	Rule of Half approach i.e. (0.5*(Ref Demand + Test Demand) * (Test Cost - Ref Cost)) Separate calculations for crowding and GJT benefits	

Appendix E – Equipment Variables and Base Costs

Item	**Units**	
Overhead Line Equipment		
Average tension length. Mid point to mid point distance (not anchor to anchor i.e. length of parallel running at overlaps counted once)	m	1,500
Average span length (new)	m	55
Average span length (existing cantilevers)	m	60
Average span length (existing portals)	m	60
Average span length (existing headspans)	m	65
Overlap span length	m	50
Anchor span length	m	60
Replace cantilever incl insulators	£ each	1,000
Replace standard 4 track headspan incl. span wires, insulators, live drop verticals etc.	£ each	4,800
Replace 4 track overlap headspan incl. span wires, insulators, live drop verticals etc.	£ each	5,200
Remove cantilever and structure. Foundations not removed	£ each	1,700
Remove cantilevers and 4 track portal. Foundations not removed	£ each	6,000
Remove headspan equipment and 2 off masts. Foundations not removed	£ each	3,500
Foundation, mast, single track cantilever (multiple)	£ each	5,000
Foundation, mast, single track cantilever (one off)	£ each	7,000
Foundation, mast, twin cantilevers (Overlap)	£ each	9,000
Foundations (2 off), anchor mast, single track cantilever, backties	£ each	8,000
Foundations (2 off), 4 track portal, 4 off MIR's/Catenary support (multiple)	£ each	30,300
Foundations (2 off), 4 track portal, 4 off MIR's/Catenary support (one off)	£ each	35,000
Foundations (2 off), 4 track portal, 8 off MIR's/Catenary support (overlap)	£ each	34,500
Foundations (4 off), 4 track portal, 4 off MIR's/Catenary support, backties	£ each	34,300
Remove along track equipment including catenary, contact, droppers, return conductor	£/m	20
Supply & install along track equipment including catenary, contact, droppers, return conductor	£/m	60
Tensioning equipment	£ each	1,200
MPA including tie wire, foundations (2 off), backties	£ each	5,000
Anchor tail wire	£/m	15
Alterations to ensure compliant signal sighting	£/STKM	4,000
Miscellaneous clearances (utilities, footbridges etc.)	£/route km	5,000
Neutral Sections spacing	km	25
Neutral Sections	£ each	8,000
Average switching equipment spacing (excluding substations)	km	5
Switching equipment (isolator, jumpers and cut in insulation)	£ each	5,000
Booster transformers spacing	km	3

Item	**Units**	
Booster transformers (transformer, jumpers to adjacent track, cut in insulation)	£ each	25,000
Booster transformers (transformer, jumpers to remote track, cut in insulation)	£ each	27,000
Remove booster transformer	£ each	1,500
Track to track bond spacing	m	250
Track to track bond	£ each	250
Structure to rail bond	£ each	250
Re-wiring: new structures	no./km	2
Distribution Equipment		
Feeder Stations spacing (for classic BT & RC)	km	50
Feeder Stations (for classic BT & RC single or 2 track) Includes OLE isolators and feeder cables	£ each	1,100,000
Feeder Stations (for classic BT & RC 4 track) Includes OLE isolators and feeder cables	£ each	1,500,000
Mid point TSC (for classic BT & RC single or 2 track) Includes OLE isolators and feeder cables	£ each	900,000
Mid point TSC (for classic BT & RC 4 track) Includes OLE isolators and feeder cables	£ each	1,300,000
Intermediate TSC (for classic BT & RC single or 2 track) Includes OLE isolators and feeder cables	£ each	800,000
Intermediate TSC (for classic BT & RC 4 track) Includes OLE isolators and feeder cables	£ each	1,200,000
Removal of substation Includes OLE isolators and feeder cables/bare feeders	£ each	10,000
Miscellaneous Building/Compound Works at substations including site clearance, civils, fencing, bonding, feeding structures, UTX etc for Classic FS & TSCs	£ each	30,000
SCADA including telecoms, control room alterations and RTU	£/route km	4,500
ESI grid connection work at each feeder station (for classic BT & RC)	£ each	2,000,000
Removal of grid connection	£ each	12,000
Auto transformer spacing	km	10
Auto transformers including all associated equipment	£ each	250,000
Auto transformer compounds including site clearance, civils, fencing bonding etc.	£ each	10,000
Feeder Stations spacing (AT)	km	100
Feeder Stations (AT)	£ each	1,500,000
Miscellaneous Building/Compound Works at substations including site clearance, civils, fencing, bonding, feeding structures, UTX etc for AT FS	£ each	70,000
ESI grid connection work at each feeder station (for AT) including civils site works	£ each	9,100,000

Item	**Units**	
Electrification on-costs		
Contractor's Preliminaries for electrification works including mobilisation, site establishment, temporary works & services, staff costs, fixed charges, project management, insurance, overheads & profit etc.	%	20
Contractor's Design including scheme design, detailed design, site investigation/survey (new works)	%	3
Contractor's Design including scheme design, detailed design, site investigation/survey (de-wire)	%	1
Interfaces with Existing OLE		
Enabling Works	£ each	50,000
Contractor's Preliminaries	%	10
Contractor's Design	%	5
Immunisation		
Signalling equipment	£/STKM	5,000
Telecoms equipment	£/route km	1,000
Contractor's Preliminaries	%	20
Contractor's Design	%	3
Over Bridges		
Civil Works	£/bridge	240,000
Contractor's Preliminaries	%	18
Contractor's Design	%	7.5
Platform canopies	£/platform	1000
Tunnels (Track Slue)		
Permanent Way Works	£/m	44
Contractor's Preliminaries	%	20
Contractor's Design	%	3
Tunnels (Track Lower Ballast)		
Permanent Way Works	£/m (single track)	574
Drainage works	£/m (route)	354
Contractor's Preliminaries	%	20
Contractor's Design	%	3
Tunnels(Track Lower Slab Track)		
Permanent Way Works	£/m	1,850
Contractor's Preliminaries	%	20
Contractor's Design	%	10

Item	**Units**	
Depots		
New depot	£/depot	20,000,000
Convert existing depot including provision of specific equipment for electric trains (i.e. pantograph maintenance and transformer oil facilities) and wiring sidings and sheds	£/depot	5,000,000
On-Costs		
Testing & Commissioning	%	2
Non Contractor Design (including Scheme Design/OPS, detail design, site investigation/correlation, handover package, planning consents/third party consultation)	%	10
Other on-costs (including Network Rail project management, possession/isolation management)	%	15
Environmental costs associated with construction activities including noise abatement, disposal of spoil, protecting sites of special scientific interest (SSSI) etc	£/route km	5,000
Electrification equipment maintenance	£/km/year	5,068

Appendix F – 25 kV Electrified Lines

Strategic Route	Sub-section	Electrification	Year Electrified	40th Year
Kent		mostly 3rd rail, some OLE (Dollands Moor & Ashford)		
Brighton Main Line & Sussex		mostly 3rd rail		
South West Main Line		all 3rd rail		
Wessex Routes		no electrification		
West Anglia		• Bethnal Green - Hackney Downs - Bury Street - Cheshunt • Hackney - Chingford • Bury Street - Enfield Town ▪ Cheshunt - Bishops Stortford ▪ Broxbourne Jn - Hertford East	1960	2000
		▪ Clapton Jn - Cheshunt Jn.	1969	2009
		▪ Bishops Stortford - Cambridge	1987	2027
		▪ Royston - Shepreth Branch Jn	1988	2028
		▪ Seven Sisters - Tottenham South	1989	2029
		▪ Stratford - Coppermill	1989	2029
		▪ Stansted Jn - Stansted Airport	1990	2030
		• Hitchin - Royston	1978	2018
		▪ Cambridge - Kings Lynn	1992	2032
North London Line & Thameside		• Camden Jn - Camden Road Jn	1966	2006
		• Navarino Road Jn - Reading Lane Jn • Freight Terminal Jn - Camden Road East Jn	1985	2025
		• Stratford - Hackney - Dalston - Camden • Canonbury Jn - Finsbury Park	1987	2027
		▪ Camden Road Jn - Acton Central	1998	2038
		• Kensal Green Jn - Willesden Jn.	2000	2040
		• Willesden Jn - Mitre Bridge Jn ▪ West London Jn - Westway	1993	2033
		• Fenchurch St - Gas Factory Jn - Bow Jn (Slow lines)	1949	1989
		• Fenchurch Street - Limehouse (fast lines) • Southend Central - Shoeburyness • Gas Factory Jn - Barking - Tilbury - Pitsea • Barking - Forest Gate Jn ▪ Upminster - Grays	1961	2001
		some 3rd/4th rail (NLL)		

Strategic Route	Sub-section	Electrification	Year Electrified	40th Year
Great Eastern	Liverpool Street to Colchester and branches	• Liverpool Street - Shenfield	1949	1989
		▪ Shenfield - Chelmsford • Shenfield - Southend Victoria	1956	1996
		▪ Chelmsford - Colchester	1963	2003
		• Colchester Jn - Clacton • Thorpe-le-Soken - Walton-on-Naze	1959	1999
		• Witham Jn - Braintree	1977	2017
		▪ Romford - Upminster ▪ Wickford - Southminster	1986	2026
	Colchester to Norwich	• Colchester - Ipswich	1985	2025
		• Manningtree - Harwich • Ipswich - Stowmarket	1986	2026
		• Stowmarket - Norwich	1987	2027
	Non electrified lines			
East Coast Main Line	London to Peterborough	• Drayton Park - Finsbury Park - Wood Green - Welwyn G.C. • Wood Green - Hertford North	1976	2016
		• Kings Cross - Finsbury Park • Welwyn Garden City - Stevenage - Hitchin	1978	2018
		• Hertford North - Stevenage	1979	2019
		▪ Hitchin - Huntingdon	1986	2026
		▪ Huntingdon - Peterborough	1987	2027
	Peterborough to Leeds	▪ Peterborough - Doncaster - Leeds	1989	2029
	Doncaster to Edinburgh	▪ Doncaster - York	1989	2029
		▪ York - Newcastle	1990	2030
		▪ Newcastle - Edinburgh	1991	2031
		3rd rail (Moorgate - Drayton Park)		
Northeast Routes		Pelaw - Sunderland 1500V DC OHL		
North Trans-Pennine, North & West Yorks	Leeds suburban electrified routes	▪ Leeds to Bradford, Skipton and Ilkley	1994	2034
	Non-electrified lines			
South Trans-Pennine, South Yorks & Lincs		no electrification		
Reading to Penzance		no electrification		
Great Western Main Line	Paddington to Airport Junction	• London (Paddington) to Heathrow Airport	1998	2038
	Non-electrified lines			

Strategic Route	Sub-section	Electrification	Year Electrified	40th Year
South and Central Wales and Borders		no electrification		
South Wales Valleys		no electrification		
Chilterns		no electrification (except where operating on LUL)		
West Midlands	Electrified lines	• Wolverhampton - Stafford • Wolverhampton - Bescot • Portobello Jn - Bushbury Jn • Portobello Jn - Crane St Jn (Portobello Loop) • Rugby - Coventry - Birmingham - Wolverhampton • Birmingham - Walsall (via Aston & Soho) • Aston - Stechford	1966	2006
		• Aston to Lichfield High Level • Birmingham New Street to Redditch.	1993	2033
	Non-electrified lines			
West Coast Main Line	London to Rugby	• London (Euston) - Rugby • Roade - Northampton - Rugby	1965	2005
	Rugby to Manchester & Carstairs	• Rugby - Nuneaton - Lichfield	1964	2004
		• Lichfield - Stafford - Crewe	1963	2003
		• Crewe - Weaver Jn - Liverpool (Lime Street)	1962	2002
		• Weaver Jn - Bamfurlong - Preston	1973	2013
		• Preston - Carlisle - Carstairs - Motherwell - Glasgow	1974	2014
		• Crewe - Wilmslow - Stockport - Manchester	1960	2000
		• Macclesfield - Cheadle Hulme	1965	2005
		• Colwich - Stone - Macclesfield • Stone - Norton Bridge	1966	2006
		• Watford - St. Albans Abbey	1988	2028
		• Crewe - Kidsgrove	2003	2043
		some 3rd/4th rail (Euston - Watford)		
Midland Main Line & East Midlands	London to Bedford	• London (St Pancras) - Bedford • London (Moorgate) - Dock Junction	1983	2023
	North of Bedford			

Strategic Route	Sub-section	Electrification	Year Electrified	40th Year
North West Urban	Electrified lines	• Manchester Oxford Road - Cornbrook		
		• Manchester - Hadfield - Glossop (ex DC)	1951	1991
		• Wilmslow - Slade Lane Jn (Styal Line)	1958	1998
		• Cornbrook Jn - Trafford Park FLT	1979	2019
		• Edgeley - Hazel Grove	1981	2021
		• Heald Green Jn - Manchester Airport	1993	2033
	Non-electrified lines			
Merseyrail		all 3rd rail		
North Wales and Borders		no electrification		
North West Rural		no electrification		
East of Scotland	Electrified lines	• Edinburgh - Carstairs • Drem Jn - North Berwick	1991	2031
	Non-electrified lines			
Highlands		no electrification		
Strathclyde and South West Scotland	Electrified lines	• Helensburgh - Glasgow Queen Street - Airdrie • Dalreoch - Balloch • Dalmuir Park - Hyndland (via Westerton) • Bellgrove - Springburn • Dalmuir Park - Yoker - Parkhead	1960	2000
		▪ Rutherglen - Kelvinhaugh (Finnieston Jn)	1979	2019
		• Airdrie - Drumgelloch	1989	2029
		• Glasgow Central - Kings Park - Uddingston - Motherwell • Cathcart Circle • Cathcart - Neilston	1962	2002
		• Bridge Street Jn (Glasgow) - Gourock • Wemyss Jn - Wemyss Bay	1967	2007
		• West Street Terminus - Muirhouse Jn	1975	2015
		• Lanark Branch	1974	2014
		• Mossend Yard - Coatbridge FLT	1981	2021
		• Paisley - Ayr • Kilwinning - Ardrossan South Beach • Dubbs Jn - Byrehill Jn	1986	2026
		• Ardrossan South Beach - Largs • Ardrossan South Beach - Ardrossan Harbour	1987	2027
		• Larkhall Branch	2005	2045
	Non-electrified lines			

Appendix G – Cash Flow and Net Benefits Curves

Cash flow and net benefits curves for GWML and MML cases

The cash flow/benefits profile for MML and GWML (Swansea, Oxford, and Bristol) are shown below. These figures have been derived from the economic modelling undertaken for these routes which does not generally reflect what is required for a financial appraisal for the following reasons:

1) The cash flow to Central Government includes the market price adjustment, optimism bias and indirect tax loss. It is also in real terms and does not include general inflation.

2) In reality the scheme would be added to Network Rail's Regulatory Asset Base (RAB) and amortised over 30 years from the end of the relevant Control Period. For the purpose of this study it was agreed with David Miller at DfT that a simple upfront grant funded scenario should be used. Therefore in reality the profile of the subsidy to Network Rail would be smoother but more expensive over the 30 year amortisation period as the rate on return allowed on the RAB exceeds the discount rate used.

These curves have been plotted assuming a project start date in 2012/13 with demand increasing until 2026 and then remaining constant.

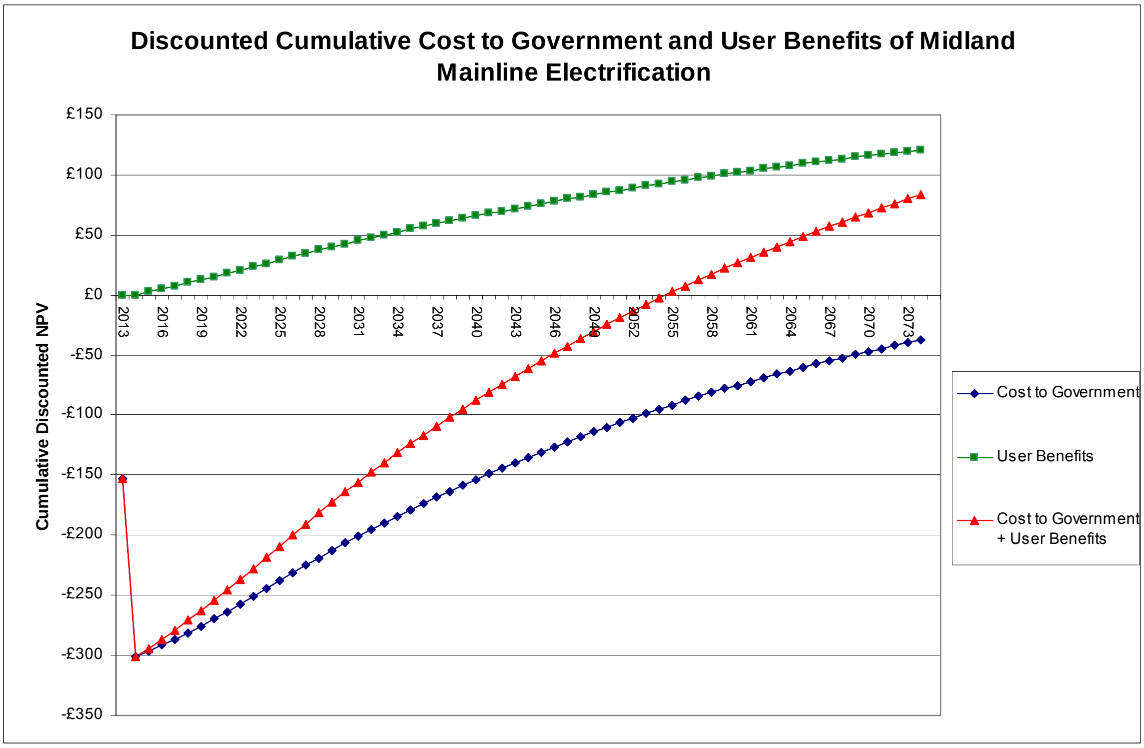

Figure G.1 – Midland Mainline Discounted Cumulative Cashflow

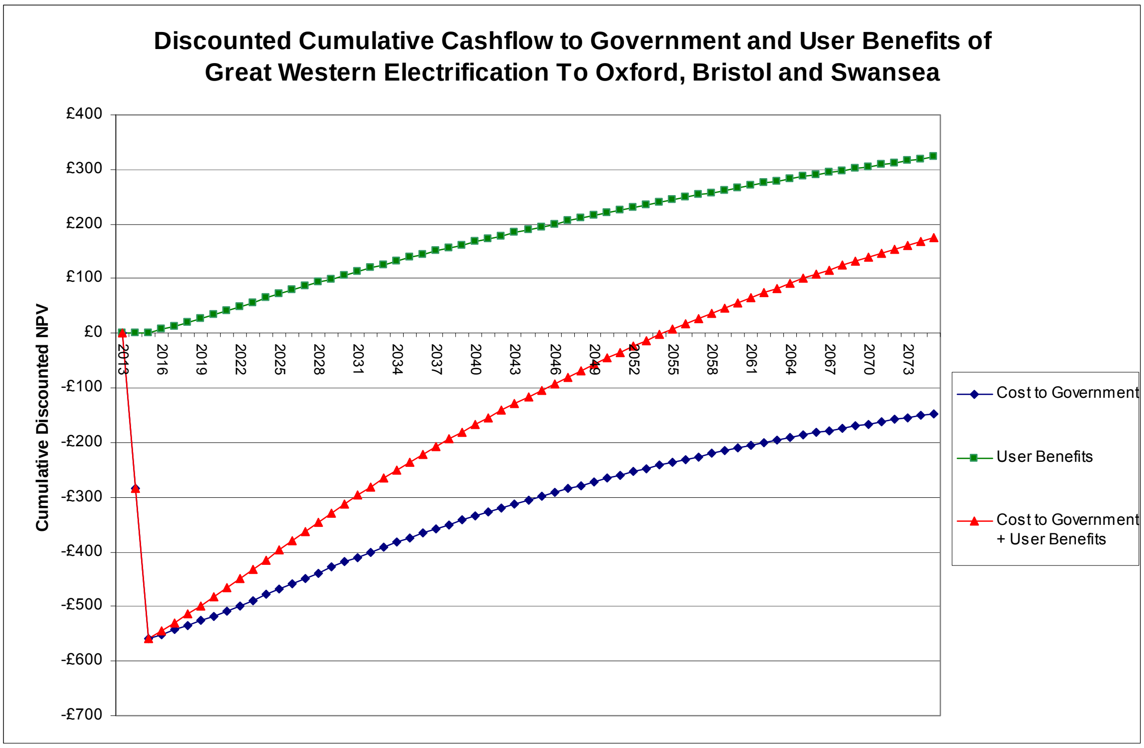

Figure G.2 – Great Western Discounted Cumulative Cashflow

Appendix H – IEP Functional Specification

	IEP Functional Specification	*Electrification Model*
Capacity	It is an essential requirement that the Intercity Express train should provide a minimum increase in furnishable space per train of [10%] for the self powered trainset and [18%] for the electric trainset. It is desirable that these are increased further.	It has been assumed that the IEP electric trainset has an approximately 20% greater capacity than the IEP diesel based on the furnishable space per train provided by in the Key Technical Requirements and that seating per area of furnishable space remains constant.
Journey Time and Maximum Speed	It is an essential requirement that the train be capable of the stated performance to a maximum speed of 125mph. It is a desirable requirement that the train has a top speed up to 140mph, but only where this does not lead to a significant change in weight, cost or complexity.	A maximum speed of 125mph has been assumed for both diesel and electric trains.
Dwell Times	It is an essential requirement that existing dwell times at stations shall be maintained, even with the increased passenger capacity per train. This also applies to turn around times at terminal stations and turnback times at intermediate stations where around times at terminal stations and turnback times at intermediate stations where	Existing dwell times are maintained as timetable is not altered in the model.
Emissions	In addition it is essential that the self powered trainset should demonstrate how it will deliver carbon savings including a reduction in CO2 emissions, per seat km of [30%]. It is desirable that CO2 emissions are reduced by [40%].	No future change in the difference between emissions between diesel and electric trains was assumed. Cost implications to achieve IEP specification would need to be understood for any meaningful analysis to be conducted.
Energy Efficiency	The Intercity Express train shall deliver improved energy efficiency, measured per seat km moved, and taking account of auxiliary loads, as follows: electric trainset - Essential [35%] Desirable [45%], self powered trainset - Essential [20%] Desirable [50%].	Fuel and EC4T consumption based on observed data from Pendolinos for electric Inter City trains and Meridien for diesel Inter City trains. Cost implications to achieve IEP specification would need to be understood for any meaningful analysis to be conducted on the impact.
Train Performance	It is an essential requirement that all of the train configurations shall have an accelerating performance equivalent to that of a Class 220 Voyager train.	Acceleration rates based on the technical specs for the Voyager were used for IEP trains.
Reliability	It is an essential requirement that the trainsets shall provide a Mean Distance Between (in service) Failure of [60,000] miles for the self powered trainset and [80,000] miles for the electric trainset. It is desirable that the rates should be increased to [120,000] and [160, 000] miles respectively.	Electric train assumed to be 30,000 miles per casualty and diesel 15,000 miles per casualty.
Electric Braking and Energy Recovery	It is an essential requirement that the Intercity Express train shall be fitted with a fully rated electric brake, which, when operating under the 25kV shall be capable of regenerating back into the line.	It is assumed in the operating cost model that all future trains have regenerative braking and EC4T costs are discounted accordingly.

Appendix I – Cost of Carbon

Introduction

The DfT have requested that further tests are undertaken to investigate the sensitivity of the cost of carbon on the case for electrification.

The central case for each exemplar route is based upon the central estimate in WebTAG unit 3.3.5 which equates to £78.66 per tonne of carbon. Tests have also been conducted based on using the Upper and Lower bounds in the guidance which is £151.11 and £42.44 respectively, and on higher figures suggested by DfT of £238, £1000 and £5000. These figures are the assumed carbon costs in 2006 (using a 2002 price base) and it has been assumed that carbon costs grow at £1.035 per annum as per WebTAG guidance.

Using the range of prices indicated above the BCR's for the exemplar routes as previously modelled have been calculated. No other variable has been changed.

Chiltern and Cross Country

Figure 1 shows the exemplar routes showing poor value for money which are:

- Chiltern Test 1 – Electrify to Aylesbury and Birmingham;
- Chiltern Test 2 – Electrify to Aylesbury Only;
- Cross Country.

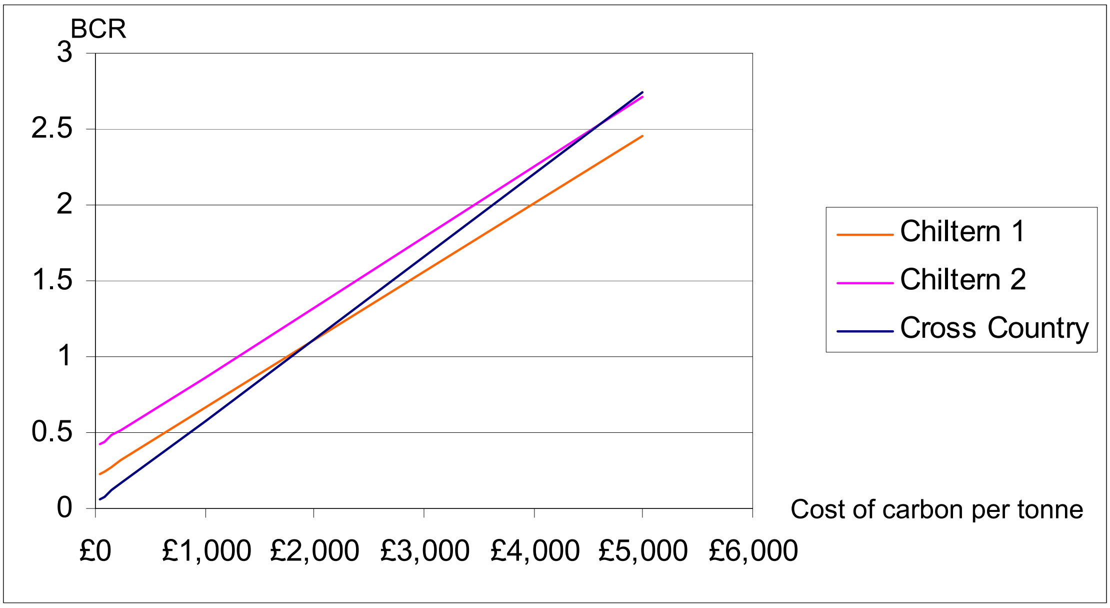

Figure I.1 – Impact of Carbon Cost Change on Chiltern and Cross Country

Figure 1 shows that carbon costs need to be in the region of £3000 to £4000 per tonne for these schemes to have BCR's around 2.

Midland Main Line and Great Western Main Line

Figure 2 below shows the impact of changes in carbon costs on the Midland Mainline and Great Western exemplar routes which have BCR's exceeding 2 using the central estimate in WebTag (£78.66). The tests are for the following electrified routes:

- Great Western – Electrify to Bristol, Swansea and Oxford;
- Midland Main Line – Electrify from Bedford to Nottingham and Sheffield via Derby.

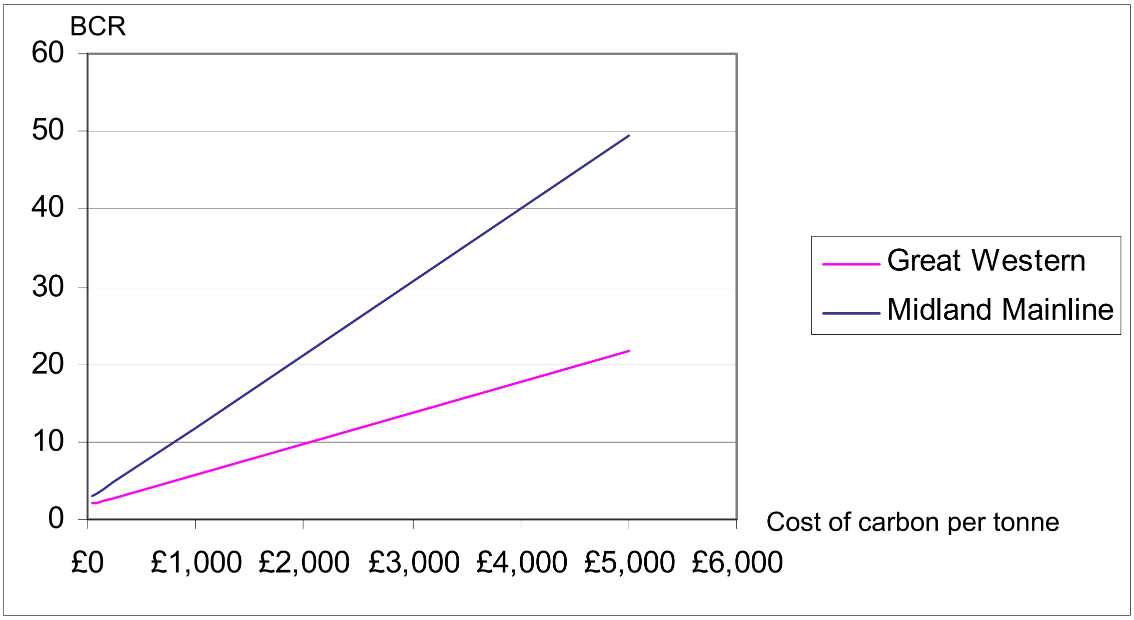

Figure I.2 – Impact of Carbon Cost Change on Great Western and Midland Mainline

Figure 2 shows that any increase in the cost of carbon will significantly increase the BCR, particularly for Midland Main Line. Using the cost of £238 /tC as suggested by Stern gives a BCR of 2.83 for Great Western and 4.72 for Midland Main Line. It should be noted that the Midland Main Line BCR is far more sensitive to changes in the inputs to the model as the capital cost is relatively low (because St Pancras to Bedford is already electrified) and hence benefits have a more significant impact.

Analysis

These results should not be taken out of context. The economic model compares diesel and electric traction. As detailed in section 3.2 of our draft final report, electric trains are forecast to emit 19% less CO_2 in 2010 and 24% less CO_2 in 2020 than equivalent diesel trains. This is considered pessimistic compared to Interfleet's calculation which indicate 36% less CO_2 for intercity trains (Interfleet T618 – Traction Energy Metrics report no. ITLR-T18659-002 issue 1 Draft dated 12 January 2007 Figure 18). The relative carbon impact of diesel and electric trains is also dependent on future developments in diesel traction (including the impact of NRMM regulations) and the mix of primary energy sources used for generating electricity.

The social cost of carbon aims to reflect people's willingness to pay for a reduction in carbon emissions and given that people should make valuations based on their income, justification is therefore needed that people will view carbon reduction more important than other considerations to validate any increased cost of carbon. Therefore the impact of significant increases in the cost of carbon is likely to change the acceptability of burning fossil fuels in both portable traction equipment and power stations. Hence the justification for electrification of Chiltern and Cross Country routes on carbon benefits would require such large increases in carbon that it is likely that the energy market and the transport sector across all modes would be significantly different to what has been modelled.

Conclusions

The results of the modelling undertaken shows that there is a business case for electrifying the Midland Main Line and Great Western routes but not the Chiltern and Cross Country using the input parameters defined. Increasing the cost of carbon increases the BCR for all routes but only significant increases (by a factor of ~50) would raise the BCR to ~2 for Chiltern and Cross Country.

Recommendations

These results show that the cost of carbon on its own does not have a significant impact on the BCR. However there are related parameters in the model and future developments in portable traction equipment and national electricity generating strategies will also have an impact on the BCR. Further analysis on the range of CO_2 emissions from both diesel and electric traction in parallel with the cost of carbon could be investigated further.

Appendix J – Dual Fuel Trains

Introduction

As requested by DfT we have incorporated dual fuel trains into the economic model. In the time available the models have then been run for the electrified Great Western route using the train characteristics set out below.

Train Characteristics

The following characteristics have been assumed to apply for dual fuel trains:

- 10 car fixed formation dual fuel IEP with a passenger capacity assumed to be the average of the all diesel and all electric IEPs used in the original model.
- 2 MW electric traction equipment at one end of the train and a 2 MW diesel generator at the other end with distributed electric traction motors along the train.

Electrified areas:

- Intelligent control will use the electric supply from the overhead line first, i.e. where 50% or less power (<2 MW) is required, and the diesel generator will be on idle.
- Where greater than 50% power (>2 MW) is required, the diesel generator will gradually supply the additional power. This is inefficient use of a diesel engine which will be subject to a harsh duty cycle. Operating costs have been based on Diesel engine operating throughout. Dual fuel train fuel cost is more than IEP electric when ‘under the wires’.
- Maximum Speed 125 mph (200 kph)
- Acceleration as per IEP electric train.

Non Electrified areas:

- Maximum power available 2 MW from diesel generator (similar to that in 4/5 car Voyager).
- Low speed performance (up to 45 mph) same as electric train acknowledging that the torque limits/wheel slip control will limit the power usage during initial acceleration.
- Higher speeds (45 to 90 mph) - reduced acceleration compared to all diesel IEP as working on ½ power.
- Maximum Speed 90 mph (150 kph) but may be less on routes with steep rising gradients.

Model Representation

Modelling the impact of dual fuel scenarios for passengers involves representing impacts on capacity and journey time, taking into account changes in acceleration and deceleration performance and operating speed.

Passenger capacity is assumed to be the average of the capacity for electric and diesel IEP trains and is entered to the model directly for use in the calculations of crowding benefits.

The representation of journey time impacts is more complicated because the model is timetable based. It contains information on total travel time for each service between key strategic stations but not on the amounts associated with stopping at minor stations, accelerating and decelerating and travelling at operating speed. These proportions are estimated in the model on the basis of an assumed operating speed of 75% of maximum permissible speed (to account for factors such as speed restrictions and gradients) and the assumption that the difference between timetabled time and the time required to travel the route section is increased due to the reduced acceleration capability of the dual fuel train at the additional stops not covered by the national MOIRA model.

The journey time impacts changes in stock type are calculated on the basis of changes in acceleration/deceleration times and associated distances and the assumption that the route distance not required for acceleration and deceleration is covered at the operating speed.

This works well for the types of test the model was originally specified to represent (i.e. the estimation of journey time savings associated with changes in acceleration performance for stock with a given operating speed). However, it is likely to overestimate the disbenefits associated with reducing the operating speed of a train on a given service (as occurs on the non-electrified sections of dual fuel services). The approach cannot reflect the fact that some impacts on speed (particularly speed limits) will have differential impacts on different train types. For instance a 90 mph speed limit along a route could potentially remove the journey time differences between 125 mph and 90 mph trains.

This effect is significant because, for instance, much of the Great Western network beyond the core route is affected by speed limits of between 75 and 90 mph. However, it will be mitigated to some extent by the assumption of maximum operating speed of 75% of the maximum speed and detailed treatment of acceleration and deceleration times. The results produced should therefore provide a good estimate of the scale of likely impacts.

Scenarios Modelled

Two dual fuel tests have been carried out on the Great Western route with the assumption of the line being electrified to Bristol, Swansea and Oxford (BCR of 2.2 for previous test with either all electric or all diesel trains).

Services Altered

Test A) This test assumed that any GW service with more than 2% and less than 100% of its route on electrified lines after electrification would be run using dual fuel rather than the all diesel previously modelled - this resulted in 92 services switching to dual fuel compared to the previous tests using either all electric or all diesel:

Between Paddington and	
	Cheltenham Spa (16)
	Plymouth (15)
	Penzance (14)
	Exeter St Davids (10)
	Hereford (8)
	Weston Super Mare (8)
	Great Malvern (6)
	Worcester Shrub Hill (5)
	Taunton (3)
	Carmarthen (2)
	Paignton (2)
	Worcester Foregate St (2)
	Moreton In Marsh (1)
	Bristol Parkway (1)

These services are in addition to the 381 services switching to become fully electrified i.e.:

Between Paddington and	
	Oxford (100)
	Reading (90)
	Ealing (64)
	Bristol (48)
	Swansea (39)
	Cardiff (18)
	Twyford (5)
	Maidenhead (4)
	Didcot Parkway (1)
Between Bristol and	
	Cardiff (3)
	Swansea (1)
Between Reading and	
	Oxford (4)
	Maidenhead (2)
	Twyford(2)

Test B) The second test assumed that GW services would only switch to dual fuel if more than 65% of route length was on electrified lines - this resulted in 30 services switching to dual fuel in addition to the full electrification of the same 381 services:

Between Paddington and	
	Cheltenham(16)
	Weston Super Mare (8)
	Taunton (3)
	Camarthen (2)
	Moreton in Marsh (1)

The remaining services remain as all diesel.

Costs

Operating cost assumptions were made on the basis of the train characteristics outlined above. Operation on the electrified route sections involves additional costs as trains make use of both power sources. However, operation on the non-electrified sections provides cost savings compared to standard diesels as the consumption rate is less than that assumed for the diesel IEP train.

Maintenance was assumed to be an average of the diesel and electric and VTAC (variable track access charge) was based on the IEP assumptions which also form the basis of EC4T (electricity cost for traction) cost per train mile and fuel consumption. For carbon emissions we assumed that emissions are half that of a standard diesel which follows from the assumptions from the IEP.

Model Results

The economic performance of the dual fuel tests depends on the relative balance between a number of effects, particularly passenger benefits and operating costs.

Passenger Benefits

Dual fuel scenarios would generate both costs and benefits for passengers on the services affected.

The main benefits would result from crowding relief generated by the additional passenger space made available by the requirement for only one engine in the train (compared to the two used in standard diesel trains).

The key disbenefits would occur where the trains travel over non-electrified route sections. When operating on diesel power alone, the performance of the trains is considerably reduced compared to the performance of the standard diesel trains they are assumed to replace. Maximum speeds are 90 mph compared to 125 mph and acceleration and deceleration rates are considerably reduced. This causes increased journey times, resulting in passenger time losses which offset crowding gains. The larger the proportion of the route travelled on non-electrified routes, the greater the journey time losses experienced by passengers will be.

As discussed above, it is noted that the time losses might be overestimated to an extent in the model.

Operating Costs

The net impact of a Dual Fuel scenario on operating costs will vary according to the balance between distances travelled on electrified and non-electrified sections. Operation on electrified sections involves extra costs as both power sources are used but there are cost savings on non-electrified sections compared to standard diesels because the fuel consumption rate is less than that assumed for the diesel IEP train, due to operating on only one power unit with lower performance. Hence where a large proportion of the dual fuel train routes use non-electrified sections, dual fuel scenarios can bring operating cost savings because the upside of the reduced performance of the trains is that they are much cheaper to run.

Test Results

The combination of the influences described above produce a negative, meaningless BCR for Test A (all trains on partially electrified routes changed to dual fuel). Although the impact on operating cost is relatively slight, the extended journey times associated with the long stretches of many journeys on non-electrified portions of the route completely offset the crowding and carbon benefits along with the user benefits associated with the main electrification scheme, leaving user disbenefits and a cost.

Test B represents a smaller roll out of dual fuel (only allowing dual fuel trains to run services which have a minimum of two thirds of route length on electrified lines) and gives a BCR of 1.44. Although smaller in scale, the loss of journey speed due to the 90 mph speed limit and reduced acceleration outweighs the user benefits associated with the main electrification scheme, reducing journey benefits to almost nothing and leaving only crowding and carbon savings. The BCR is therefore considerably lower than the 2.2 obtained for electrification of the Oxford/Bristol/Swansea route without allowing dual fuel stock.

Summary

The model results and analysis suggest that the economic case for dual fuel scenarios is only likely to be viable in certain circumstances. Impacts on operating costs are variable but tend to be relatively moderate, depending on the balance between electrified and non-electrified operation. However user impacts could potentially be significant and either positive or negative depending on the balance between crowding benefits and possible journey time losses associated with reduced train performance on non-electrified route sections. In addition, the models have been run leaving all other variables the same, including fuel and carbon costs.

It is recognised that the model results presented are likely to overestimate the time losses associated with reduced maximum operating speed. However where performance is reduced on non-electrified sections, the best cases for dual fuel are likely to occur where trains can be operated over predominantly electrified routes, perhaps to avoid the electrification of relatively short extensions to the route.

Recommendations

It is recommended that further tests are undertaken using different combinations of the extent of electrified lines and dual fuel services to give an optimised solution to the balance between user costs and benefits, operating cost savings and benefits and possible electrification cost savings. Potentially useful tests include an assessment of the electrification of the network as far as Cardiff (reducing capital cost of electrification to Swansea) and allowing Dual Fuel trains to operate services to Swansea (39 services), Weston Super Mare (8) and Taunton (3). Similar tests could be undertaken with no electrification beyond Bristol. The fuel and carbon costs could also be varied as higher diesel and carbon costs are likely to improve the BCR for dual fuel. Other forms of stored energy traction units in combination with 25 kV core operation could also be considered as an alternative to the diesel/electric dual fuel train considered here.

Use of operating models (such as Railsys) for routes to be considered could provide a more accurate assessment of the increased journey times on a route by route basis taking into account actual speed limits and gradients. These results could then be input to the economic model to give a better understanding of the case for dual fuel and to optimise the extent of any proposed electrification.

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