



PLANET Framework Model Audit Report

Model Implementation and Standard Case Forecast

High Speed Two Ltd

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Executive Summary

Background

SKM Colin Buchanan, in association with Jacobs, has audited the transport demand modelling framework developed on behalf of High Speed Two Limited (HS2 Ltd) for the demand forecasting and business case work for the High Speed Two project. This is known as PLANET Framework Model (PFM). This framework has been developed over a period of years by HS2 Ltd's consultants, including Arup, Atkins, Mott MacDonald, MVA and, more recently, RAND Europe.

The SKM Jacobs audit team has wide ranging experience in the specification, development, application and review of complex demand forecasting models for major transport schemes around the world and our project roles have included those of project auditors as well as recipients of model audits.

The aim of our audit was to provide independent verification to HS2 Ltd that the model processes and inputs meet the specification for PFM version 4.3 (v4.3) and the standard case forecast and appraisal results obtained from that model version.

The audit focussed on the accurate implementation of HS2 Ltd's transport modelling and forecasting processes, not the underlying methodologies which had already been the subject of a separate series of external reviews by John Bates and Andrew Daly published on the HS2 Ltd website.

The model audit commenced in July 2012 with a scoping exercise and was completed in September 2013. The audit was undertaken concurrently with much of the model development that culminated in the release of PFMv4.3.

Throughout the audit process, we have checked the parameters and assumptions used in various parts of the modelling suite. In total, over 4,000 values were checked. HS2 Ltd has published a separate assumptions report which documents the main assumptions used in PFM.

Confidence in the implementation of the model and standard case analysis

We have audited the implementation of a number of versions of PFM, leading up to the final PFMv4.3 and the use of the model to produce the standard case. In the later versions of PFM we have only audited elements of the model that have changed (as described to us by the model developers), rather than re-auditing the whole PFM model.

From the information that we have reviewed and subject to the specific details raised in the body of this report and in exercising the degree of skill and care to be expected from a competent professional consultant experienced in undertaking such services, we confirm that users of the model and its results can be confident the implementation of PFMv4.2 and specific elements that were changed in the development of PFMv4.3 correctly reflects the documented methodology. According to our findings, the standard case is consistent with this methodology and the documented inputs and assumptions used.

Our assessment of assumptions has not identified any input errors of significance for the model results.

In the remainder of this Executive Summary we describe PFM, the scope of our audit, our audit methodology and some observations on the implementation and use of the model to guide future improvement and development.

Overview of the modelling suite

PFM has been developed as a bespoke tool to forecast demand, revenue and benefits impacts of HS2 on national rail services to inform the business case for the project. The set-up of the modelling suite is complex. In addition to the complexities of representing real behaviour in a mathematically-based model, the model set-up reflects its development history: PFM was created from a series of existing models and tools such as PLANET Long Distance (PLD), the regional PLANET models and inputs from other sources such as RAILPLAN, combined with bespoke modules such as the Station Choice Model (SCM), the Heathrow Access Model (HAM) and the Appraisal spreadsheets, all linked together through a series of bespoke interfaces.

This set-up, using a wide range of software and processes, makes the PFM difficult and time-consuming to run, makes diagnostic testing difficult and increases the scope for error. A bespoke model developed from scratch would be less complex in its set-up while it could retain the same sophistication in its forecasting capabilities. Bespoke modelling is not risk free and we understand that the external model review at the outset of the model development concluded time constraints precluded a model being developed from scratch, and existing models had to be used as the basis, with suitable enhancements. The scope and depth of our audit and the use of “vertical” (line by line checking of the model code) and “horizontal” (following the calculations at a zone to zone cell level through the calculations) audit approaches throughout the audit process reflected the complexity of the modelling suite.

Audit scope

The audit process was thorough and included:

- the complete mapping of the modelling system;
- an audit of all batch files, macros and spreadsheets;
- the review of assumptions;
- an audit of the implementation of formulae and calculations; and
- the audit of model outputs.

The aim of the audit was a systematic verification of model compliance with method.

The audit has not included checking the implementation and prior processing of external inputs and data. Thus we have not audited the derivation of base year and future year matrices by mode, nor have we audited data processing by models such as LENNON, MOIRA, NRTS, and DfT’s EDGE and NAM data processing, etc. In addition, the methodology adopted within the PFM model was out of scope of this audit. Thus, for example, we have not audited the derivation of the values of time adopted in the model, which we understand have been the subject of a separate series of external reviews by DfT.

In the course of our audit we have also provided information to the National Audit Office for their review of the case for, and the progress made in pursuing the HS2 project¹. They comment on the scope of our audit as follows:

“In the summer of 2012, the Department set up a group with HS2 Limited to jointly oversee the economic analysis. In addition, HS2 Limited had already in November 2011 begun to plan an independent model audit. This work, which is being carried out by Sinclair Knight Merz and Jacobs, is checking that the High Speed 2 modelling framework operates as specified, is documented correctly and complies with the Department’s latest transport analysis guidance. Based on our review of the scope and terms of reference of the audit and a meeting with the contractors performing the work, we gained assurance that the audit would be detailed and thorough.”

Audit methodology

Macros and program code were mapped out and were checked on a line by line basis where required to provide a full understanding of their functionality and the outputs they provide.

This then led to an audit of whether the specified modelling methodology has been implemented correctly. Where required, we created shadow modelling spreadsheets and compared the results to the model output, to review the correct implementation of the calculation steps. We also checked if the parameters used in the model were consistent and identified any inconsistencies within and between the sub models.

The networks were checked in detail within the HS2 corridor. Other areas of the networks were examined in outline. This included rail, air and highway networks in PLD and rail networks in the regional PLANET models, including the implementation of the latest Department for Transport (DfT) do-minimum (DM) rail network assumptions. Checks of rail networks included link and transit line coding, routeing of rail services, frequencies and capacity assumptions as well as fares for PLD. Highway networks were checked for consistency in the coding of link types and the correct application of volume-delay functions. In the air networks, we checked frequency, capacity and fares of relevant routes.

Checks were also made of the process to transfer trips between PLD and the regional PLANET models (the “preload” and “wormhole” implementation) in the models and outputs generated. The demand checks were done for key Origin-Destination (OD) pairs (in the HS2 corridor) and the forecast demand growth factors were checked for their correct implementation in the forecast models.

The demand matrices for rail, highways and air in PLD and for rail in the regional PLANET models were checked for overall consistency of matrix totals, sectorised trip patterns and selected OD pairs. The audit has also included the process to derive a cap year for demand growth.

The set-up of the regional PLANET models is less complex than that of PLD as the demand is supplied externally and the models contain rail modes only (or in the case of PLANET South (PS) some bus routes too). The most complex process within the regional PLANET models is the crowded assignment process which was a focus of the audit. Other complexities relate to the way the regional PLANET models interact with other modules of the PFM and these

¹ National Audit Office: High Speed 2: A review of early programme preparation, May 2013.

interfaces have been another focus of the audit. We have also reviewed the process of producing forecast year trip matrices in some detail.

The Heathrow Access Model (HAM) audit² consisted of the review of the base and forecast (2026 and 2036) HAM models. The HAM model was initially developed by SKM and subsequently updated by Atkins. The model parameters were derived from values in the London Airport Surface Access Model (LASAM).

The HS1-HS2 Connection Model audit consisted of a cell by cell audit of all 86 linked-spreadsheets in the model.

We have fully reviewed the appraisal spreadsheet and its inputs and assumptions through visual checks of spreadsheet structure, the use of audit software, line by line audit, check of macros, sensitivity testing and model runs.

We have undertaken similar checks on the costs and carbon spreadsheets that calculate capital and operating costs as well as the carbon emissions model that processes these impacts into a present value (PV).

Wider Impacts are appraised using the Department for Transport's beta version on WITA software and we have reviewed and verified the WITA calculation.

We have subjected PFMv4.3 to a full model framework review and run checks. We have successfully reproduced the results reported by the model developers for the do-minimum, Phase 1 and full network runs for all forecast years.

As part of the review of overall model files, structure, interfaces, applications, model runs and model convergence, we had an active exchange of queries and responses with the model developers which successfully resolved any issues.

Audit Findings and their impacts

In reporting our findings in this report we have provided observations on implementation, consistency and remaining uncertainty which, in our judgement, should be taken into account in determining model acceptability.

Our audit findings are listed below under the following three headings:

- Observations that relate to the Benefit Cost Ratio (BCR);
- Observations that have a minor or local impact; and
- Observations of model transparency.

Audit observations relating to the standard case Benefit Cost Ratio

In our view none of the issues identified here will have a material impact on the overall benefit calculations.

Within the modelling suite, we note the insensitivity of the PLD model to changes in monetary costs. This does not affect the standard case analysis as HS2 services are assumed to have the

² While the overall audit programme was delivered jointly by SKM and Jacobs, the audits of the HAM, and HS1-HS2 Connections Model were undertaken by Jacobs only because of SKM's earlier involvement in the development of these models.

same fares as standard rail services. However, it does support the use of separate analysis of commercial impacts and make PFM unsuitable for testing differential fares or differences in air fares or (highway) vehicle operating costs between the Do Minimum and Do Something scenarios.

Do Minimum (DM) rail services were automatically coded direct from the CIF database supplied by DfT with some manual intervention whereas Do Something (DS) rail service coding were manual interpretations of the HS2 Ltd specifications. As a result, the DS service coding could not be directly compared to the DM service coding. Thus while we have been able to audit the DM and DS transit line services separately, it has not been possible (and was not part of our audit scope) for us to ascertain whether the differences in frequencies and stopping patterns for some classic rail services between DM and DS are in line with intended service changes. This observation applies to PLD as well as the three regional PLANET models.

We identified 56 issues with the coding of the DM and DS services in the PLD model. The model developers tested 37 of these issues aggregated (with other issues) in four separate sensitivity tests. The cumulative impact of these tests was a reduction in predicted transport economic benefits of just under £1bn PV, or 1.5% of the benefits for the full network. Furthermore, 15 issues related to the coding of the transit lines and HS2 Ltd have confirmed that the coding has been specified as intended. Of the remaining issues: 12 have been assessed to have a minor impact and seven are cosmetic issues affecting the transparency of the model.

Observations that have a minor or local impact

We have identified a number of issues that we judge will have a minor or local impact within the modelling suite and the resulting forecasts. A sample of these is given below.

No growth rates are applied to car occupancy rates in the PLD forecast year models. We understand that this is consistent with the methodology adopted by HS2 Ltd but note that WebTAG provides advice on future vehicle occupancy rates. Changing this assumption would have a minor impact on future highway congestion levels in the DM and DS scenarios and may lead to a minor increase in the potential decongestion benefits.

In the SCM access costs between the zones³ and the stations have been updated as a result of early audit findings. However, the same inputs to the gravity model have not been updated at the same time. As the gravity model determines how the PLD zones are disaggregated for input to the SCM, this could lead to some minor but insignificant impact. The impact of this will be limited as it the gravity model is only used where there are gaps in the NRTS data.

We have audited the version of Heathrow Access Model (HAM) contained within PFMv4.1. We have not been commissioned to audit any later version of the HAM and we understand (but have not checked) that the model structure remains unchanged between v4.1 and v4.3. The audit of the HAM has found some minor differences in the base year demand, growth factors and between the parameters in the HAM and those reported in LASAM.

In developing LASAM to form the HAM, the original model developers (SKM) changed the hierarchical structure of the HAM, by adding an air mode to the public transport nest and adding

³³ Termed “mzones” in the SCM.

HS2 to the rail sub-nest, without recalibrating the model parameters. Furthermore, we understand that when Atkins took over the running of the PFM, they did not apply the hierarchical mode choice structure as documented in the SKM report, but instead applied zero HS2 skims, implying a single rail sub-mode below the rail mode in the higher public transport nest. However, Atkins also retained the nesting parameters of the LASAM model, although they had made changes to the hierarchical structure. Thus the hierarchical structure of the mode choice model is not implemented as documented, and has adopted the parameters of the LASAM model, despite a different structure.

Ideally, the model parameters should have been recalibrated, but time did not permit this re-estimation as the overall impact of the HAM on the total benefits is small. This was demonstrated by the results of sensitivity tests found that the impact of modifying the mode parameters was small (rail flows reduced by around 2%) and thus we can conclude that this issue is insignificant. The impact of changing the nesting structure increased the rail mode share to and from Heathrow by around 30%. Thus we can conclude that adopting the current nesting structure is probably resulting in an underestimate of total HAM rail demand, rather than an overestimate. Furthermore, it should be borne in mind that the HAM results make a small contribution on the overall business case.

Issues of model transparency

We have identified the following issues that affect model transparency, and have no evidence they impact on result.

In the coding, macro writing and output procedures for the PLD rail networks, a number of inconsistencies have been identified with regard to the identification of certain services for data transfer or output routines. We have confirmed that none of these affect the result produced from the current version of the model.

In the HAM, the (auto) distance skims within the 2036 Phase 1 scenario are not consistent with the PLD (auto) distance skims. We also understand that the input demand data in the PFM v4.1 of HAM was derived from data provided by the DfT, but we have been unable to verify the data as there is no documentation for these values.

The appraisal spreadsheet has been updated to reflect values of time from the new (forthcoming) October 2013 WebTAG update. The final benefit numbers are based on values of time in 2010 prices and values from, which are correctly adjusted to 2011 prices and values (but via an adjustment to and from 2002). We understand that this is for historical reasons. However, this makes the review of the implemented values of time difficult and this complexity can only increase with any future updates.

Our review of WITA impacts has concluded that the calculations are implemented as specified. However, the WITA calculations use relatively new DfT software that is only available in a prototype, beta version and whose internal workings cannot easily be verified. However, an examination of the results shows the impacts are concentrated along the route of HS2 as expected.

Recommendations for further versions of PFM

We recommend that HS2 Ltd and their model developers take account of our findings and observations in preparing and undertaking any future updates of the model and its inputs.

We would also note that there are a number of redundant macros that are run and outputs generated, but these outputs are not used in any way. We recommend that these redundant macros are removed, to aid model transparency so that any future audits can omit a review of these macros.

1. Introduction

1.1. Purpose and objectives

- 1.1.1. SKM Colin Buchanan, in association with Jacobs and Leigh Fisher, has audited the transport demand modelling framework developed on behalf of High Speed Two Limited (HS2 Ltd) for the demand forecasting and business case work for the High Speed Two (HS2) project. This is known as PLANET Framework Model (PFM). This framework has been developed over a period of years by HS2 Ltd's consultants, including Arup, Atkins, Mott MacDonald, MVA and, more recently, Rand Europe.
- 1.1.2. The aim of our audit was to provide independent verification the model processes and inputs meet the specification for PFMv4.3. In addition to the implementation of PFMv4.3, the audit also covered the inputs and results of the standard case forecast produced in 2013.
- 1.1.3. The model audit commenced in July 2012 with a scoping exercise and was completed in July 2013. The audit was undertaken concurrently with model development. Three version of the model were released for our audit:
- PFMv3.8 was released in Nov 2012, and this was the version that we undertook an audit of all the model components;
 - Further to our audit findings of PFMv3.8 and further model development work resulting in versions 4.0 and 4.1. PFMv4.2 was issued in May 2013, and our remit was to audit the components that had changed between PFMv3.8 and PFMv4.2; and
 - Further to our audit findings of PFMv4.2 and further model development work, PFMv4.3 was issued in July 2013, and our remit was to audit the components that had changed between PFMv4.2 and PFMv4.3 and to audit the PFMv4.3 standard case forecast and appraisal.
- 1.1.4. Thus whilst the aim of our audit was to provide verification of the model processes and inputs meet the specification for PFMv4.3, there are parts of the model that should not have changed from earlier audits, that we have not re-audited since the earlier audit. Such occurrences are identified in the following sections of the report,

1.2. Our audit experience

- 1.2.1. The SKM Jacobs audit team has wide ranging experience in the specification, development, application and review of complex demand forecasting models for major transport schemes around the world and our project roles have included those of project auditors as well as recipients of model audits. We have performed these roles for key clients including the Department for Transport, Transport for London and rail franchise bidders in the UK as well as a wide range of overseas clients.

1.3. Audit scope

- 1.3.1. The scope of the audit is focussed on the implementation of the modelling framework rather than its methodology and includes:
- Checking the implementation of the model and input data are consistent with the model theory as set out in model documentation, and any relevant model guidance and underlying theory.
 - Confirming that any divergence of the PLANET Framework Model from the Department for Transport Analysis Guidance (WebTAG), or other relevant guidance, is documented.
 - Checking the provenance and implementation of all of input assumptions and their sources.
 - Systematic, bottom-up review of spreadsheets, programs and software code at a detailed level to confirm that the model processes and results are correct and error free.
 - Confirming that the transport models' base and future year matrices, transport networks and growth forecasts are consistent with the stated methodology and are implemented correctly and consistently.
 - Confirmation that model outputs are consistent with model methodology and model inputs.
 - Shadow modelling to reproduce the model's calculations.

1.4. Exclusions from the audit scope

- 1.4.1. The audit focussed on checking the accurate implementation of HS2 Ltd's transport modelling and forecasting processes. An audit of the underlying methodologies was specifically excluded from our scope, as they had already been the subject of a separate series of external reviews.
- 1.4.2. Furthermore, the scope of the audit also specifically excludes modelling methodology and the audit of underlying datasets provided by third parties such as LENNON data or the CAA air passenger survey.

1.5. Structure of this document

- 1.5.1. The remainder of this document is structured as follows:
- Chapter 2 gives an overview of the modelling suite;
 - Chapter 3 reports on the model framework review and run checks;
 - Chapter 4 covers PLANET Long Distance;
 - Chapter 5 covers the regional PLANET models
 - Chapter 6 deals with the Station Choice Model;
 - Chapter 7 reports on the Heathrow Access Model

- Chapter 8 covers the HS1-HS2 Connections Model;
- Chapter 9 reports on the Appraisal spreadsheets; and
- Chapter 10 deals with the inputs to the standard case forecast and appraisal.

1.5.2. Appendix A contains a glossary of relevant terms.

2. Overview of the Modelling Suite

2.1. Development of the modelling framework

- 2.1.1. The HS2 Modelling Framework (known as the PLANET Framework Model) has been developed by a number of consultants including Atkins, Arup, Mott MacDonald, MVA and, more recently, RAND Europe, to forecast the demand and revenue impacts of HS2 between London and the West Midlands and further north, as an input to the business case.
- 2.1.2. At the outset of the HS2 project development, the specification of the model was defined. This included: the ability to model in detail train patterns of both HS2 and conventional rail services; the interaction between local and long distance passengers; mode shift from existing rail services to HS2; wider mode shift from air and car modes to HS2 and the impacts of HS2 on trip frequency and trip generation. An additional key requirement of the modelling approach was “transparency of forecasting approach, where forecast results can be easily analysed and an “audit trail” produced to support model outputs”.
- 2.1.3. A number of options were considered against this specification, including enhancing the existing PLANET Strategic Model (PSM), developing a new non-network-based model and developing a new network-based model. In order to meet the requirements of the specification, a network-based model was required. Furthermore, the tight work-programme precluded the development of a new network-based model to replace PSM. Thus it was concluded that the development of the PSM was the only realistic option for the HS2 modelling framework. PSM also had the advantage of being an accepted and well-understood modelling tool.

2.2. Structure of the modelling framework

- 2.2.1. As part of the HS2 model development, PSM was updated and enhanced to form a new PLANET Long Distance (PLD) model. PLD, run on the EMME software platform, forms the core of the HS2 modelling framework and has the following key specifications:
 - It models long-distance journeys;
 - It is an all-day average weekday model (24 hours for the demand model, 16 hours for the network representation);
 - It splits Great Britain into 235 zones;
 - It models the detailed train paths of both HS2 and conventional rail services;
 - It includes separate models for highway trips (by car) and domestic GB air services;
 - It takes overall demand growth for each mode from inputs external to the modelling suite;

- It predicts changes in mode choice between rail, car and air using an incremental hierarchical nested logit model;
- The demand for the respective modes is assigned to networks for rail, highway and air;
- HS2 is modelled within the rail assignment model (HS2 is not a separate mode within the mode choice hierarchy);
- The model iterates between mode choice and assignment (with costs and flows being passed between two stages); and
- Demand is capped when it reaches a certain level (“the cap year”).

2.2.2. Whilst the PLD is the core of the HS2 Modelling Framework, it is too coarse for some of the detailed rail modelling required. The HS2 Modelling Framework was thus further developed in three areas to overcome this limitation: more detailed modelling of local rail services in the London, Midlands and Northern conurbations; a more detailed station choice model and the development of the Heathrow Access Model⁴ for surface access trips for international flights using Heathrow. These are briefly summarised below.

2.3. Model components

2.3.1. Separate uni-modal, AM peak period, rail models had been developed for the PLANET South (PS), PLANET Midlands (PM) and PLANET North (PN) geographic areas, again within the EMME software platform. These were firstly adapted to exclude long-distance rail trips as these are included in the PLD, leaving trips wholly within London and the SE, the Midlands and the Northern conurbations within the three regional PLANET models respectively. However, crucially, these local rail trips do not only travel on local rail services, some travel on long distance services and impact on the available capacity, through crowding, for long distance rail passengers on these services. Thus an interaction has been built within the HS2 Modelling Framework between the PLD and the three regional PLANET models, with local trips on long-distance services being fed from PLANET Midlands and PLANET North by means of “pre-loaded” demand volumes. The interface between PLANET South and PLD is different, in that select link matrices of long-distance trips crossing the PLANET South/PLD boundary are derived and then included in the model through the use of “wormholes”, which are effectively dummy zones which feed Origin - Destination information from PLD to PLANET South. Link-based preloads are also passed from PS to PLD.

2.3.2. The 235 zones in PLD are at too coarse a level for key decisions on station choice to be made (e.g. Birmingham is a single zone and Greater London is represented by seven zones). Therefore a Station Choice Model (SCM) has been developed with a much finer zones system (3,962 zones) to link Origin – Destination pairs at a fine level

⁴ Previously known as the Airport Demand Model.

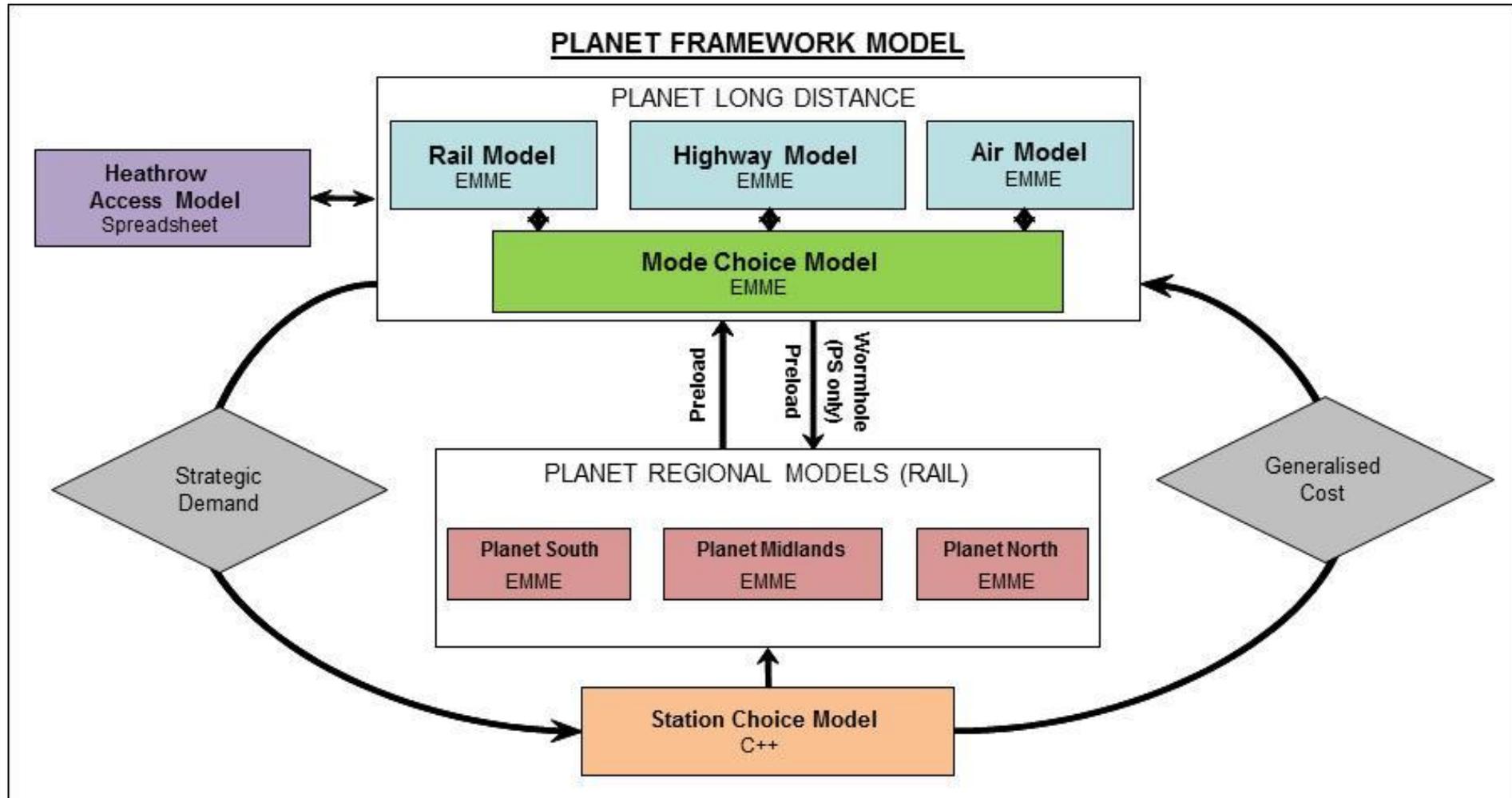
with up to 15 accessible stations. The SCM is a C++ based nested logit model which interfaces with the PLD to provide disaggregated station-to-station matrices and generalised costs. The SCM provides access/egress rail demand to the PLANET regional models. The SCM also incorporates a calibrated gravity-based allocation process to distribute PLD zonal demand to the finer zone system.

- 2.3.3. Whilst wholly domestic air trips within Great Britain are included in the PLD model, surface-access trips to Heathrow and “interlining” trips from GB domestic airports to foreign destinations via Heathrow are not, and a separate Heathrow Access Model (HAM) was developed to forecast the potential of these trips to transfer to HS2. The HAM is a spreadsheet model, inputting costs from PLD, air passenger data from CAA and predicting the mode choice between different modes, including HS2, which is modelled in a sub rail-nest in the mode choice hierarchy. There is also the HS1-HS2 Connections model to forecast the transfer to HS2/HS1 of current air trips between GB regional airports and high speed accessible cities in Europe. This does not form part of the HS2 PFM modelling suite but provides separate input into the business case appraisal spreadsheets.

2.4. Specification, input data and processes

- 2.4.1. The overall structure of the HS2 Modelling Framework is illustrated in Figure 1 and a summary of the model specification is presented in Table 1.

Figure 1: PFM modelling suite



Note: the diagram excludes the HS1-HS2 Connections Model which feeds directly into the economic appraisal and does not interact with the rest of the modelling suite.

Table 1: Specifications and input data of PFMv4.3 model components

| PFM Model Components | Zones | Time Period | Journey Purposes | Base Year | Input Data | Assignment Methodology | Forecasting Methodology | Software Platform |
|--------------------------|-------|-------------------------|---|-----------|---|--|---|-------------------|
| PFM PLANET Long Distance | | | | | | | | |
| PLD Rail Model | 235 | All week day (24 hours) | <ul style="list-style-type: none"> • Business <ul style="list-style-type: none"> – Car Available From – Car Available To – Non Car Available • Commuting <ul style="list-style-type: none"> – Car Available From – Car Available To – Non Car Available • Leisure/Other <ul style="list-style-type: none"> – Car Available From – Car Available To – Non Car Available | 2010/11 | 2010/11 LENNON data 2010/11 MOIRA data 2010/11 Guard's counts data 2004-05 National Rail Travel Survey (NRTS) data 2012 Exogenous Demand Growth Estimator (EDGE) outputs 2010/11 National Accessibility Model (NAM) data ATCO CIF data Regional Models 'Preloads' output SCM outputs WebTAG/DfT Passenger Demand Forecast Handbook (PDFH) | Multiclass frequency based assignment with crowding process | Based on EDGE output | EMME |
| PLD Highway Model | 235 | All week day (24 hours) | <ul style="list-style-type: none"> • Business • Commuting • Other | 2010/11 | PRISM NoTAM TEMPRO PLANET Long Distance Model (LDM) Other regional models Pre-load estimate of local trips WebTAG/DfT | Multiclass generalised cost equilibrium assignment for an average hour | Based on TEMPRO | EMME |
| PLD Air Model | 235 | All week day (24 hours) | <ul style="list-style-type: none"> • Business • Leisure | 2010/11 | 2010 CAA DfT NAPALM data | Frequency based assignment, no crowding process | DfT NAPALM forecasts | EMME |
| PLD Mode Choice Model | 235 | All week day (24 hours) | <ul style="list-style-type: none"> • Business <ul style="list-style-type: none"> – Car Available From – Car Available To – Non Car Available | 2010 | Revealed Preference data (demand data identified above) Stated Preference research undertaken for this model development | Hierarchical nested logit mode choice model | Linked with PLD rail/ highway/ air models forecast Based on PDFH | EMME |

| PFM Model Components | Zones | Time Period | Journey Purposes | Base Year | Input Data | Assignment Methodology | Forecasting Methodology | Software Platform |
|---------------------------------|-------|-------------------------|---|-----------|---|---|---|------------------------|
| | | | <ul style="list-style-type: none"> • Commuting – Car Available From – Car Available To – Non Car Available • Leisure/Other – Car Available From – Car Available To – Non Car Available | | PDFH WebTAG/DfT | | and WebTAG/DfT parameter forecasts (EDGE) | |
| PFM Station Choice Model | | | | | | | | |
| SCM | 3962 | All week day (24 hours) | <ul style="list-style-type: none"> • Business – Car Available From – Car Available To – Non Car Available • Commuting – Car Available From – Car Available To – Non Car Available • Leisure/Other – Car Available From – Car Available To – Non Car Available | 2010/11 | PLD outputs RAILPLAN 2010/11 NAM data 2004/05 NRTS data Trafficmaster link speed data Ordinance Survey Integrated transport Network (ITN) data WebTAG/DfT | Fixed Gravity Model and Nested Logit Model with highway and PT access modes | Linked with PLD forecast assignment | MS Visual C++ 2008 SP1 |
| PFM Regional Models | | | | | | | | |
| PS (rail model) | 1372 | 07-10 AM weekday | <ul style="list-style-type: none"> • Business • Commuting • Leisure/Other | 2010/11 | 2010/11 LENNON data TfL's RAILPLAN data Observed TOC data DfT's Network Modelling Framework data 2004/05 NRTS data 2001 LATS data 2010 EDGE outputs 2010/11 NAM data | Multiclass frequency based assignment with crowding process | Based on EDGE forecasting process | EMME |

| PFM Model Components | Zones | Time Period | Journey Purposes | Base Year | Input Data | Assignment Methodology | Forecasting Methodology | Software Platform |
|-------------------------------------|-------------------|-------------------------|--|-----------|---|--|--|----------------------------|
| | | | | | ATCO CIF data PLD 'Wormhole' output SCM outputs WebTAG/DfT Passenger Demand Forecast Handbook (PDFH) | | | |
| PM and PN | 1148 (each model) | 07-10 AM weekday | <ul style="list-style-type: none"> • Business • Commuting • Leisure/Other | 2010/11 | 2010/11 LENNON data Observed TOC data DfT's Network Modelling Framework data 2004/05 NRTS data 2010 EDGE outputs 2010/11 NAM data ATCO CIF data SCM outputs WebTAG/DfT Passenger Demand Forecast Handbook (PDFH) | Multiclass frequency based assignment with crowding process | Based on EDGE forecasting process | EMME |
| Aviation Models | | | | | | | | |
| HAM (formerly Airport Demand Model) | 235 | All week day (24 hours) | <ul style="list-style-type: none"> • UK Business • Foreign Business • UK Leisure • Foreign Leisure | 2010/11 | 2010/11 DfT NAPALM data LASAM v2 parameters DfT NAPALM forecasts PLD outputs | No assignment within HAM but trips from the HAM mode choice logit model fed to PLD | Based on DfT's growth forecasts | MS Excel spreadsheet model |
| HS1-HS2 Connections Model | 72 city pairs | Annual | Single trip purpose | 2010/11 | Air traffic demand between 72 city pairs, IPS Rail traffic demand data between 72 city pairs, Eurostar data for total demand, IPS data for split | No assignment. Mode choice undertaken in logit model | DfT forecasts of growth in air traffic between 72 city pairs | MS Excel spreadsheet model |

3. Model Framework Review and Run Checks

3.1. Introduction and context

3.1.1. The objective of the Model Framework Review and Run Checks was to review the overall model before auditing its individual components. This objective was set in order to facilitate the following:

- Ensure that SKM-Jacobs have received all model files and related components in correct required directories/folders in full duplication as used in the PFM suite of models;
- Check that SKM-Jacobs could replicate the overall model runs output as provided by the model developers with the PFM models;
- ‘Unpack the whole model’ to review model structure, interfaces and application;
- Undertake a line-by-line audit of the coding and execution of batch files and macros used for the overall model runs and their convergence; and
- Create procedures to report assumptions and issues resulting from the audit of the models and their components which should be used throughout the audit process. This has also led to us working proactively with the model developers to resolve issues as we progress with the model auditing tasks.

3.1.2. The audit tasks for the model framework review fall under following categories:

- Workshop to map the model’s functions and interfaces;
- Review model directories/folders/files received from model developers;
- Overall model runs in SKM/Jacobs offices;
- Audit the whole model structure, interfaces and application; and
- Review PFM model convergence.

3.2. Workshop

3.2.1. Following receipt of PFMv3.8 a full day interactive workshop of the PFM modelling suite was conducted on the 12th of November 2012 in Jacobs’s office in Central London. This was attended by both the SKM/Jacobs model audit team and members of the model development teams.

3.2.2. This workshop concentrated on a review of our understanding of the PFM models and the confirmation of this by the model developers. We also took the opportunity to discuss some initial observations on the overall PFM model run batch files and processes. We presented and agreed our overall model run methodology with the model developers during this workshop, prior to running the models in our offices.

3.2.3. The workshop comprised of a flip chart presentation of each of the model batch files, expanded to sufficient detail to demonstrate our understanding of the model structure and run process.

- 3.2.4. A model audit process flowchart was created to set up a common audit methodology for all tasks during the whole model review process. The aim was to set up not only a consistent approach to the audit process, but also to establish a common understanding of the process and reporting of different audit task teams, the model developers and HS2 Ltd.
- 3.2.5. We checked the assumptions applied in the model are up to date, consistent and correctly implemented. Any issues that arose from the input assumptions, their sources, age and version, documentation and implementation were resolved with the model developers and HS2 Ltd.

3.3. Review of received models

- 3.3.1. All the PFM models were made available to us by the model developers, copied through their ftp (File Transfer Protocol) site. A first vital check that we undertook was to verify that we received all the folders, directories, sub-directories, files and other reports and documents as used by the model developers to run the PFM models.
- 3.3.2. The intention of this review was to identify any missing files at an early stage and discuss the relevance of missing files in the model runs with the model developers. We aimed to resolve any file and/or location issues with the model developers prior to running the models, to then try to duplicate the output as produced by the model developers.
- 3.3.3. The starting point of this process was to copy all received model directories, sub-directories, folders and files as provided by the model developers to our computers. All the models were provided in zipped format therefore after copying all the zip files, we unzipped all the models in an identical structure as provided by the model developers.
- 3.3.4. After copying all the models, we created a spreadsheet-based model files map to check all received batch files, executable files and macros against the existence of these files, and their related paths, as coded in the models for the full model run.
- 3.3.5. We developed four different worksheets to check the files mapping process tree. In the first worksheet, we listed all received batch files from the model developers. The second worksheet lists all executable files used in the overall model runs process by various batch files. In the third worksheet, we listed all model macro files received from the model developers which are used in various batch operations. The final worksheet describes the final process tree as generated by the combinations of these batch files, executable files and macros.
- 3.3.6. The process tree describes the various levels of the overall model run structure. At the top of the tree is the Run_All_yy batch file (where yy represents the forecast year), which is then branched to four different sub-batch files (del_crap.bat, inputs_All.bat, yyyy_DM.bat and yyyy_DS.bat). These sub-batch files were further branched horizontally to further six levels making a total eight levels branching from the run process tree.

- 3.3.7. We identified some 1,200 original file calls (many more if loops are counted) with 483 such files supplied with each model year. We have listed vertically 73 batch files in 16 different folders, 42 executable files in six different folders and 256 macros in 28 different folders for each overall model run scenario in eight horizontal levels in the process tree.
- 3.3.8. Each of the processes (batch files and macros) at each level were then audited line-by-line to check for: their correct location within the model directories/folders; correct interface to input and output files and their location in the model folders; the correct representation of the related scenario (command line variable); its predecessor command from which it is called and the correct implementation of its functionality within the overall model run structure. This spreadsheet-based map represents the full unpacking of all PFM models. The process tree map, for the Do Minimum (DM) and Do Something (DS) models respectively, was compared against the documented model run process diagrams provided by the model developers (reproduced as Figure 2 and Figure 3 below).
- 3.3.9. Our audit of the model structure of all PFM forecast years modelling suites did not find any issues with the overall model set-up, structure and the locations (file paths) of the respective input, output and process files.

Figure 2: PLD Do minimum model run structure

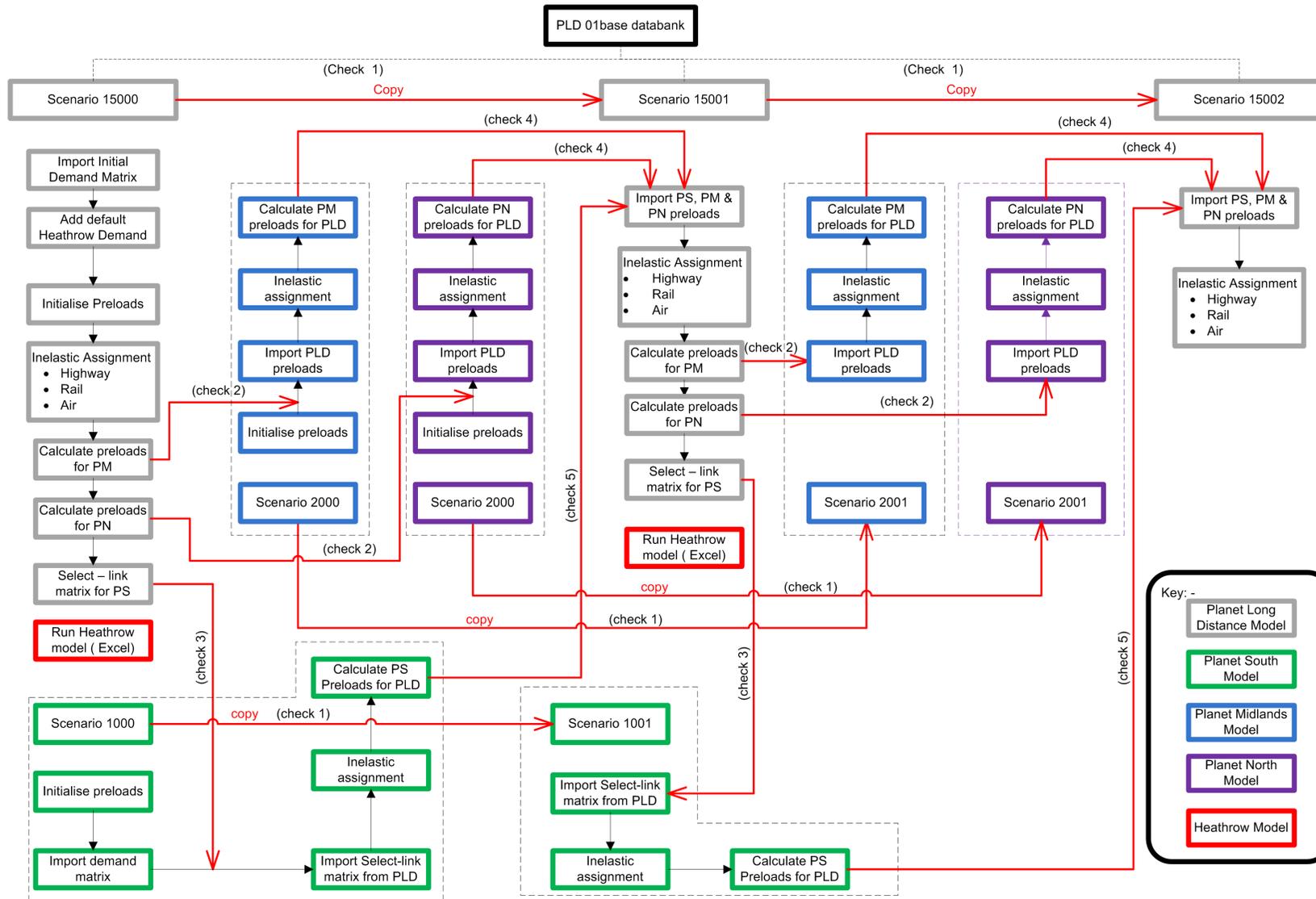
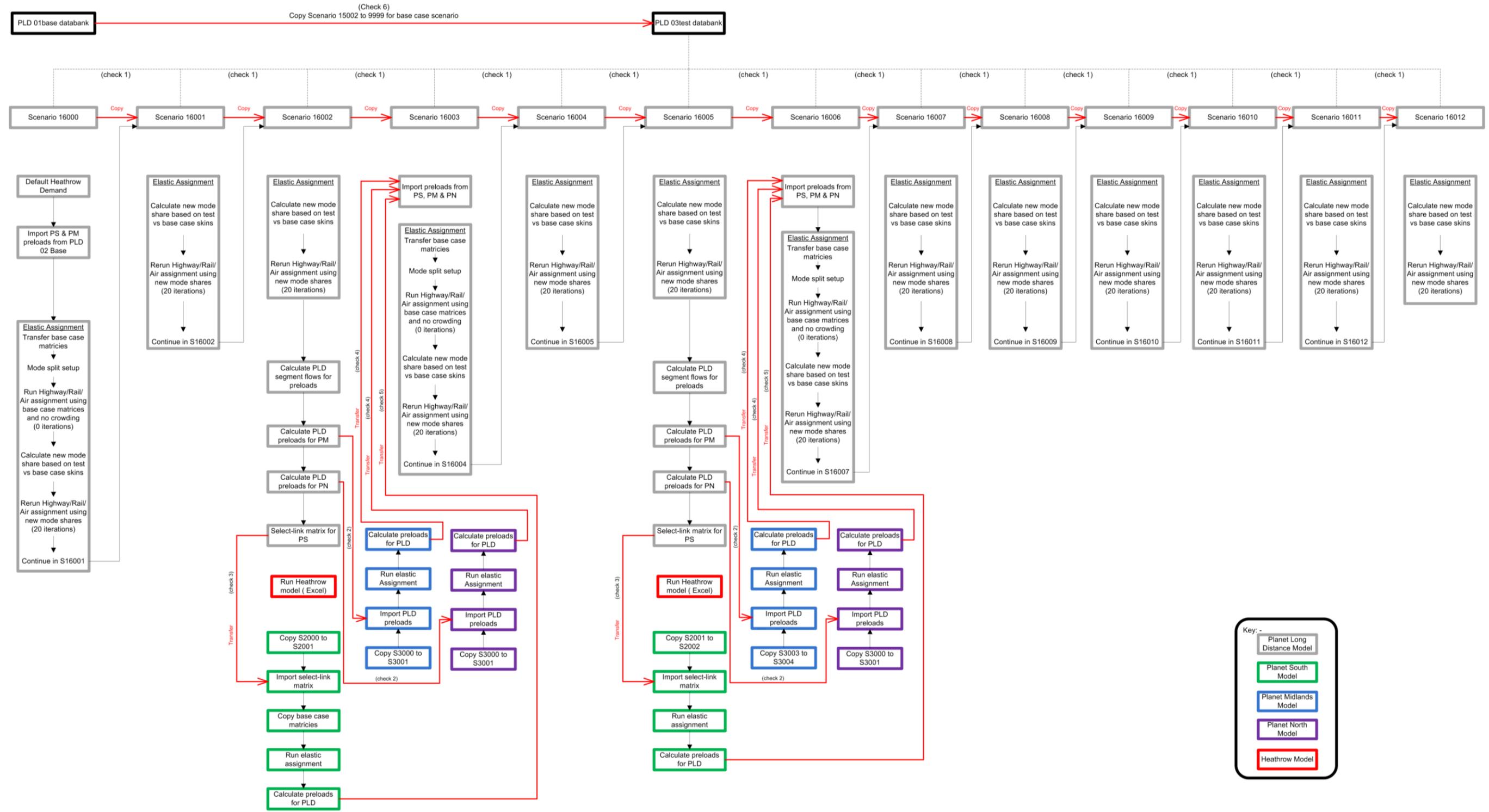


Figure 3: PLD Do something model run structure



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3.4. Model run methodology

- 3.4.1. One of the important elements in the model audit process was to run all the received models in our offices and replicate the output/results provided and documented by the model developers.
- 3.4.2. The main objective of this task was to ensure we have all the correct input data, process files and interfaces (fixed or modelled) used in the model runs and can replicate the results and outputs reported by the model developers.
- 3.4.3. The audit of the model run methodology was based on running each version of the model that we received (PFMv3.8, PFMv4.2 and PFMv4.3) and checking that the results on our computers replicate the results which were supplied by the model developers. During the model runs, issues encountered and run times were discussed with the model developers, if required.
- 3.4.4. We executed the model runs for the 2026 and 2036 forecast years standard case PFM models for both Phase 1 and the full network respectively. Based on our model runs, we generated outputs in a spreadsheet which were then compared to the original outputs supplied by the model developers. The model outputs we generated from our model runs were identical with the outputs generated by the model developers. These are summarised in Table 2 below.

Table 2: Overall model runs comparison – PFMv4.3

| Model | Matching of the outputs |
|---------------------|-------------------------|
| 2026 – Phase 1 | Reproduced precisely |
| 2036 – Phase 1 | Reproduced precisely |
| 2026 – full network | Reproduced precisely |
| 2036 – full network | Reproduced precisely |

- 3.4.5. Results were similarly matched for earlier versions of the model.

3.5. Model convergence

- 3.5.1. This task checks the convergence between the demand and supply elements in the overall PFM model, as different results from different scenarios could be due to non-convergence issues, rather than differences in the specification of the scenarios.
- 3.5.2. Key recommendations for convergence of demand-supply models are set out in WebTAG 3.10.4 (April 2011), and apply equally to highway models, rail transport models or any multi-modal models.
- 3.5.3. As stated in WebTAG 3.10.4, a percentage gap value of less than 0.1% is desirable for the convergence of both individual mode models as well as for the convergence of demand and supply in the overall PFM model runs iterations.
- 3.5.4. The assignment, msa and gap macros in the PLD model macro folders were audited

line-by-line to check for the correct implementation of the convergence methodology as described in WebTAG 3.10.4.

- 3.5.5. A method of successive averages (msa) was adopted in PFM for convergence with the parameter “percentage gap” used to measure the level of convergence between iterations. In addition to the audit of the overall demand-supply convergence in the PFMv4.2 modelling suite, we also checked convergence within the individual mode models.
- 3.5.6. The key issue identified in the line-by-line audit of the msa convergence macros was the implementation of the gap value formula in the model. The gap value formula in macro (...HS2\01PLD\Macros\MSA) to assess convergence of demand and supply in the model was based on the cost difference weighted by demand. In contrast, WebTAG 3.10.4 defines the gap value to assess convergence of the demand and supply in a model as based on demand difference weighted by cost, the alternative approach based on the cost difference weighted by demand is not documented in WebTAG.
- 3.5.7. We raised this issue with the model developers and were informed that the gap value measure adopted in PFM was defined on the basis of advice received by one of HS2 Ltd’s independent advisors, John Bates. We have verified that this method has been correctly implemented.
- 3.5.8. From an analysis of the convergence output files generated by the model runs it was established that all rail, highway and overall PFM (demand-supply) models achieved satisfactory convergence in all scenarios and forecast models in PFMv4.2. We have not re-audited the model convergence in PFMv4.3.

3.6. Audit findings

- 3.6.1. The review of PFM overall model files, structure, interfaces, applications, model runs and models convergence raised no fundamental issues.
- 3.6.2. The key issue identified in this review relates to the clear and transparent management of the model files and the provision of better documentation. There are several unused batch files and macros in the model folders and similarly there are a few missing macros which are called (but not used) in the model runs and are not available in the model folders. These files are redundant in the model and therefore more efficient housekeeping would prevent both abortive review and potential future mishandling in the model.
- 3.6.3. Another issue identified relates to the better commenting of the macros, which could also benefit from more efficient housekeeping.

3.7. Implications of audit findings

- 3.7.1. Our audit of the model framework confirmed that file structure of the model was implemented as documented and that we could replicate the model developers’ model

results. Whilst we only fully unpacked the model structure of PFMv3.8, we have no reason to believe that the model structure of PFM4.2 or PFMv4.3 differs in any respects other than those we have been informed of by the model developers. We audited the model convergence performance of PFMv3.8 and PFMv4.2, but not PFMv4.3.

- 3.7.2. Our main findings of these elements of the model relate to the housekeeping and documentation issues, which in turn impact on the ability to undertake QA and audit checks for future versions of the model.

4. PLANET Long Distance

4.1. Introduction and context

- 4.1.1. The PLANET Long Distance Model (PLD) is an all-day (24 hours) multimodal (rail, air and highway) strategic model covering all domestic long distance trips in Great Britain by rail (conventional and high speed), air and road. The PLD model constitutes the core of overall PFM model suite.
- 4.1.2. The PLD model is primarily developed in the EMME platform and is supported by various macros, batch files and executable files. The PLD model represents a 2010/11 base year and is validated against independent 2010/11 data. The standard set-up of PLD contains four sets of forecast models, each with a 'base' (do minimum, DM) and a 'test' (do something, DS) scenario, as follows:
- 2026 Phase 1 model;
 - 2026 full network model;
 - Cap year Phase 1 model; and
 - Cap year full network model.
- 4.1.3. The PLD base or reference model is an assignment only model with the demand model element switched off.
- 4.1.4. The fundamental objectives of reviewing the PLD and its components were:
- Undertaking a line-by-line audit of the coding and execution of batch files and macros used in the PLD model runs;
 - Auditing the implementation of documented methodologies and assumptions in the PLD model;
 - Reviewing the outputs from the key PLD processes and components;
 - Reporting on the assumptions and issues resulting from the audit of the PLD models and their components; and
 - Working proactively with the model developers to resolve issues in parallel with continuing with the model auditing tasks.
- 4.1.5. We fully audited the PLD within PFMv3.8 and the elements of the model that changed to from PFMv4.2 and PFMv4.3.
- 4.1.6. The audit is reported under following categories:
- Diagnostic sensitivity testing;
 - Parameters used in the PLD model;
 - Link based preload process between PLD and PM/PN;
 - Wormhole based preload process from PLD to PS;

- Crowded assignment process;
- Mode choice model;
- Derivation and implementation of the 'cap year';
- Demand matrices; and
- Rail and air fares.

4.2. Diagnostic sensitivity testing

- 4.2.1. The PLD model contains a number of assumptions and parameters which are 'hard wired' in the model coding. These parameters are derived from various sources and databases. The database authors, version numbers and dates varied to a great extent in the PLD model. Part of our audit scope was to check the consistency of the parameters within different elements with the PFM suite of programs.
- 4.2.2. We appreciate that whilst it is difficult to harmonise all these input data and parameter sources, it is extremely important to ensure that the implementation of the input data and relevant parameters from various sources in the PLD model are consistent and produce intuitive outputs.
- 4.2.3. In order to understand the operation and logic of the PLD model results, we specified three diagnostic tests and ran the PLD model with the assumptions specified for these tests.
- 4.2.4. The running of diagnostic tests also had the advantage of enabling us to engage with the model developers early in the PLD model audit process. We held a workshop with the PLD model developers at which the fundamental objective was to check our understanding of the implementation of the PLD modelling methodology and highlight any fundamental issues to prioritise for further investigation.
- 4.2.5. The run methodology and specification of the PLD diagnostic tests was discussed in detail and agreed with the model developers.
- 4.2.6. The following diagnostic sensitivity tests were performed within PLD:
- 20% increase in the rail fare in forecast year PLD models;
 - 20% increase in the rail journey time in forecast year PLD models; and
 - 20% increase in the fuel cost for highway trips in forecast year PLD models.
- 4.2.7. The demand outputs were generated after full convergence of the model⁵. The demand outputs from the diagnostic test runs were then compared against the demand outputs from the existing model runs provided by the model developers. This was done using the demand elasticity approach as defined in section 1.6 of WebTAG unit 3.10.4 (April

⁵ In this instance, this was to ensure the outputs were derived from a fully converged model run and not to test the convergence process itself. The latter is covered in section 3.5.

2011) using the following equation:

$$e = (\log(T^1) - \log(T^0)) / (\log(C^1) - \log(C^0))$$

where the superscripts 0 and 1 indicate values of demand, T, and cost, C, before and after the change in cost, respectively.

- 4.2.8. These tests were carried out with the purpose of identifying at an early stage if the PLD model run parameters were consistent and to understand the sensitivity of the results. It should be noted that these tests were not proxy to the realism tests performed by the model developers as a part of their PLD demand model testing. Moreover, the test was conducted within PLD for which rail fares, rail journey times and highway costs are largely exogenous, their primary influence being determined through EDGE, network and NTEM inputs. Therefore, we did not compare the absolute results with those advised in the WebTAG 3.10.4 guidance notes. Furthermore, we did not compare the results from these diagnostic tests with those of the realism test reported by the model developers.
- 4.2.9. The general guide that we followed in our analysis of the results from these tests was firstly to review how increasing the cost, fare and time of a representative mode affected total demand of this mode. Also, we reviewed the size of the elasticity obtained due to the increase of the cost of travelling on this representative mode.
- 4.2.10. The task gave us a good introduction to the structure, logic and operation of PLD and how it relates to the full PFM. Conducting sensitivity tests with PLD while useful for our purpose does not reveal the full sensitivity of PFM to a variable unless the input is varied across the full framework. This led us to investigate the details of the parameters used in the PLD demand model and assignment.
- 4.2.11. We undertook a number of sensitivity tests with changes in monetary costs. This indicated that the model is very insensitive to changes in cost as would be expected for an incremental model like PFM and without concurrent changes to the growth inputs (EDGE, NAPLAM, TEMPRO). Thus it should be noted that PFM in itself is insensitive to and inappropriate for testing scenarios which include cost changes to other modes (e.g. rising highway congestion or air fare competition to HS2), or for any HS2 premium fare scenarios.

4.3. Parameters used in the PLD model

- 4.3.1. A number of parameters are used in the PLD model to generate generalised costs for rail, air and highway movements, which are then used in the mode choice model and for assignment. In the mode choice model these parameters are defined in scalar matrices, or as attributes of links, transit lines and line segments in network files. They are also 'hard wired' at various places in batch files and macros.
- 4.3.2. The parameters used in the PLD model are either fixed inputs, or are variables calculated during the model runs using (EMME) macros and functions (e.g. transit time functions, volume-delay functions). A key part of the audit was to check the network

parameters and attributes used in calculation of generalised cost used in the mode choice and assignment elements of the model. For this purpose, we audited all the relevant macros and functions used in the PLD model, and checked the input values and calculations within the PLD model.

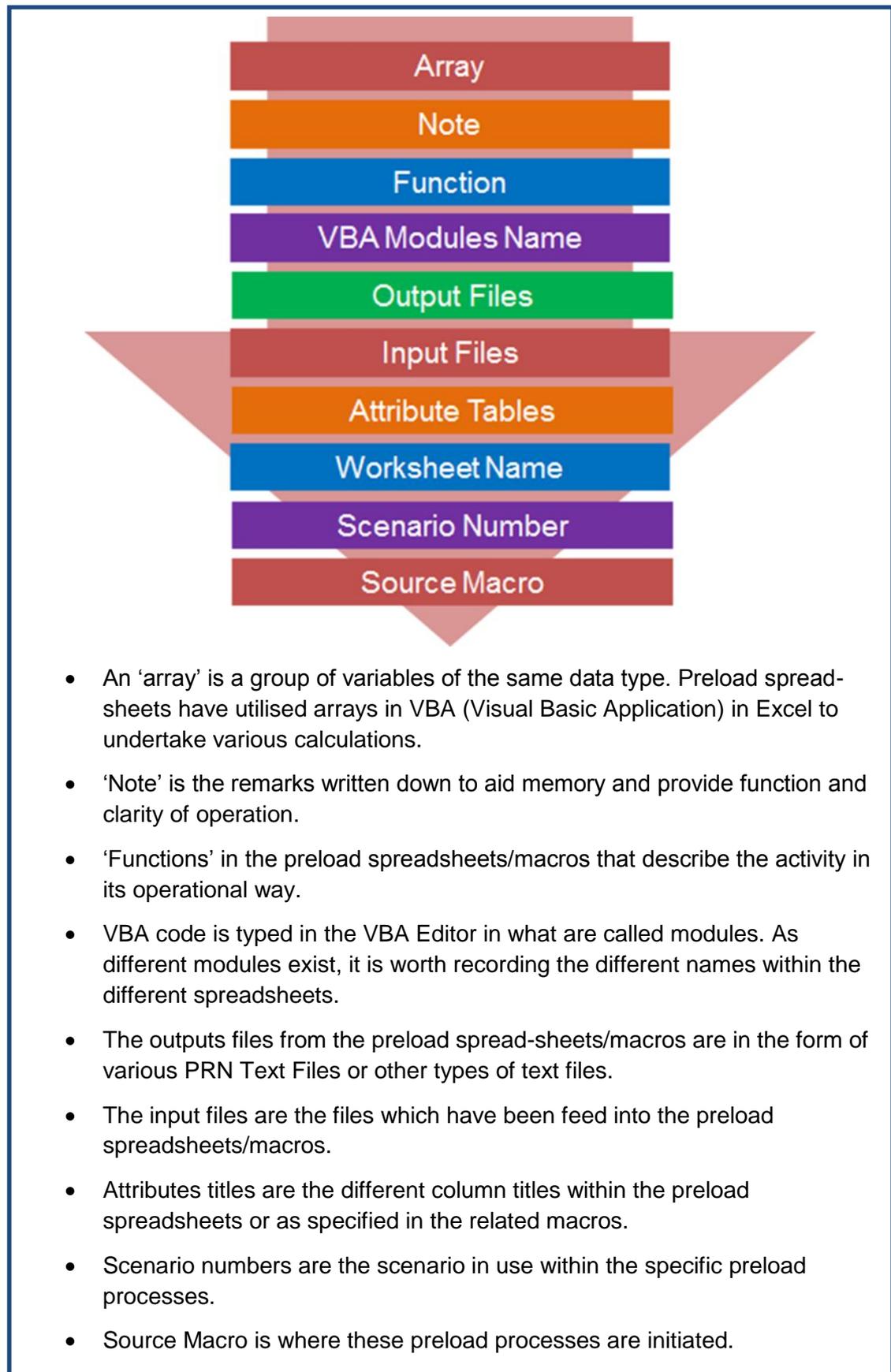
- 4.3.3. The parameters applied in the PLD model were derived from various “industry standard” sources, such as DfT, ATOC, Network Rail, Highways Agency and the CAA. A typical example is DfT's WebTAG values for value of time parameters, vehicle operating cost parameters, growth parameters, highway speed-flow curves parameters (from COBA manual) etc.
- 4.3.4. The PLD has also used several model specific parameters described in various HS2 documents including model development reports, baseline reports and user guides.
- 4.3.5. In our review of the parameters used in the PLD mode choice and assignment models, we first listed all the key parameters in the model from a review of all relevant EMME macros, functions, input files, scalar matrices and model attributes. The list included parameters values, the location where it was used in the PLD model, its scalar reference, and reference to it in existing documentation provided by the model developers.
- 4.3.6. These parameters were then compared against their documented values and against industry standards to verify their consistent and correct implementation.

4.4. Link based preload process from PLD to PM/PN

- 4.4.1. The transfer of trips from the PLD model to PM/PN and from PS to PLD is undertaken with the use of preloads on selected services. This process inputs long distance trips from the PLD model to the PM and PN models by identifying the level of long distance passengers on long distance service groups and then adjusting them to reflect the AM peak demand levels. The preload trips from the selected PLD model services to PM and PN models services are identified through a control matrix (text) file.
- 4.4.2. The objective of this task audit was to review the correct implementation of the preload process from the PLD model to PM and PN models by:
 - Reviewing the implementation of the preload control matrix in the model;
 - Reviewing the relevant preload spread-sheets and line-by-line audit of the preload macros; and
 - Reviewing the key outputs.
- 4.4.3. The preload trips calculation for PLD to PM/PN models was undertaken using the following spreadsheets:
 - Preload_PLD_to_PM_DM.xls;
 - Preload_PLD_to_PN_DM.xls; and
 - Preload_PLD_to_PN_DS.xls.

- 4.4.4. These spreadsheets are at the core of the transfer of trips from the PLD model to the PM and PN models. We identified various elements in these spreadsheets for the audit as shown and explained in Figure 4 below:

Figure 4: Unpacking of the preload process within the preload spreadsheets



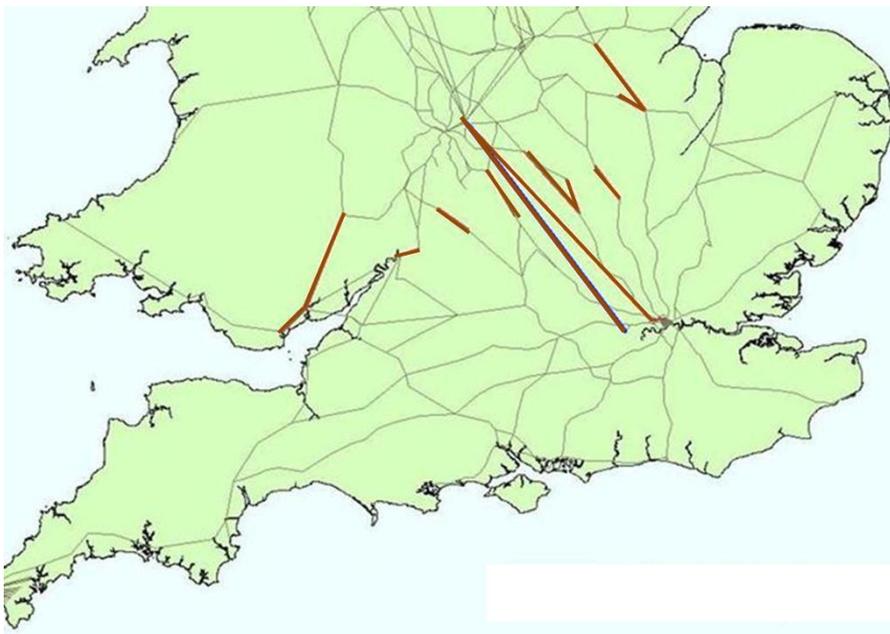
- 4.4.5. The preload process audit was undertaken using a top-down review approach as follows:
- At the top level in the preload spreadsheets are the ranges where the data are analysed in rows and columns. These should be identical for all scenarios (e.g. scenario 15000 to scenario 15002 in the DM, scenario 16000 to scenario 16005 in the DS etc.) within the same forecast year runs and for the same test model (day-1 or Y-network). We investigated if the ranges in the same model run were identical between various scenarios.
 - At the next level we checked that the number of transit lines used in the preload process in different scenarios of the same model run were identical. We targeted the identification of transit lines that had been removed and added between the DM to the DS models. This was to ensure that the correct transit lines had been transferred in the preload operation from the PLD model to PM/PN models.
 - The next level in the audit hierarchy was a detailed check of the number of preload trips in each model (DM and DS) and for each forecast year. The analysis of the preload trips was undertaken by comparing the preload trips in the DM and the DS models (same forecast year) and then comparing these against the forecast preload trips generated in different forecast years model runs. Intuitively, we hypothesized that PLD to PM/PN preload trips should be higher in the DS results when compared to the DM results. In the same way PLD to PM/PN preload trips from a later forecast year should be higher than the preload trips from an earlier year.
 - The final detailed audit level in this task was a check that the MOIRA factors had been applied consistently in the preload process across all models.
- 4.4.6. Our initial audit identified a range of issues that were reviewed with the model developers and adjusted in PFMv4.3 and the standard case scenario.

4.5. Wormhole process from PLD to PS

- 4.5.1. Demand transfer from PLD to PS is undertaken in PLD by means of select link matrices. This ensures that the pattern of demand in PLD is retained in PS. This process (termed “wormhole”) is undertaken for each direction and for all demand segmentations, then aggregated to one matrix in each direction for each link.
- 4.5.2. To transfer long distance demand to the PS model, it is important to identify the detailed route chosen and the impact on local services of the change in long distance demand. In this process, the demand using each corridor is transferred using a series of “select link” processes and assigned alongside the local demand. The representation of such transferred trips is included in the calculation of the crowding level and crowding penalty.
- 4.5.3. The “wormholes” are effectively dummy zones that feed origin-destination demand information from PLD to PS to nodes at the edge of the PS network area, after being factored down from all-day to the peak-only levels.

- 4.5.4. The main objective of this task was to audit the implementation of the wormhole process from PLD to PS and ensure that it was undertaken correctly. All day demand matrices are extracted from the PLD model at cordon points along the PLANET South modelled area. These are then converted to 3 hour matrices for import to PS as long distance demand.
- 4.5.5. Demand transfer from PLD to PS is undertaken by means of a series of select link matrices to enable the pattern of demand to be retained and assigned in PS. This process is undertaken for each direction and for each journey purpose, although the demand by purpose is then aggregated to a single matrix prior to export. The selected links are defined in the additional attribute @pslnk by macro reset_@pslnk.mac.
- 4.5.6. As the zoning systems differ between PLD and PS, the demand is exported using zone groups which can then be converted and disaggregated in PS where appropriate. The trip end outside the PS model area is given a unique zone group, which is represented as a specific additional zone in PS. The trip end within the PS model area is exported using a zone group “gs” where each PLD zone has a unique definition (gs01 to gs235). In addition, factors are applied to convert the daily demand exported from PLD to an equivalent AM Peak period demand, as used in PS.
- 4.5.7. The wormhole process enables the model to identify the detailed route chosen and assess the impacts on local services of the change in long distance demand. The demand using each corridor is transferred and assigned alongside the local demand. In each model, the representation of such transferred passengers is included in the calculation of the crowding level and crowding penalty.
- 4.5.8. In total, 20 directional links in the DM and 26 in the DS models have been defined for the wormhole process. These are shown in Figure 5 below.

Figure 5: Select links as defined in the PLD/PS wormhole process



- 4.5.9. In order to extract and analyse the wormhole process results, the scenario for which the analysis was performed was first copied to scenario 99999 using macro scencopy.mac.
- 4.5.10. The following macros were then called to perform the wormhole process in the Do-Minimum stage:
- reset_@pslnk.mac;
 - PSMSelect.mac;
 - HS2Select.mac; and
 - HS2batch.mac.
- 4.5.11. In the Do-Something the related macros were:
- reset_@pslnk.mac;
 - PSMSelect_hs.mac;
 - HS2Select_hs.mac;
 - HS2batch_hs_in.mac;
 - HS2batch_hs_out.mac;
 - HS2batch_hsEUS_in.mac;
 - HS2batch_hsEUS_out.mac;
 - HS2batch_hsOOC_in.mac; and
 - HS2batch_hsOOC_out.mac.
- 4.5.12. In the DM scenario, the process was repeated for scenarios 15000 and 15001. In the DS scenario, this was performed for scenarios 16000, 16002 and 16005. In addition to links in the DM, the wormhole process was also performed to high speed links between Euston, Old Oak Common and the North. Trips alighting at Euston or Old Oak Common as their final rail station and those which continued their trips elsewhere in the South were extracted separately.
- 4.5.13. We did not find any major issues in the review of the implementation of the wormhole process from PLD to PS in the PLD model, or from the line-by-line audit of the macros coded in the model for this purpose.
- 4.5.14. However, we found that there are several redundant files in the process. Some of these are called upon to be copied over and over, without being used or updated.
- 4.5.15. The identification of PLD links from which trips are extracted for the wormhole process is integral to the network coding and needs to be reviewed for every new network used in the forecasting process. We therefore comment further on this under the standard case network audit later in this report.

4.6. Crowded assignment process

- 4.6.1. The rail assignment in the PLD model is based on a generalised cost parameter comprising of the crowded station to station journey times for rail (perceived journey time with the crowding penalty based on loading levels of each transit segment) derived using a transit function in EMME/3. The assignment is a multiclass assignment, considering various demand segments and related assignment attributes (demand, generalised cost etc.).
- 4.6.2. The main objective of this task was to audit the coding of the crowded rail assignment process and related macros. We also checked that the assignment read the correct input demand and generalised cost files for each demand segments during the assignment.
- 4.6.3. The PLD rail assignment is a headway based multi-class crowded assignment process. The assignment uses the generalised cost obtained from weighted sum of the elements of the perceived journey time as follows:
- Access and egress time obtained from National Accessibility Model (NAM) database;
 - In-vehicle time derived from the timetable data from CIF database;
 - Waiting Time;
 - Interchange and Boarding penalty; and
 - Crowding penalty.
- 4.6.4. The crowding penalty is estimated by applying a calculated multiplicative factor (based on TOC groups, demand segmentations and seat utilisation using PDFH v 5.0 crowding parameters) to the un-crowded in-vehicle time. Crowding is measured in terms of seat utilisation (up to 100% seat utilisation), above which it is measured in terms of passengers standing per m². Crowding parameters from PDFH v5.0 are weighted by the proportion of seated and standing passengers in the model.
- 4.6.5. The rail assignment process, including the response to crowding, is performed by the following key macros:
- Rassignsetup.mac;
 - Pre-rail.mac;
 - HSLpre-rail.mac;
 - Rail.mac;
 - HSLrail.mac; and
 - Hslmarker.mac.
- 4.6.6. The audit process in this task consisted of a line-by-line check of the coding of all the above macros and input/output files.

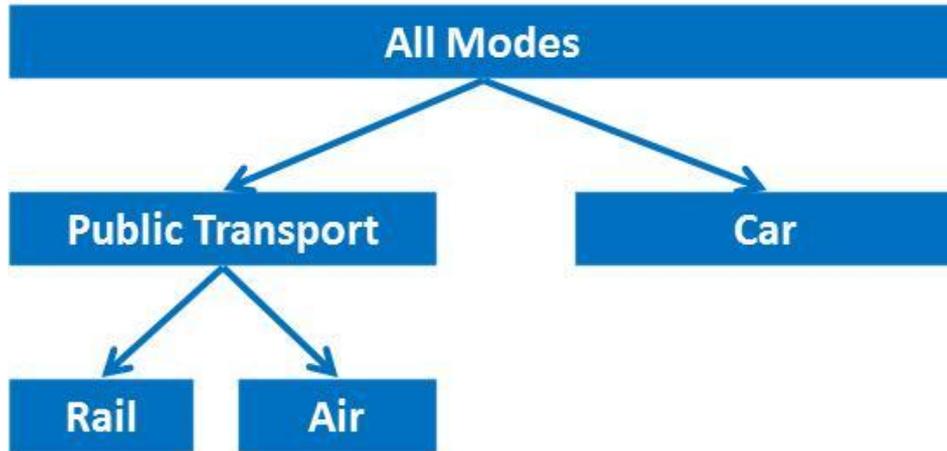
- 4.6.7. The crowding penalty and its peak hour adjustment factors were audited by comparing the equation implemented in macro rail.mac against the equation documented by Atkins.
- 4.6.8. A spreadsheet analysis was performed to estimate the variations in crowding penalties based on varying seat utilisations, using the equation implemented in the PLD rail model assignment.
- 4.6.9. We concluded that all parameters used in the rail assignment process are correctly implemented in the model. An audit of the convergence results from the elastic crowded rail assignment process, for all scenarios from scenario 16000 through to scenario 160012, was found to be satisfactory. All gap values obtained in the final iteration of the 20 iterations were found less than 0.1% for both forecast years and networks
- 4.6.10. A sense check of the sensitivity of the crowding penalties showed that the variation in the crowding penalty is low up to nearly full-utilisation of the seating capacity and is much higher for seating utilisation above capacity in the case of the long distance trips, which was expected for the long distance trips.
- 4.6.11. We concluded that the crowded rail assignment process used in the PLD model was implemented as specified.

4.7. Mode Choice Model

- 4.7.1. The mode choice model in PLD is an incremental hierarchical logit model which predicts changes in the mode choice (between rail, air and highway modes) of long distance domestic travel demand. The mode choice model is implemented by a series of model choice model macros which are further supported by various parameters and assumptions.
- 4.7.2. The mode choice model parameters were previously estimated based on stated preference surveys and other information collected for HSL study. These surveys date back to the late 2001/early 2002 and were focussed on long distance travel only. Therefore, as part of the PFMv4.2 update, the mode choice model parameters were re-estimated using National Travel Survey data collected between 2002 and 2010. As part of the PFMv4.2 audit, we checked all the new model parameters against those documented and can confirm that the new model parameters have been correctly incorporated in the model.
- 4.7.3. On the implementation of the base year values of time for non-business users, we have had extensive discussions with the model developers, John Bates and the Department for Transport (DfT) as the implemented approach anticipated changes to WebTAG published in Unit 3.10.2c, February 2013. We concluded these values were implemented as intended.
- 4.7.4. Although the calibration of the mode choice parameters was done at an absolute level, the model is implemented incrementally for car or public transport (PT) and rail or air

choices. The figure below shows the structure of the mode choice model implemented in the PLD model:

Figure 6: Mode choice model structure



- 4.7.5. The main objective of this audit task was to review the implementation of input data/assumptions to the mode choice model, to check the calculations contained within the mode choice model and to check the key outputs from the mode choice model. The aim was to ensure that the model correctly implements the mode choice methodology and the logit model structure as documented.
- 4.7.6. There are two key macros which implement the mode choice model in the PLD model are as follows:
- modesplit5.mac; and
 - modesplit2.mac
- 4.7.7. The macro modesplit5.mac is used in scenario 16000 of the DS model runs for the initial mode split estimation, without implementation of cost elasticity in the model. The macro modesplit2.mac is used in all model scenarios in the DS model runs which implement the full mode choice model with the implementation of cost elasticity in the model.
- 4.7.8. In this audit task, we checked the line-by-line coding of the above two macros. We audited the calculation of composite costs, logit model implementation and the use of the parameters for each demand segment in the mode choice macros.
- 4.7.9. We checked that the mode choice model reads the correct demand matrix files (scenario, year etc.), generalised cost matrix files (scenario, year etc.) and parameter scalars for each demand segment in the PLD model.
- 4.7.10. We also created a shadow spreadsheet-based mode choice model with a similar structure and assumptions as used in the PLD mode choice model. We used the input demand, parameters (scaling parameters, VOT etc.) and assumptions (access/egress costs, rail fares etc.) together with the time and other cost attributes from the crowded

assignment process and replicated the outputs, for the selected demand segments, reported from the actual model runs.

- 4.7.11. The shadow mode choice spreadsheet model was based on the model structure used in modesplit2.mac and targeted to replicate the mode choice model results in scenario 160012 for the years 2026 and the cap year. The journey purposes of interest were Business CA and Others NCA. Relevant cost matrices were extracted from the HS2 PLD models as specified in the file modesplit2.mac.
- 4.7.12. The analysis consisted of a cell by cell calculation and comparing the calculated outputs with the original outputs.

4.7.13. Table 3 and Table 4 below show the input demand, input costs and output demands from the mode choice model which was replicated through the shadow spreadsheet assessment.

Table 3: Inputs and outputs of mode choice model: Business CA, Scenario 16012

| Input Demand | Input Cost | Output Demand |
|---------------------------------|--|--|
| mf 514 – Business Trips (Total) | mf35 – Straight line distance between zones mf501 – Business (Base Case) C Rail pass mf502 – Business (Base Case) Air pass mf503 – Business (Base Case) HW pass mf602 – Business (Test Case) C Rail cost mf602 – Business (Test Case) C Rail cost mf603 – Business (Base Case) HSL cost mf604 – Business Change in air cost mf605 – Business Change in HW cost mf606 – Business Change in rail cost mf607 – Business Change in PT cost mf608 – Business Change in Travel Cost ms613 – Business scaling factor (gen) ms614 – Business scaling factor (pt/hw) ms615 – Business scaling factor (rail/air) ms616 – Business scaling factor (cr/hsl) | mf519 – Business (HSL) mf511 – Business (C Rail) mf512 – Business (Air) mf513 – Business (HW) |

Table 4: Inputs and outputs of mode choice model: Other NCA, Scenario 16012

| Input Demand | Input Cost | Output Demand |
|-----------------------------------|--|--|
| mf 574 – Others NCA Trips (Total) | mf35 – Straight line distance between zones mf561 – NCA Others (Base Case) C Rail pass mf562 – NCA Others (Base Case) Air pass mf563 – NCA Others (Base Case) HW pass mf662 – NCA Others (Test Case) C Rail cost mf663 – NCA Others (Base Case) HSL cost mf664 – NCA Others Change in air cost mf665 – NCA Others Change in HW cost mf666 – NCA Others Change in rail cost mf667 – NCA Others Change in PT cost mf668 – NCA Others Change in Travel Cost ms673 – NCA Others scaling factor (gen) ms674 – NCA Others scaling factor (pt/hw) ms675 – NCA Others scaling factor (rail/air) ms676 – NCA Others scaling factor (cr/hsl) | mf570 – NCA Others (HSL) mf571 – NCA Others (C Rail) mf572 – NCA Others (Air) mf573 – NCA Others (HW) |

4.7.14. Both generalised costs and composite costs were calculated and mode split was estimated based on the logit formula implemented in the mode choice model by modesplit2.mac macro.

4.7.15. Table 3 and Table 4 above, for each cell in the matrices. No major issues were found in the audit of the implementation of the PLD mode choice model.

4.8. Derivation and implementation of cap year

- 4.8.1. The cap year is defined in the PLD model (and in the overall PFM modelling suite) as “the forecast year at which long distance rail demand ceases to grow”, i.e. it is a proxy for saturation of long distance rail demand in the long term. The definition of the year that the cap is reached is one of the key assumptions in the model, and has a significant impact on the appraisal.
- 4.8.2. The cap year calculation determines the year at which rail trips of over 100 miles reach a certain level (approximately 290,000 trips). For PFMv3.8, the cap year was calculated to be 2043. We audited this process in PFMv3.8 and concluded that it had been implemented correctly. The audit of the cap year process was repeated for PFMv4.2 and we found that it was correctly calculated and implemented as 2036 in that version. There was no requirement to update this for PFMv4.3 and therefore no need to re-audit the cap year processes for this version.

4.9. Demand matrices

Overview

- 4.9.1. The objective of this part of the audit was to review the PFMv3.10 base year and forecast year demand matrices for all modes (rail, highway and air), and journey purposes used in the PLD models. The same matrices are used in PFMv4.3.
- 4.9.2. The base year rail matrices were developed by processing 2010/11 LENNON⁶ rail data. The process of the extraction of the LENNON data was out of scope of this study. Thus we have assumed that the model developers implemented the processing of the LENNON data correctly in developing the base year rail demand matrices.
- 4.9.3. The rail matrices were segmented into various journey purposes based on NRTS data. We reviewed the demand segmentation process for the base year matrices and compared the final matrix demand segmentations against NRTS.
- 4.9.4. The matrix building process used to define the rail demand matrix followed the following methodology:
- Read in LENNON data;
 - Convert joint codes to stations;
 - Allocate trips from stations to zones;

⁶ LENNON (Latest Earnings Networked Nationally Over Night) is the rail industry’s ticket sales database through which the vast majority of data for rail tickets purchased in Great Britain is processed. LENNON is used to allocate the revenue from ticket sales between train operating companies and is subject to its own QA processes.

- Distribute zone-to-zone flows for car ownership;
 - Aggregate results to O-D combinations;
 - De-annualise to average weekday; and
 - Convert to journey purpose.
- 4.9.5. The forecast rail matrices were based on updated EDGE growth factors. We reviewed the EDGE factors and their implementation to derive forecast year matrices for each journey purpose, although the methodology used to derive the EDGE factors was out of scope of this audit.
- 4.9.6. We developed a shadow spreadsheet of growth forecasts and replicated the results at journey purpose level. However, we did not audit the prior processing information on how these purposes were further segregated into CA and NCA segments and therefore used the same EDGE growth factors for both CA and NCA segments.
- 4.9.7. The base year highway matrices were derived from 2008 LDM and rebased to 2010 using NTS long distance trips and latest TRADS data. We have reviewed both the base and forecast highway matrices in this audit. As the highway matrices were obtained from third party highway models, we only performed a high level audit on these matrices. The trip length distributions were checked and were compared against NTS data to review the implementation of the base year highway matrices in the PLD model. The forecast highway demand was based on growth factors obtained from TEMPRO 6.2, which was also reviewed and checked in this audit using a shadow spreadsheet approach
- 4.9.8. The base year air matrices were based on 2010 DfT air matrices segregated into journey purposes using CAA data. The forecast air matrices were based on growth factors applied from DfT's air model data. We have checked the overall demand distribution using desire lines. We have also checked the aggregation of the journey purposes for air matrices.

Base Year Rail Demand

- 4.9.9. The base year rail matrices were developed from LENNON data and converted to PA/OD matrices by journey purposes using NRTS data. The audit of the raw LENNON and NRTS data was out of the scope of this audit work.
- 4.9.10. For the purpose of this audit, the rail demand was split into 10 classes in PA format. The matrices from each segment were plotted in GIS and desire lines of selected PA pairs were analysed. This enabled us to review how the trips in the base year rail matrices were distributed in the PLD model.
- 4.9.11. We also selected around 100 of the highest cell-to-cell rail passenger movements, to analyse in detail if these movements were implemented correctly from the input data provided by the model developers.
- 4.9.12. All the base year rail demand matrices with the PLD zone plan were imported to

ArcGIS to enable us to analyse rail passenger movements at both a discrete and aggregate level. This also provided us with a comparative analysis both in tabular and graphical forms.

- 4.9.13. For more effective analysis, we grouped these movements into sectors and categorised them in colour bands and line widths based on the number of trips in each sectors.
- 4.9.14. From the analysis of the rail passenger movements, we found that the majority of the commuting trips were between Glasgow and Edinburgh and between Liverpool, Birmingham and Leeds. There were many commuting trips in the PLD model to Birmingham from neighbouring sectors and similarly to Southampton from neighbouring sectors. These patterns are to be expected as only longer distance trips are included in the PLD model, thus more local trips are included in the regional PLANET models.
- 4.9.15. There were substantial car available business trip movements between Glasgow and Edinburgh. There were also high numbers of business trip movements between London-Birmingham, London-Manchester and London-Leeds. The other trip purposes showed intuitive sector-to-sector distributions and passenger movements in the PLD base year matrices.
- 4.9.16. In general, it was noticed that the sectors between Glasgow and Edinburgh contained a higher number of rail passenger trips in almost all base year rail matrices, for all demand segmentation. Although it was deemed sensible that the car available (CA) demand, in general, was higher than non-car available (NCA) demand, we noticed that some major cities had much higher car available long distance trip demand than non-car available demand.
- 4.9.17. For example, in the base year rail matrices, the total number of car available commuting rail trips was around five times higher than the non-car available commuting rail trips. There were 6,388 CA commuting rail trips attracted to Central London while the NCA commuting rail trips attracted to the Central London were only 420 trips. Similarly, total CA commuting rail demand from Central London was 9,362 compared to 881 NCA commuting rail demand from Central London. This gives a ratio of approximately 11:1 for CA:NCA commuter rail demand from Central London.
- 4.9.18. We compared this ratio with the LTS (London Transport Study) transport model base 2007 demand data for rail commuter trips from Central London and found this ratio to be approximately 2:1. We could not identify with certainty if this is an issue in the PLD rail base year matrices because of the un-availability of the underlying raw base year data used to develop these matrices. The home-based car available business trips were also found around 8-9 times higher than the home-based non-car available business trips. The results from the individual corridor analysis showed consistency with the journey purpose split on these corridors documented by Atkins.

Table 5: Matrix totals by purpose and corridor – proportions

| Journey Purpose | Average | From London | To London | Lon-Birmingham | Birmingham-London | London-Leeds | Leeds-London | London-Manchester | Manchester-London | London-Liverpool | Liverpool-London |
|-----------------|---------|-------------|-----------|----------------|-------------------|--------------|--------------|-------------------|-------------------|------------------|------------------|
| CA | 83% | 90% | 90% | 91% | 90% | 87% | 87% | 89% | 88% | 86% | 86% |
| NCA | 17% | 10% | 10% | 9% | 10% | 13% | 13% | 11% | 12% | 14% | 14% |
| Sum | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| Com | 40% | 18% | 17% | 15% | 15% | 4% | 4% | 5% | 5% | 12% | 12% |
| Bus | 15% | 47% | 47% | 56% | 56% | 56% | 56% | 64% | 64% | 48% | 48% |
| Oth | 44% | 35% | 36% | 29% | 29% | 40% | 40% | 31% | 31% | 40% | 40% |
| Sum | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| CA Com | 83% | 91% | 91% | 89% | 89% | 85% | 85% | 75% | 75% | 84% | 84% |
| NCA Com | 17% | 9% | 9% | 11% | 11% | 15% | 15% | 25% | 25% | 16% | 16% |
| Sum | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| CA Bus | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| NCA Bus | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Sum | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| CA Oth | 78% | 75% | 76% | 73% | 72% | 70% | 69% | 67% | 66% | 71% | 70% |
| NCA Othe | 22% | 25% | 24% | 27% | 28% | 30% | 31% | 33% | 34% | 29% | 30% |
| Sum | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

Source: PFMv3.10

- 4.9.19. We also selected the highest 100 major trip movements from London in the base year rail matrices and analysed their trip patterns. To review the forecast rail matrices, we created a shadow spreadsheet incorporating the latest EDGE growth forecasts provided by the model developers. This spreadsheet was then used in conjunction with the supplied base year rail demand to generate forecast year rail trips by journey purpose. We then compared the results from the spreadsheet and the forecast rail trips provided in the forecast year rail matrices by the model developers.
- 4.9.20. As a further check, we selected the top 25 London to other sectors rail passenger movements (>500 trips) in the base year matrices and compared them with the population of the selected regions and their respective straight-line distance from London zones.
- 4.9.21. This helped us to analyse the relative attraction of selected zones to/from London. We assumed, for the purpose of this sense check, that trip attraction is directly proportional to the population of the destination zone and inversely proportional to the square of the distance between the destination zone and London.
- 4.9.22. The analysis of the attraction of the PLD rail demand from London to selected key zones by the simple gravity method as defined above is illustrated in Table 6 below and showed intuitive and sensible results.

Table 6: Attraction of PLD rail demand from London to selected key zones

| From Zone | To Zone | Trips | Population | Distance (km) | Gravity | Gravity Rank |
|---------------------------------|-------------------------------------|---------|------------|---------------|---------|--------------|
| London | Birmingham | 4007 | 1,974,300 | 163 | 75 | 1 |
| | Northamptonshire WCML | 3738 | 693,900 | 99 | 71 | 2 |
| | Coventry | 1403 | 316,900 | 139 | 16 | 3 |
| | Leicester | 1049 | 329,600 | 144 | 16 | 4 |
| | Sheffield | 1127 | 551,800 | 231 | 10 | 5 |
| | Leeds | 2356 | 750,700 | 275 | 10 | 6 |
| | Nottingham | 1139 | 303,900 | 177 | 10 | 7 |
| | Cardiff | 1008 | 346,100 | 213 | 8 | 8 |
| | Derby City | 572 | 248,700 | 182 | 8 | 9 |
| | Manchester including Metrolink area | 3889 | 502,900 | 265 | 7 | 10 |
| | Cheltenham & Cotswold | 788 | 115,600 | 137 | 6 | 11 |
| | Liverpool | 1536 | 465,700 | 284 | 6 | 12 |
| | Doncaster | 513 | 302,402 | 235 | 5 | 13 |
| | Wellingborough | 672 | 49,087 | 97 | 5 | 14 |
| | Stoke & Staffordshire North | 612 | 249,000 | 219 | 5 | 15 |
| | Solihull | 1090 | 94,753 | 152 | 4 | 16 |
| | Rugby | 933 | 61,988 | 129 | 4 | 17 |
| | York | 1182 | 197,800 | 282 | 2 | 18 |
| | Lincoln City and Coast | 703 | 93,100 | 193 | 2 | 19 |
| | Stockport | 610 | 136,082 | 251 | 2 | 20 |
| City of Glasgow | 652 | 598,830 | 556 | 2 | 21 | |
| Newcastle & Rest of Tyne & Wear | 1243 | 279,100 | 400 | 2 | 22 | |
| City of Edinburgh | 1233 | 495,360 | 534 | 2 | 23 | |
| Chester & Ellesmere Port | 550 | 118,925 | 267 | 2 | 24 | |
| Preston, Fylde, Wyre | 584 | 114,300 | 316 | 1 | 25 | |

Source: PFMv3.10

Base Year Highway Demand

- 4.9.23. In PLD trip lengths less than 50 miles were not in the scope of the model and therefore were excluded from the PLD matrix audit. The trip length distribution of highway trips > 50 miles were compared with NTS data.
- 4.9.24. The observed NTS LDJ (National Travel Survey Long Distance Journey) trips by distance were used to compare against the model data. These observed trips were defined as all purpose, car driver & car passenger, whole GB, weekday trips. The comparisons are illustrated in Table 7 to Table 9 and Figure 7 below and show good correspondence between the PLD and NTS matrices.

Table 7: Trip length distribution comparison (all purposes)

| Distance Band | NTS | Model |
|---------------|-----|-------|
| 50-75 miles | 42% | 42% |
| 75-100 miles | 19% | 20% |
| 100-150 miles | 20% | 23% |
| 150-250 miles | 14% | 13% |
| 250-350 miles | 3% | 1% |
| >350 miles | 1% | 0% |

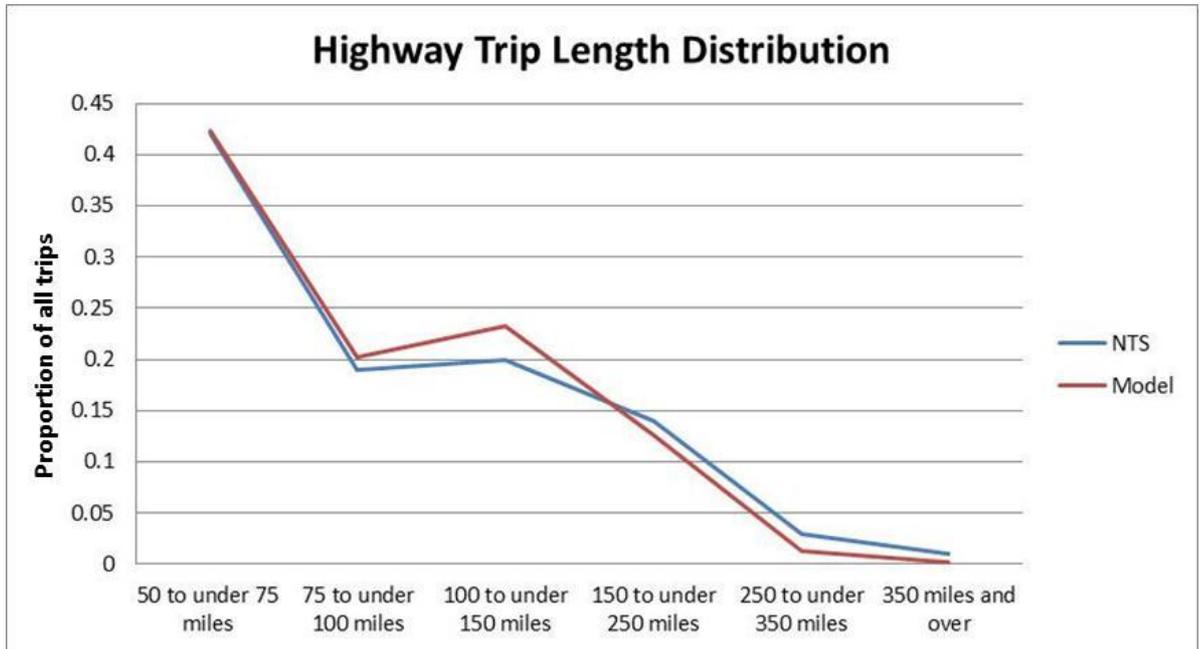
Table 8: Trip length distribution comparison (home-based work)

| Distance Band | NTS | Model |
|---------------|-----|-------|
| 50-75 miles | 73% | 70% |
| 75-100 miles | 16% | 15% |
| 100-150 miles | 6% | 11% |
| 150-250 miles | 3% | 3% |
| 250-350 miles | 2% | 0% |
| >350 miles | 0% | 0% |

Table 9: Trip length distribution comparison (NTS and model)

| NTS | | | |
|------------------------|-------------|-------------|-------------|
| Distance Band | HBW | HBEB | HBO |
| 50 to under 75 miles | 73% | 38% | 40% |
| 75 to under 100 miles | 16% | 23% | 20% |
| 100 to under 150 miles | 8% | 24% | 20% |
| 150 to under 250 miles | 3% | 14% | 15% |
| 250 to under 350 miles | 0% | 2% | 4% |
| 350 miles and over | 0% | 0% | 1% |
| Total | 100% | 100% | 100% |
| MODEL | | | |
| Distance Band | Commuting | Business | Other |
| 50 to under 75 miles | 70% | 39% | 40% |
| 75 to under 100 miles | 15% | 23% | 20% |
| 100 to under 150 miles | 11% | 26% | 24% |
| 150 to under 250 miles | 3% | 11% | 15% |
| 250 to under 350 miles | 0% | 1% | 2% |
| 350 miles and over | 0% | 0% | 0% |
| Total | 0% | 0% | 0% |

Figure 7: Highway trip length distribution, all purposes



Base Year Air Demand

4.9.25. Sector-to-sector air passenger movements were analysed and presented as desire lines in GIS, similar to the review of base rail matrices above. These were then compared against the DfT air matrices to sense check the sector movements of the air passengers to the base air matrices. It can be seen from the figures below that most of the air trips were generated between London and the major cities in Scotland. No abnormal individual route movements were identified.

Figure 8: Air demand (business)

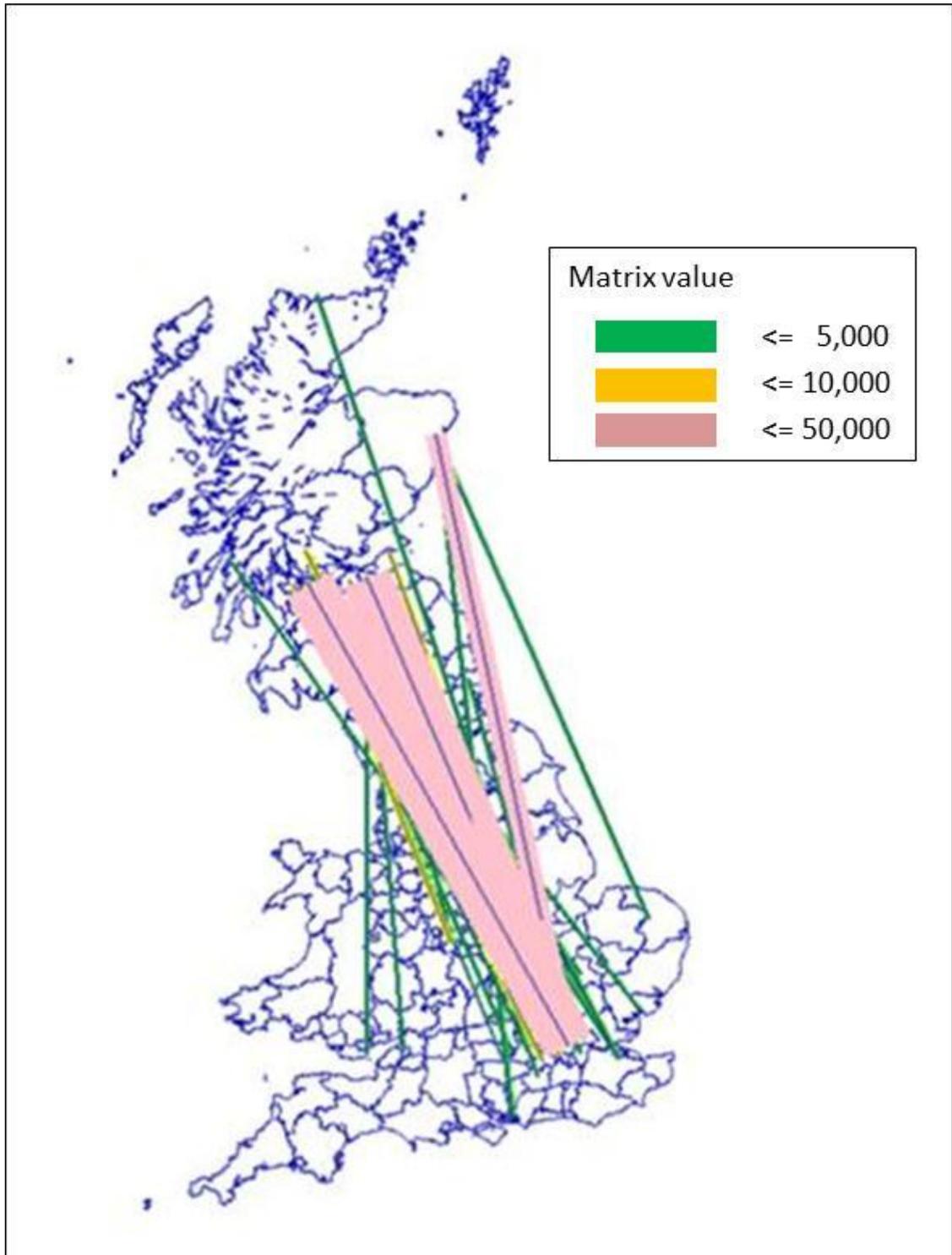
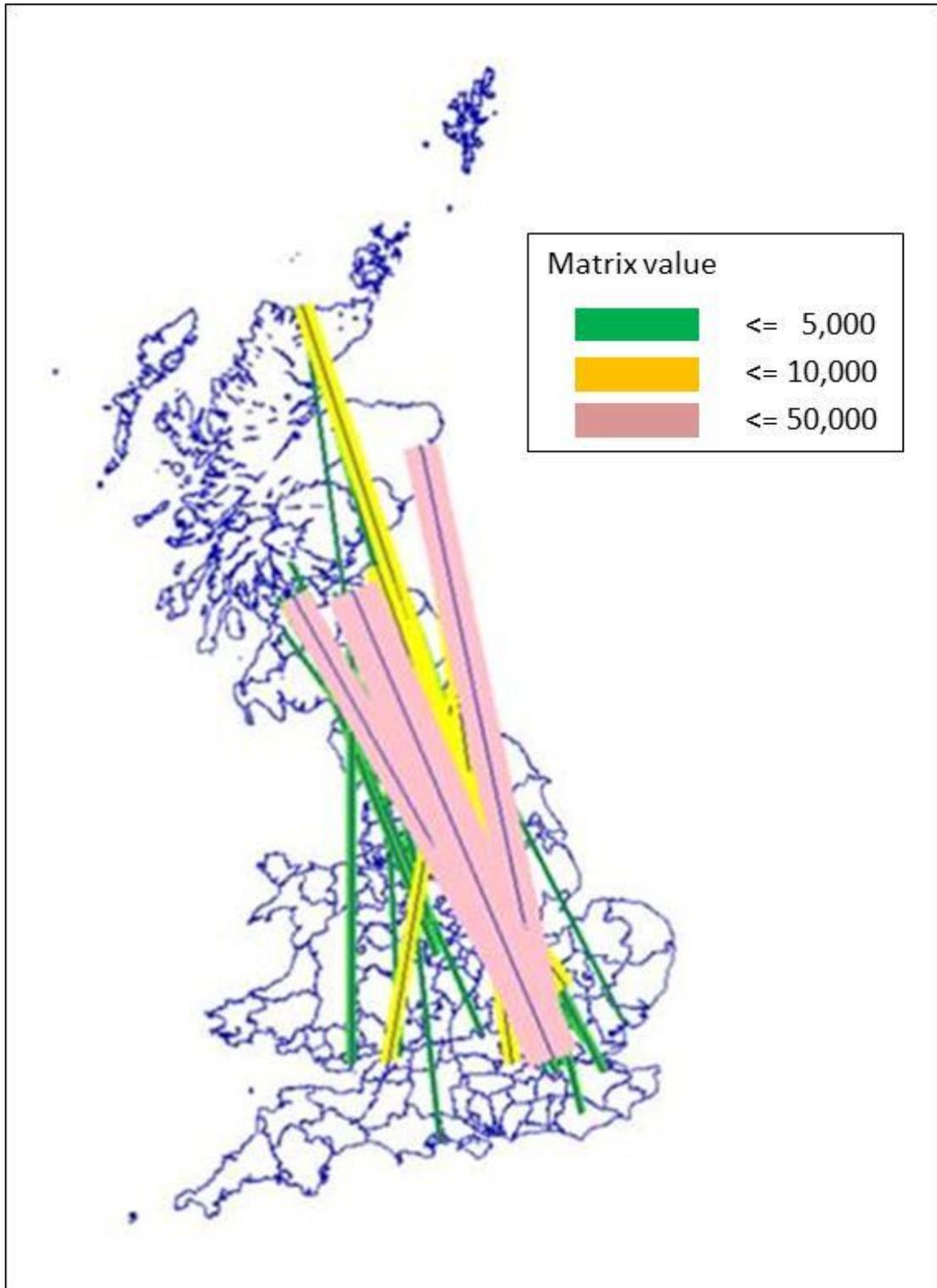


Figure 9: Air demand (other)



4.9.26. The journey purpose split in the model and CAA data was compared and to match as illustrated in the table below:

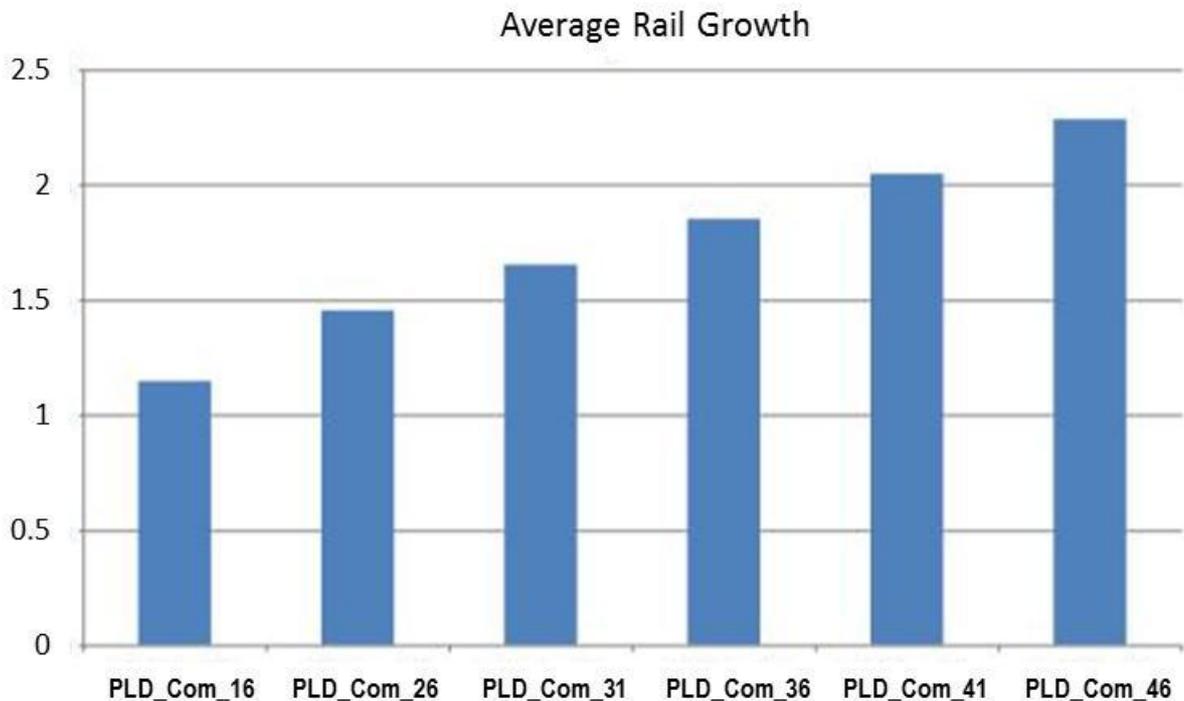
Table 10: Journey purpose comparison

| Journey Purpose | CAA | Model |
|-----------------|-----|-------|
| Business | 56% | 56% |
| Other | 44% | 44% |

Forecast Year Rail Demand

4.9.27. The forecast matrices were checked using a shadow spreadsheet approach for each OD pair. This was undertaken for 2026 (PA and OD) and 2036 (PA). An example of the growth (for the commuting journey purpose) across the forecast years is given below.

Figure 10: Rail growth across the forecast years



4.9.28. A comparison between our shadow spreadsheet approach and the model results is presented in Table 11 below. It can be seen that whilst an exact match was achieved at the aggregate level for each journey purpose, imbalances were found at the disaggregate level of car-available (CA) and non-car-available (NCA). As EDGE does not provide separate growth factors for car-available and non-car-available trips, we understand that the model developers made further car availability adjustments to the matrices to reflect rising car ownership. For 2026, this reflects an increase of approximately 3% for the car-available matrices, and a decrease of 17% for the non-car available matrices. Checking the prior processing of these calculations was out of scope for the audit.

Table 11: Comparison between shadow spreadsheet approach and the model

| Year 2026 | PA | | | | OD | | | | Comments |
|------------------|--------|--------|-------|--------|-----------|--------|--------|--------|----------------|
| | Given | Audit | Diff | Diff % | Given | Audit | Diff | Diff % | |
| CommutingCA | 234326 | 227853 | 6472 | 3% | | | | | |
| CommutingCA from | | | | | 234326 | 227853 | 6472 | 3% | same as PA |
| CommutingCA to | | | | | as above | | | | |
| CommutingNCA | 38389 | 44862 | -6472 | -17% | 76781 | 89725 | -12944 | -17% | |
| BusinessCA HB | 81909 | 80500 | 1409 | 2% | | | | | |
| BusinessCA NHB | 32977 | 32181 | 797 | 2% | | | | | |
| BusinessCA from | | | | | 125884 | 125884 | 0 | 0% | |
| BusinessCA to | | | | | 93704 | 93704 | 0 | 0% | |
| Business NCA | | | | | see notes | | | | OD matrix zero |
| Business NCA HB | 9008 | 10416 | -1409 | -16% | | | | | |
| Business NCA NHB | 4780 | 5576 | -797 | -17% | | | | | |
| LeisureCA HB | 207114 | 199115 | 7999 | 4% | | | | | |
| LeisureCA NHB | 78902 | 75553 | 3349 | 4% | | | | | |
| LeisureCA from | | | | | 284346 | 274668 | 9679 | 3% | |
| LeisureCA to | | | | | 208794 | 199115 | 9679 | 5% | |
| Leisure NCA | | | | | 117162 | 136519 | -19357 | -17% | |
| Leisure NCA HB | 48577 | 56576 | -7999 | -16% | | | | | |
| Leisure NCA NHB | 19939 | 23288 | -3349 | -17% | | | | | |

Notes - a CA / NCA adjustment is done after the growth as detailed in 5105963 TN28.
This explains why the CA s are higher and the NCA s lower.
The Business NCA is apportioned to the CA for OD

Source: PFMv3.8

Forecast Year Highway Demand

4.9.29. The forecast highway matrices are based on growth factors from TEMPRO v6.2. The following table compares the growth factors between TEMPRO and the model for the major cities along a HS2 corridor (defined as Birmingham, Liverpool and Manchester). A relatively close comparison is observed.

Table 12: Comparison between model and TEMPRO

| TEMPRO | 2026 | | 2036 | |
|-------------------|--------|-------------|--------|-------------|
| | Origin | Destination | Origin | Destination |
| Birmingham | 1.13 | 1.13 | 1.20 | 1.20 |
| Liverpool | 1.08 | 1.08 | 1.11 | 1.10 |
| Manchester | 1.12 | 1.12 | 1.17 | 1.17 |
| Model | 2026 | | 2036 | |
| | Origin | Destination | Origin | Destination |
| Birmingham | 1.12 | 1.12 | 1.18 | 1.18 |
| Liverpool | 1.10 | 1.10 | 1.14 | 1.14 |
| Manchester | 1.10 | 1.10 | 1.14 | 1.14 |

Source: PFMv3.8

4.9.30. No major issues were identified in the audit of the base year and forecast year demand matrices.

4.10. Rail and air fares

4.10.1. The rail fare matrices were sense checked against documented data for selected cells in the matrices. The selection of the cells (zone to zone fares) was based on the major HS2 catchment area. We also checked the application of growth factors from EDGE data, which was used to derive the forecast fare matrices.

4.10.2. The air fares were checked by journey purposes against documented air fares.

4.10.3. Base year rail fare matrices (mf141 to mf149) were extracted from the base year model, based on journey purposes and car ownership. Key zone pairs along the HS2 catchment area were selected and the weighted average fares were compared with documented fares. The application of the growth factors to derive forecast rail fare was also checked against the documented references. The average single air fare in the forecast years 2026 and 2036 were checked against the DfT’s forecast.

4.10.4. The following process was adopted:

- Zone pairs were selected for the fare checks (London to Birmingham, London to Leeds and London to Manchester).
- The base year zone to zone fares for the above zone pairs were extracted from the model based for each journey purpose.
- The modelled zone to zone fares were then weighted and averaged for all journey purposes and compared with documented rail fares.
- The forecast rail fare matrices in 2026 and 2036 were directly extracted from the model and the growth factor from 2026 to 2036 was calculated and then compared against documented values.
- The average single air fare in the forecast years 2026 and 2036 was also calculated and compared against DfT’s forecast.

4.10.5. The following Tables present show the modelled rail fares in the base year, extracted from PFMv3.8.

Table 13: Modelled rail fares (from London)

| Base Year Modelled Rail Fare (£) | | | | |
|---|-------------------|------------------|-----------------|--------------|
| From | To | Commuting | Business | Other |
| London | Birmingham | 21.23 | 28.50 | 25.49 |
| | Manchester | 30.64 | 43.98 | 41.37 |
| | Leeds | 11.05 | 49.02 | 44.51 |

Table 14: Modelled rail fares (to London)

| Base Year Modelled Rail Fare (£) | | | | |
|----------------------------------|--------|-----------|----------|-------|
| From | To | Commuting | Business | Other |
| Birmingham | London | 21.59 | 31.28 | 24.85 |
| Manchester | | 28.52 | 46.24 | 40.37 |
| Leeds | | 26.43 | 60.40 | 49.10 |

4.10.6. Table 15 and Table 16 present the journey purpose distribution used in the base year model.

Table 15: Journey purposes (from London)

| Journey Purpose (%) | | | | |
|---------------------|------------|-----------|----------|-------|
| From | To | Commuting | Business | Other |
| London | Birmingham | 15% | 56% | 29% |
| | Manchester | 5% | 64% | 31% |
| | Leeds | 4% | 56% | 40% |

Table 16: Journey purposes (to London)

| Journey Purpose (%) | | | | |
|---------------------|--------|-----------|----------|-------|
| From | To | Commuting | Business | Other |
| Birmingham | London | 15% | 57% | 30% |
| Manchester | | 5% | 63% | 31% |
| Leeds | | 4% | 56% | 40% |

4.10.7. Table 17 and Table 18 present the comparison of rail fares between the model and the documented values and identify some small⁷ inconsistencies between the two sources.

Table 17: Comparison of rail fares (from London)

| From | To | Estimated Rail Fare (£) | Documented Rail Fare (£) | Difference (%) |
|--------|------------|-------------------------|--------------------------|----------------|
| London | Birmingham | 26.55 | 26.24 | 1.2% |
| | Manchester | 42.49 | 42.03 | 1.1% |
| | Leeds | 45.72 | 45.73 | 0.0% |

Table 18: Comparison of rail fares (to London)

| From | To | Estimated Rail Fare (£) | Documented Rail Fare (£) | Difference (%) |
|------------|--------|-------------------------|--------------------------|----------------|
| Birmingham | London | 28.38 | 26.46 | 7.3% |
| Manchester | | 42.88 | 41.87 | 2.4% |
| Leeds | | 54.57 | 52.16 | 4.6% |

4.10.8. Table 19 below shows the comparison of rail fares growth factors implemented in the

⁷ We know that the overall forecasts produced by PFM are not very sensitive to the rail fare.

PLD model against the document growth factors. The factors are identical.

Table 19: Comparison of growth factors

| Growth Factors (From 2026 to 2036) | | |
|------------------------------------|------------------------|--------------------------|
| Journey Purpose | Modelled Growth Factor | Documented Growth Factor |
| Commuting | 1.1046 | 1.1046 |
| Business | 1.1046 | 1.1046 |
| Leisure | 1.1046 | 1.1046 |

4.10.9. Table 20 and Table 21 below show the comparison of air fares between the model and the documented values and identifies some inconsistencies between them. Our recommendation would be to either adjust the model values or update the documentation. However, we do not believe that such discrepancies would have a material impact on the overall forecasts produced by PFM.

Table 20: Comparison of forecast average air single fare, UKBD

| Forecast Average Single Domestic Business Fare (£) | | | |
|--|-------|----------|----------------|
| Year | Model | Document | Difference (%) |
| 2026 | 91.82 | 86.51 | 6.1% |
| 2036 | 84.04 | 86.07 | -2.4% |

Table 21: Comparison of forecast average air single fare, UKLD

| Forecast Average Single Domestic Leisure Fare (£) | | | |
|---|-------|----------|----------------|
| Year | Model | Document | Difference (%) |
| 2026 | 48.13 | 48.25 | -0.2% |
| 2036 | 48.30 | 49.43 | -2.3% |

4.11. PLD audit findings

4.11.1. We fully audited PLD within PFMv3.8 and PFM4.0 and the elements of the model that changed to form PFM4.1, PFMv4.2 and PFMv4.3.

4.11.2. Our findings from the audit of PLD can be summarised as follows:

- All the parameters used in the PLD were checked against those documented and validated;
- A number of issues in the preload process from PLD to PM/PN were identified in earlier versions of PLD, and were corrected in the latest version (PFMv4.3);
- A number of issues in the wormhole process from PLD to PS were identified in earlier versions of PLD and addressed in later versions. Four of these were tested as sensitivity test IR11 in PFMv4.2 and had an impact of reducing benefits by

£89M, or 0.3% of total benefits. No further audit of wormholes was undertaken as part of the audit of PFMv4.3;

- The crowded assignment process has been implemented correctly; and
- We found no issues with the implementation of the mode choice model.

4.11.3. No growth rates are applied to car occupancy rates in the PLD forecast year models. We understand that this is consistent with the methodology adopted by HS2 Ltd but note that WebTAG provides advice on future vehicle occupancy rates. Changing this assumption would have a minor impact on future highway congestion levels in the DM and DS scenarios and may lead to a minor increase in the potential decongestion benefits from HS2.

4.11.4. We note that a limitation of PLD methodology is the insensitivity of the model to changes in monetary costs. This does not affect the standard case analysis as HS2 services are assumed to have the same fares as standard rail services. However, it does support the use of separate modelling of commercial impacts and make the current modelling suite unsuitable for testing any premium fare regime, or differences in air fares or (highway) vehicle operating costs between the Do Minimum and Do Something scenarios.

4.11.5. We audited cap year processes in PFMv3.8 and PFMv4.2 and concluded that it had been implemented correctly. We have not re-audited the implementation of the cap year calculation for PFMv4.3 because we understand that it has not changed from v4.2.

4.11.6. Furthermore:

- We found no issues with demand segmentation;
- We identified a number of minor issues in the demand matrices; and,
- We identified a number of minor issues in the calculation of rail fares.

4.12. Implications of audit findings

4.12.1. We conclude from our audit that the PLD model within PFMv4.3 is implemented in line with the documented specification, with the exception of a few minor issues listed in section 4.11 above and a few other components that we have audited in earlier versions of PLD, but not the final version.

5. Regional PLANET Models

5.1. Introduction and context

- 5.1.1. The audit of the regional PLANET models focused on the implementation of the models. The objectives were to:
- Review the implementation of the control matrix set-up (for passing data between regional PLANET models and PLANET Long Distance (PLD));
 - Check procedures and application of wormholes and preloads;
 - Check zone correspondence process; and
 - Audit the crowded assignment process.

5.2. Approach

- 5.2.1. PLANET South (PS) was first developed in the 1980s. It has been used for many rail investment appraisals since then. Over time the use and continual development of the model has provided assurance of its quality. PLANET Midlands (PM) and PLANET North (PN) evolved from PS and have been implemented following a similar, though simpler, structure and method. The historic, evolving but well established nature of the regional models – particularly PLANET South (PS), meant that a ‘full audit’ of these models would not represent an efficient use of HS2 Ltd’s audit resource. Instead we have checked the consistent application of parameters across the three Regional models. Following the client workshop held on 12 November 2012, a ‘process tree’ was developed by the audit team documenting each process, the location of the file and its function.
- 5.2.2. The process tree identified that to complete a model run for a single model year/network, some 1,200 process files are called from *Run_all_#.bat*, comprising EMME macros, MS DOS batch files, a VB compiled executable file and Excel VBA macros. Input and report files are generally stored on the model folders supplemented by model specific parameters stored within EMME and the model executable files.
- 5.2.3. Many processes are duplicated across the model suite. To inform the audit (supplemented by documentation where this is available and current) each process file (with the exception of *planettransfer.exe*) used within the PLANET Regional and Transfer parts of the model suite was audited to the following degree:
- Ten key control matrix, wormhole and preload process files were audited line by line;
 - The inputs/outputs and key processes of a further 126 files were logged. Many of these occur numerous times through the model suite;
 - Each duplicate of the files in the two steps above occurring elsewhere in the model suite was compared (a ‘vertical’ check) using text comparison software for .mac/.bat files and for macro code within the VBA spreadsheet models, and by

comparing the 'internal' worksheets (i.e. those used within the macro rather than as inputs/outputs) using manual checking; and

- The first instance of each file within the control matrix and the inputs/outputs process has been compared with its 'sister' file in the model suite ('horizontal' check), and these vertical/horizontal checks are logged in the full process tree.

5.2.4. As part of understanding the behaviour of the regional PLANET models, we have run a series of diagnostic tests. This was not to comment on the sensitivity of the model which is out of scope for this audit. Rather, the tests were to point to areas where the model might not be behaving as expected, prompting a more detailed review of the parameters and processes concerned and how they feed through the model process to results.

5.2.5. By default the sections consider PS first; however, where our initial investigation of PLANET Midlands (PM) revealed particular information common to all models then this is provided first.

5.3. Control matrix set-up

5.3.1. The control matrix provides 'instruction' as to where the flows should be modelled (PLD, PS, PM, or PN) and ensures there is no demand that is represented in both PLD and the regional model. The correspondence of zoning systems is integral to this and is dealt with in the next section.

5.3.2. PLD is a multi-modal model with an emphasis on long distance trips. In PLD, a long distance trip is one whose origin and destination are not within the same 'Travel to Work area', or whose origin and destination are not in adjacent zones in PLD along the key corridors of the WCML, MML and ECML, or whose origin and destination fall wholly outside the regional PLANET model areas.

5.3.3. Local trips are modelled within the regional PLANET models. The application of the definition of local and strategic trips is therefore dependent on the coverage, size (and overlaps in the case of PLD) of the zoning systems and the definition of these trips as relating to particular distances is a useful guide.

5.3.4. The audit has focussed on a review of matrix processes as revealed within the file process tree and input/output files referenced within each process/macro and searched for within the demand modules of the databanks.

5.3.5. The inputs are model matrices and 'flag' matrices denoting presence in one model or another. No specific assumptions are included in this process.

5.3.6. Referencing between PLD and the Regional models is controlled by zone flags held within mf630 for PLD and text files of O-D flags (*PM_Control_Matrix.txt* for instance) for the regional PLANET models. The process is summarised in Figure 11.

Figure 11: Apply_Control_Matrix_PLD.mac process

Macro Name: Apply_Control_Matrix_PLD.mac. This Macro Calls sp_mattot.mac

The output produced by this Macro are:

Apply_Control_Matrix_PLD.prn, Check_MatTot_1_Pre_Control_Matrix.out,
Check_MatTot_2_Post_Ctrl_Mat.out and Check_MatTot_3_Post_Intrazonal.out

- The main aim of this macro is it batches the control matrix and applies it to the PLD demand matrices.
- Initially it deletes the existing output file from the folder to avoid over writing. (In this case it deletes Apply_Control_Matrix_PLD.prn)
- EMME database has nine Rail Matrices (mf11-mf19) and three Highway Matrices (mf21-mf23) which are used to run the PLD model.
- This Control Matrix Process consists of three stages:
 - Prepare Pre Control Matrices
 - Prepare Post Control Matrices
 - Remove inter-zonal trips from Post Control Matrices
- Pre Control Matrix: In this process it outputs the matrix total (of mf11-mf19 and mf21-mf23) into ms799 and saved into txt file called Check_MatTot_1_Pre_Control_Matrix.out
- Post Control Matrices: Multiplies the matrices (mf11- mf19 and mf21-mf23) with mf630 and re-saves them with the same name as mf11-mf19 and mf21-mf23 (mf630 matrix consist of OD trips of either 1 or 0, effectively applies mf630 as a mask for mf11-19 and mf21-23 where it deletes the trips which are not required by multiplying them with "0"). Outputs the new matrix total of (mf11- mf19 and mf21-mf23) into ms799 and saved into txt file called Check_MatTot_2_Post_Ctrl_Mat.out
- Remove intra-zonal trips: Multiplies the matrices (mf11- mf19 and mf21-mf23) with 1 if origin zone not equal to destination zone, multiplies the matrices (mf11- mf19 and mf21-mf23) with 0 if origin zone equal to destination zone (effectively deleting the trips with the same zone). (It uses (p.ne.q) equation which means when p not equal to q, where p is the origin and q is the destination. So if there are any trips which have same origin and destination then it will be multiplied with "0" or else it is "1"). Outputs the new matrix total of mf11- mf19 and mf21-mf23) into ms799 and saved into txt file Check_MatTot_3_Post_Intrazonal.out.
- Individual process in EMME checked manually and the numbers match.

PLANET Midlands

- 5.3.8. The EMME process (Apply_Control_Matrix_PM.mac) applies the flagging ('1/0') process matrix mf130 (or rather the text file PM_Control_Matrix.txt as described above, instances of which are compared and found to be identical in size to each matrix and updates that same matrix (i.e. "mf111 = mf111 * mf130") rather than creating a new matrix, thereby 'interrupting' the audit trail. As described above the equivalent process in Apply_Control_Matrix_PLD.mac applies mf630 matrix to remove intra-zonal trips from PLD, which also overwrites the input file.
- 5.3.9. The PM 'mf130' O-D flags were applied by the audit team to a matrix manually (using MS Access) and the resulting control matrix total was replicated. In the case of PM the post control matrices (as recorded in the outmf####. 311 files) were between 48% and 79% of their corresponding base matrix depending on user class. We conclude the variation is satisfactorily explained by different ranges of trip lengths for different user classes.
- 5.3.10. Checks of the correspondence of 'mf130' text file with the PM zoning system are described in Section 5.4.
- 5.3.11. Application of the PM control matrix generates no output files other than a summary report text file (Apply_Control_Matrix_PM.prn) and so the detailed results may not be independently audited without interruption of a model run (in a similar way the PLD .out files report progress at each stage as described above but intermediate matrices are not stored). It is a relatively straightforward process, however, and a check of the matrix totals in the regional PLANET model *.prn files confirmed that these corresponded with the mf* totals following application of the control matrix.
- 5.3.12. A number of redundant files (for instance matrixtotal_pm.prn generated by matrixtotal_pm.mac) contain values which do not correspond with matrix totals identified in the model runs. We recommend that such files are removed.

PLANET North

- 5.3.13. The process adopted is the same as in PLANET Midlands.

PLANET South

- 5.3.14. The application of the control matrix occurs within the Wormhole process in relation to transfer from PLD to PS. Effectively, the demand is modelled in both PLD and PS, which is different from the PM and PN approach.
- 5.3.15. For PS to PLD the process is equivalent to the other regional PLANET models.
- 5.3.16. Transfer of the demand between the matrices is undertaken within the demand modules of the relevant models.

5.4. Zone correspondence

- 5.4.1. In order to transfer demand between models with different zoning systems a process of corresponding between these zones is required. We have established how information is passed between PLD and the regional models (the relation with the control matrix process). In PS zones are grouped to facilitate the transfer of select link matrices from PLD to the PS zoning system. The impact on the control matrix approach is described above, and the relevant files for the process are investigated in Section 5.6.
- 5.4.2. Inputs (including those provided for this audit) include:
- Model matrices (various versions of which are stored in the model folders);
 - Control matrix files (PM and PN only);
 - D*net.in files (PS);
 - OS GR files (in the transfer model folders, files dated 2009);
 - GIS Data (received by the audit team 10 Dec 2012) with tables provided for each model defining zone number, and in the case of PS also a PS Marker and numerous additional columns (which are scenario results); and
 - Model documentation.

PLANET Midlands

- 5.4.3. The model suite OS Grid reference data of nodes contains 1,146 zones which is consistent with the documented method.
- 5.4.4. Rather than having 1/0 flags representing the full zoning system as in the case of PLD, the PM Control Matrix files include '1' flags only; these refer to zones numbered from 1 to 1,101, of which 1,047 zones are included within the Control correspondence process. These therefore represent a subset of the full zoning system to which the control matrix flagging is to be applied; we completed this task with the full '1/0' matrix from which the '1' flagged list was derived.
- 5.4.5. Mapping by the audit team of these files, compared with the zoning system supplied, indicated some inconsistencies in the north and west of the Midlands area and missing zones in the centre of the model area due to updates undertaken to the zone structure in the past without updating the corresponding GIS data. The GIS data plays no role in the forecasting process and we therefore regard this as a cosmetic issue. However, it will affect the display of geographically disaggregated model results. In our view, the transparency of the model would be improved if there was a single file/location storing all zone boundaries, centroids and names, stating all inter-relations.

PLANET North

- 5.4.6. The node grid reference data contain 961 nodes although the documentation indicates there are between 1,114 and 1,558 zones and some 850 nodes. The control matrices include reference to zones 1 – 923, of which 836 are included within the Control

correspondence process.

- 5.4.7. As with PLANET Midlands, we recommend the creation of a single file/location where all zone boundaries, centroids and names, stating all interrelations, are stored.

PLANET South

- 5.4.8. Documentation refers to 1,362 standard zones plus 19 international zones (1,381 in total) while the GIS data provided to us comprises 1,358 zones across four 'PS Marker' categories.
- 5.4.9. Equivalent node grid reference data are provided for PS in '*dmnet.in*' files within the model suite. These contained 1,392 zones, with 1,394 zones in the equivalent '*ds*' file reflecting two additional HS2-related dummy zones for the wormhole process.
- 5.4.10. The number of zones referenced within the models varies from scenario to scenario; this reflects the addition of dummy zones (as described above).
- 5.4.11. We compared one matrix (2037BusinessAPPS_060212.311) with the PS marker dataset; there were 13 zones in the trip matrix that did not appear in 'PS marker' dataset because the GIS dataset is superseded. As with PM and PN, we regard this as a cosmetic issue but we recommended the updating of the GIS data.
- 5.4.12. There are no equivalent 'control matrix' files for PS. This is because the PS model structure pre-dates more recent updates to PFM to incorporate PM and PN. As described earlier the process for PS is necessarily different.

5.5. Preloads

- 5.5.1. The preloads process allows local trips to be represented within PLD and strategic trips to be represented in the regional PLANET models, albeit by means of a different process for PS.
- 5.5.2. The matching of transit lines is undertaken using flags; these and the application of factors (described below) required checking. This was undertaken by line-by-line checks of the macro process. Diagnostic tests were also undertaken to confirm that these were operating correctly.
- 5.5.3. Particular attention was given to the spreadsheet models. These are summarised in Table 22; two files are stored in demand folders and which are redundant and we recommend that these are removed from subsequent model versions.

Table 22: Preload spreadsheet files

| File & Location | Status |
|---|----------|
| 01PLD\01Base\01base_assign\Preload_PLD_to_PM_DM.xls | used |
| 01PLD\01Base\01base_assign\Preload_PLD_to_PN_DM.xls | used |
| 01PLD\02Base\02base_assign\Preload_PLD_to_PM_DS.xls | used |
| 01PLD\02Base\02base_assign\Preload_PLD_to_PN_DS.xls | used |
| 01PLD\03Test\03test_assign\Preload_PLD_to_PM_DS.xls | used |
| 01PLD\03Test\03test_assign\Preload_PLD_to_PN_DS.xls | used |
| 01PLD\03Test\03test_demand\Preload_PLD_to_PM_DS.xls | not used |
| 01PLD\03Test\03test_demand\Preload_PLD_to_PN_DS.xls | not used |
| 02PS\01Base\Preload_PS_to_PLD_DM.xls | used |
| 02PS\02Test\Preload_PS_to_PLD_DS.xls | used |
| 03PM\PMAM\MidTest\02AssignDB\Preload_PM_to_PLD_DM.xls | used |
| 03PM\PMAM\MidTest\02AssignDB\Preload_PM_to_PLD_DS.xls | used |
| 04PN\PNAM\NorthTest\02AssignDB\Preload_PN_to_PLD_DM.xls | used |
| 04PN\PNAM\NorthTest\02AssignDB\Preload_PN_to_PLD_DS.xls | used |

5.5.4. The spreadsheet models comprise:

- A audit sheet – this confirms among other things that the calculations have been checked; These are not updated as part of a model run and so we recommend that following each model run the spreadsheet should be checked and updated accordingly;
- Input sheets – network data listing the eligible services and segment flows imported from the prior assignments;
- Internal sheets – used to store factors and to provide a basis for ‘corresponding’ between PLD/Regional datasets; and
- Output sheets – stored as worksheets to provide a record for that model run of the output saved as a .prn text file.

PLANET South to PLD

5.5.5. Local trips are preloaded using spreadsheet macros:

- Preload_PS_to_PLD_DM.xls
- Preload_PS_to_PLD_DS.xls

5.5.6. The process is summarised in Figure 12.

Figure 12: Preload_PS_to_PLD process

Auto_Open.

This macro loads data from two input files, runs preload macro, then saves self & output as prn and closes. The range imported from PS is line, i, j, 6*flow categories, headway, 'result'. The range from PLD is line, i,j,headway only.

CalcPreload_PS_PLD.

This macro:

Empties previously calculated columns in input 'PS_Segment' sheet;

Looks up PLD i or j node in internal 'node_matching' worksheet;

Then over-writes existing (imported) PS nodes with looked-up nodes, concatenates i-j and looks up link data from internal 'TTW_Area_PLD_Links' sheet;

Calculates:

- packet pre-load flow by summing for three user classes,
- Number of trains for each segment,
- Number of trains summed across packets
- Blueness segment⁸ ID (TOC, i,j), marker denoting unique TOC-i-j combinations
- 'Blueness' volume in i-j and j-i directions
- Blueness factor (ratio of ij/ji flow)

Counts rows from 'input2' sheet then clears yellow cells only in 'PLD_Segment' (output) sheet. Looks up PLD segment ID in 'internal 'line_matching' sheet, if no error looks up i-j concatenation in 'TTW_Area_PLD_Links' sheet and returns 1/0 marker (worksheet header = 'within TTW Area') – many hundreds of error values therefore returned as per line 261, and these are replaced as '0's in what is described as a temporary fix to enable the remainder of the macro to function;

Intermediate stage is overwritten (empties Input2 file data & segment marker from current (PLD_Segment) sheet and replaces with equivalent data for 'PLD Segment to Preload' links only. Then looks up 'PLD Packet data from Line_Matching IDs (i-j= dirn A, j-i = dirn B);

Looks up equivalent ID and headway data in PReg from internal worksheet and imported link data, then lookups flow from 'PLD_Segment_2'. Macro then looks up total flow (with flow factors for each direction) and link/segment train frequencies and calculate flow * PReg trains / segment trains in 'PS_Segment' sheet then summarises the preload data for export in 'PLD_Output';

Looks up total PS packet flow from 'PS_Segment' sheet for forward and reverse dirns;

Looks up period-to-day factors for each TOC (from internal 'Period to all day factors' sheet);

If there is a Dirn A flow only use this, or if Dirn A+B use average of these, apply factors to them and divide by number of trains on segment to get average preloaded flow.

⁸ A Moira1/2 definition – though not used in final preload calculation

- 5.5.7. Within the spreadsheets cross-referencing is done between equivalent lines (with most having the same i-j nodes in both models), segments and packets in PS and PLD models. This is undertaken using 'lookup' functions within the spreadsheet model code.
- 5.5.8. Formulae are overwritten during the macro by pasted values to save processing time and we recommend that efficiencies be incorporated into the model code – these would typically result in hard-coded values being recorded but crucially a clearer audit trail would be maintained.
- 5.5.9. The following diagnostic tests were undertaken:
- **Test 1** – Test application of factors. TOC Factors were set to 50%. Result: Preload results exactly 50% of original values. **Pass**
 - **Test 2** – Test Packet. PS Segment flows were set to zero with the exception of line CH407D / 765 / 955. Result: preload exported for all PLD Packets corresponding to this PS Segment (PSCH01A/B). The total PLD segment flow is 238 in each direction (1.6 times the imported segment flow) which when summed in both directions matches the peak/PLD factor of 3.2. The source for the factor itself requires to be confirmed as described in Assumptions above. **Pass.**
 - **Test 3** – Test Node & line matching lookups. PS Segment flows were set to zero with the exception of line SW102D / 593 / 635. Result: Converted segment flow nodes to PLD nodes. No preloaded flow exported as line-i-j is not in PLD/PS line matching area. **Pass**

PLD to PLANET South

- 5.5.10. See section 5.6.

PLANET Midlands to PLD

- 5.5.11. Strategic trips are preloaded using spreadsheet macros:
- Preload_PM_to_PLD_DM.xls
 - Preload_PM_to_PLD_DS.xls
- 5.5.12. The model code was compared with the equivalent PS to PLD model. The process adopted is the same; differences in code are due to the larger numbers of PS transit line segments (around 50,000 in PS compared with around 5,000 in PM) requiring pasting of values at more frequent intervals, and the absence of a node lookup function in the PM and PN models.

PLD to PLANET Midlands and PLANET North

- 5.5.13. Local trips are preloaded using spreadsheet macros (with equivalent ones for PN):
- Preload_PLD_to_PM_DM.xls
 - Preload_PLD_to_PM_DS.xls

5.5.14. Unlike Regional to PLD preloads, there are no node lookups in this macro and no preload in the reverse i/j or j/i direction is calculated. The process is summarised in Figure 13.

Figure 13: Preload_PLD to PM process

Auto_Open

This macro loads data from two import files, runs preload macro, then saves self & output as prn and closes. The range imported from PLD is line, i, j, 6*flow categories, headway, 'result' and an empty column. The range from PReg is line, i,j,headway only.

CalcPreload.

This macro looks up segment ID for PLD links from a number of internal worksheets. It then sums flows, headways for each segment, copies to 'PLD_Segment_2' sheet. It then looks up equivalent ID and headway data in PReg from an internal worksheet and from imported link data, then lookups flow from 'PLD_Segment_2'. The macro then looks up total flow (with flow factors for each direction) and link/segment train frequencies and calculate flow * PReg trains / segment trains in 'PM_Segment' sheet then summarises this preload data for export in 'PM_Output'

5.5.15. The following diagnostic tests were undertaken:

- **Test 1a** – Test application of factors. U & D⁹ factors were doubled to 0.68 and 0.1 respectively; – Factor unchanged. Result: Preloads exported were 200% of original values for U/D segments. **Pass**
- **Test 2** – Test Packets. PLD Segment flow was set to zero with exception of line AW105-94689-94690 (total segment flow 596). Headway in PLD is 192 minutes, that in PM is 60 (taking into account model time periods the equivalent headway factor is 3.2, which is consistent with the regional PLANET model to PLD transfer approach. **Pass**
- **Test 3** – Test line matching lookup. PLD Segment flows were set to zero with the exception of line AW105-94690-94387 (total segment flow 596). Result: No PM Segment flow calculated as i-j falls outside TTW / PM boundary area. **Pass**

5.5.16. We have compared the outputs for PM preloads and confirm they are consistent (i.e. they generate preloads for the same links) and stable (with the R-squared measure comparing the “goodness of fit” of the first and last model iteration of 99% in the case of both the 2026/27 DM and DS models).

5.5.17. The model documentation identified that the mode choice elasticity-based approach

⁹ Up and Down – referring to the service direction.

could generate very large time savings and hence negative transit flows as a result of network miscoding or changes in GJT. However, we found no negative transit volumes in the DM and DS segment flow files.

- 5.5.18. Maps of PM and PN preload.prn files were generated by the audit team (Figure 14 and Figure 15 respectively). These display the complete set of rail links and stations coded in the models, with preloads indicated by the blue bars along the links. The thickness of the bar on either side of the link indicates the passenger volume by direction. As PM and PN are AM peak models only, there is an (expected) imbalance in flows along the links by direction.
- 5.5.19. This shows that flows represent consistent preloaded flows along key links, with transfer between the models at consistent locations. More detailed checks of the particular segments on which the preloads were loaded have been undertaken as part of the audit of the standard case network coding.

Figure 14: Preload PLD to PM outputs

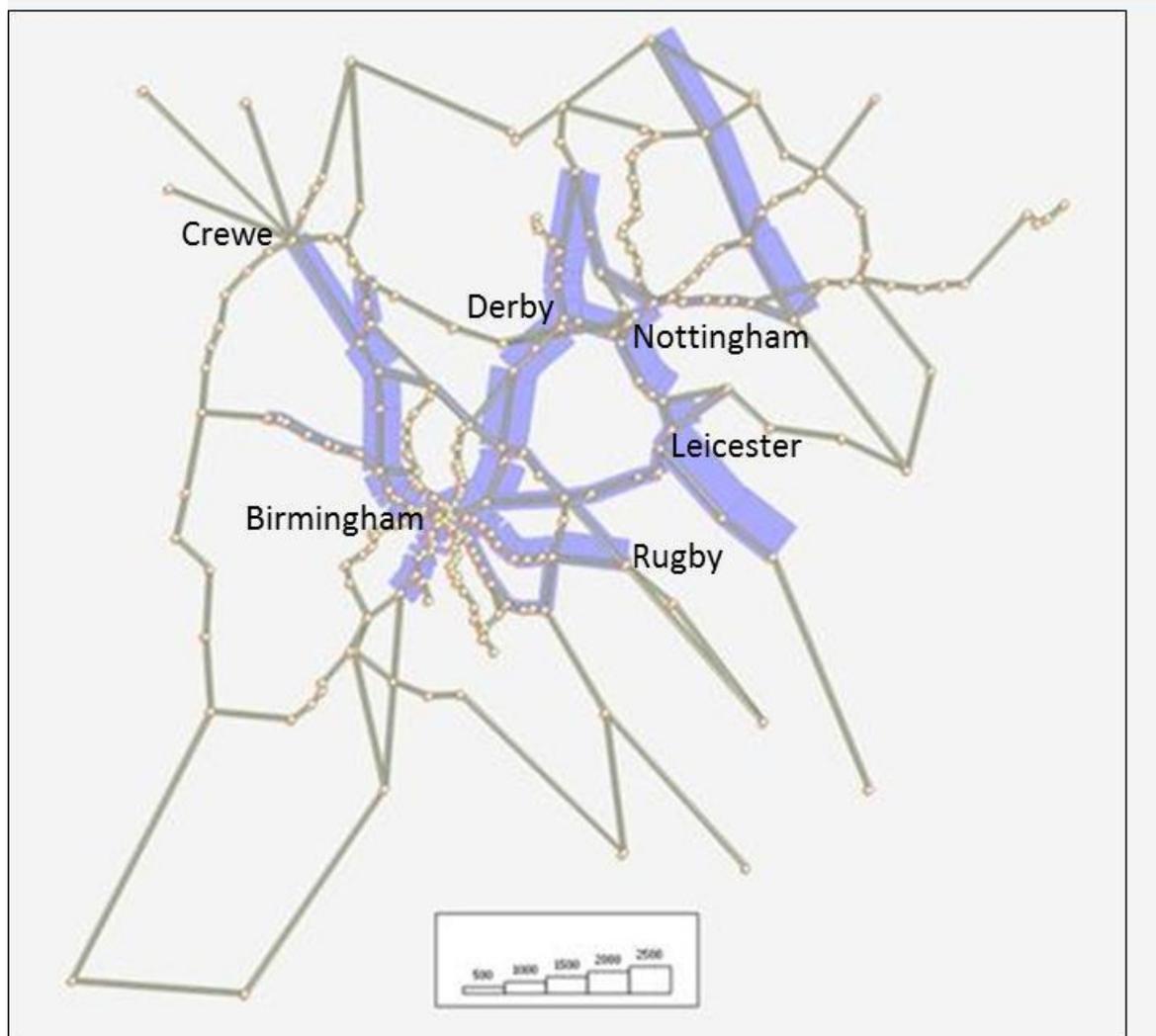
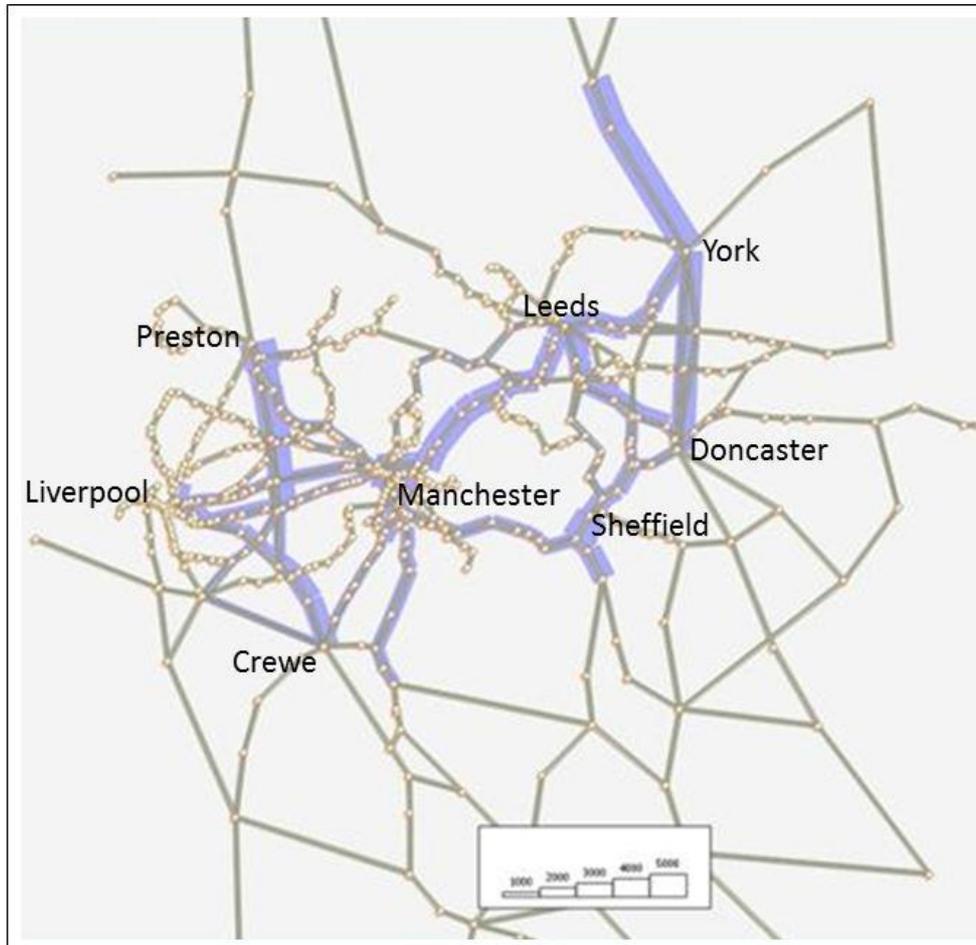


Figure 15: Preload PLD to PN outputs



5.6. Wormholes

- 5.6.1. The wormhole process is only applied to PS. It extracts demand from PLD to convert all-day PLD flows crossing a PS cordon to peak period demand for use in PS. Matrices of PLD demand are extracted for each link/direction across the cordon; PS matrices are then updated with this demand using dummy zones to represent the links in question.
- 5.6.2. Although already covered in section 4.5 from the point of view of PLD, the process has also been reviewed in detail as part of the PS audit.
- 5.6.3. The wormhole process is called during each iteration of the PS model (twice in the DM using the same macros) and three times in the DS (using some filename variants e.g. *hs, *hs2). Output files are over-written by each instance of the process.
- 5.6.4. Cordon_links and cordon_links_hs in the PS model define the screen line links to which the wormhole process is applied.
- 5.6.5. As the zone systems differ between PLD and PS, the demand is exported using zone groups which can then be equivalenced and disaggregated in PS where appropriate. The trip end outside the PS model area is given a unique zone group, which is

represented as a specific additional zone in PS. The trip end within the PS model area is exported using a zone group (gs*) where each PLD zone has a unique definition (gs01 to gs235).

- 5.6.6. All-day to period factors applied to each link vary widely by links/directions. This is due to variations in validation between models as well as variations in actual peak/all day flows. They were derived for base year models (using a subset of operator data) and applied to future year operators including HS2.
- 5.6.7. The wormhole process is described in Figure 16.

Figure 16: Wormhole DM process

- PSMSselect.mac
 - Calls HS2select.mac
 - Defines assignment parameters in a scalar matrix as boarding time, waiting time factor, waiting time weight, auxiliary transit time weight nca, boarding time weight, auxiliary transit time weight ca – commuting, auxiliary transit time weight ca – business and auxiliary transit time weight ca – other.
 - Then it saves the values of the scalar matrix in the text file.
 - To run a select link analysis, EMME performs the process in a new assignment and to do the SL it copies the crowding factors of the main assignment into the SL assignment.
 - Then it runs the fixed demand transit assignment. Then it reads the text file which saved the user defined effective head ways (saves it in @srel2), Boarding time, boarding time, wait time factor, wait time factor, wait time weight, auxiliary transit time, boarding time weight factor applied;
 - Then it runs the SL process and saved the demand of that process into a matrix.
 - This process is repeated for different user classes and each time it is saved as a matrix with different name.
 - This process is carried out on 10 links (in each direction) and each time the demand is saved as a new full matrix.
 - Calls HS2batch.mac
 - It then adds all the demand for different user classes and multiplies each group by specific factors to convert from 24 hour PLD flow to 3 hour PS flow.
 - Then exports it into a new matrix mf195. Later it aggregates the origins and destination using the zone aggregation codes which already define the zones. And it is saved as dmd%1%.314.

5.6.8. The process is the same for DS, but with additional select link analysis performed for HS2 links. The macros which are related to these processes in DS are:

- scencopy.mac
- PSMSelect_hs.mac
- HS2Select.mac
- HS2batch.mac
- HS2Select_hs.mac
- HS2batch_hs_out.mac
- HS2batch_hs_in.mac
- HS2batch_hsOOC_out.mac
- HS2batch_hsOOC_in.mac
- HS2batch_hsEUS_out.mac
- HS2batch_hsEUS_in.mac

5.6.9. EMME files are transferred using *scencopy* to create new scenarios (i.e. in the first instance it copies scenario 15000 into Scenario 99999 to commence calculations). Record/text files (.prn files etc.) are not copied across the model structure though, instead they are overwritten at each iteration thereby losing the audit trail. Because of this '*PSImport.prn*' (generated by *psimport.mac*) is stored on the project folders only once for each of the DM and DS.

5.7. Crowded assignment process

5.7.1. The assignment in the three regional PLANET models, as well as in PLANET Long Distance (PLD), uses a crowding algorithm, whereby a time penalty is applied to the uncrowded in-vehicle time based on the relationship between link segment demand and available seated and standing capacity.

5.7.2. While the formulation of the algorithm differs somewhat for PLD, it is identical for the three regional PLANET models as far as rail modes are concerned. However, PS has additional modes to consider (London Underground, Docklands Light Railway and Croydon Tramlink as well as a central London bus network).

5.7.3. The audit of the crowded assignment covered a review of the formulae implemented in EMME macros and of the parameters used in the calculation. We checked:

- The set-up of the assignment process in the macro, including the definition of wait time and the specification of weightings applied to different journey elements as well as the application of the boarding penalty;
- The definition of the transit time functions (ttf) which specify how journey time is calculated from distance, speed or link time information within the EMME databank;

- The correct coding of the key parameters used by the function including the uncrowded link segment time;
 - The parameters and formulae used to calculate the crowding penalty in the assignment process; and
 - The process used to calculate and report crowded and uncrowded times for appraisal purposes.
- 5.7.4. The inputs to the calculation of crowding within the regional models are:
- Parameters determining the crowding penalty to be applied to seated and standing passengers at seated and total capacity by journey purpose and trip type category;
 - Values of standard deviation to be applied to calculate variance in passenger load over the modelled time period, by trip type; and,
 - Passenger demand and service capacity over the time period modelled, by transit segment.
- 5.7.5. The methodology underpinning the crowded assignment process is detailed in the document *5105963 TN10 PDFH5 Crowding Factors v3.pdf*. It has been recently updated to include updates contained in Passenger Demand Forecasting Handbook (PDFH) 5.
- 5.7.6. The following paragraphs extracted from *5105963 TN 10 PDFH5 Crowding Factors v3.pdf* summarise the methodology and assumptions.
- Crowding is modelled in PLANET by applying a crowding 'penalty', in the form of a multiplicative factor, to passengers' in-vehicle time (IVT), with separate factors for seated and standing passengers as the load factor increases. These factors are taken from PDFH and are dependent on the journey purpose (business, leisure, commuting) and the type of trip (London inter-urban, London suburban, Non-London).*
- Because the PLANET models are frequency based, depicting a 3 hour AM Peak average, and the factors given in PDFH are train specific, the two are not directly compatible. To overcome this, the crowding factors are adjusted, based on the probability that a train will be more or less crowded than the average levels which are shown in the model.*
- 5.7.7. The aim of the audit was primarily to check that the crowded assignment within the regional PLANET models has been implemented in accordance with the PDFH 5 methodology described in *5105963 TN 10 PDFH5 Crowding Factors v3.pdf*, although the audit has not been exclusively limited to this aim.
- 5.7.8. A more generic approach has also been applied to understand and check the implementation of the entire public transport assignment (of which the modelling of crowding is a part) through line by line interrogation of the EMME macro language within each of the regional models.

- 5.7.9. A separate investigation was undertaken to ascertain whether there are any differences in the assignment macros in PM and PN, between the “base” and “test” assignments and with the full network scenarios.
- 5.7.10. This found the crowding algorithm implemented as specified. There are some differences with the PS procedure which relate to documented differences in the method in which these different assignments are performed e.g. PM and PN exclude long-distance trips and include preload flows in the demand volumes. There are also differences in the way in which the assignments are called, the way they are set up and in the reporting of results.
- 5.7.11. There are no differences in the implementation of the public transport assignment, except for those differences which are expected based on the differences in methodology between each regional model. As a result of this exercise, no additional checks of the public transport assignment were required beyond that undertaken of the PLANET South model.
- 5.7.12. One key aspect of the audit was a check of the crowded assignment methodology against that specified in PDFH 5.
- 5.7.13. Using the document *5105963 TN 10 PDFH5 Crowding Factors v3.pdf*, a checklist was drawn up of the key aspects of the crowded assignment methodology used in PFMv3.8. Most of these revolve around the actual calculation of the crowding penalty contained in lines 690 to 708 of *equilibrium_2009.mac* and have been audited in the following way:
- Confirmation that the equation¹⁰ given in section 3.2.1 of *5105963 TN 10 PDFH5 Crowding Factors v3.pdf* has been correctly implemented in lines 690 to 708 of *equilibrium_2009.mac*;
 - Replication of the actual calculation of the crowding penalty in lines 690 to 708 of *equilibrium_2009.mac* in a spreadsheet;
 - Development of another spreadsheet to calculate the crowding penalty excluding the probability of passenger load variance i.e. the average crowding penalty over the AM Peak. The following differences were found when comparing the modelled crowding penalties with the average crowding penalties thus confirming that the inclusion of passenger load variance gives realistic changes in the crowding penalty;
 - Greater variation in the crowding penalty the lower the standing capacity;

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$$C_{r,p}(\bar{x}) = \frac{1}{\sqrt{2\pi\delta_r^2}} \int_{-\infty}^{\alpha_{r,p}} e^{-\frac{(x-\bar{x})^2}{2\delta_r^2}} dx + \frac{1}{\sqrt{2\pi\delta_r^2}} \int_{\alpha_{r,p}}^1 (A_{r,p} + B_{r,p}x) e^{-\frac{(x-\bar{x})^2}{2\delta_r^2}} dx + \frac{1}{\sqrt{2\pi\delta_r^2}} \int_1^{\infty} (C_{r,p} + D_{r,p}x) e^{-\frac{(x-\bar{x})^2}{2\delta_r^2}} dx$$

- Greater variation in the crowding penalty the higher the load factor between 0 and 1 – due to the ‘jump’ in the size of the crowding penalty applied from a situation where seats are not fully utilised to a situation where seats are fully utilised and standing occurs
- Declining variation in the crowding penalty where load factors are greater than 1 – due to the lower increases in the crowding penalty between situations where seats are fully utilised but the level of standing varies
- Least variation on Inter Urban services, followed by Suburban services and Non-London services respectively – due to the size of the relative standard deviations applied to each TOC Group respectively within the modelling (Inter Urban = 0.3, Suburban = 0.4, Regional = 0.5). However, these values differ from those documented (Inter Urban = 0.15, Suburban = 0.2, Regional = 0.25).

5.7.14. The audit found the crowding algorithm implemented correctly – in particular:

- Separate crowding penalties applied to seated and standing passengers;
- Crowding is measured in terms of seat utilisation (up to 100% seat utilisation) above which it is measured in terms of passengers standing per square meter;
- Total capacity of a train assumes 2.5 standing passengers per square meter. This assumption is applied equally to all rolling stock types in PFM;
- Crowding factors assumed (when excluding the probability equation);
- Crowding penalties are correctly weighted by the proportion of seated and standing passengers; and,
- The probability of the level of crowding on a particular train being higher or lower than the average value calculated by the model is correctly calculated.

5.7.15. In addition, the following checklist items were audited separately by checking the relevant parts of the assignment macros.

5.7.16. Passengers’ uncrowded in-vehicle time is hardcoded into the ‘us1’ attribute within the public transport service coding which is ‘batched’ in to the model as part of a full HS2 model run (in text format). As there is no calculation which is performed to attain this value, it is not possible to check that it represents passengers’ in-vehicle time rather than value of time. However, through dialogue with the model developers it was confirmed that it does represent passengers’ in-vehicle time.

5.7.17. The crowding penalty is applied as a multiplicative factor to uncrowded in-vehicle time ($us1 * us2$). The evidence for this is function *ft2* in module 4.14 of the model, this being the transit time function used in assignment for all rail modes (refer to line 67 of *setup_2009.mac*).

5.7.18. Lines 118 to 162 of *setup_2009.mac* show these parameters are equivalent except the lower crowd limit which is not explicitly defined in Table 3. However, the lower crowd limit in *setup_2009.mac* is within the boundaries set out in Table 3 i.e. between 70% and 80% for suburban and regional services (the lower crowd limit in these instances is

75%) and between 60% and 70% for Intercity services (the lower crowd limit in this instance is 0.65). Through further dialogue with the model developers it was confirmed that PDFH5 only defines the lower crowd limit at 10% intervals of load factor so an assumption was made to take the lower crowd limit as the mid-point between these intervals.

- 5.7.19. The parameters are identical for each journey purpose which is in accordance with TN 10.
- 5.7.20. The crowded assignment algorithm is an internally complete, free-standing module.
- 5.7.21. The outputs of the crowded assignment algorithm are the crowding penalties applied to the in-vehicle time during the assignment. These have been audited as part of checking the calculations as highlighted above.
- 5.7.22. In general, the sequence of commands which are applied within the assignment macros are logical for the purpose of performing a public transport crowded assignment, including the definition of parameters and assumptions prior to, and the saving/reporting of results after assignment.

5.8. Demand Matrices

- 5.8.1. Base and future year demand matrices were received for PM, PN and PS. The forecast years provided were 2016, 2021, 2026, 2031, 2036, 2041 and 2046. Only the 2026 and 2046 future matrices were reviewed, as these were deemed sufficient to verify and analyse the growth processes. The matrices were received after the main audit of PFMv3.8 but before receipt of later model versions that implemented these matrices. Thus 2046 was chosen as a suitable future year before the cap year that was eventually implemented in later model versions was known. This does not affect the validity of any of the analysis or conclusions in this section.
- 5.8.2. A series of EMME macros was also provided. The purpose of these macros within the EMME model was to carry out additional factoring of the base matrices to produce the future matrices.
- 5.8.3. Extensive documentation has been provided about the PLANET Long Distance (PLD), PLANET South (PS), PLANET Midlands (PM) and PLANET North (PN) models at a strategic level. Throughout the reports, sufficient information is provided about how the models interact with each other, and how they model future rail passenger growth.

PM/PN Models

- 5.8.4. The PN and PM models operate in a similar way, tabulating demand on an origin destination (OD) basis and dividing the demand into three categories according to purpose (Business, Leisure and Commuting) and then creating another subdivision into Car Available (CA) commuters and No Car Available (NCA) households. These six classes are treated separately in the model, and each has its own distinct trip matrix for base and future years. Both PM and PN model demand in the AM peak between 0700

and 1000 hours.

- 5.8.5. The models essentially operate with two major data elements: the passenger demand matrices that are developed from LENNON data, and the network of public transport services that these demands are assigned to. The documentation adequately describes the process of producing base OD matrices from the raw unprocessed data (and the difficulties associated with this process).

PS Model

- 5.8.6. The PS model generates network demand on an Attraction-Production (AP) or Production-Attraction (PA) basis unlike the PM and PN matrices (which use origin-destination). It also adopts six distinct base matrices by partitioning trips into Business, Leisure and Commuting trips and then partitioning again according to the AP or PA criterion. Like the PM and PN models, PS models the demand during the AM peak between 0700 and 1000 hours.
- 5.8.7. Similarly to the PN and PM models, the limitations of the LENNON data were well documented. These relate to the unavailability of time of travel information for season tickets and the use of multi-modal tickets in some urban areas. This is of increased significance in the PS model, where more processing was required to produce the base matrices due to the high prevalence of Travelcards within the London area. Here, NRTS surveys and RODS data were used to augment the LENNON data.

Growth Factors

- 5.8.8. In all three of the regional PS, PM and PN matrices, growth in demand was attributed to two sources: exogenous growth in demand driven by factors external to the matrix, and endogenous growth in demand from within the model.
- 5.8.9. Exogenous growth was modelled by a process using the Department for Transport's (DfT's) Exogenous Demand Growth Estimation (EDGE) tool.
- 5.8.10. For the PM and PN models, separate growth rate matrices are produced for Business, Leisure and Commuting classes. For the PS model, PA information is also included, resulting in six distinct growth matrices classified by trip purpose and whether it was an AP or PA trip.
- 5.8.11. Endogenous growth is caused by changes in rail supply or road congestion and is controlled by the parameters of the model.
- 5.8.12. Our audit was concerned with the resulting future year matrices that are generated by applying these growth factors.

Matrices analysed

- 5.8.13. We have only commented on the matrices themselves, rather than the processes and methods used to generate the original base year matrices and growth factors. In this

review we have:

- Reviewed the differences between the base and future matrices;
- Reviewed the way in which growth has been applied; and
- Commented on the growth rates and whether these seem reasonable.

5.8.14. The matrices are structured into three trip purposes:

- Business
- Commuting
- Leisure

5.8.15. For the PM and PN models, matrices are further segmented into:

- Car Available
- No Car Available.

5.8.16. The PS matrices are segmented into production and attraction:

- PA
- AP

5.8.17. Thus, there are six matrices for each model for each year. The matrices we have analysed are summarised in Table 23.

Table 23: Matrices reviewed

| Model | Purpose | Type | Base | 2026 | 2046 |
|-------|----------|------|--------------------|------------------------|------------------------|
| PM | Business | CA | PM2010BusinessCA | 2026BusinessCA130412 | 2046BusinessCA130412 |
| | | NCA | PM2010BusinessNCA | 2026BusinessNCA130412 | 2046BusinessNCA130412 |
| | Commuter | CA | PM2010CommutingCA | 2026CommutingCA130412 | 2046CommutingCA130412 |
| | | NCA | PM2010CommutingNCA | 2026CommutingNCA130412 | 2046CommutingNCA130412 |
| | Leisure | CA | PM2010LeisureCA | 2026LeisureCA130412 | 2046LeisureCA130412 |
| | | NCA | PM2010LeisureNCA | 2026LeisureNCA130412 | 2046LeisureNCA130412 |
| PN | Business | CA | PN2010BusinessCA | 2026BusinessAP060412 | 2046BusinessCA130412 |
| | | NCA | PN2010BusinessNCA | 2026BusinessPA060412 | 2046BusinessNCA130412 |
| | Commuter | CA | PN2010CommutingCA | 2026CommutingAP060412 | 2046CommutingCA130412 |
| | | NCA | PN2010CommutingNCA | 2026CommutingPA060412 | 2046CommutingNCA130412 |
| | Leisure | CA | PN2010LeisureCA | 2026LeisureAP060412 | 2046LeisureCA130412 |
| | | NCA | PN2010LeisureNCA | 2026LeisurePA060412 | 2046LeisureNCA130412 |
| PS | Business | AP | PS2010BusinessAP | 2026BusinessAP060412 | 2046BusinessAP060412 |
| | | PA | PS2010BusinessPA | 2026BusinessPA060412 | 2046BusinessPA060412 |
| | Commuter | AP | PS2010CommutingAP | 2026CommutingAP060412 | 2046CommutingAP060412 |
| | | PA | PS2010CommutingPA | 2026CommutingPA060412 | 2046CommutingPA060412 |
| | Leisure | AP | PS2010LeisureAP | 2026LeisureAP060412 | 2046LeisureAP060412 |
| | | PA | PS2010LeisurePA | 2026LeisurePA060412 | 2046LeisurePA060412 |

5.8.18. Growth rate matrices were also supplied for each of the six segmentations as above. Separate growth rates were received for the PS AP and PA matrices. For PM and PN, the same growth matrices applied to the CA and NCA matrices as shown in Table 24.

Table 24: Growth rate matrices reviewed

| Model | Purpose | Type | 2026 | 2046 |
|-------|----------|--------|-------------|-------------|
| PM | Business | CA/NCA | PM_2026_Bus | PM_2046_Bus |
| | Commuter | CA/NCA | PM_2026_Com | PM_2046_Com |
| | Leisure | CA/NCA | PM_2026_Lei | PM_2046_Lei |
| PN | Business | CA/NCA | PN_2026_Bus | PN_2046_Bus |
| | Commuter | CA/NCA | PN_2026_Com | PN_2046_Com |
| | Leisure | CA/NCA | PN_2026_Lei | PN_2046_Lei |
| PS | Business | AP | PS_2026_Bus | PS_2046_Bus |
| | Commuter | AP | PS_2026_Com | PS_2046_Com |
| | Leisure | AP | PS_2026_Lei | PS_2046_Lei |
| | Business | PA | PS_2026_Bus | PS_2046_Bus |
| | Commuter | PA | PS_2026_Com | PS_2046_Com |
| | Leisure | PA | PS_2026_Lei | PS_2046_Lei |

Data processing methodology

5.8.19. Matrices were processed using the statistical analysis package Stata. Stata enabled

the efficient and automated production of statistics for the numerous large matrices produced for the PLANET Regional Models.

- 5.8.20. Results were also analysed visually using GIS mapping. This allowed an understanding of the geographical distribution of results.

Growth Rate Analysis Methodology

- 5.8.21. The exogenous growth rates were applied differently by each model. The sections below outline the growth process for each of the respective models. The verification process was developed after inspection of the macros provided.
- 5.8.22. The production of the future base matrices from the base matrices from PM and PN models include a step to account for growth in car ownership. This is modelled by taking a fraction of the NCA trips from each origin-destination cell within the NCA matrices and adding it to the corresponding origin-destination cell in the CA matrix (see Equation 1).

$$\begin{bmatrix} 1 & NCA\ factor \\ 0 & 1 - NCA\ factor \end{bmatrix} * \left(\begin{bmatrix} CA\ base \\ NCA\ base \end{bmatrix} * \begin{bmatrix} Growth\ Factor\ CA \\ Growth\ Factor\ NCA \end{bmatrix} \right) = \begin{bmatrix} Future\ CA \\ Future\ NCA \end{bmatrix}$$

Equation 1: PM/PN Growth Process

- 5.8.23. The NCA factors are contained within additional matrices provided and are specified on an origin basis, with a single factor applied to all destinations corresponding to these origins.
- 5.8.24. The factors are derived from the car availability growth input used in the economic forecasting, based on TEMPRO forecasts of car ownership and households. The factors are required to adjust the proportion of car available demand in the future year.
- 5.8.25. It should be noted that due to this transfer of demand between CA and NCA matrices, the number of non-zero cells in the CA matrices increased due to the NCA matrices containing non-zero origin-destination pairs which did not appear in the CA matrices.
- 5.8.26. The PS model partitions trips according to AP or PA rather than the NCA or CA used by the PM and PN models. Hence, no adjustments were needed to account for the change in car ownership proportions over time.
- 5.8.27. However, the PS model contains several airports which have distinctly different growth patterns from non-airport zones. To account for differences in airport growth rates, an extra set of adjustment factors was applied to trips that had an origin or destination in an airport zone. The process is summarised in Equation 2.

$$Base * Growth\ Factors * Airport\ Growth\ Factors = Future$$

Equation 2: PS Growth Process

- 5.8.28. These Airport Growth Factors are provided by DfT as one of the driver inputs to the economic forecasting undertaken in EDGE.

Comparison between base year and future matrices

- 5.8.29. Table 25 provides a summary of base year and future matrix totals and the number of non-zero sells in each matrix.
- 5.8.30. The numbers of non-zero cells in the base case and future matrices were analysed to check for spurious trips being added to the future matrices. The PS, PM NCA and PN NCA matrices should have the same number of non-zero values in the base and future matrices, as only multiplicative growth factors were applied to the matrices. However, the PM and PN CA matrices also have an additive factor applied to them. This means that they may have differing numbers of non-zero cells in the base and future matrices.
- 5.8.31. It should be noted:
- The number of non-zero cells is only a small fraction of the total matrix. The matrices are all quite sparsely populated, especially the PM and PN matrices.
 - The number of non-zero cells in the PS, PM NCA and PN NCA matrices are identical between years, as anticipated by the process.
 - The number of non-zero cells in the PM and PN CA matrices is always lower in the base than in the future year matrices, reflecting growth in car ownership.

Table 25: Summary of matrices

| Model | Purpose | Type | Total matrix cells | Non-Zero Cells | | | Sum of Trips | | |
|-------|-----------|------|--------------------|----------------|---------|---------|--------------|-----------|-----------|
| | | | | Base | 2026 | 2046 | Base | 2026 | 2046 |
| PM | Business | CA | 1,364,224 | 7,167 | 8,349 | 8,349 | 10,374 | 14,208 | 18,773 |
| | | NCA | 1,364,224 | 1,802 | 1,802 | 1,802 | 1,572 | 1,828 | 2,249 |
| | Commuting | CA | 1,364,224 | 11,463 | 13,490 | 13,490 | 51,130 | 70,130 | 94,341 |
| | | NCA | 1,364,224 | 3,566 | 3,566 | 3,566 | 9,818 | 11,286 | 13,782 |
| | Leisure | CA | 1,364,224 | 6,751 | 7,887 | 7,887 | 9,299 | 12,844 | 17,112 |
| | | NCA | 1,364,224 | 1,824 | 1,824 | 1,824 | 1,547 | 1,797 | 2,193 |
| PN | Business | CA | 923,521 | 14,202 | 16,945 | 16,945 | 23,638 | 32,212 | 45,621 |
| | | NCA | 923,521 | 4,826 | 4,826 | 4,826 | 5,168 | 5,793 | 7,145 |
| | Commuting | CA | 923,521 | 21,148 | 24,900 | 24,900 | 74,211 | 98,950 | 134,259 |
| | | NCA | 923,521 | 7,584 | 7,584 | 7,584 | 18,757 | 20,618 | 24,749 |
| | Leisure | CA | 923,521 | 13,410 | 16,006 | 16,006 | 19,240 | 26,527 | 38,056 |
| | | NCA | 923,521 | 4,650 | 4,650 | 4,650 | 4,326 | 4,915 | 6,137 |
| PS | Business | AP | 1,937,664 | 31,800 | 31,800 | 31,800 | 7,945 | 11,830 | 17,129 |
| | | PA | 1,937,664 | 198,429 | 198,429 | 198,429 | 120,765 | 182,823 | 262,522 |
| | Commuting | AP | 1,937,664 | 82,024 | 82,024 | 82,024 | 26,542 | 38,658 | 50,874 |
| | | PA | 1,937,664 | 259,253 | 259,253 | 259,253 | 1,261,296 | 1,873,750 | 2,497,730 |
| | Leisure | AP | 1,937,664 | 20,367 | 20,367 | 20,367 | 15,257 | 22,446 | 32,519 |
| | | PA | 1,937,664 | 182,783 | 182,783 | 182,783 | 127,326 | 195,779 | 281,594 |

- 5.8.32. There are a number of cells in the trip matrices with negative trip values. With one minor exception, these are confined to the PS model. Trip matrices should not normally contain negative values. In discussion with the model developers, it became clear that this was not an issue with the matrix processing calculations but that some negative values had been fed through from the LENNON database that contains a small number of negative values of tickets. We recommend that such values should be filtered out in any future matrix processing but do not believe that the very small number of small negative values (0.01%) in the present trip matrices has any measurable impact on the overall results from the modelling suite.
- 5.8.33. Table 26 to Table 28 show the distribution of trips between regions. Business CA/AP matrices are shown below. For all three models, future trip distributions are similar in proportional terms to demand in the base.

Table 26: PM Business CA sectored matrices

Sector

| Sector | East Anglia | East Midlands | London | North East | North West | Scotland | South East | South West | Wales | West Midlands | Yorkshire and Humberside | Total |
|--------------------------|-------------|---------------|--------------|------------|------------|----------|------------|------------|-----------|---------------|--------------------------|---------------|
| East Anglia | 0 | 39 | 0 | 5 | 31 | 0 | 0 | 0 | 0 | 34 | 29 | 138 |
| East Midlands | 47 | 925 | 410 | 7 | 60 | 0 | 8 | 14 | 4 | 194 | 298 | 1,966 |
| London | 0 | 142 | 0 | 51 | 280 | 0 | 0 | 0 | 10 | 263 | 162 | 907 |
| North East | 6 | 7 | 98 | 0 | 0 | 0 | 3 | 2 | 0 | 15 | 0 | 130 |
| North West | 15 | 32 | 263 | 0 | 97 | 0 | 56 | 24 | 6 | 251 | 1 | 744 |
| Scotland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 0 | 5 | 0 | 3 | 49 | 0 | 0 | 0 | 0 | 125 | 19 | 201 |
| South West | 0 | 7 | 0 | 2 | 21 | 0 | 0 | 0 | 0 | 144 | 20 | 194 |
| Wales | 1 | 3 | 9 | 0 | 5 | 0 | 1 | 0 | 5 | 28 | 2 | 54 |
| West Midlands | 8 | 75 | 526 | 3 | 134 | 0 | 69 | 28 | 8 | 4,402 | 31 | 5,285 |
| Yorkshire and Humberside | 28 | 146 | 392 | 0 | 0 | 0 | 68 | 26 | 2 | 96 | 0 | 757 |
| Total | 104 | 1,380 | 1,698 | 71 | 676 | 0 | 204 | 94 | 36 | 5,551 | 562 | 10,374 |

Sector

| Sector | East Anglia | East Midlands | London | North East | North West | Scotland | South East | South West | Wales | West Midlands | Yorkshire and Humberside | Total |
|--------------------------|-------------|---------------|--------------|------------|------------|----------|------------|------------|-----------|---------------|--------------------------|---------------|
| East Anglia | 0 | 61 | 0 | 7 | 52 | 0 | 0 | 0 | 0 | 54 | 44 | 219 |
| East Midlands | 67 | 1,299 | 521 | 9 | 87 | 0 | 12 | 19 | 6 | 286 | 417 | 2,722 |
| London | 0 | 180 | 0 | 64 | 357 | 0 | 0 | 0 | 12 | 341 | 205 | 1,158 |
| North East | 8 | 8 | 123 | 0 | 0 | 0 | 4 | 2 | 0 | 20 | 0 | 165 |
| North West | 19 | 41 | 333 | 0 | 132 | 0 | 69 | 30 | 7 | 344 | 1 | 976 |
| Scotland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 0 | 8 | 0 | 4 | 71 | 0 | 0 | 0 | 1 | 191 | 28 | 302 |
| South West | 0 | 10 | 0 | 3 | 29 | 0 | 0 | 0 | 0 | 205 | 28 | 275 |
| Wales | 2 | 4 | 11 | 0 | 6 | 0 | 1 | 0 | 7 | 38 | 3 | 71 |
| West Midlands | 11 | 120 | 666 | 4 | 203 | 0 | 96 | 37 | 11 | 6,154 | 43 | 7,344 |
| Yorkshire and Humberside | 36 | 185 | 498 | 0 | 0 | 0 | 90 | 33 | 3 | 132 | 0 | 976 |
| Total | 142 | 1,915 | 2,152 | 92 | 936 | 0 | 271 | 122 | 47 | 7,763 | 768 | 14,208 |

Sector

| Sector | East Anglia | East Midlands | London | North East | North West | Scotland | South East | South West | Wales | West Midlands | Yorkshire and Humberside | Total |
|--------------------------|-------------|---------------|--------------|------------|--------------|----------|------------|------------|-----------|---------------|--------------------------|---------------|
| East Anglia | 0 | 85 | 0 | 11 | 69 | 0 | 0 | 0 | 0 | 76 | 64 | 305 |
| East Midlands | 95 | 1,840 | 571 | 14 | 134 | 0 | 18 | 28 | 8 | 426 | 600 | 3,733 |
| London | 0 | 195 | 0 | 70 | 388 | 0 | 0 | 0 | 13 | 369 | 222 | 1,257 |
| North East | 11 | 12 | 133 | 0 | 0 | 0 | 5 | 3 | 0 | 27 | 0 | 191 |
| North West | 27 | 57 | 361 | 0 | 188 | 0 | 96 | 42 | 10 | 467 | 1 | 1,248 |
| Scotland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 0 | 12 | 0 | 6 | 105 | 0 | 0 | 0 | 1 | 274 | 41 | 437 |
| South West | 0 | 15 | 0 | 5 | 42 | 0 | 0 | 0 | 0 | 296 | 42 | 399 |
| Wales | 2 | 5 | 12 | 0 | 9 | 0 | 1 | 0 | 10 | 53 | 4 | 96 |
| West Midlands | 16 | 181 | 723 | 6 | 306 | 0 | 137 | 53 | 15 | 8,383 | 61 | 9,879 |
| Yorkshire and Humberside | 52 | 262 | 540 | 0 | 0 | 0 | 134 | 48 | 4 | 187 | 0 | 1,227 |
| Total | 202 | 2,663 | 2,340 | 110 | 1,240 | 0 | 391 | 174 | 62 | 10,557 | 1,034 | 18,773 |

Table 27: PN Business CA sectored matrices

Sector

| Sector | East Anglia | East Midlands | London | North East | North West | Scotland | South East | South West | Wales | West Midlands | Yorkshire and Humberside | Total |
|--------------------------|-------------|---------------|--------------|------------|---------------|----------|------------|------------|------------|---------------|--------------------------|---------------|
| East Anglia | 0 | 25 | 0 | 12 | 31 | 0 | 0 | 0 | 0 | 2 | 41 | 112 |
| East Midlands | 31 | 1,367 | 314 | 13 | 297 | 0 | 13 | 19 | 7 | 173 | 367 | 2,599 |
| London | 0 | 145 | 0 | 102 | 358 | 0 | 0 | 0 | 7 | 31 | 272 | 914 |
| North East | 12 | 13 | 152 | 473 | 55 | 0 | 4 | 3 | 0 | 23 | 151 | 885 |
| North West | 17 | 47 | 340 | 26 | 9,192 | 0 | 40 | 22 | 49 | 209 | 316 | 10,258 |
| Scotland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 0 | 10 | 0 | 5 | 72 | 0 | 0 | 0 | 1 | 5 | 20 | 112 |
| South West | 0 | 12 | 0 | 2 | 38 | 0 | 0 | 0 | 0 | 2 | 17 | 70 |
| Wales | 1 | 4 | 11 | 1 | 112 | 0 | 0 | 0 | 159 | 19 | 5 | 311 |
| West Midlands | 4 | 111 | 64 | 8 | 198 | 0 | 3 | 2 | 16 | 474 | 52 | 931 |
| Yorkshire and Humberside | 33 | 186 | 430 | 126 | 558 | 0 | 20 | 21 | 3 | 96 | 5,975 | 7,446 |
| Total | 98 | 1,918 | 1,310 | 766 | 10,912 | 0 | 79 | 67 | 242 | 1,032 | 7,215 | 23,638 |

Sector

| Sector | East Anglia | East Midlands | London | North East | North West | Scotland | South East | South West | Wales | West Midlands | Yorkshire and Humberside | Total |
|--------------------------|-------------|---------------|--------------|--------------|---------------|----------|------------|------------|------------|---------------|--------------------------|---------------|
| East Anglia | 0 | 40 | 0 | 17 | 51 | 0 | 0 | 0 | 0 | 4 | 62 | 173 |
| East Midlands | 44 | 1,925 | 477 | 17 | 410 | 0 | 17 | 25 | 9 | 248 | 508 | 3,680 |
| London | 0 | 199 | 0 | 135 | 488 | 0 | 0 | 0 | 9 | 43 | 372 | 1,247 |
| North East | 15 | 16 | 213 | 618 | 73 | 0 | 5 | 4 | 1 | 30 | 197 | 1,172 |
| North West | 24 | 68 | 489 | 37 | 12,109 | 0 | 54 | 29 | 65 | 297 | 443 | 13,615 |
| Scotland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 0 | 15 | 0 | 7 | 107 | 0 | 0 | 0 | 1 | 7 | 30 | 167 |
| South West | 0 | 17 | 0 | 3 | 53 | 0 | 0 | 0 | 0 | 2 | 24 | 99 |
| Wales | 2 | 5 | 16 | 1 | 148 | 0 | 1 | 0 | 208 | 25 | 6 | 411 |
| West Midlands | 5 | 152 | 97 | 12 | 268 | 0 | 4 | 3 | 22 | 671 | 71 | 1,306 |
| Yorkshire and Humberside | 44 | 240 | 629 | 167 | 774 | 0 | 27 | 28 | 5 | 132 | 8,296 | 10,342 |
| Total | 134 | 2,677 | 1,921 | 1,014 | 14,480 | 0 | 108 | 89 | 321 | 1,459 | 10,009 | 32,212 |

Sector

| Sector | East Anglia | East Midlands | London | North East | North West | Scotland | South East | South West | Wales | West Midlands | Yorkshire and Humberside | Total |
|--------------------------|-------------|---------------|--------------|--------------|---------------|----------|------------|------------|------------|---------------|--------------------------|---------------|
| East Anglia | 0 | 62 | 0 | 26 | 71 | 0 | 0 | 0 | 0 | 5 | 93 | 257 |
| East Midlands | 64 | 2,734 | 857 | 26 | 583 | 0 | 25 | 36 | 14 | 363 | 734 | 5,435 |
| London | 0 | 262 | 0 | 174 | 640 | 0 | 0 | 0 | 13 | 56 | 492 | 1,636 |
| North East | 22 | 23 | 364 | 845 | 108 | 0 | 7 | 5 | 1 | 42 | 284 | 1,701 |
| North West | 36 | 100 | 852 | 54 | 16,180 | 0 | 79 | 41 | 91 | 428 | 654 | 18,514 |
| Scotland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 0 | 22 | 0 | 11 | 158 | 0 | 0 | 0 | 1 | 11 | 44 | 247 |
| South West | 0 | 25 | 0 | 5 | 80 | 0 | 0 | 0 | 0 | 3 | 36 | 148 |
| Wales | 3 | 8 | 27 | 1 | 207 | 0 | 1 | 0 | 280 | 35 | 8 | 570 |
| West Midlands | 8 | 219 | 174 | 18 | 385 | 0 | 6 | 4 | 32 | 957 | 102 | 1,904 |
| Yorkshire and Humberside | 65 | 348 | 1,144 | 244 | 1,187 | 0 | 42 | 42 | 7 | 193 | 11,938 | 15,210 |
| Total | 196 | 3,804 | 3,417 | 1,402 | 19,598 | 0 | 159 | 129 | 438 | 2,093 | 14,384 | 45,621 |

Table 28: PS Business PA sectored matrices

| Sector | | | | | | | | | | | | |
|--------------------------|--------------|---------------|----------------|------------|------------|----------|--------------|--------------|----------|---------------|--------------------------|----------------|
| Sector | East Anglia | East Midlands | London | North East | North West | Scotland | South East | South West | Wales | West Midlands | Yorkshire and Humberside | Total |
| East Anglia | 1,283 | 10 | 9,236 | 0 | 0 | 0 | 345 | 72 | 0 | 0 | 0 | 10,946 |
| East Midlands | 8 | 0 | 199 | 0 | 0 | 0 | 7 | 1 | 0 | 0 | 0 | 215 |
| London | 3,243 | 39 | 76,558 | 0 | 0 | 0 | 4,369 | 1,581 | 0 | 0 | 0 | 85,790 |
| North East | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| North West | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Scotland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 268 | 4 | 17,008 | 0 | 0 | 0 | 4,359 | 419 | 0 | 0 | 0 | 22,057 |
| South West | 12 | 0 | 1,159 | 0 | 0 | 0 | 322 | 266 | 0 | 0 | 0 | 1,758 |
| Wales | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| West Midlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Yorkshire and Humberside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 4,814 | 53 | 104,159 | 0 | 0 | 0 | 9,402 | 2,338 | 0 | 0 | 0 | 120,765 |

| Sector | | | | | | | | | | | | |
|--------------------------|--------------|---------------|----------------|------------|------------|----------|---------------|--------------|----------|---------------|--------------------------|----------------|
| Sector | East Anglia | East Midlands | London | North East | North West | Scotland | South East | South West | Wales | West Midlands | Yorkshire and Humberside | Total |
| East Anglia | 1,954 | 14 | 14,389 | 0 | 0 | 0 | 524 | 106 | 0 | 0 | 0 | 16,987 |
| East Midlands | 11 | 0 | 295 | 0 | 0 | 0 | 9 | 1 | 0 | 0 | 0 | 316 |
| London | 5,016 | 54 | 118,270 | 0 | 0 | 0 | 6,043 | 2,180 | 0 | 0 | 0 | 131,564 |
| North East | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| North West | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Scotland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 406 | 6 | 23,918 | 0 | 0 | 0 | 6,392 | 599 | 0 | 0 | 0 | 31,321 |
| South West | 18 | 0 | 1,803 | 0 | 0 | 0 | 449 | 366 | 0 | 0 | 0 | 2,635 |
| Wales | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| West Midlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Yorkshire and Humberside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 7,405 | 73 | 158,676 | 0 | 0 | 0 | 13,417 | 3,252 | 0 | 0 | 0 | 182,823 |

| Sector | | | | | | | | | | | | |
|--------------------------|---------------|---------------|----------------|------------|------------|----------|---------------|--------------|----------|---------------|--------------------------|----------------|
| Sector | East Anglia | East Midlands | London | North East | North West | Scotland | South East | South West | Wales | West Midlands | Yorkshire and Humberside | Total |
| East Anglia | 2,914 | 19 | 22,028 | 0 | 0 | 0 | 794 | 157 | 0 | 0 | 0 | 25,912 |
| East Midlands | 16 | 0 | 502 | 0 | 0 | 0 | 13 | 2 | 0 | 0 | 0 | 533 |
| London | 7,042 | 71 | 166,696 | 0 | 0 | 0 | 8,563 | 3,040 | 0 | 0 | 0 | 185,412 |
| North East | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| North West | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Scotland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 596 | 9 | 35,201 | 0 | 0 | 0 | 9,570 | 871 | 0 | 0 | 0 | 46,246 |
| South West | 25 | 0 | 3,206 | 0 | 0 | 0 | 661 | 526 | 0 | 0 | 0 | 4,418 |
| Wales | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| West Midlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Yorkshire and Humberside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 10,593 | 100 | 227,633 | 0 | 0 | 0 | 19,601 | 4,596 | 0 | 0 | 0 | 262,522 |

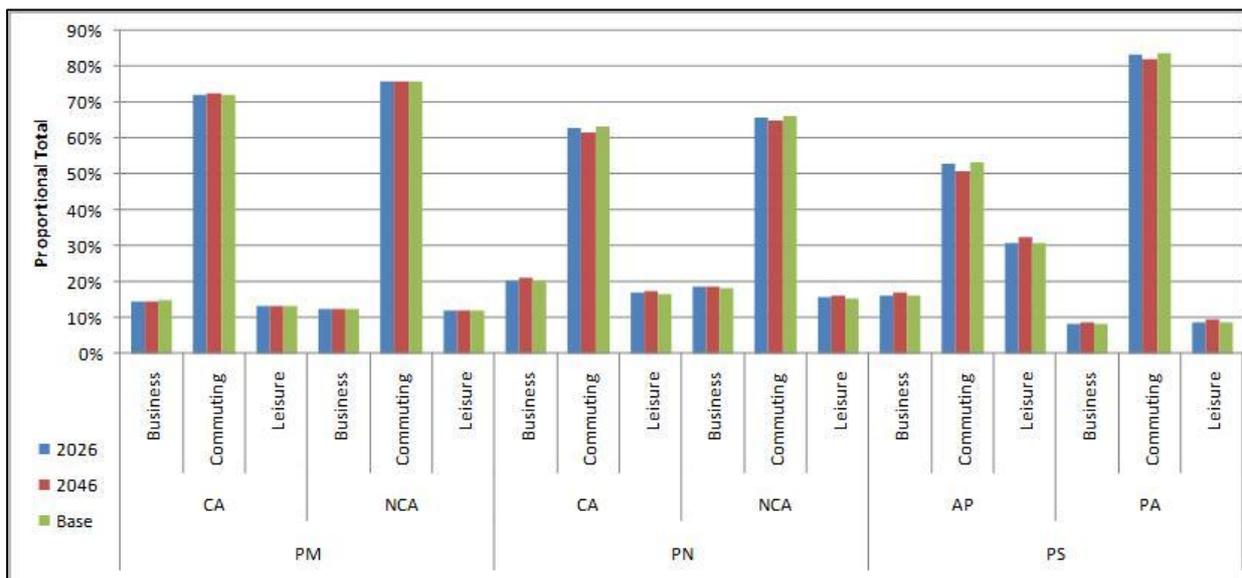
Trip Purpose

5.8.34. Table 29 and associated graph in Figure 17 summarise the proportion of travel in each year by trip purpose. This is split by CA/NCA and AP/PA. It can be seen that the proportions of travel for each purpose remain effectively steady between the base and future years.

Table 29: Proportion of travel by purpose

| Model | Type | Purpose | Year | | |
|-------|------|-----------|------|------|------|
| | | | Base | 2026 | 2046 |
| PM | CA | Business | 15% | 14% | 15% |
| | | Commuting | 72% | 72% | 72% |
| | | Leisure | 13% | 13% | 13% |
| | NCA | Business | 12% | 12% | 12% |
| | | Commuting | 76% | 76% | 76% |
| | | Leisure | 12% | 12% | 12% |
| PN | CA | Business | 20% | 21% | 20% |
| | | Commuting | 63% | 62% | 63% |
| | | Leisure | 17% | 17% | 16% |
| | NCA | Business | 18% | 19% | 18% |
| | | Commuting | 66% | 65% | 66% |
| | | Leisure | 16% | 16% | 15% |
| PS | AP | Business | 16% | 17% | 16% |
| | | Commuting | 53% | 51% | 53% |
| | | Leisure | 31% | 32% | 31% |
| | PA | Business | 8% | 9% | 8% |
| | | Commuting | 83% | 82% | 84% |
| | | Leisure | 9% | 9% | 8% |

Figure 17: Proportion of travel by purpose



Application of Growth Process

- 5.8.35. Using the process outlined above, the growth factors and associated adjustments were applied to the base matrices and the results compared with the future matrices. In the analysis, a tolerance of 1% was allowed in each cell comparison to allow for small inconsistencies caused by rounding. Indeed, almost all cells matched to within 0.001 in absolute terms, indicating that rounding errors were insignificant. Each model performed slightly differently under this analysis, and the results are in their relevant sections below.
- 5.8.36. In the PN model, applying the growth rates in accordance with the documented process produced matches for every cell in both the 2026 and 2046 cases. It was concluded that the process was correctly applied to the PN model.
- 5.8.37. In the PM model, applying the growth rates and additional factoring resulted in matrices which matched in all but a very small number of cases. After inspection of the cells that fell outside a 1% threshold, it was found that these were due to very small trip volumes which caused rounding errors of greater than 1%. In every case where the threshold was exceeded, the number of trips in the matrix cell was less than 0.01 units.
- 5.8.38. It was therefore concluded that the process was also correctly applied to the PM model. In PS, using the additional factors from the airport macro, as well as the new base matrices, the PS methodology was also found to be correctly implemented, with one slight inconsistency.
- 5.8.39. The macro applied additional growth factors to trips which ended or began at airport zones. For Heathrow airport, there were a small number of trips internal to the airport. For these internal trips, factors were applied for both the origin and destination within the Heathrow airport terminals, leading to a double factoring. As these trips are entirely contained within Heathrow and not assigned by the network model, this is of no consequence.
- 5.8.40. With the exception of these zones, all zones matched according to the process defined above and the process was also found to be correct.

Review of Growth Rates

- 5.8.41. The purpose of this section is to review the growth rate matrices provided and to make an assessment of whether these growth rates seem reasonable.
- 5.8.42. An initial statistical analysis was undertaken for all of the growth rates. Table 30 shows these summary statistics. It can be seen that the mean growth rate is reasonably similar for all of the trip purposes for each of the future years. The range of growth rates, as indicated by the standard deviation (sd), is reasonably narrow.

Table 30: Summary statistics for growth rates

| Model | Year | Purpose | Type | Count (no. of matrix cells) | Growth rate | | | |
|-------|------|-----------|------|-----------------------------|-------------|----------|--------|--------|
| | | | | | Mean | sd | min | max |
| PM | 2026 | Business | | 1364224 | 1.376773 | 0.162556 | 1.2233 | 2.6018 |
| PM | 2026 | Leisure | | 1364224 | 1.363495 | 0.166496 | 1.2025 | 2.6157 |
| PM | 2026 | Commuting | | 1364224 | 1.422534 | 0.151579 | 1.1468 | 2.4805 |
| PM | 2046 | Business | | 1364224 | 1.954462 | 0.156653 | 1.3642 | 3.0825 |
| PM | 2046 | Leisure | | 1364224 | 1.900591 | 0.151827 | 1.3745 | 3.3027 |
| PM | 2046 | Commuting | | 1364224 | 2.125298 | 0.258605 | 1.2294 | 2.7845 |
| PN | 2026 | Business | | 923521 | 1.307527 | 0.123253 | 1.1338 | 2.6018 |
| PN | 2026 | Leisure | | 923521 | 1.294251 | 0.126084 | 1.1158 | 2.6157 |
| PN | 2026 | Commuting | | 923521 | 1.353418 | 0.124751 | 1.0574 | 2.4805 |
| PN | 2046 | Business | | 923521 | 1.854417 | 0.239602 | 1.4121 | 3.8331 |
| PN | 2046 | Leisure | | 923521 | 1.801832 | 0.235513 | 1.4515 | 4.1036 |
| PN | 2046 | Commuting | | 923521 | 2.020235 | 0.316845 | 1.0105 | 3.3797 |
| PS | 2026 | Business | AP | 1937664 | 1.451174 | 0.131292 | 1 | 1.9031 |
| PS | 2026 | Business | PA | 1855044 | 1.471908 | 0.090687 | 1.2147 | 1.9031 |
| PS | 2026 | Leisure | AP | 1937664 | 1.474176 | 0.13759 | 1 | 1.8989 |
| PS | 2026 | Leisure | PA | 1855044 | 1.495942 | 0.094748 | 1.2377 | 1.8989 |
| PS | 2026 | Commuting | AP | 1937664 | 1.359174 | 0.145868 | 1 | 1.9227 |
| PS | 2026 | Commuting | PA | 1855044 | 1.375719 | 0.126686 | 1.0617 | 1.9227 |
| PS | 2046 | Business | AP | 1937664 | 2.120134 | 0.333125 | 1 | 3.1408 |
| PS | 2046 | Business | PA | 1855044 | 2.171771 | 0.23616 | 1.5097 | 3.1408 |
| PS | 2046 | Leisure | AP | 1937664 | 2.199097 | 0.367461 | 1 | 3.3324 |
| PS | 2046 | Leisure | PA | 1855044 | 2.254251 | 0.268663 | 1.5498 | 3.3324 |
| PS | 2046 | Commuting | AP | 1937664 | 1.753192 | 0.351968 | 1 | 2.9903 |
| PS | 2046 | Commuting | PA | 1855044 | 1.788147 | 0.320149 | 1.0475 | 2.9903 |

5.8.43. The maximum growth rates shown do not raise any concerns because they are clearly outliers, as shown in the histograms in Figure 18 to Figure 41, which display the distribution of growth rates.

Figure 18: Growth rate distribution – PM 2026 Business

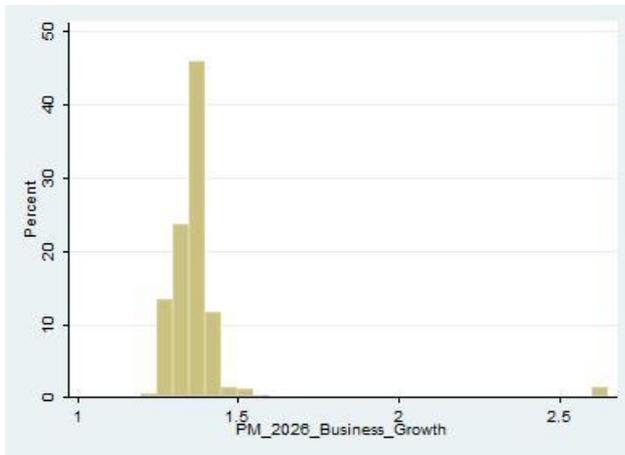


Figure 19: Growth rate distribution – PM 2046 Business

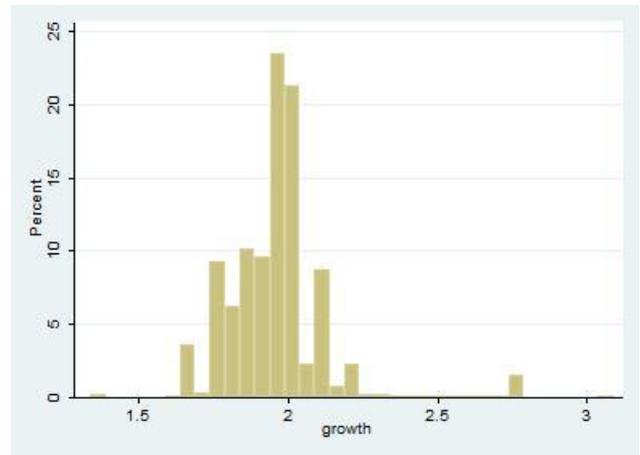


Figure 20: Growth rate distribution – PM 2026 Commuting

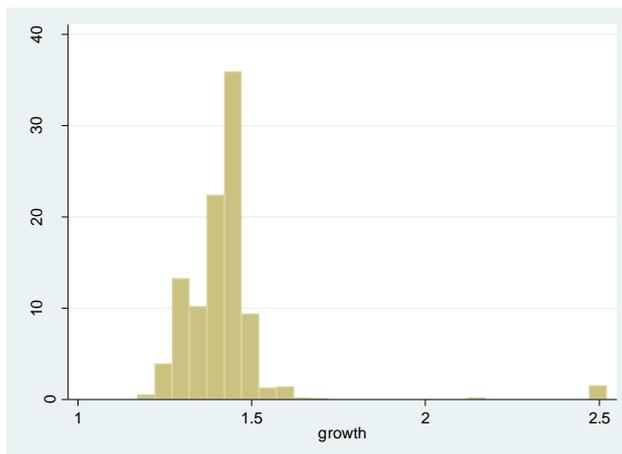


Figure 21: Growth rate distribution – PM 2046 Commuting

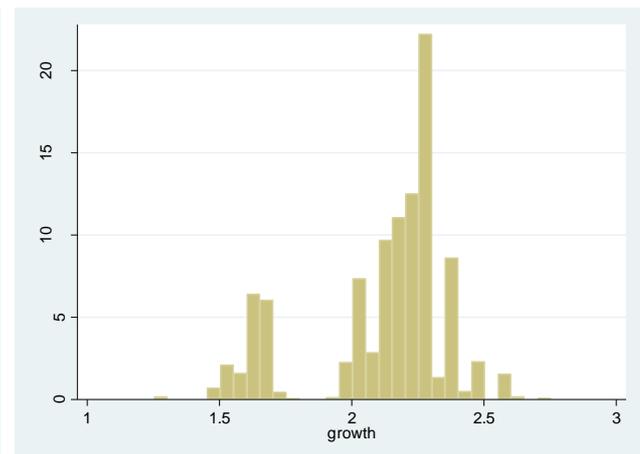


Figure 22: Growth rate distribution – PM 2026 Leisure

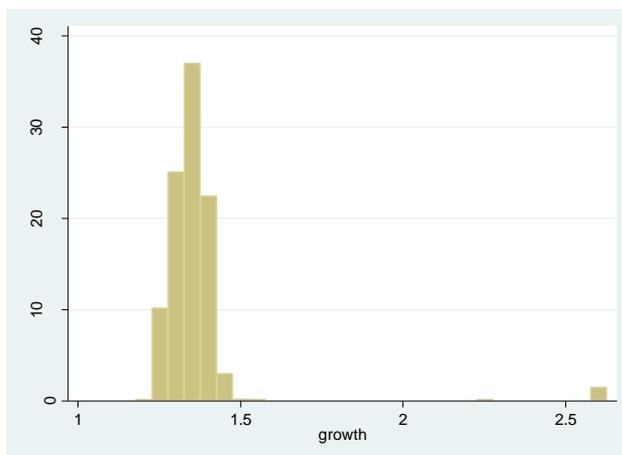


Figure 23: Growth rate distribution – PM 46 Leisure

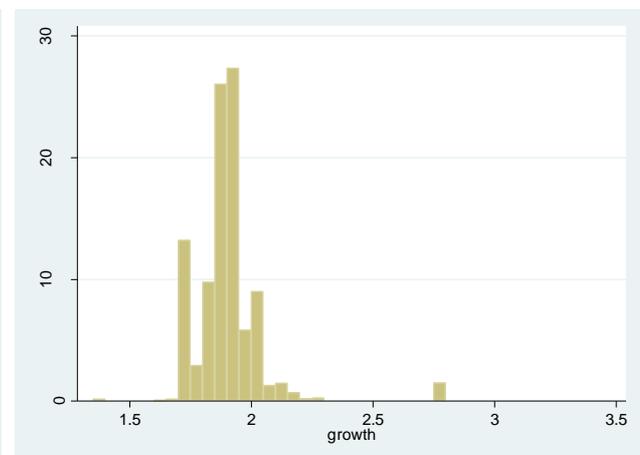


Figure 24: Growth rate distribution – PN 2026 Business

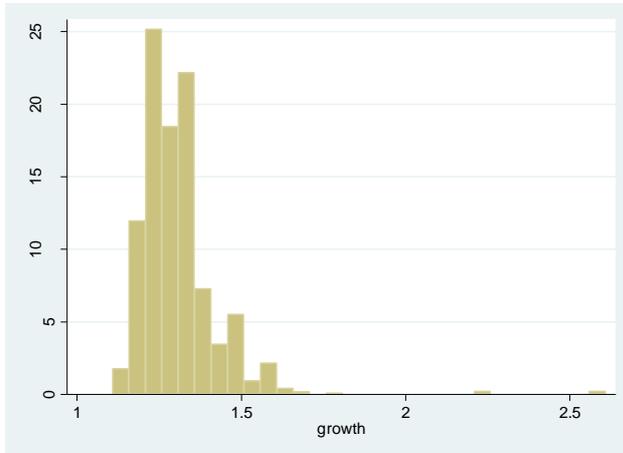


Figure 25: Growth rate distribution – PN 2026 Business

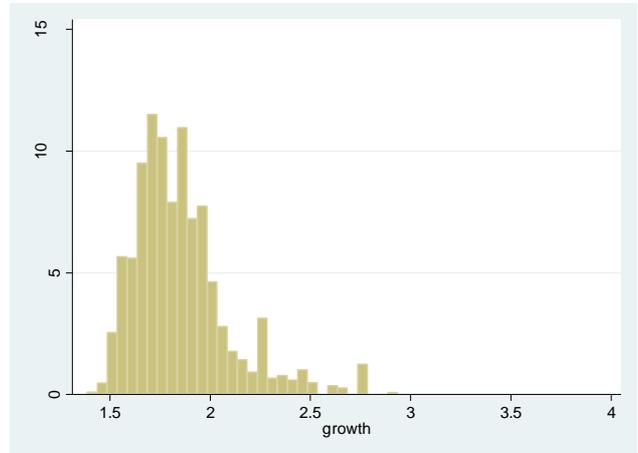


Figure 26: Growth rate distribution – PN 2026 Commuting

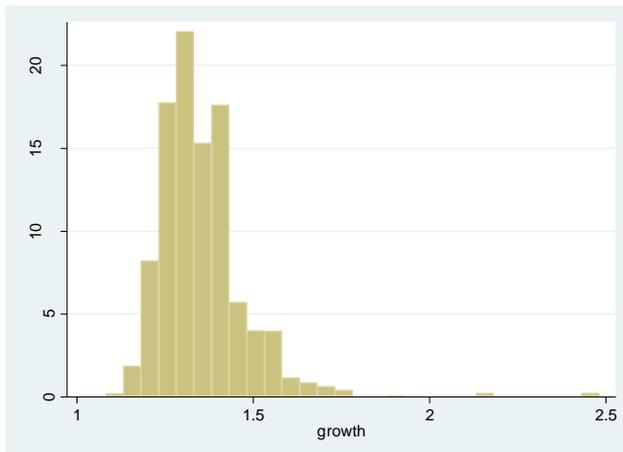


Figure 27: Growth rate distribution – PN 2026 Commuting

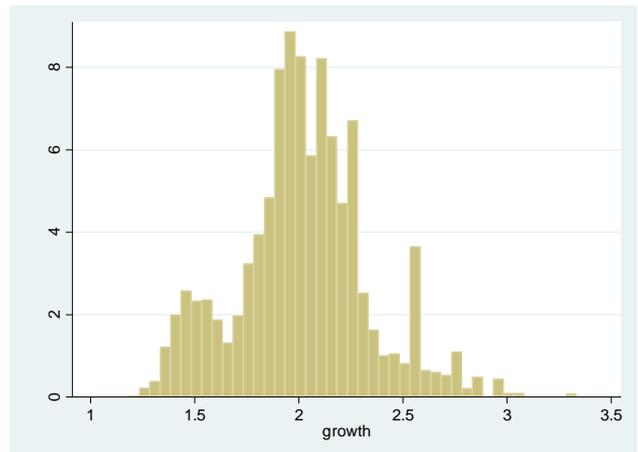


Figure 28: Growth rate distribution – PN 2026 Leisure

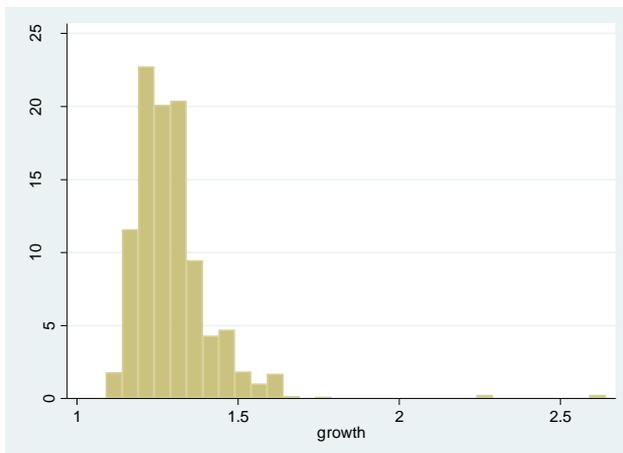


Figure 29: Growth rate distribution – PN 2026 Leisure

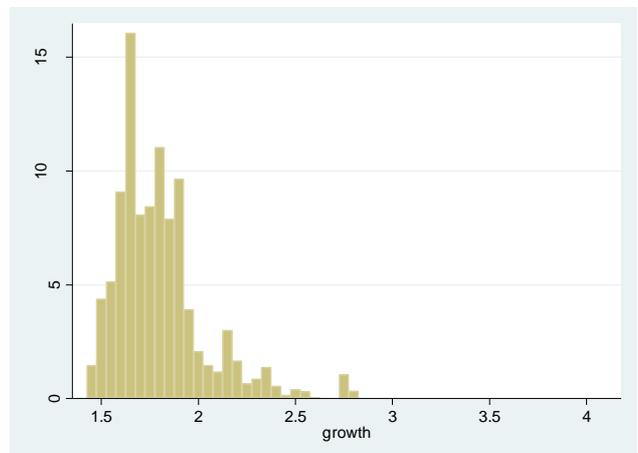


Figure 30: Growth rate distribution – PS 2026 Business AP

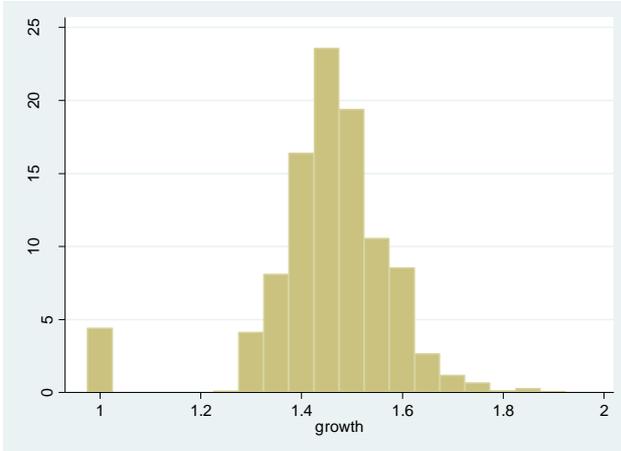


Figure 31: Growth rate distribution – PS 2046 Business AP

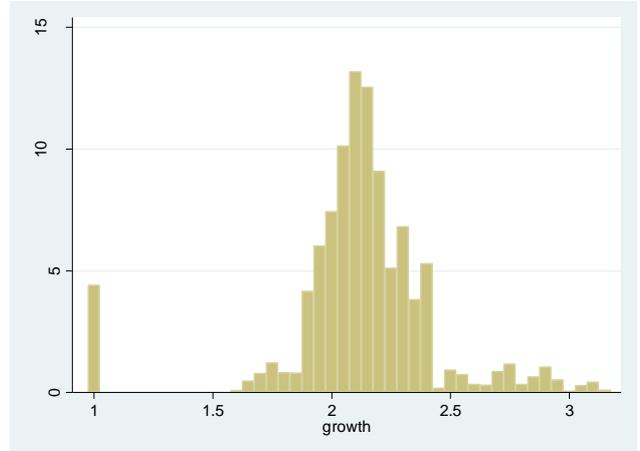


Figure 32: Growth rate distribution – PS 2026 Business PA

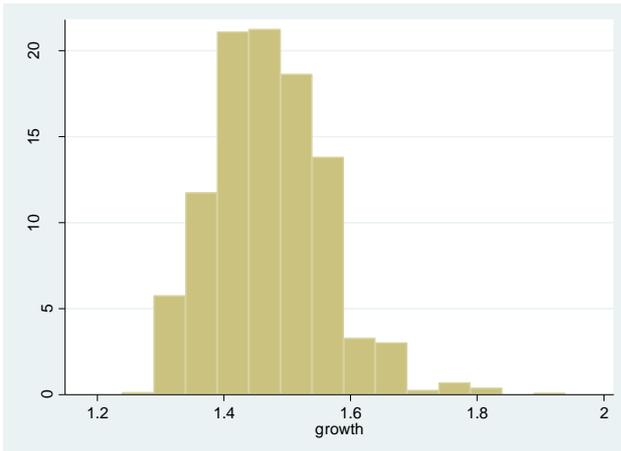


Figure 33: Growth rate distribution – PS 2046 Business PA

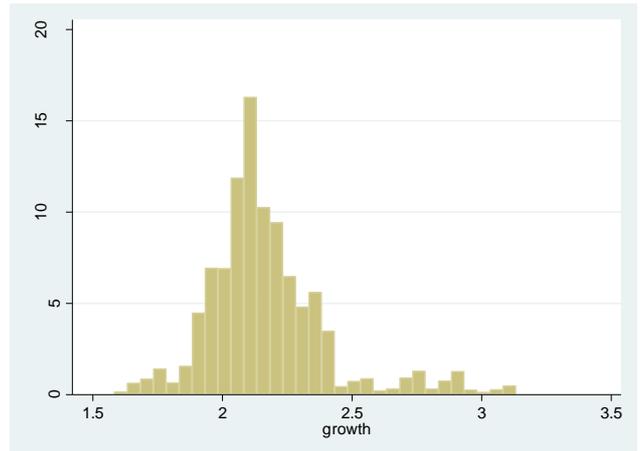


Figure 34: Growth rate distribution – PS 2026 Commuting AP

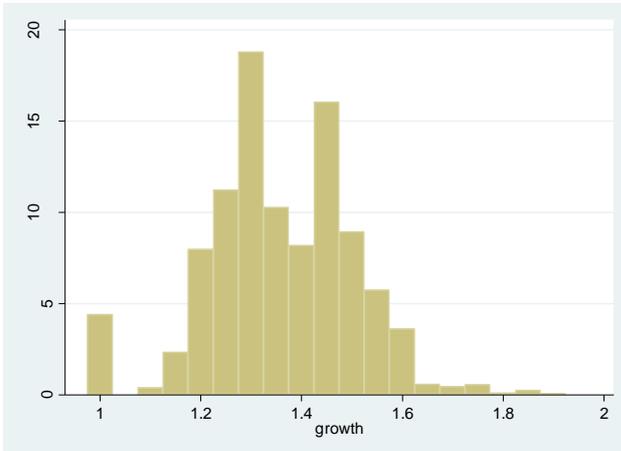


Figure 35: Growth rate distribution – PS 2046 Commuting AP

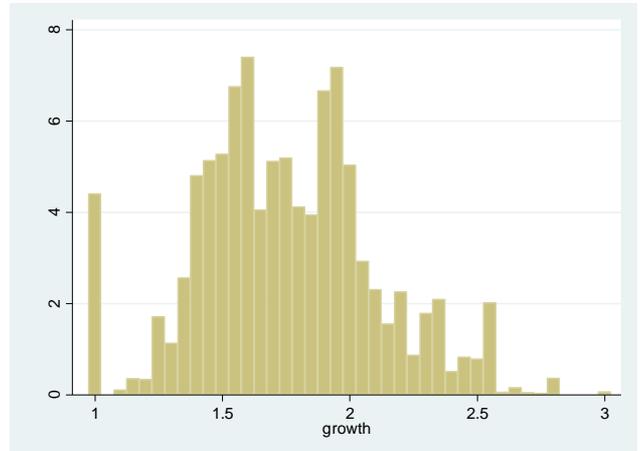


Figure 36: Growth rate distribution – PS 2026 Commuting PA

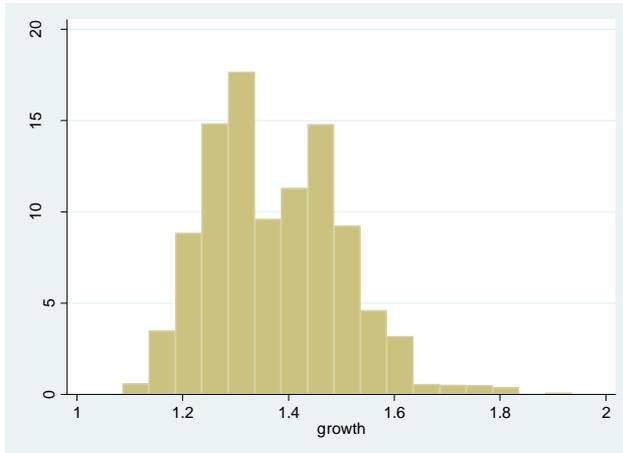


Figure 37: Growth rate distribution – PS 2026 Commuting PA

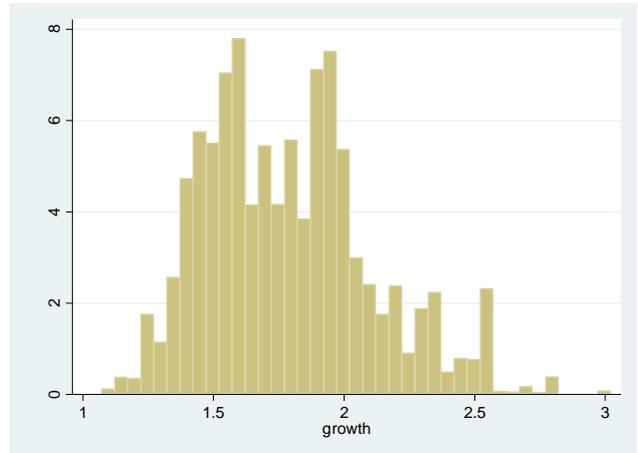


Figure 38: Growth rate distribution – PS 2026 Leisure AP

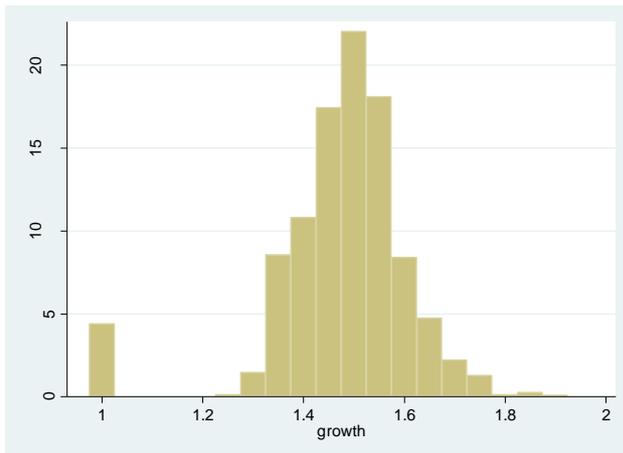


Figure 39: Growth rate distribution – PS 2026 Leisure AP

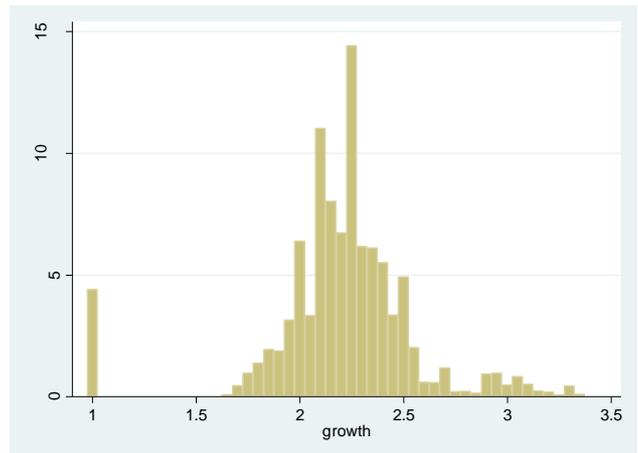


Figure 40: Growth rate distribution – PS 2026 Leisure PA

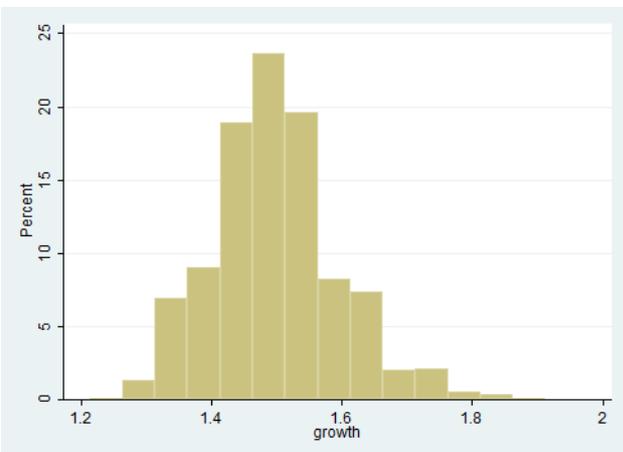
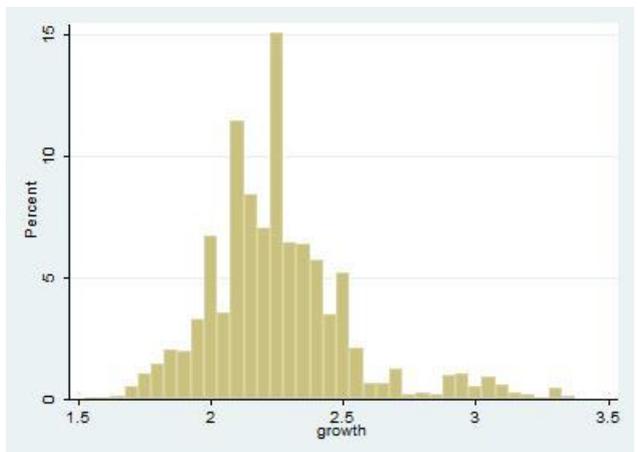


Figure 41: Growth rate distribution – PS 2026 Leisure PA



5.8.44. Inspection of the distributions showed that:

- The growth rates tend to be applied uniformly to regions, with identical growth typically applied to several adjacent zones
- All growth rates are greater than or equal to 1.0.
- There are a large number of PS AP zones with growth rates of 1.0. However, these all correspond to external trips for which growth is assigned separately by the airport macro.
- There are several cells containing growth rates which appear to be outliers. However, on examination of these rates, they appear to be reasonable. Table 31 shows zones for which growth rates are larger than 2.0 in 2026. These growth rates appear to be in locations in which high growth is expected (as in the airport zones of Luton and Birmingham International or where significant rail improvements are expected).

Table 31: Zones with growth rates larger than 2.0 in 2026

| Model | Zone | Location | Note |
|-------|-----------|------------------------------------|--|
| PM | 230 | Birmingham International (airport) | Reasonable: growth in flights |
| PM | 1136 | Luton (airport) | Reasonable: growth in flights |
| PN | 275 | Manchester (airport) | Reasonable: growth in flights |
| PN | 926 | Central London | Large zone representing Central London, considered reasonable. |
| PN | 454 | Bradford | Bradford: starts from a low base |
| PS | 4000-4600 | Central London | Reasonable |
| PS | 6000-6100 | Outer London | Reasonable |

5.8.45. The maps in Figure 42 to Figure 47 show the average growth rates by origin zone for a selection of car-available (CA) matrices. The average growth rate has been calculated by grouping all trips by origin zone, and dividing the future matrix by the base matrix. For PM and PN, the majority of zones have average growth rates as would be expected from the growth rates discussed above. The charts below are for CA matrices, meaning that there are some zones which will have no trips in the base but will have trips in the future due to the re-allocation of the NCA matrices as described above. There are also a handful of zones with higher than expected growth for this reason.

5.8.46. For PS, all zones appear to have growth in the range expected for each year.

Figure 42: PM Business CA 2026 – average growth rate by origin zone

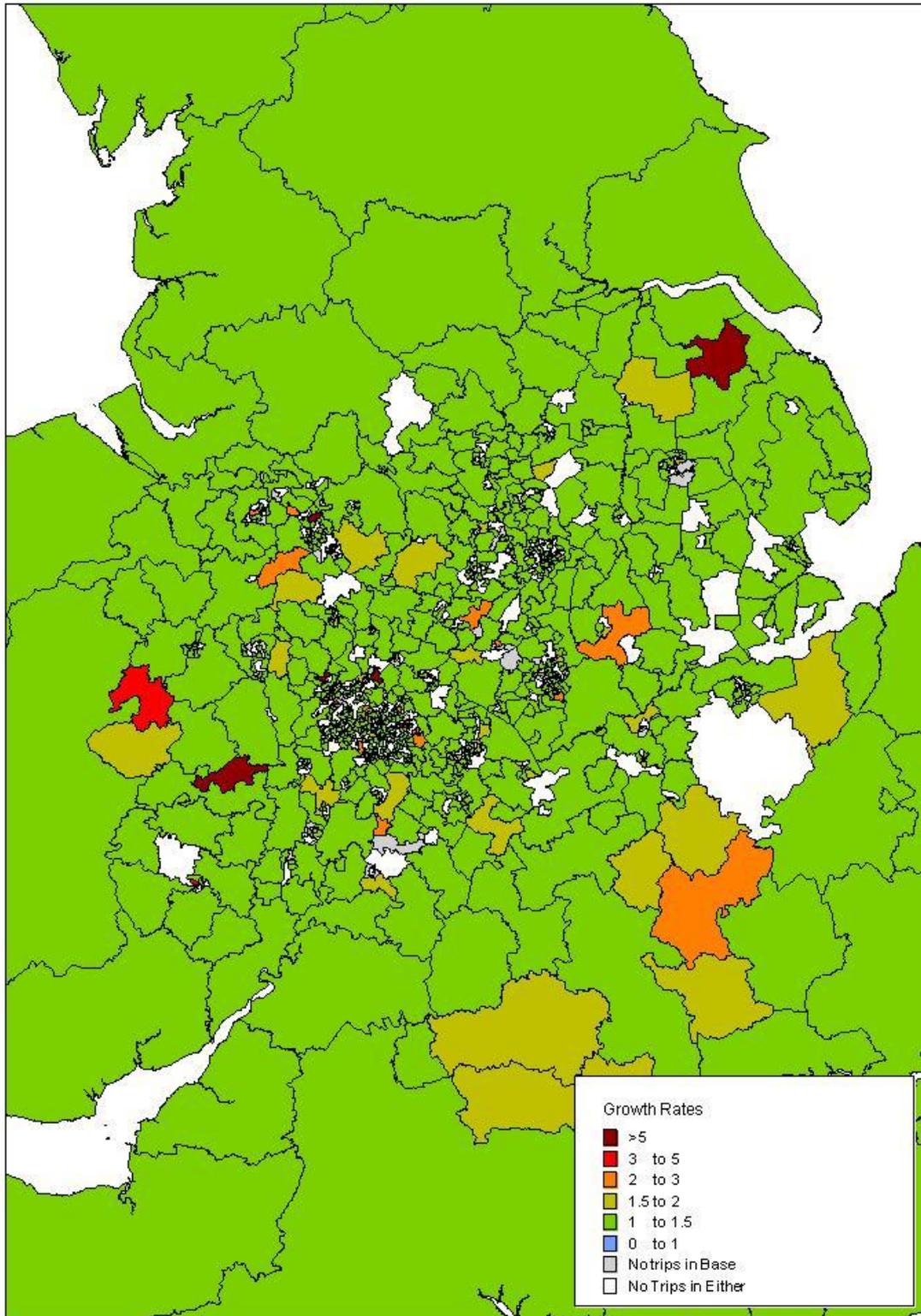


Figure 43: PM Business CA 2046 – average growth rate by origin zone

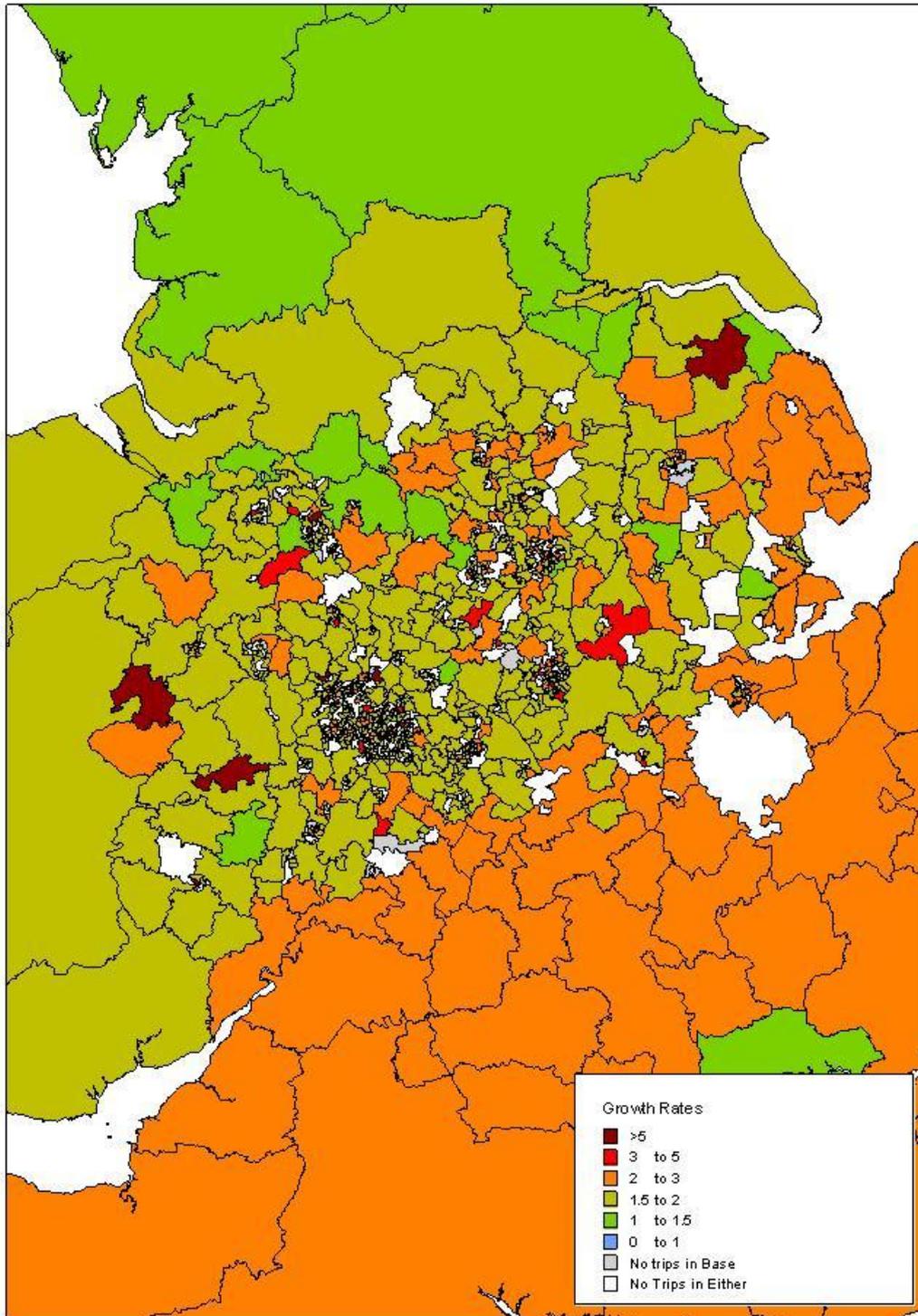


Figure 44: PN Business CA 2026 – average growth rate by origin zone

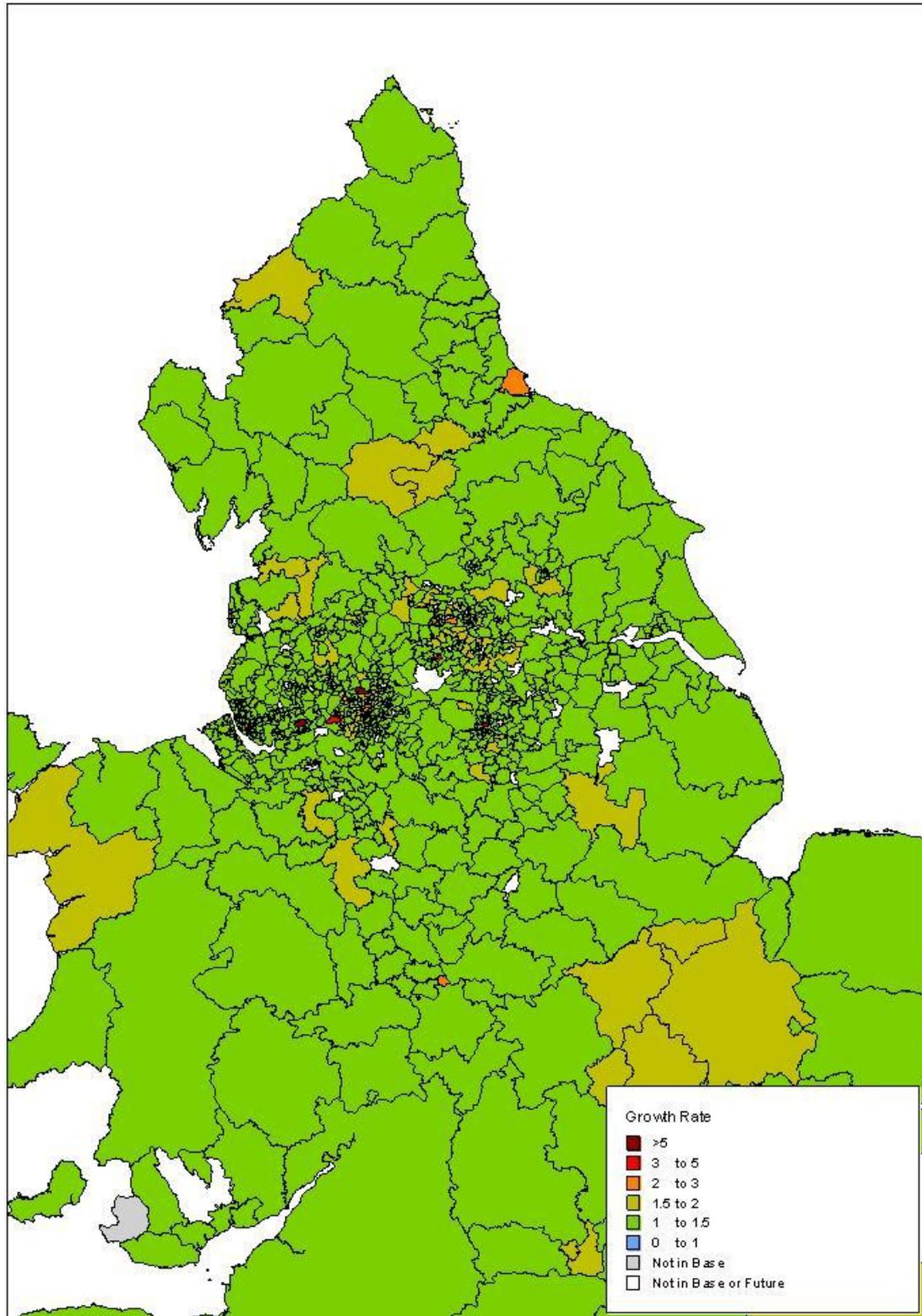


Figure 45: PN Business CA 2046 – average growth rate by origin zone

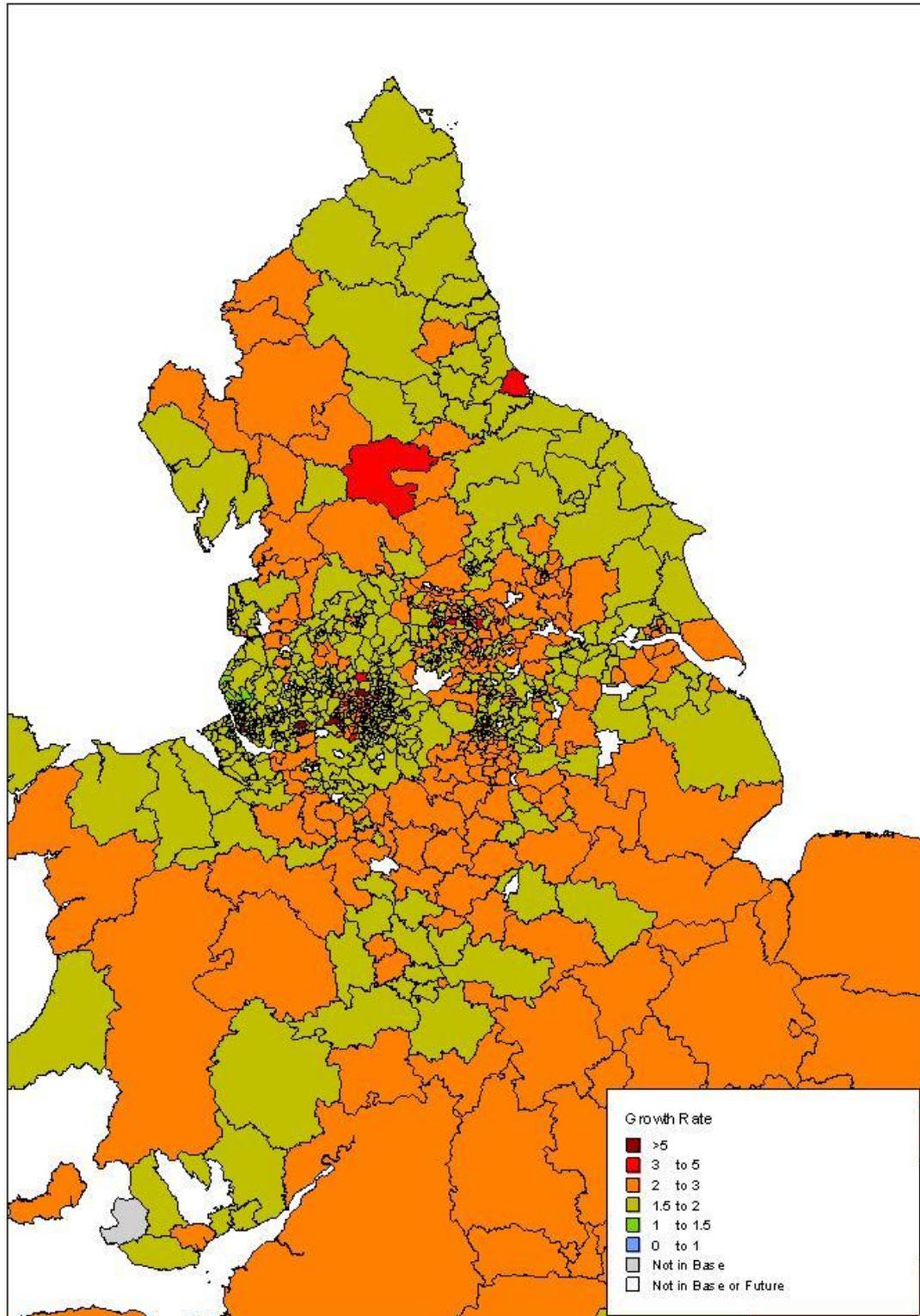


Figure 46: PS Business AP 2026 – average growth rate by origin zone

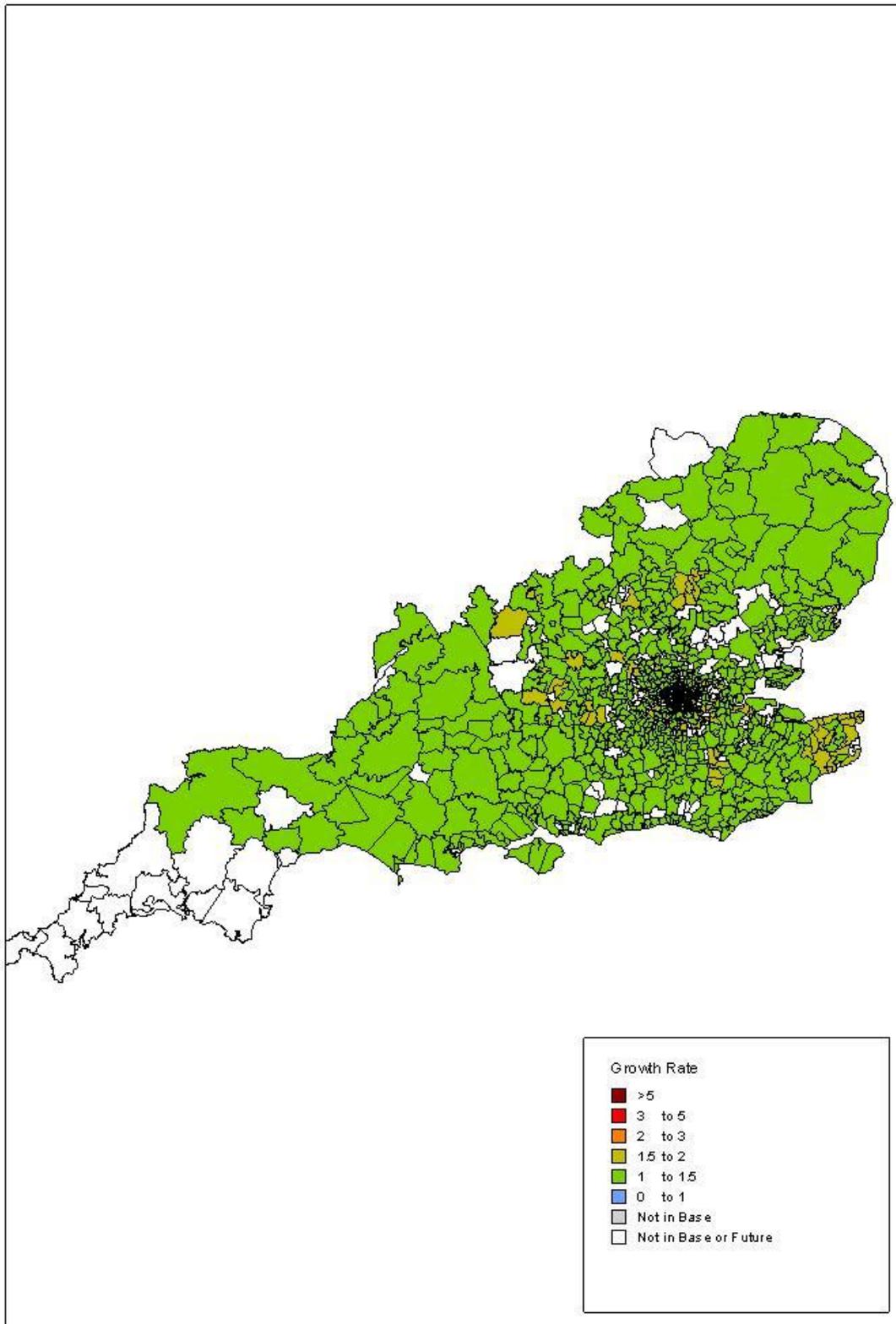
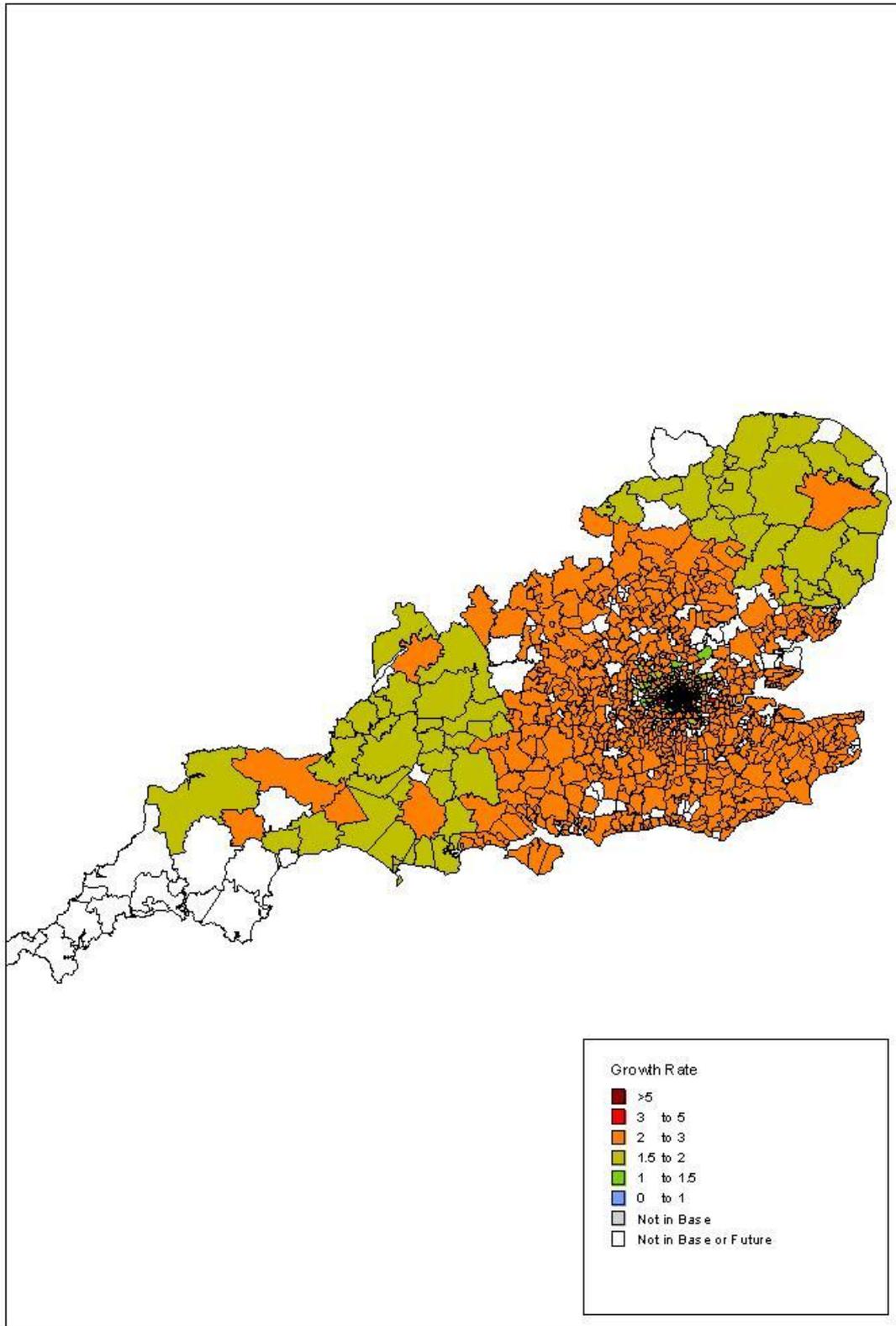


Figure 47: PS Business AP 2046 – average growth rate by origin zone



5.9. Audit findings

- 5.9.1. Our audit has found the regional PLANET models as used in PFMv4.3 implemented in line with their specification.
- 5.9.2. We have a small number of recommendations, mainly in connection with model transparency, file housekeeping and documentation.
- 5.9.3. Maintaining a single numbering convention throughout the model suite would assist auditability - currently parts of the model suite use the '1000 16000' PFM structure (including 3000), some use a 1.0 – 4.0 structure, while some make no reference to either. Naming conventions should also be consistently applied – so that a 'MidTest' for instance refers to a DS rather than a do minimum or a base year model.
- 5.9.4. Updates made to the zone structure in the models over the last few years are not reflected in the available GIS data, which should be updated. This is of no consequence for the model runs but will affect the display of any geographically based results. In our view, the transparency of the model would be improved if there was a single file/location storing all zone boundaries, centroids and names, stating all inter-relations.
- 5.9.5. Some processes copy files en masse between model scenarios while others use or over-write the same input/process/output file a number of times across the model suite. This interrupts the audit trail and makes QA checks difficult. We recommend that the model code should be amended accordingly.
- 5.9.6. Using the processes and base matrices provided, it was possible to conclude that the future matrices were correctly derived from the base year matrices. However, at the time of the audit, there was a significant lack of documentation in relation to some parts of the process. Comprehensive overarching model documentation is being drafted for HS2 Ltd concurrently with the production of this report.
- 5.9.7. The existence of a small number of negative values in the trips matrix should not have any measurable impact on the results obtained from the modelling suite. However, we recommend that such values be screened out in any future trip matrix development.

5.10. Implications of audit findings

- 5.10.1. We conclude from our audit that the regional PLANET models in PFMv4.3 are implemented in line with their documented specification. Our main audit findings relate to model transparency, file housekeeping and documentation only.

6. Station Choice Model

6.1. Introduction and context

6.1.1. The objectives of the Station Choice Model (SCM) audit were:

- To confirm that the model structure and model parameters of the implemented nested logit model are consistent with the results of the model calibration;
- To check the implementation of the parameters and model form of the 'gravity distribution' model; and
- To verify the coding in C++ of the model interfaces.

6.1.2. To achieve the above objectives, the following tasks were defined:

- Workshop to map the model's functions and interfaces;
- Specify and run key diagnostic tests, produce graphs and plots;
- Review implementation of nested logit models;
- Review implementation of 'gravity' model;
- Audit C++ code for interfaces;
- Audit key outputs and results from SCM;
- Discussion with the demand model developers on implications for SCM; and
- Reporting.

6.2. Inputs and assumptions

6.2.1. The main inputs to the SCM are cost skims and demands from the PLANET Long-Distance (PLD) model which change on each iteration of the model. There are also a number of "fixed" inputs to the model which include:

- The stations considered within the choice for each zone;
- Access costs between each permitted zone-station combination;
- Distribution of trips used to disaggregate PLD zones to the finer mzone system used by the SCM;
- Factors, such as values of time and distance, used to adjust the raw input cost skims to generalised time; and
- Scaling parameters and mode constants used by the choice model equations.

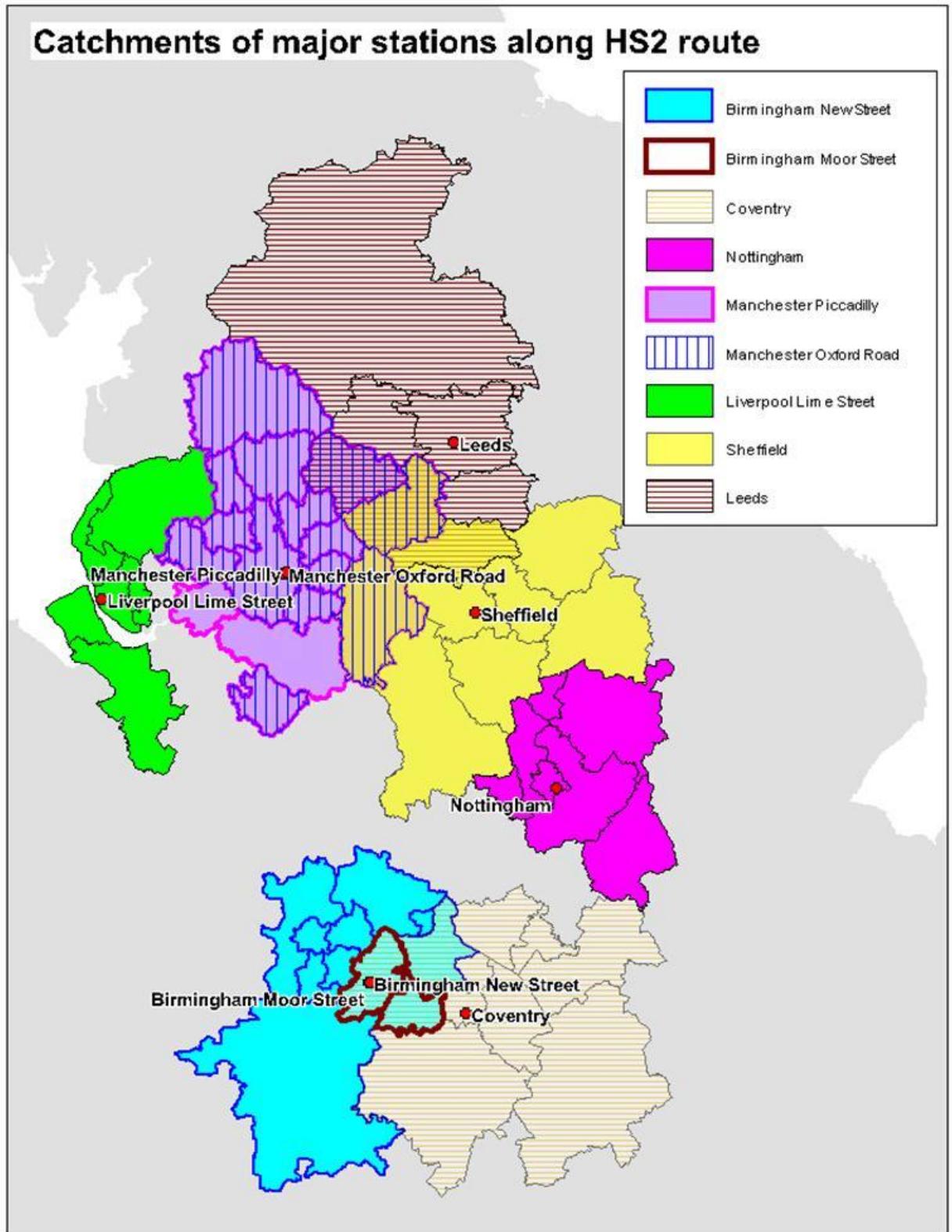
6.2.2. The large number of input values meant that it was impractical to check every single value. Instead, a series of diagnostic tests were undertaken with the model to help identify any incorrect or outlying values. These are described in more detail in Section 6.3.

6.2.3. The use of the SCM model within the PLANET Modelling Framework was reviewed,

with a specific aim to ensure that the correct inputs and outputs were being passed between the SCM and the other parts of the model, and also to ensure that the SCM was being called at the appropriate point within the model.

- 6.2.4. The distribution of trips used to disaggregate the demand matrices from the larger PLD zones to the mzone system was largely derived from NRTS data. In areas of sparse data, a gravity model based on NAM data was used to infill the gaps. The implementation of the gravity model was checked as part of this audit.
- 6.2.5. The provenance and source of the input parameters to the SCM, such as values of time and distance were not specifically audited, but the audit checked that these parameters were consistent with other parts of the model.
- 6.2.6. The catchments of each station were also checked as part of the audit. This was done spatially using GIS; an example is shown below in Figure 48.

Figure 48: Station catchment plots



6.3. Process

6.3.1. The Station Choice Model (SCM) program is a stand-alone application written in C++. As such, it is difficult to test individual sections of the process. Auditing of the SCM process therefore consisted of three main tasks:

- Diagnostic testing;
- Emulation; and
- Line-by-Line Checking

Diagnostic Testing

6.3.2. The objective of the diagnostic tests was to isolate the SCM from the rest of the modelling framework and assess the SCM's outputs for a range of inputs. These tests would quickly ascertain if there are any major issues in the SCM program by checking that the outputs are logical for the given inputs. For example, if public transport access costs are increased, then the model would be expected to allocate more trips to the highway access mode.

6.3.3. The SCM operates in three different modes. Two of these modes are "quick" modes which do not run the station choice function. Instead the results of the previous run are used to quickly aggregate costs or disaggregate demands.

6.3.4. In "full" mode, the SCM uses PLD zonal-level demands and station-level costs as inputs and allocates trips by station and access mode. In this mode, the SCM outputs station-station demand matrices to be used in the PLD assignment model, it also outputs aggregated zonal-level costs back to the PLD demand model.

6.3.5. These diagnostic tests use the output demands to examine the response of the SCM function to changing inputs.

6.3.6. There are a large number of inputs and parameters which are used by the SCM including a number of different cost elements from the PLD model and access costs to each station by mode. There are also a number of "global" parameters. Throughout the audit, all of these parameters and inputs were tested in this way. However, with the exception of key global parameters, small changes to most of the inputs had very little impact on the output results. Most of the analysis was therefore limited to the following global parameters.

- PT In-vehicle time factor;
- Petrol cost per kilometre;
- PT Fares (distance-based element);
- Value of time (commuting trips);
- PT Wait time factor; and
- PT Walk time factor.

- 6.3.7. The Station Choice Model is a stand-alone executable which reads input files and writes outputs to sub-directories of the folder it is run from. This fact allows us to easily isolate the program and manipulate the input files.
- 6.3.8. Each parameter to be tested is altered so that it is factored by a value of between 0.7 and 1.3. In each case, the model is run seven times with the parameter being changed each time. The outputs from the model are then compared to see how station demand and access mode share change in relation to the input parameter.
- 6.3.9. For each parameter to be tested, seven copies of the SCM executable and the input files are created. In each copy, the relevant input parameter is changed in the appropriate file, but all other input files remain unchanged.
- 6.3.10. The initial tests involve global parameters which are all stored in the "Input_Parameters.txt" file. The original and amended value of each parameter is given in Table 32 below.

Table 32: Global parameters tested

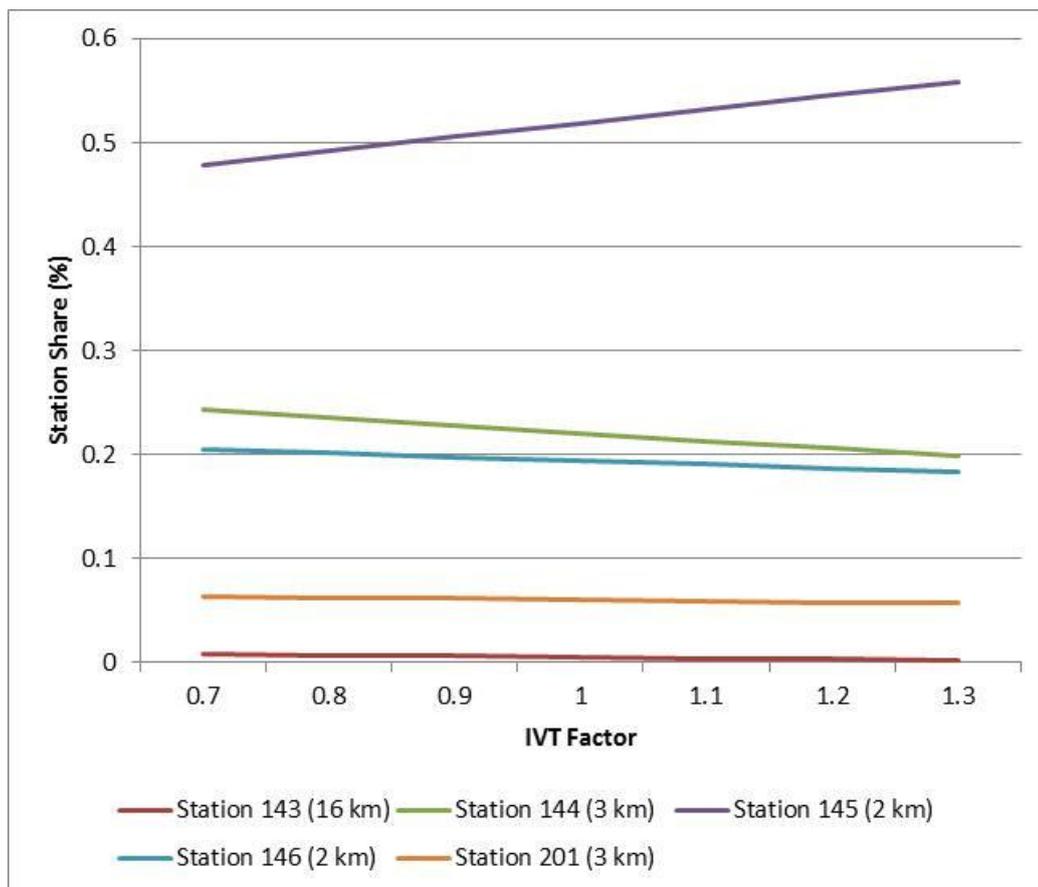
| Parameter | Row in input file | Original value | Lower limit | Upper limit |
|--------------------|-------------------|----------------|-------------|-------------|
| Petrol costs / km | 1 | 9.32 | 6.524 | 12.116 |
| PT fare | 2 | 12.43 | 8.701 | 16.159 |
| PT walk time | 5 | 1 | 0.7 | 1.3 |
| PT wait time | 6 | 2 | 1.4 | 2.6 |
| PT In-vehicle time | 7 | 1 | 0.7 | 1.3 |
| VOT commuting | 10 | 15.21 | 10.647 | 19.773 |

- 6.3.11. The testing process was controlled by an Excel VBA macro to minimise the risk of human error when preparing the input files. The macro created copies of the SCM model and input files and then amended the appropriate input file in each case. The macro then ran the SCM executable file in each test folder and extracted the relevant outputs for comparison.
- 6.3.12. By automating the testing process, we were able to ensure that the tests were undertaken consistently, but it also meant that we could be introducing additional errors through the scripting process. To ensure that there were no errors in the testing process, all input and output files were retained after the process for manual verification. All of the results presented have been verified to ensure that the input files are correct and that the extracted outputs correspond to the correct output files.
- 6.3.13. The volume of input and output data used by the SCM makes it difficult to evaluate the response of the model and observe any meaningful trends. Therefore to reduce the volume of data and make the assessment easier, we have extracted data for a single origin-destination (O-D) within the PLD model. This O-D represents journeys from zone 130 (Manchester) to zone 5 (Birmingham), chosen as a non-London O-D pair that could be expected to have a reasonably high level of demand. There are 137 mzones and 14 stations modelled for the origin zone, compared with 131 mzones and 10

stations for the destination zone.

- 6.3.14. Our assessment considers two aspects of the SCM function: firstly, how mode share changes in response to the change in each parameter, and; secondly, how station choice is affected by the same change. The graphs comparing mode share for each test are done using aggregated data for the chosen O-D (i.e. all trips from every mzone and station in the origin and destination zones). However, due to the large number of mzone/station combinations and the difficulty in identifying trends in aggregate data, comparisons on station choice have generally been undertaken for one mzone and for one mode only.
- 6.3.15. The objective of these tests was to isolate the SCM from the rest of the modelling framework and assess the SCM's outputs for a range of inputs. These tests would quickly ascertain if there are any major issues in the SCM program by checking that the outputs are logical for the given inputs. For example, if public transport access costs are increased, then the model would be expected to allocate more trips to the highway access mode. It would also highlight inconsistencies within the model inputs. An example of the type of output from the diagnostic tests is shown below in Figure 49.

Figure 49: Sensitivity tests



Emulation

6.3.16. This test sought to emulate the station choice functionality of the SCM manually using Microsoft Excel and verify that the SCM outputs matched those of the manual process. This would highlight any issues with the implementation of the choice function, and in particular if there were problems with the program coding.

Line-by-Line Checking

6.3.17. The purpose of this task was to check the code for any specification and algorithmic errors, and to check that the code provided is consistent with the methodology outlined in the supporting documentation.

6.4. Outputs

6.4.1. The SCM outputs were mapped using GIS software to highlight travel patterns and allow us to see if there was any unusual behaviour.

6.4.2. The following stations have been analysed:

- Birmingham (New Street, Moor Street, Snow Hill);
- Manchester (Piccadilly, Oxford Road, Victoria, Salford Central);
- Chester;
- Coventry;
- Lancaster;
- Nottingham;
- Preston; and
- York.

6.4.3. Outputs were analysed in two ways: firstly to identify for a particular station, the proportion of trips using the station from each zone; and secondly, for a selection of zones, the proportion of trips using each station. Examples of the analysis are shown below in Figure 50 to Figure 52, plotted at MSOA¹¹ level.

¹¹ Middle Layer Super Output Area (MSOA): Definition used by the Office for National Statistics for a geographical area with an average population of 7,500 persons based on Census information.

Figure 50: MSOA station demand, Birmingham

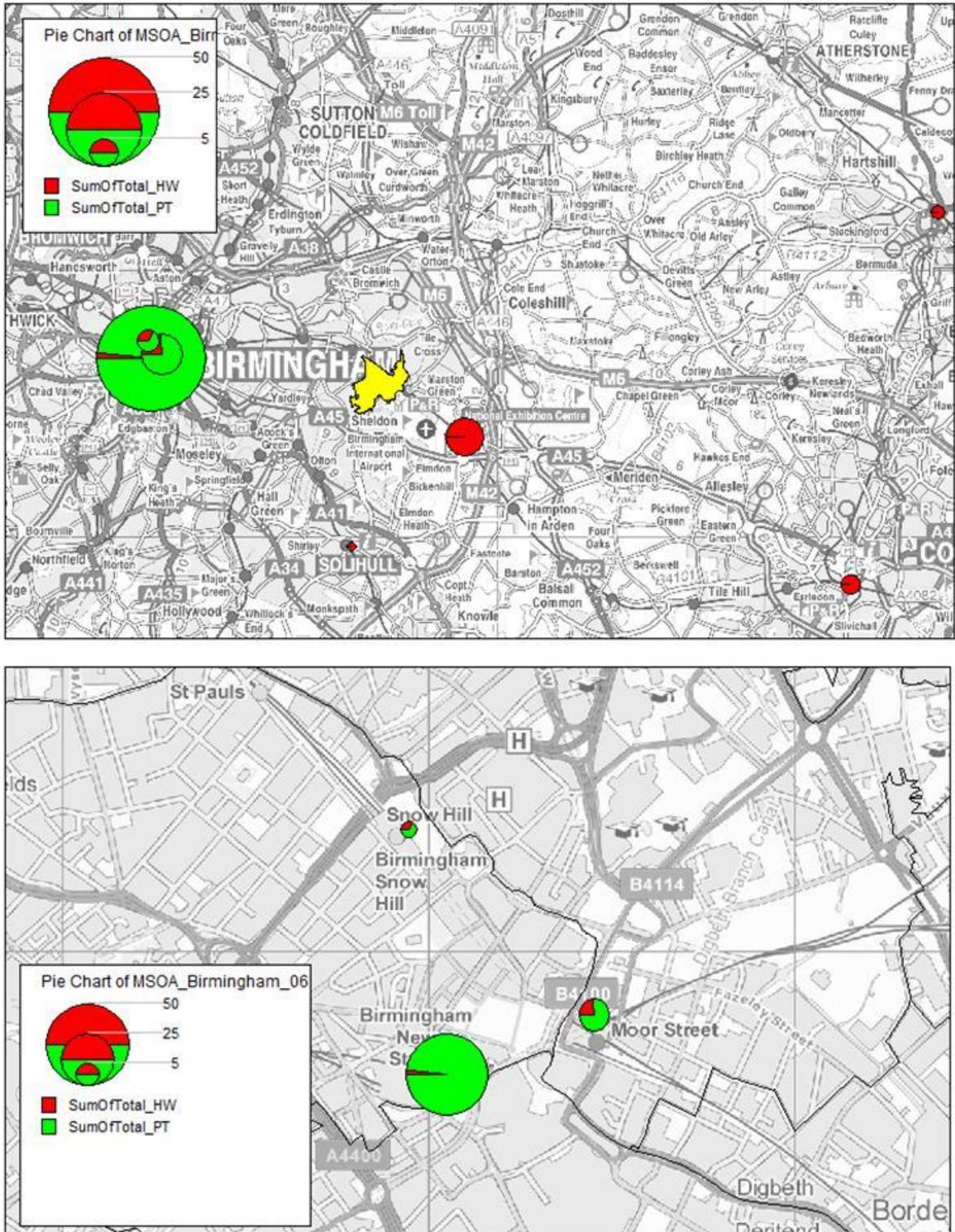


Figure 51: Birmingham Moor Street station demand by MSOA

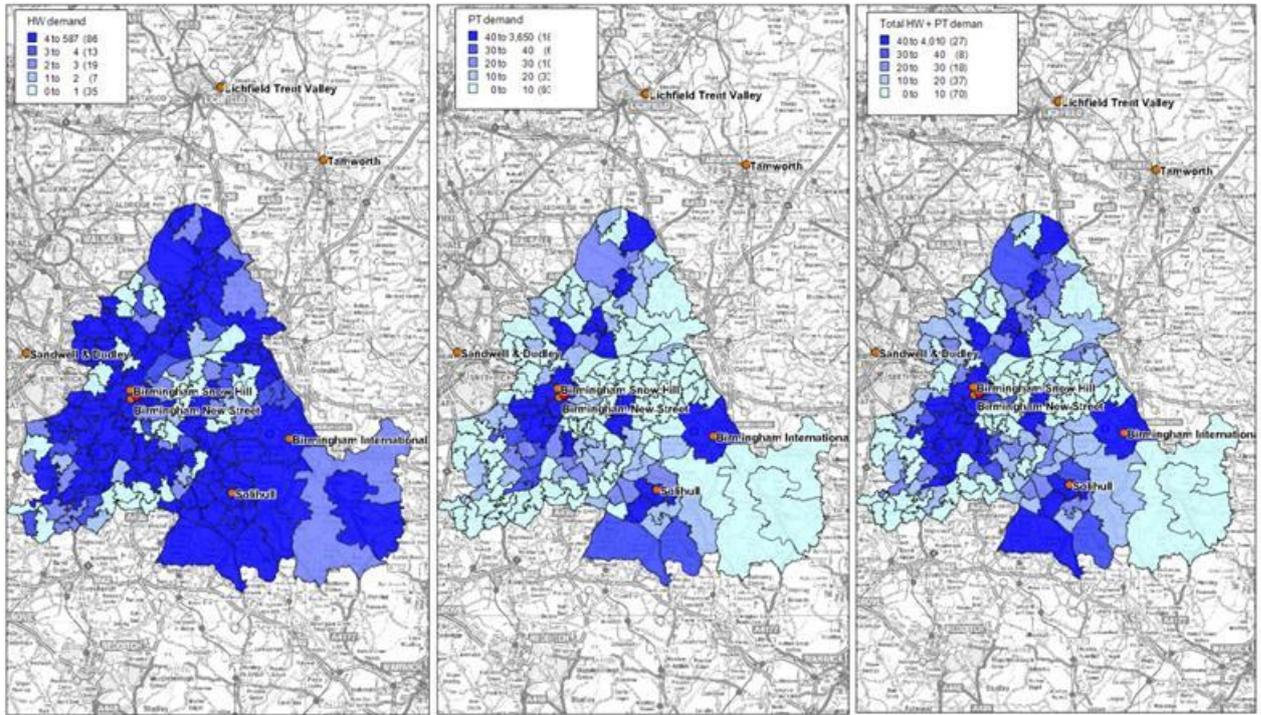
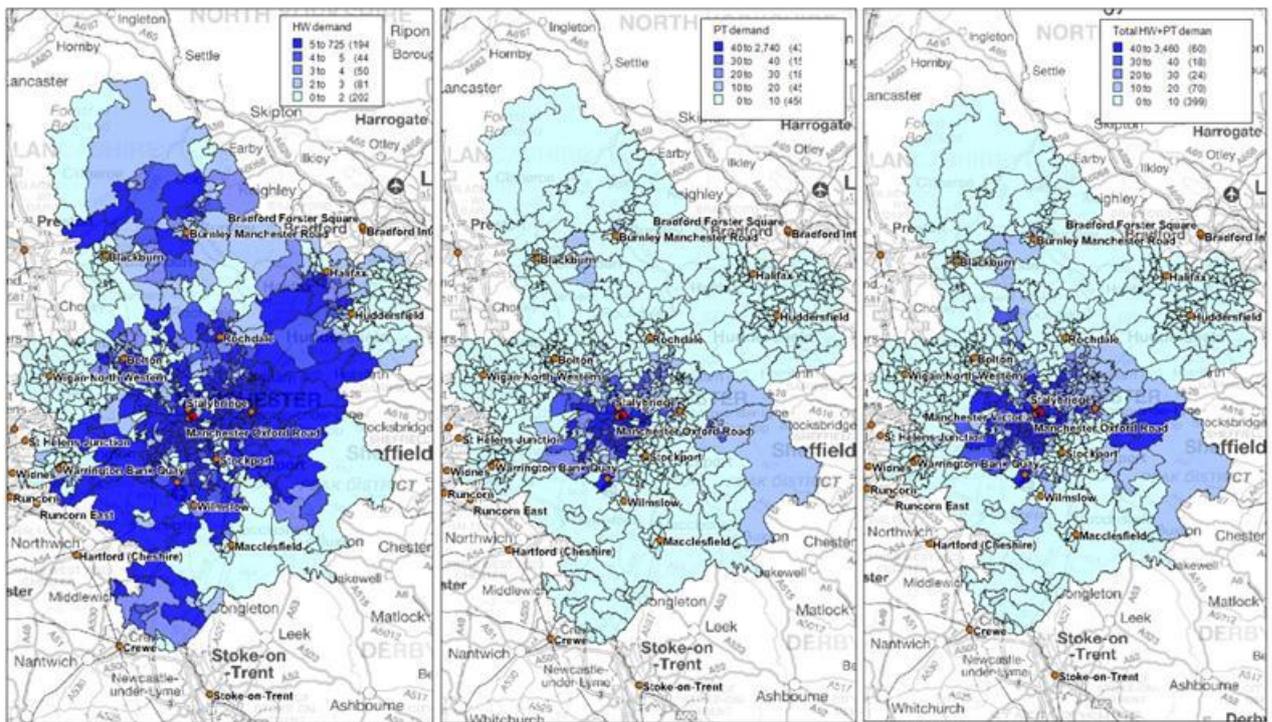


Figure 52: Manchester Piccadilly station demand by MSOA



6.5. Audit findings

- 6.5.1. We conclude the SCM has been correctly implemented aside from three minor concerns:
- Access costs between the mzones and the stations have been updated as a result of early audit findings. The gravity model was calibrated using NAM data and has not been updated with new access cost data at the same time as the rest of the SCM. As the gravity model determines how the PLD zones are disaggregated for input to the SCM, this could lead to some minor but insignificant impact.
 - Local access times in SCM are adjusted as part of the model calibration to reproduce the base year observed station allocations. This makes the allocation and interpretation of appropriate access times for new HS2 station locations difficult and may introduce a local bias. However, the new HS2 stations are now represented by dummy nodes as part of the DM coding and care has been taken to ensure that the access times to the new stations are consistent with existing ones. Therefore, there is unlikely to be an impact using the current data in the standard case. Care will be needed if any additional new HS2 stations were introduced in an entirely new location.
 - There is some indication that rail times have been included in the PT access costs to mainline stations, this is particularly evident by the relatively large number of trips allocation to central Birmingham stations that originate in Solihull.

6.6. Implications of audit findings

- 6.6.1. It is unlikely that any of the remaining issues identified will have a significant impact on the model outputs.
- 6.6.2. The impact of the gravity model will be limited as it is only used where there are gaps in the NRTS data, and any impact caused by the use of old data is likely to be insignificant in any case.
- 6.6.3. The calibration of local access times in the SCM has been adjusted in areas with separates HS2 stations, so that the modelled times more accurately reflect the actual costs. The issue still remains in other areas, but this will not affect the outcome of the model. However, this may have implications for future changes to the model, and care will need to be taken if any new HS2 stations are introduced in the future.
- 6.6.4. The use of rail times in access costs is not likely to be widespread and the only impact is likely to be a reduction in the overall number of passenger-kms on the rail network. As this will affect the without-HS2 and with-HS2 tests equally, this will have no material impact on the overall business case.

7. Heathrow Access Model

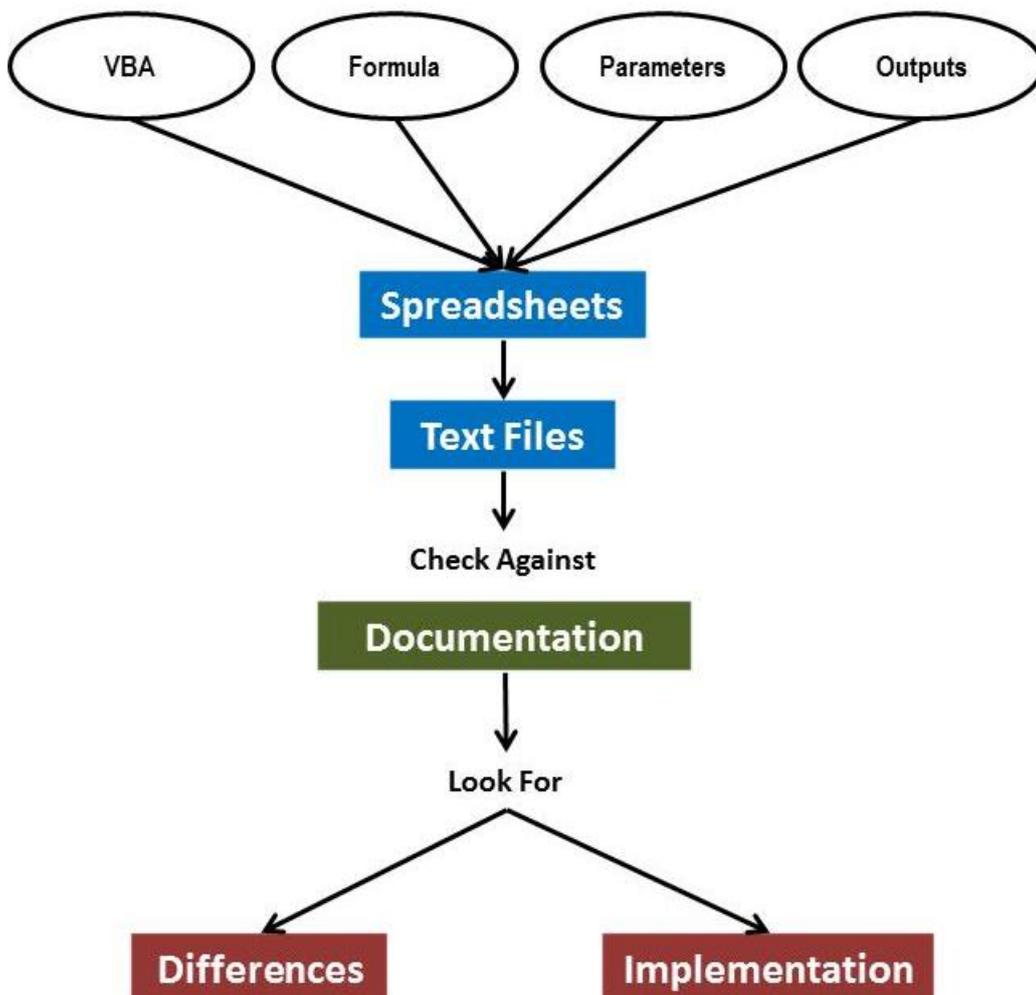
7.1. Introduction and context

7.1.1. The objectives of the Heathrow Access Model (HAM, formerly known as the Airport Demand Model, ADM) audit were:

- To confirm that the model structure and model parameters of the implemented model are consistent with those documented in the 'HS2 Airport Demand Model: A Report for HS2, Final Report', issued by the model developers in July 2010.
- To check the inputs to the model;
- To check the calculations undertaken within the model; and
- To check the model outputs.

7.1.2. To achieve the above objectives, the audit process illustrated in Figure 53 was followed.

Figure 53: HAM Audit Process



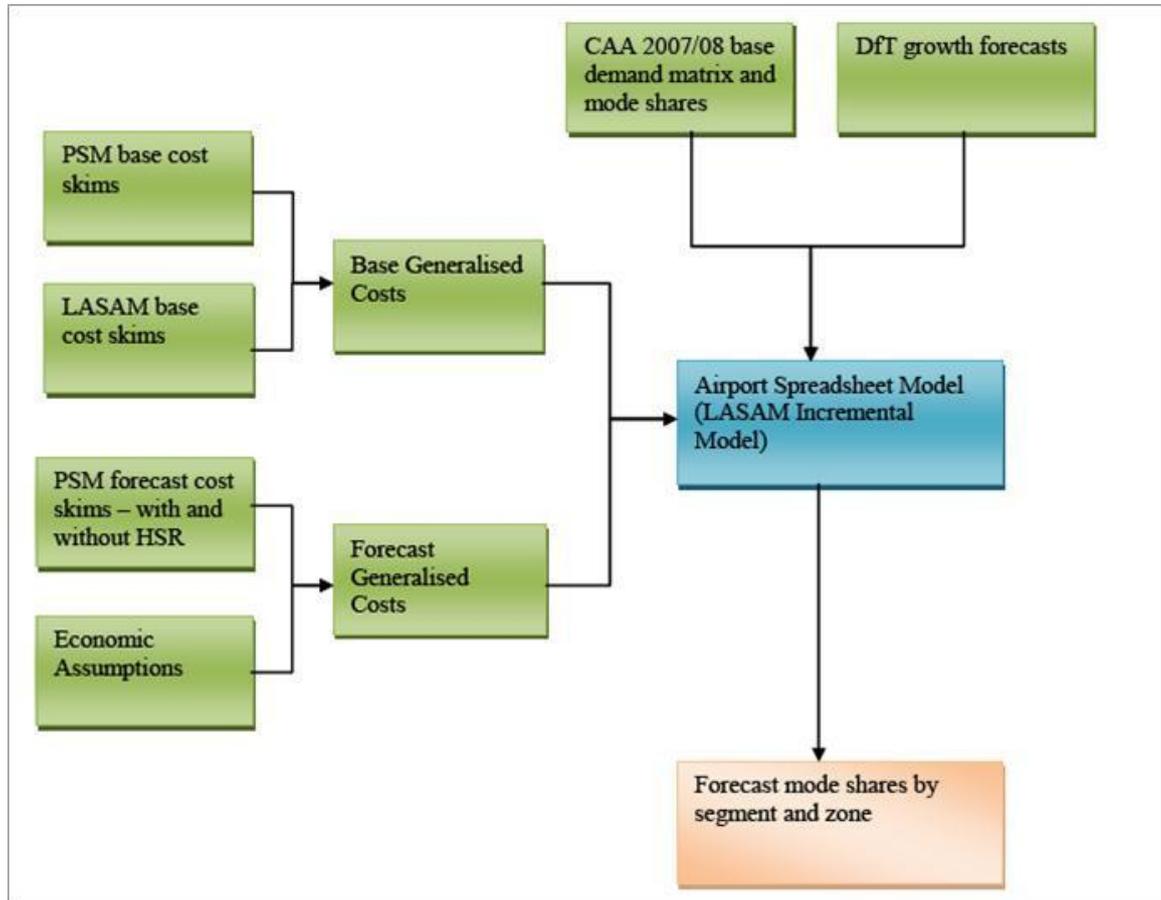
7.1.3. In summary, the following tasks were defined:

- Receiving PFMv4.1 of the model, ‘unpacking’ the model and mapping of the model’s functions and interfaces;
- Undertaking a workshop with the model developers to discuss a first set of our questions, following our reading of the model documentation and our initial assessment of the linkages within the model;
- Checking the input data;
- Checking assumptions against documentation;
- Receiving the ‘London Airports Surface Access Modelling (LASAM) Estimation Report’, produced by SKM for BAA in July 2006, which provided the source for many of the model parameters, and checking the model parameters in the HAM against this source;
- Reviewing the revisions to the model structure of the HAM compared to LASAM and assessing the appropriateness of adopting some of the model parameters from LASAM;
- Checking the calculations undertaken within the model;
- Checking the model outputs; and
- Reporting.

7.2. Methodology

7.2.1. The HAM is a stand-alone excel spreadsheet model (with some visual basis front-end elements), within the PFM suite of programs. The structure of the HAM model is illustrated in Figure 54 below.

Figure 54: Heathrow Access Model Structure



7.2.2. The various stages can be summarised as follows:

- **In-scope demand.** The HAM deals with two specific segments of HS2 passenger demand that cannot be easily represented in the PLD model:
 - Diversion to HS2 of current Heathrow surface access trips in the HS2 corridor, (excluding trips from London) as an improved service to Heathrow airport, for example, through interchange at Old Oak Common, could be expected to attract an increased rail mode share compared with the existing connecting services through central London, which are longer.
 - Diversion from HS2 of air passengers that currently take a domestic flight to/from Heathrow to connect with an international flight to/from Heathrow. It should be noted that passengers not making an international connection are not in-scope within the HAM, as they will be modelled in the PLD model. Furthermore, passengers who currently fly internationally from non-London airports who could divert to HS2 are also out of scope in the HAM model; they are instead modelled in the 'HS1-HS2 Connection Model', see Chapter 8 below.
- **Catchment area.** A rail catchment area along the route of HS2 has been defined, reaching from an area just north of Heathrow through Birmingham to the north.

This catchment area contains less than 10% of all air passengers accessing Heathrow. Since there are no domestic flights to Heathrow from Birmingham, East Midlands or Liverpool, the air catchment area has been defined primarily as Manchester, with some services also from Newcastle, Edinburgh and Glasgow airports. In 2008 the Manchester to Heathrow service carried 910,000 passengers, although the total has declined in recent years and is expected to continue to do so.

- **Base year definition:** This was originally 2007/08, but it has since been updated to 2010/11.
- **Methodology.** The HAM has been based on the LASAM, developed originally by SKM for BAA in 2006. The LASAM v2 model was adapted to form a spreadsheet HAM model, by making the following changes:
 - focus on the study corridor: Heathrow – the Midlands – and North;
 - three catchment areas (an intermediate area containing Oxford and Milton Keynes, Birmingham and Manchester), each containing all PLD zones within these catchment areas;
 - retain the same hierarchical model choice structure as LASAM;
 - remove Heathrow Express, Underground, Rail Air Coach and Airport transfers as main mode options as they are only relevant to trips from London;
 - add HS2 as a rail sub mode;
 - add air as a public transport sub mode;
 - retain the same sensitivity parameters as LASAM;
 - select an appropriate mode constant for HS2;
 - select an appropriate mode constant for air; and
 - use of one zone to represent Heathrow.

7.2.3. The HAM is used to forecast the change in mode shares from a current situation, and can therefore be defined as an incremental model. The model has been set up to allow different HS2 routes to be tested, although it was calibrated based on the assumption of HS2 passing through the West Midlands to Manchester.

- **Demand segmentation.** The 6 demand segments within LASAM were aggregated to 4 demand segments to be consistent with the PLD. These 4 demand segments are defined as: UK business; foreign business; UK leisure and foreign leisure.
- **Time period.** LASAM models four time periods (weekday AM peak, interpeak and PM peak, and weekend), whereas the PLD matrices represent an average weekday. In order to be consistent with the PLD, the three weekday LASAM cost skims were weighted to form a single weekday skim.

- **Base year matrices.** A base year matrix of annual air passengers by segment, origin and mode was created by combining surface access modes and domestic air passengers. The base matrix represents all passengers that could switch to HS2 in order to access Heathrow Airport.
- **Base year surface access demand.** CAA air passenger surveys for 2007 and 2008 were analysed to define the 'main mode' of access to Heathrow.
- **Base year domestic air access demand.** CAA surveys on air passengers travelling between Manchester and Heathrow airports were analysed to determine the proportion of passengers transferring to an international flight at Heathrow. In 2007/2008, 65% of air passengers on the Manchester-Heathrow route transferred to another flight at Heathrow. The same detailed level of analysis was not possible at Edinburgh, Glasgow or Newcastle airports, as CAA does not survey them as regularly as other UK airports. The last available survey at each airport was 2005. The distribution of trips by segment and zone from the 2005 survey was applied to the 2008 total transfer passengers at Heathrow.
- **Future year surface access demand.** The DfT provided forecasts for the number of non-transfer air passengers at Heathrow, segmented by zone and segment for 2020 and 2030. These forecasts were used to represent 2021 and 2031.
- **Future year domestic air access demand.** The DfT provided forecasts for the volume of domestic air travel from UK airports to Heathrow for 2020 and 2030 and these forecasts were used to represent 2021 and 2031. Only air passengers from Manchester, Edinburgh, Glasgow and Newcastle that transfer to an international flight at Heathrow were included. It should be noted that the numbers of such passengers are predicted to drop considerably from 2.02 million in 2008 to 1.63 million in 2030.
- **Mode choice hierarchy.** PLD cannot supply separate skims by each existing rail type; it can however supply skims with and without HS2 so that the new rail mode can be modelled separately. To accommodate this, all existing rail modes were combined and referred to as 'standard rail'. This combined mode uses the LASAM modal constant for standard rail, as the majority of trips are made on this mode. HS2 uses the modal constant for non-London Heathrow Express Passengers as SKM state in a footnote "*no recent research into modal constants for long distance high speed rail services could be found*". Thus the HAM adopted the same mode choice tree structure as LASAM, with the following modifications:
 - RailAir Coach treated as standard rail (represented only 0.6% mode share);
 - Passengers arriving at the airport by Underground or Heathrow Express are modelled as standard rail;
 - Air added to the public transport nest;
 - HS2 added to the rail sub-nest (an absolute nest);
 - Charter coach fixed at 2007/8 mode share (overall 3.0% mode share);
 - Other modes (3% mode share) ignored; and

- Air transfer not modelled as it is not valid within the catchment area.
- **Costs skims.** To ensure that the HAM is as compatible with the PLD as possible, where available, cost skims from PLD are used in preference to those from LASAM. Base and forecast year cost skims for rail, car and air are taken from the PLD and are a key input to the HAM. Cost skims for other modes such as coach and taxi are provided from LASAM as a fixed input for each forecast year.
- **Definition of generalised costs.** Generalised cost equations were defined for each mode for each of the four market segments, made up of various elements including: check in time; access time; in-vehicle time; wait time; boardings; fare; vehicle operating costs and parking costs. Each of these generalised cost components were derived from PLD or LASAM as defined above, multiplied by a parameter, sourced from LASAM.
- **Outputs.** The HAM produces forecasts of in-scope demand of air, car, rail and coach demand by zone, business and leisure passenger segments and direction for an average annual weekday. These outputs are fed back into the PFM suite of programs for aggregation to the other elements of demand and appraisal.

7.3. Auditing the inputs and assumptions

- 7.3.1. The HAM is a spreadsheet model, comprising two workbooks: Heathrow_Demand.xls and Heathrow_Cost_Components.xls. Its interaction with the other components within the PLD modelling framework is described in Atkins Report # 5082342, Model Development Report, issued in 2010.
- 7.3.2. The inputs to the HAM are defined as those below.
- Base year cost skims from PLD;
 - Base year cost skims from LASAM;
 - Future year cost skims from PLD (with and without HS2);
 - Future year cost skims from LASAM;
 - Base year demand matrix from CAA;
 - DfT growth forecasts; and
 - Model parameters from LASAM.
- 7.3.3. We had access to the PLD and were able to check the cost skims as input to the HAM. The LASAM model, developed on behalf of the owners of Heathrow Airport, was out of scope of our audit but the cost skims derived from LASAM were documented in the model report and we were able to check them against the documentation.
- 7.3.4. We compared the overall base year surface and interlining demand in the HAM model against the documented values and found some minor inconsistencies (in absolute terms) as shown in Table 33 below.

Table 33: Surface and interlining demand comparison

| Base year annual demand | Documented | HAM Model | Difference | % Difference |
|--------------------------|------------|-----------|------------|--------------|
| Base Year Surface Demand | 117,068 | 122,721 | 5,653 | 5% |
| Interlining Demand | 5,656 | 6,420 | 764 | 14% |

7.3.5. We did not have access to the base year CAA raw data so were unable to check the individual OD cells in the base year demand matrices.

7.3.6. We have compared the demand growth factors from the airport demand matrices provided to us from the model developers as ‘hard-wired’ numbers in the HAM to the documented CAA and DfT forecasts. Table 34 below shows the derived growth factors from the DfT forecasts. These are different from the growth factors implemented in the model. For example, the 2026-2036 annual growth rate implemented in the HAM model for Manchester airport was -2.66%, compared to +2.66% derived from the DfT forecasts for the period 2020-2030.

Table 34: Derived demand growth factors in the HAM

| Airport | 2008-CAA | 2020-DfT | 2030-DfT | 2020-2030 Growth Factor per year |
|------------|----------|----------|----------|----------------------------------|
| Edinburgh | 555569 | 343635 | 371390 | 0.78% |
| Glasgow | 563361 | 288015 | 448980 | 4.54% |
| Manchester | 608983 | 330413 | 429696 | 2.66% |
| Newcastle | 292138 | 292369 | 384797 | 2.79% |
| Total | 2020051 | 1254432 | 1634863 | |

7.3.7. The model parameters in the HAM are documented in the assumptions log. The assumptions can be grouped as follows:

- Scaling parameters;
- Mode constants;
- Value of time growth factors;
- Parking charges;
- Check in time;
- Annual to average weekday factors;
- Values of time;
- Vehicle operating costs;
- Time coefficients;
- Wait coefficients;
- Walk coefficients;
- Access coefficients;
- Rail interchange coefficients;

- Bus interchange coefficients;
- Kiss and fly time coefficients;
- Distance coefficients;
- Heathrow group size coefficients;
- Heathrow kiss and fly parking charge coefficient;
- Heathrow park and fly parking charge coefficient; and
- Demand forecasts.

7.3.8. Each of the individual assumptions were checked against the documentation and in almost most cases we were able to confirm that the assumption was as documented. The instances where the data in the HAM did not concur with that in the documentation are listed in Table 35. All of these are monetary values, i.e., those that depend on a change in price base from 2004 in LASAM to 2008 in the HAM model: values of time and parking charges.

Table 35: Differences between assumptions within HAM and those documented

| | HAM (2008 price base) | LASAM (2004 price base) |
|--|-----------------------|-------------------------|
| Base year value of time (p/min) | | |
| UK Business | 70.00 | 66.14 |
| UK Leisure | 25.94 | 24.79 |
| Non-UK Business | 61.61 | 58.21 |
| Non-UK Leisure | 25.90 | 24.75 |
| Base year kiss and fly parking charge (p/trip) | | |
| UK Leisure | 133.35 | 126.00 |
| Non-UK Leisure | 133.35 | 126.00 |
| Base year Park and Fly parking charge (hire car for non-UK) (p/day) | | |
| UK Business | 2010.85 | 1900.00 |
| UK Leisure | 1587.51 | 1500.00 |
| Non-UK Business | 5291.71 | 5000.00 |
| Non-UK Leisure | 5291.71 | 5000.00 |

7.3.9. Although the growth rate from the 2004 LASAM values that formed the basis of the HAM development do not look implausible and are applied in a consistent manner, we cannot exactly replicate from readily available sources how that growth was derived in the absence of appropriate documentation. This could be because the GDP deflator has since been revised. This should be reviewed in any future model development.

7.3.10. Finally, we noted in the 'standard rail' mode constant was coded as zero in the model, compared to a non-zero value in the documentation. This is a wider issue, as is discussed further in section 7.6 below.

7.4. Auditing the processes

- 7.4.1. We started our audit of the HAM with a half day workshop with the model developers. This workshop concentrated on a review of our understanding of the supplied HAM in PFMv4.1 and the confirmation of this by the model developers. We also took this opportunity to raise some initial issues with the model developers.
- 7.4.2. Prior to the audit of the HAM, we first unpacked the HAM provided by the model developers to check that the implementation of the model structure, associated folders and files, input and output data had been undertaken correctly.
- 7.4.3. The audit included:
- unpacking the HAM and undertaking a line-by-line check of the HAM spreadsheets and associated VBA programs;
 - checking the input data (as discussed in section 7.3 above);
 - checking the assumptions against those documented (as discussed in section 7.3 above);
 - checking the documented processes (including the worksheets and VBA codes)
 - checking that the structure of the hierarchical logit model choice is as documented;
 - checking that the calculation of the generalised cost is as documented;
 - checking the links between various worksheets; and
 - checking the output data.
- 7.4.4. Whilst unpacking all the elements of the HAM, we thoroughly documented each aspect of each sub-model and this proved invaluable during the rest of the audit. The documentation included:
- Level;
 - Folder and location;
 - Command file name;
 - Command variable (scenario, year etc.);
 - Input files;
 - Output files;
 - Predecessor command; and
 - Function of command,
- 7.4.5. As a part of this unpacking process, we also produced a list of all formulas and related variables used in the HAM for demand, skims and parameters to verify their application within the HAM run process. Since the base and the forecast models used the same logit formulation, we also audited the consistency of the implementation of parameters between the base and the forecast models. This helped us to identify any consistency

issues which were then raised with the model developers

- 7.4.6. In particular we checked the consistency of the cost skims, demand matrices and fares matrices between the PLD and HAM models, as they should be identical for the in-scope demand. Very small differences were identified, but to the third or fourth decimal place, which should be insignificant.

7.5. Outputs

- 7.5.1. The HAM produces forecasts of in-scope demand of air, car, rail and coach demand by zone, business and leisure passenger segments and direction for an average annual weekday. We checked the computational calculation of these outputs and that transfer of the outputs to the PFM suite of programs.

7.6. Audit findings

- 7.6.1. The finding of our audit of the HAM element of the PFMv4.1 model are summarised below:
- We found minor inconsistencies between the total base year demand in the HAM and that documented;
 - We did not audit the prior processing of detailed CAA demand data at an OD level;
 - We found minor inconsistencies between the future year growth factors derived from the DfT forecasts and those implemented in the HAM;
 - We verified the large number of parameters in the HAM against those documented and found almost all to validate exactly, apart from four base year values of time, two base year kiss and ride parking charges and four base year kiss and ride car hire charges, listed in Table 35 above.
 - We also identified two instances where the values were not documented (growth rates in values of time and parking charges).
- 7.6.2. However, the most significant audit finding refers to the structure of the mode choice model and the parameters adopted from LASAM. As discussed in section 7.2.2, the documentation ('HS2 Airport Demand Model: A Report for HS2, Final Report', issued by SKM in July 2010) states that HAM retained the same hierarchical mode structure as the LASAM, with the following changes:
- Air was added to the main public transport nest, and adopted a zero mode constant;
 - HS2 was added to the rail sub-nest, and adopted the non-London Heathrow Express mode constant; and
 - All existing rail modes (RailAir Coach, Airport Rail and Standard Rail) were combined and referred to as standard rail and adopted the LASAM mode constant for standard rail.

- 7.6.3. Our issue with this is that if the hierarchical structure of a mode choice model is

changes then the model parameters should be recalibrated, rather than adopting the parameters of the original structure. This good practice was understood at the time of development but it was not considered a priority given the time and resource available. It is, however, difficult to justify the adopted mode constants and the retention of the original nesting parameters.

- 7.6.4. Furthermore, we understand (from the 'Model Development Report # 5082342', published by Atkins in 2010) that when Atkins took over the running of the PFM, they did not apply the hierarchical mode choice structure as documented in the SKM report, but instead applied zero HS2 skims, implying a single rail sub-mode below the rail mode in the higher public transport nest. However, Atkins retained the nesting parameters of the LASAM model, although they had made changes to the hierarchical structure.
- 7.6.5. Thus the model, as implemented by HS2 Ltd, is different from that documented by BAA and LASAM, and we believe best practice dictates it should be recalibrated for the new hierarchical mode choice structure. The implications of this are discussed in section 7.7 below.

7.7. Implications of audit findings

- 7.7.1. We confirm that we have undertaken a thorough audit of the HAM PFMv4.1. We have not audited the version of the HAM in the current version of the PFM (PFMv4.3) as we understand the methodology is unchanged.
- 7.7.2. We have found a number of minor discrepancies between in the total base year demand and in the growth of this demand, which we recommend are investigated.
- 7.7.3. We have also found a number of minor discrepancies between the model parameters in the HAM and those documented, which we recommend are reviewed in future model development.
- 7.7.4. The hierarchical structure of the mode choice model is not implemented as documented, and has adopted the parameters of the LASAM model, despite a different structure. Ideally, the model parameters should be recalibrated, but time does not permit and it is not possible to predict the significance of this re-estimation of the demand parameters although we note the HAM has a small impact on scheme benefits. We therefore recommended that three sensitivity tests should be undertaken as follows:
- (i) Recoding the rail nesting parameter to unity (i.e. bringing the rail choice up to the level of the public transport choice in the hierarchy)
 - (ii) Recoding the HS2 mode constant to zero; and
 - (iii) combining tests (i) and (ii).
- 7.7.5. The impact of sensitivity test (ii) was negligible (rail flows reduced by around 2%) and thus we can conclude that the mode constant issue is insignificant. The impact of

sensitivity tests (i) and (iii) was to increase the total rail mode share by around 30%, as the costs are no longer being factored by a number less than unity. Thus we can conclude that adopting the current nesting structure is probably resulting in an underestimate of total rail demand, rather than an overestimate. Furthermore, it should be borne in mind that the HAM results make a small contribution on the overall business case.

8. HS1-HS2 Connections Model

8.1. Introduction and context

8.1.1. The objectives of the HS1-HS2 Connections Model audit were:

- To confirm that the model structure and model parameters of the implemented model are consistent with those documented in the 'Information Note' provided by the model developers;
- To check the calculations undertaken within the model; and
- To check the model outputs, particularly the appraisal results.

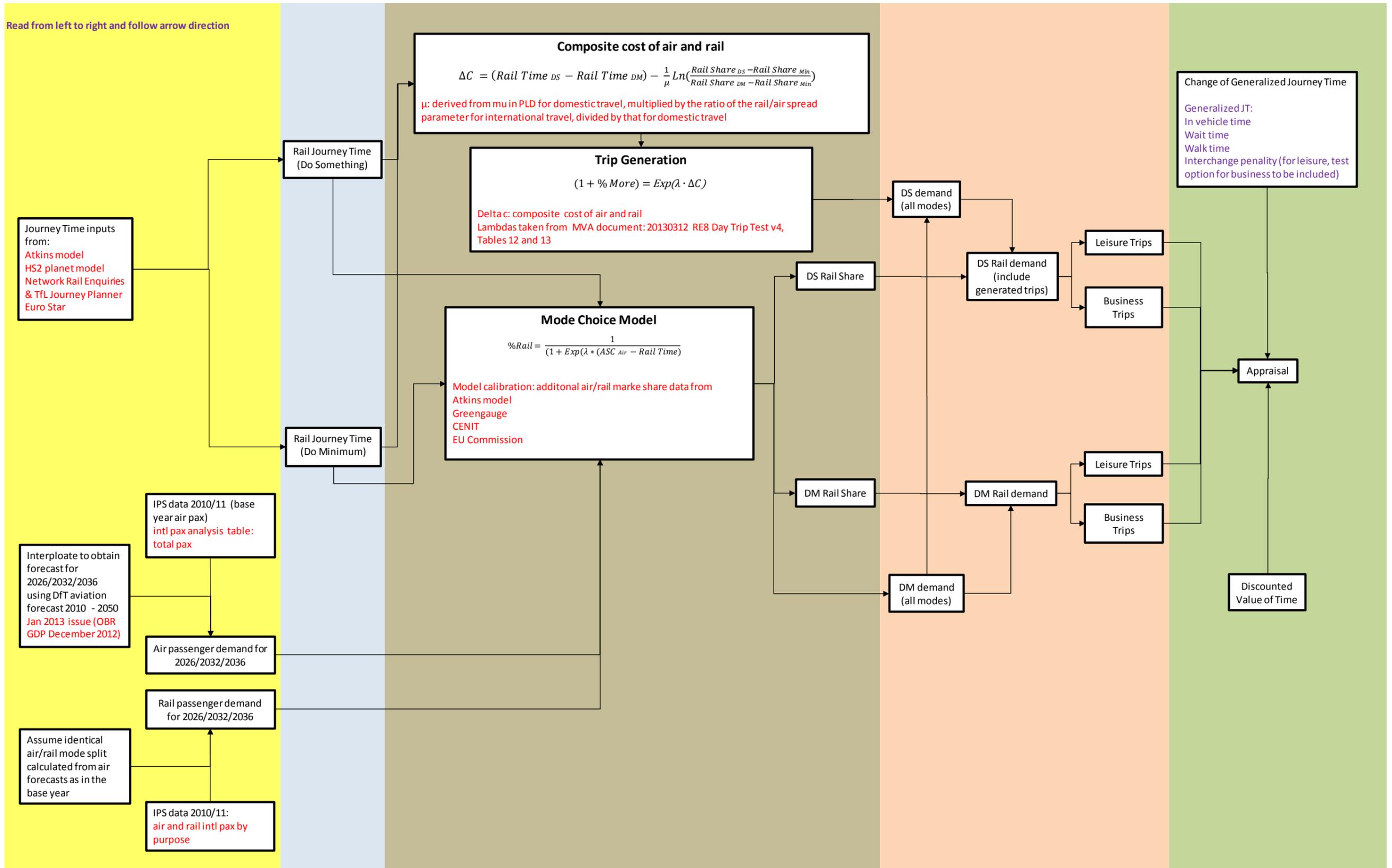
8.1.2. To achieve the above objectives, the following tasks were defined:

- Receiving v4.4 of the model and mapping of the model's functions and interfaces;
- Undertaking a workshop with the model developers to discuss a first set of our questions, following our reading of the model documentation;
- Checking the input data;
- Checking assumptions against documentation;
- Checking the calculations undertaken within the model;
- Checking the model outputs;
- Undertaking a second workshop with the model developers to agree a re-specification of the model structure and the correction of a number of issues that we identified as part of the audit;
- Receiving versions v4.7, v4.8 and v5.1 of the model and checking that the stated changes to the model structure and agreed improvements had been made; and
- Reporting.

8.2. Modelling methodology

8.2.1. The methodology for deriving the HS1-HS2 Connection demand is illustrated in Figure 55 below.

Figure 55: Flow chart of HS1-HS2 Connections Model



8.2.2. The various stages can be summarised as follows:

- **In-scope demand.** The model focusses on a small number of city pairs for which a HS1-HS2 link could be attractive to make an international journey from the UK to Northern Europe by high speed rail. 12 UK regions (West London/Rest of LSE within the OOC catchment area, Birmingham, Bristol, Cardiff, East Midlands, Edinburgh, Exeter, Glasgow, Leeds, Liverpool, Manchester and Newcastle) and 6 European regions (Amsterdam, Brussels, Cologne/Dusseldorf, Frankfurt, Lille and Paris) were identified.
- **Base year air demand.** This was derived from the 'International Passenger Survey (IPS), 2010/2011, although a comparison with CAA data was also undertaken. IPS data were used in preference to CAA data as it proved impossible to identify interlining passengers (which were subsequently excluded from the analysis) in the CAA data.
- **Base year rail demand.** This was derived from a combination of IPS data and data provided by Eurostar. The latter provided 2012 demand for trips from beyond London and the SE, and were considered more robust than the IPS data. The IPS data were used to allocate the Eurostar data to the 11 UK regions.
- **Future year air and rail demand.** This was derived by applying DfT forecasts for air demand growth to both air and rail trips, so that the forecast year (FY) Do-Minimum mode share is identical to the base year mode share.
- **Air journey times.** FY air times and costs were assumed to be identical to those in the base year. EDGE assumes that air fares are about 5% lower by 2030, so there is a minor inconsistency here.
- **Rail journey times.** DM (without HS2) rail times were calculated by summing the following elements: in-vehicle time to London; in-vehicle time from London to European destination; London interchange time; European city interchange time; Interchange penalty; wait time at interchanges and Eurostar check-in time. (Note: Access times and frequency of service were excluded, although frequency was addressed later in the process). Rail in-vehicle times were derived from current rail timetables, assuming travellers will take the fastest off peak hourly service. DS (with HS2) rail times were calculated as above, using the planned HS2 timetables.
- **Definition of scenarios.** Six scenarios were defined as follows:
 - Do Minimum;
 - Do Something, with HS2, no HS1-HS2 link;
 - Do Something, with HS1-HS2 link, 1 train per hour to Paris and Brussels, interchange at OOC;
 - Do Something, with HS1-HS2 link, 1 through train per hour to Paris and Brussels;

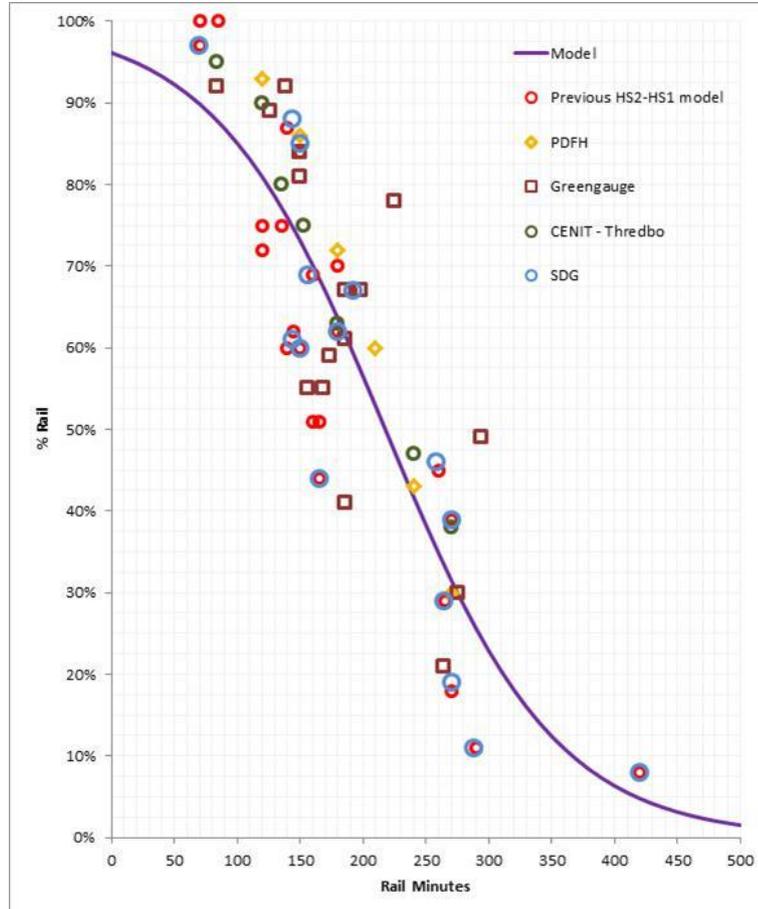
HS2 Model Audit: PFMv4.3 Implementation and Standard Case Forecast

- Do Something, with HS1-HS2 link, 3 trains per day to Paris and Brussels, interchange at OOC; and
- Do Something, with HS1-HS2 link, 3 through trains per day to Paris and Brussels.

8.2.3. Each Do Something scenario was run with the D1 (2026) and Y (2033) option.

- **Mode share estimation.** A simple bi-nominal logit curve was used to forecast future rail shares, based purely on rail journey times between city pairs, see Figure 56. Following discussion, the model developers accepted that some of the data points may have been included in more than one source, that most of the data are relatively old and that very few include interchanging passengers, but stated *“this is all the data on observed rail share that is available and we considered it best to use all data rather than reject a significant proportion that might be old”*. The model was originally specified as an absolute model, but following our concerns with the quality of the base year validation of this model structure and the later provision of the Eurostar demand data, the model structure was changed to an incremental model, with the predicted change in mode share based on the change in rail generalised journey time applied to the base observed mode share.

Figure 56: Rail/Air Mode Share Graph



Source: MVA

- **Generated demand.** Generated demand was estimated by first deriving composite costs from the PLD model and then applying a spread parameter to the change in rail journey times between the Do Something and the Do Minimum. The spread parameter was derived from the parameter, μ , in the PLD model for domestic travel, multiplied by the ratio of the rail/air spread parameter for international travel, divided by that for domestic travel.
- **Frequency of travel.** Frequency of travel was not explicitly included in the calculation of generalised cost discussed above, as the mode share graph (illustrated in Figure 56 above) does not take into account service frequency. Therefore, a model adjustment was made to proxy service frequency by dividing the demand into two types: frequency sensitive (50%) and frequency insensitive (50%). Depending on different scenarios of the number of through trains per day, the travel time is calculated as the weighted average of the two possible alternatives: using the HS1-HS2 link (either using through trains or interchanging at OOC, depending on the scenario) or transferring to St Pancras for the Eurostar (from Euston for HS2 passengers or from other London termini for Classic Rail passengers). The impact of the train frequency in the choice between the two options by each type of demand was estimated using judgement.
- **Appraisal.** Uniquely in the PFM model suite, the appraisal of the HS1-HS2 Connections Model is undertaken within the model itself, rather than the results being passed through to the PFM appraisal model. It has been assumed that the revenue from international trips balances out the additional operating costs of operating the train services, so that the two elements cancel out in appraisal. The only benefits included in the appraisal are therefore the generalised time benefits. For leisure passengers these are assessed with the same weighting as they have in the forecasting model. For business passengers, all weighting above 1 is first removed and interchange penalties are also removed. Standard WebTAG values of time are then used (as have been used in the PFM) with the standard 'rule of a half' to quantify the benefits of the HS1-HS2 Connection.

8.3. Auditing the assumptions and Inputs

8.3.1. The assumptions in the HS1-HS2 Connections Model are summarised in the separate assumptions report being published by HS2 Ltd¹². The assumptions can be grouped into the following elements:

- Model year;
- DfT forecast years;
- Generalised cost parameters and weights, demand model;
- Generalised cost parameters and weights, appraisal, business;
- Generalised cost parameters and weights, appraisal, leisure;

¹² HS2, PFM v4.3: Assumptions Report, HS2 Ltd, October 2013

HS2 Model Audit: PFMv4.3 Implementation and Standard Case Forecast

- Logit mode choice parameters;
- Generated demand parameters;
- Value of time for appraisal;
- Business/leisure split;
- Scenario parameters;
- London and SE parameters; and
- Appraisal parameters.

8.3.2. Each assumption was checked against the documentation and in most cases we were able to confirm that the assumption was as documented. In a few cases the assumption is the same in the Do Minimum as the Do Something so it gets cancelled out in the appraisal of incremental benefits and in a few cases the assumptions were not documented.

8.3.3. The inputs to the HS1-HS2 Connections Model and the checking that we undertook against the source documentation are summarised in Table 37.

Table 36: HS1-HS2 Connections Model final v5.1, Inputs

| Parameter / Data | Name / Description in model | Excel Sheet | Unit | Check against docs | Source of Assumption |
|--|-----------------------------|---|------|--|--|
| Base year (2010/2011) IPS total rail demand | Rail demand | 1. Rail pax | pax | OK (IPS rail based on stations, so Lyon is Paris) | IPS data 2010/2011 |
| GDP annual growth rate (with no deflator adjustment) - CPI Based (Central) | | 14. VOT discounted | % | Not documented | Supplied by Atkins March 2013. To be confirmed if this is real GDP growth, as no adjustment is made for inflation within the model |
| Population annual forecast growth rate | | 14. VOT discounted | % | Not documented | National Population forecast for calculation of values of time.xls (Atkins). WebTAG 3.5.6c Table 3b, Feb 2013 |
| Rail travel times (current and future network) | Time inputs | Received 20130425 IVT from Lon / 2.0 time inputs | min | Travel times on the European side are not documented | Network Rail, HS2, Eurail.com |
| Eurostar data | Eurostar Data | Eurostar, Wales, West Midlands, Scotland East Coast | pax | Not documented | Commercial data not available for review |

- 8.3.4. The base year IPS rail demand and IPS and CAA air demand were documented in Annex A of the documentation provided by the model developers and was checked against these tables. As we do not have access to the original data, no checks could be undertaken against the source data.
- 8.3.5. The growth rate inputs and the Eurostar data were not documented, and thus could not be checked.
- 8.3.6. The rail network times were documented in the Annex B of the documentation provided by the model developers and were checked against these tables.

8.4. Auditing the processes and calculations

- 8.4.1. The HS1-HS2 Connections model is a stand-alone excel spreadsheet model comprised of 86 linked spreadsheets. The spreadsheets can be grouped into the following categories: Air and rail demand data;
- Assumptions;
 - Final demand data;
 - Input rail IVT;
 - Calculated rail IVTs;
 - Main logit model;
 - Predicted new rail share;
 - Calculating composite costs;
 - Calculating generated demand;
 - DM demand;
 - Total DS demand;
 - Predicted new rail demand;
 - Difference tables;
 - Summary statistics;
 - West London analysis;
 - Appraisal calculations
 - Value of time discounting
 - Appraisal year by year; and
 - Final appraisal and demand results.
- 8.4.2. Generally, separate spreadsheets are included for each heading for each of the six scenarios defined in section 8.2.2 above.
- 8.4.3. For each of the 86 linked spreadsheets in the HS1-HS2 Connections model, the

process and calculations tests that we have undertaken are listed in 8 under the following headings:

- Worksheet name;
- Analysis grouping;
- Inputs (internal or external);
- Calculations made;
- Type of output;
- Documentation;
- Type of check undertaken;
- Result of check; and
- Comments.

8.4.4. Due to the size of the demand matrix being relatively small at 12*6 zones (i.e. 72 cells), we were able to undertake a very comprehensive audit, including checking all calculations of all cells in each of the linked 86 spreadsheets and the input and outputs linkages between all the linked spreadsheets.

8.4.5. This comprehensive audit of all each cell of each spreadsheet was undertaken on the first version of the HS1-HS2 connections model that we received (v4.4).

8.4.6. The issues identified were discussed with the model developers (see section 8.6 below) and they agreed to take them all on board in subsequent revisions of the model (v4.7, v4.8 and v5.1). With the agreement of HS2 Ltd, we audited only the parts of the v4.7, v4.8 and v5.1 models that were changed as part of each revision.

8.5. Outputs

8.5.1. The model outputs are summarised in Table 39 below. In each case we checked that the results included in the model documentation matched the numbers in the model.

Table 37: HS1-HS2 Connections Model final v5.1, Outputs

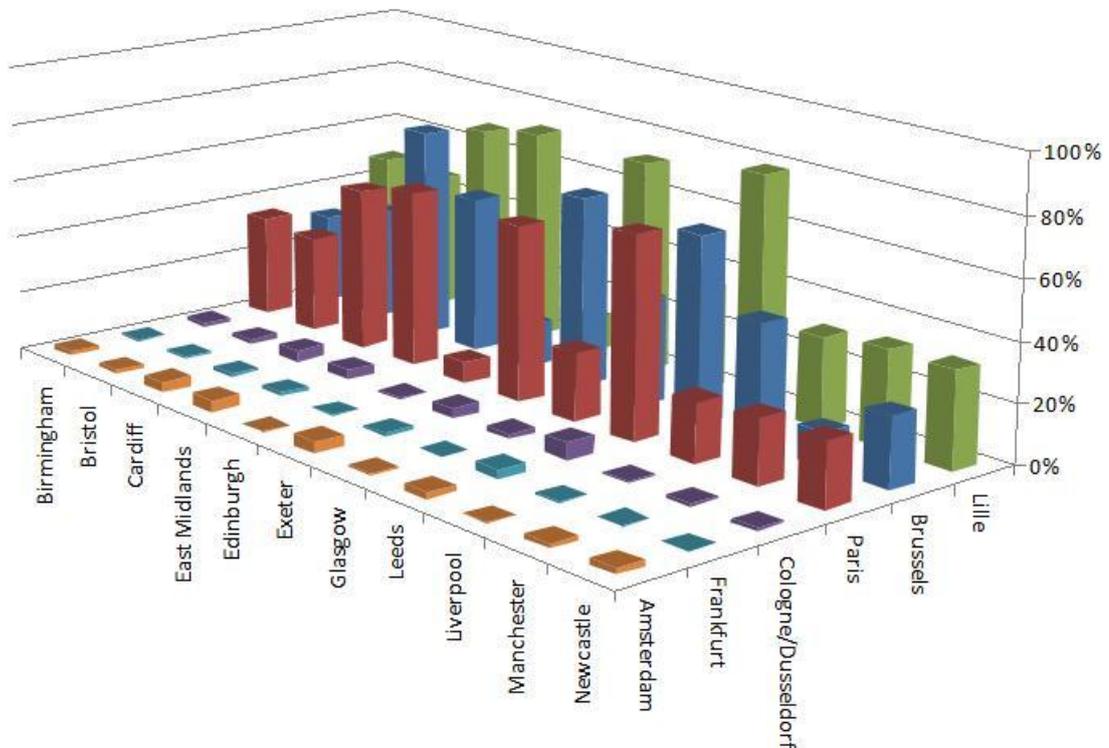
| Output | Network configuration | Unit | Excel Sheet in the model | Check | Comment |
|---|-----------------------|--------------------|--------------------------|-------|--|
| International Rail Demand (2036) | Phase 1 | Million pax / year | Result | OK | |
| International Rail Demand (2036) | Full network | Million pax / year | Result | OK | Result sheets - Cells F28,29 to be corrected - Report OK |
| Sources of International Rail Demand (2036) | Phase 1 | Million pax / year | Result | OK | |
| Sources of International Rail Demand (2036) | Full network | Million pax / year | Result | OK | |

Additional results in Result sheet - not checked

HS2 with link & through service joining at Birmingham International - 6 trains/day from each of Birmingham and Manchester to each of Paris and Brussels

- 8.5.2. The final version (v5.1) of the HS1-HS2 Connections Model predicts that the total annual trips using the link with the D1 network in 2026 will be between 0.72M-0.93M assuming an interchange at Old Oak Common and 1.23M-1.72M assuming through services. Assuming a full network (in 2036), the total annual trips using the link are predicted to be between 1.35M-1.68M assuming an interchange at Old Oak Common and 2.32M-3.28M assuming through services. Generated demand is predicted to account for up to 70% of the total demand.
- 8.5.3. We therefore undertook a more detailed analysis of the predicted level of generated demand. The observed base HS2 demand for each of the 12*6 OD pairs is illustrated in Figure 57. The HS2 mode share varies from a high of 93% (London-Lille), 88% (London-Paris) and 86% (London-Brussels), to around 60% from Leeds, 35% from Birmingham, and 20% from Manchester to the same three European cities, to very low values (less than 5%) for all non-London UK cities to Cologne/Dusseldorf, Frankfurt and Amsterdam.

Figure 57: Base Year Rail Share (2010-2011)



- 8.5.4. The predicted HS2 mode share assuming an interchange at Old Oak Common (OOC) and one train per hour are illustrated in Figure 59, interchange at OOC and 3 trains per day in Figure 60 and Figure 61, through services and one train per hour in Figure 62 and Figure 63 and through services and 3 trains per day in Figure 64 and Figure 65.
- 8.5.5. Assuming a full network, and hourly through services (Figure 63), the HS2 mode split from Leeds to Brussels/Paris/Lille is predicted to rise to between 87%-94%, that from Birmingham to the same destinations to 72%-84% and that from Manchester to the same destinations to 50%-79%. The forecast HS2 mode split from Leeds and Birmingham is thus predicted to rise to the current observed levels from London. Furthermore, generated demand is estimated to account to around 70% of these forecasts.

Figure 58: Rail Share - Phase 1 Network with Link, Interchange @ OOC, 1 tph, 2026

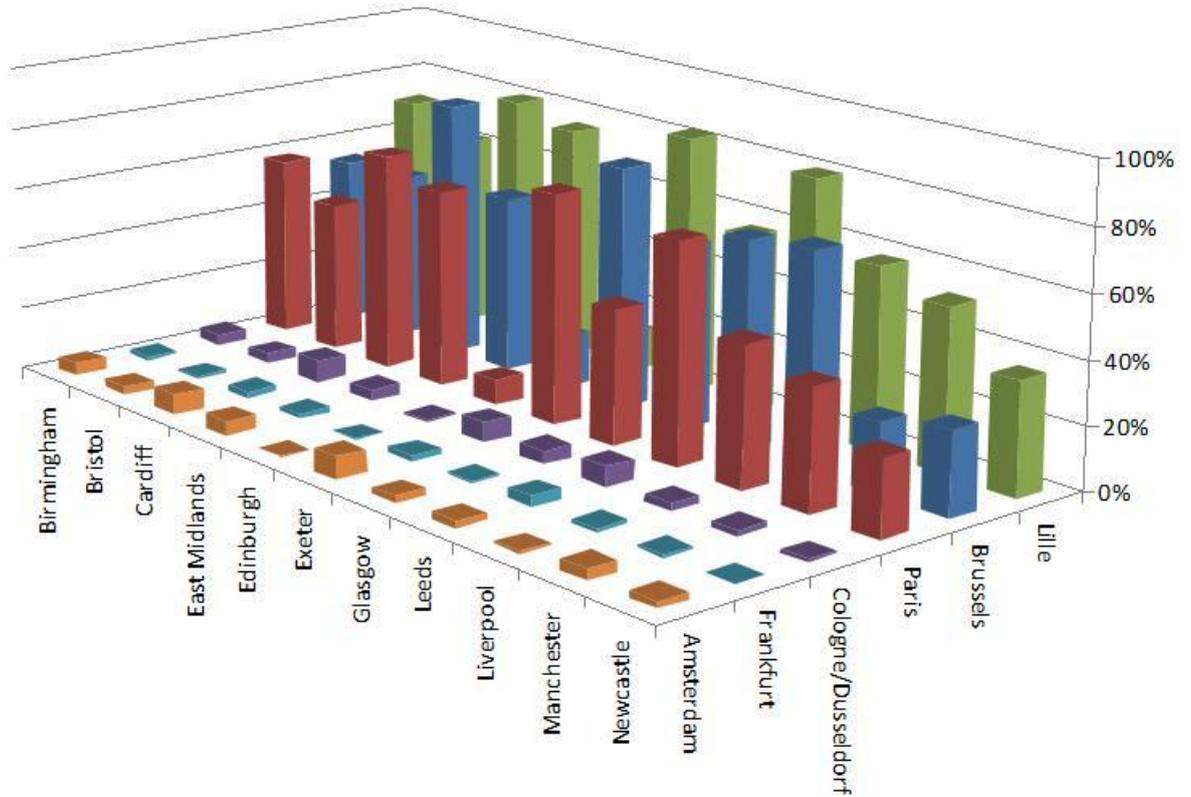


Figure 59: Rail Share – Full Network with Link, Interchange @ OOC, 1 tph, 2033

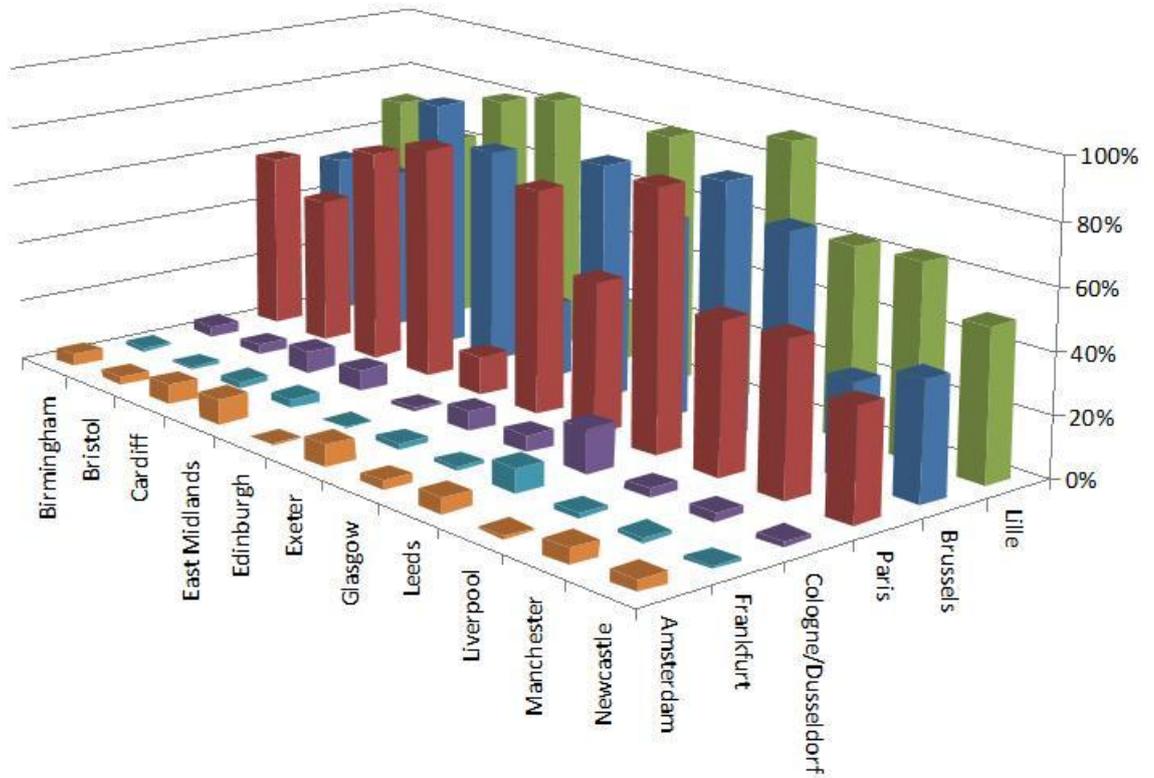


Figure 60: Rail Share, Phase 1 Network with Link, Interchange @ OOC, 3 tpd, 2026

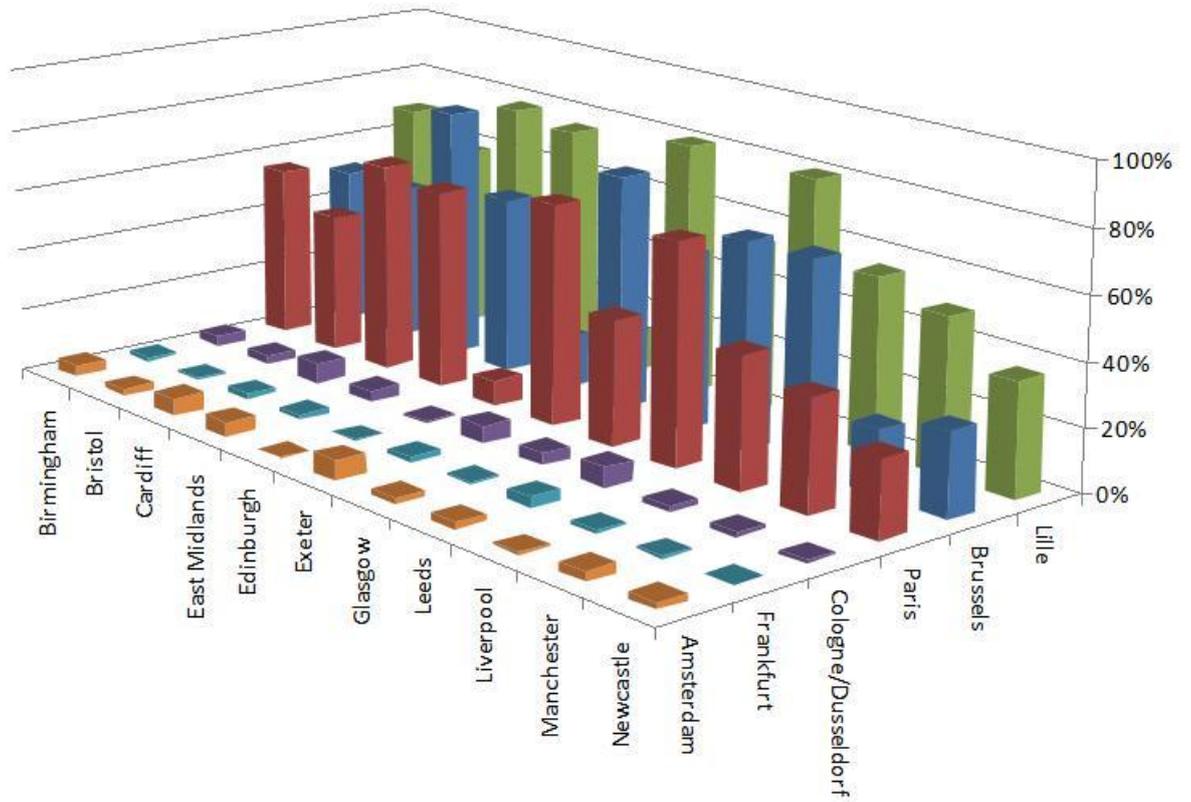


Figure 61: Rail Share – Full Network with Link, Interchange @ OOC, 3 tpd, 2033

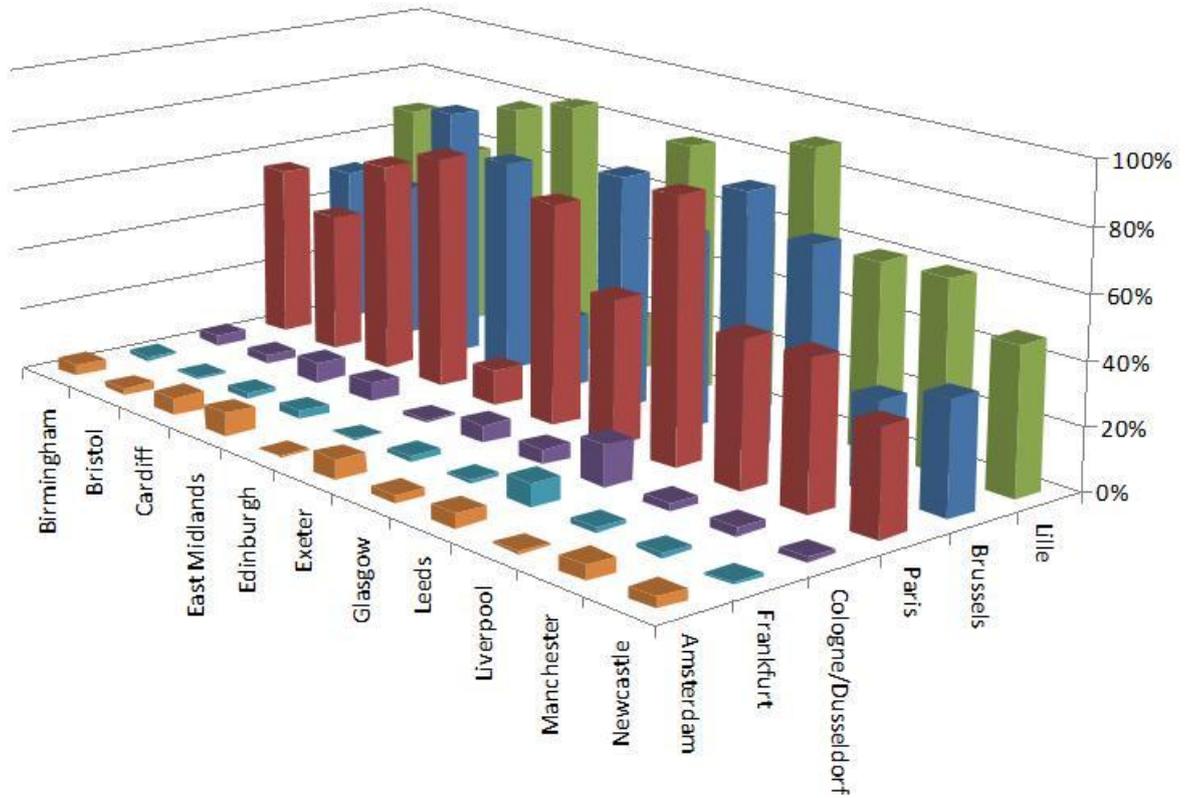


Figure 62: Rail Share - Phase 1 Network with Link, through trains, 1 tph, 2026

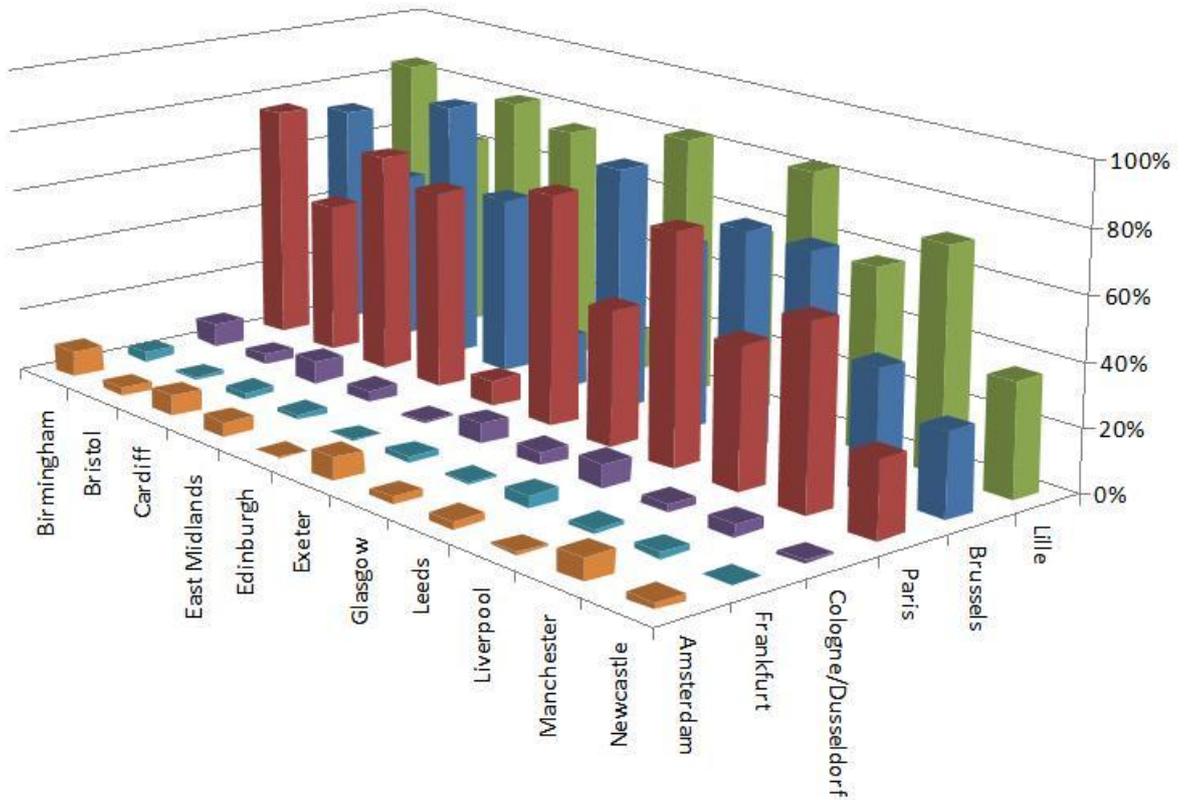


Figure 63: Rail Share – Full Network with Link, through trains, 1 tph, 2033

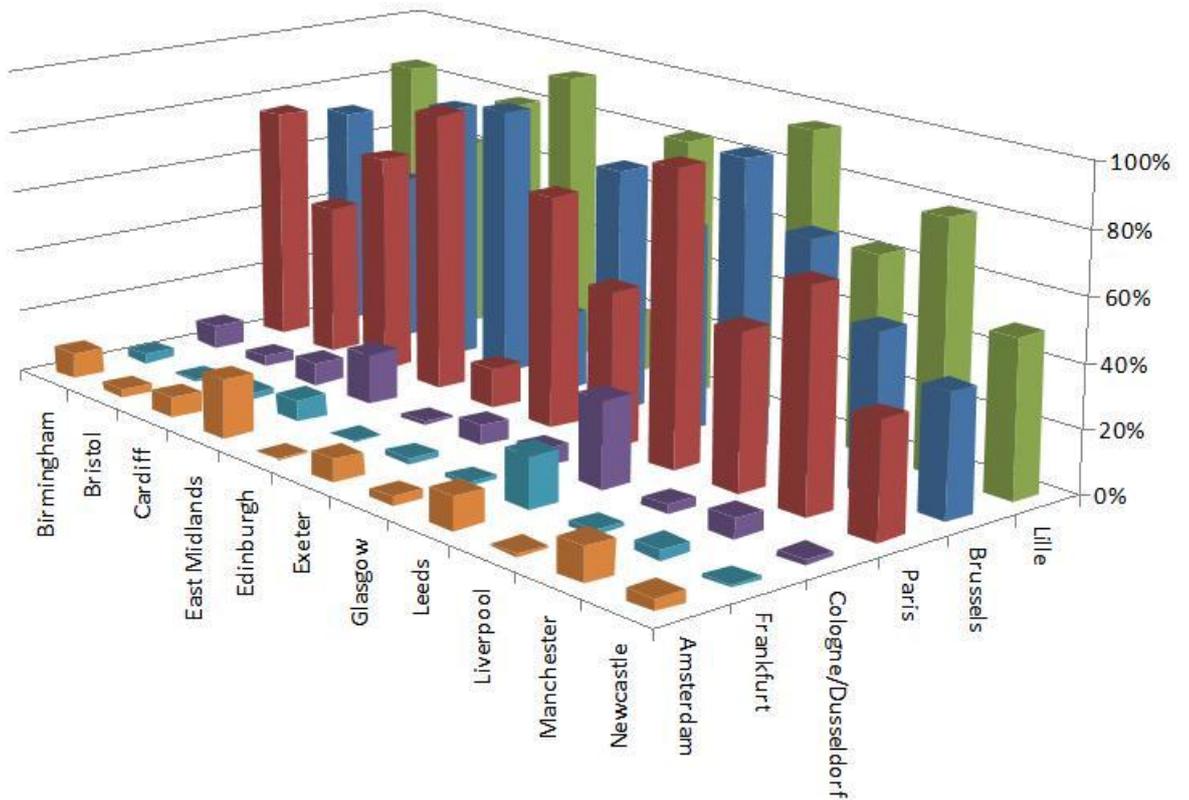


Figure 64: Rail Share - Phase 1 Network with Link, through trains, 3 tpd, 2026

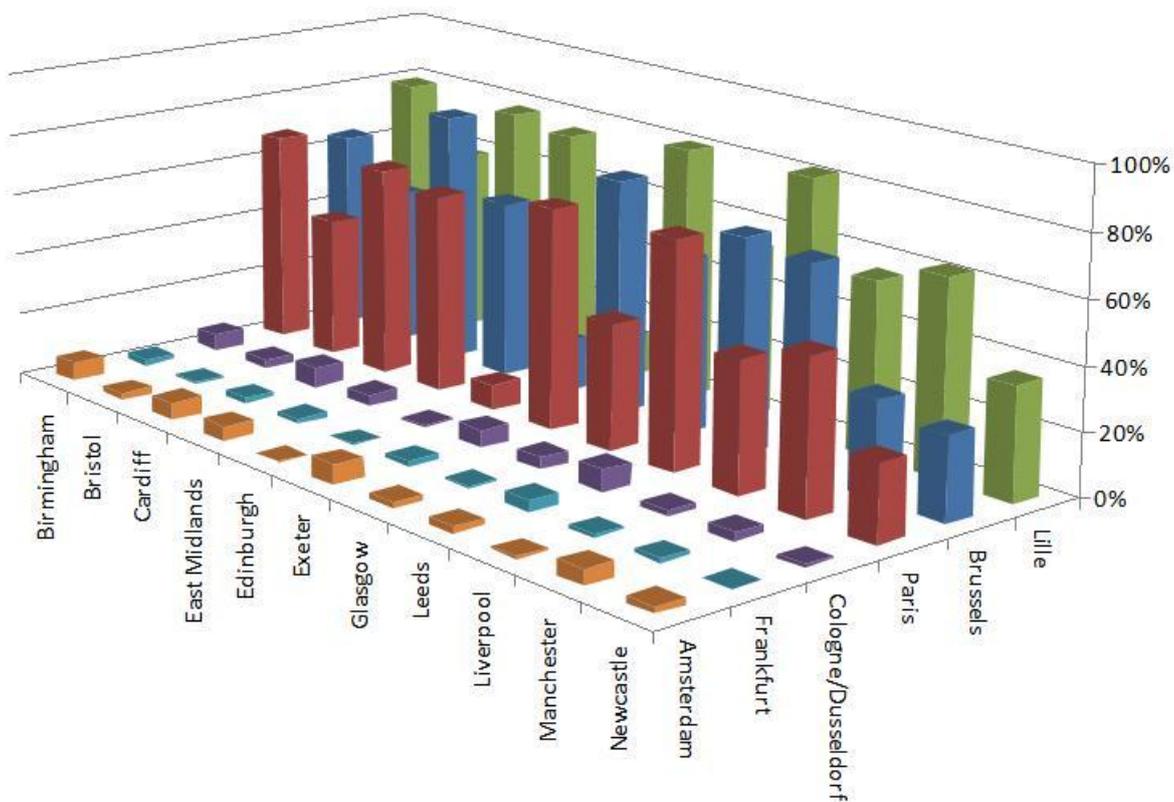
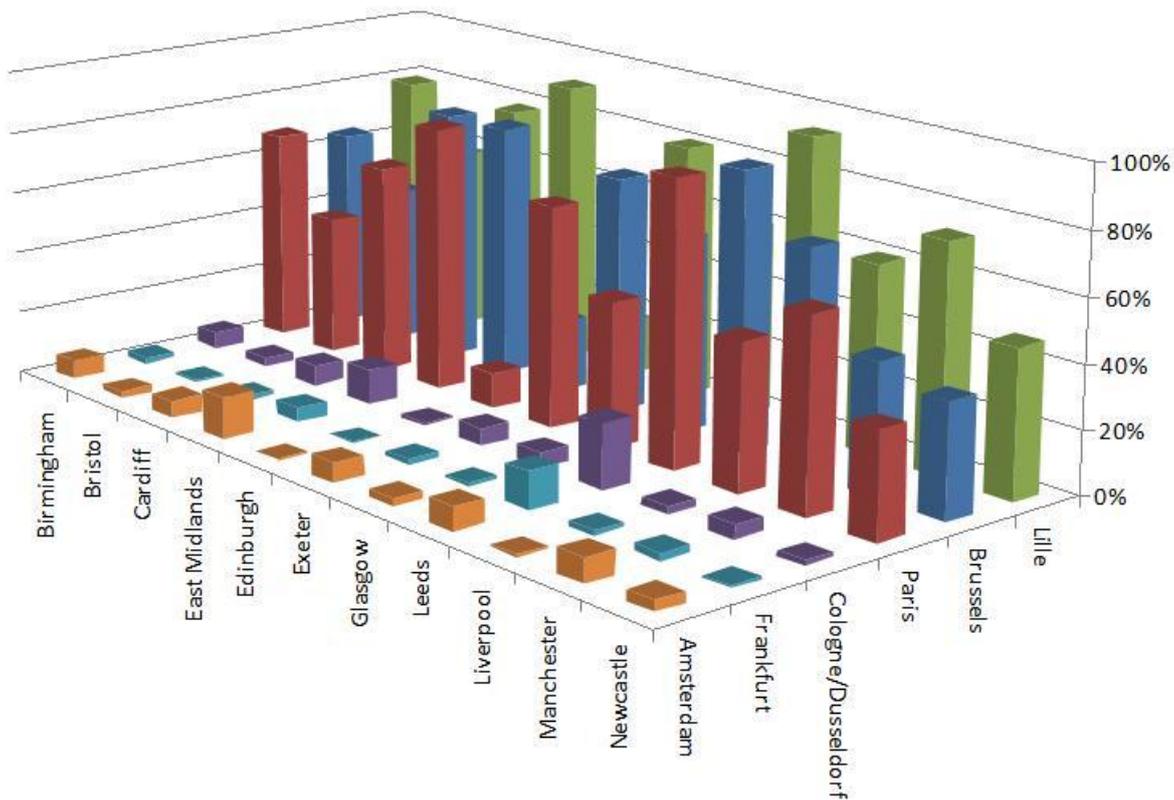


Figure 65: Rail Share - Full Network with Link, through trains, 3 tpd, 2033



- 8.5.6. We also compared the results of the MVA HS1-HS2 connections model against that of an earlier 'International Rail Travel Demand Model for HS2' developed by SKM in February 2010. SKM predicted that the HS1-HS2 link would carry between 0.7M-1.3M passengers in 2020 and between 0.86M and 1.6M passengers in 2030. These forecasts are significantly below the MVA forecasts summarised above, but do not include generated demand. Comparing like with like, i.e. the MVA 'abstracted from air' forecasts and the SKM forecasts, the SKM forecasts are higher.
- 8.5.7. As discussed in the MVA report there are a number of reasons why the MVA forecasts are different from the SKM forecasts, most notably that the MVA forecasts exclude interlining trips, generated demand has been allowed for and the impact of service frequency has now been included. However, it does reiterate the significant amount of generated demand forecast by MVA.

8.6. Audit findings

- 8.6.1. As stated in section 8.4.4. above, upon receipt of the first version of the HS1-HS2 Connections Model, we undertook a comprehensive audit of the calculations in every cell of each of the 86 linked spreadsheets, and all the input and outputs between the spreadsheets.
- 8.6.2. Our initial audit identified a number of issues that were discussed with the model developers and that fed into further updates of the model.
- 8.6.3. We have checked that all the corrections have been made in the final version of the model (v5.1) and can confirm that they have been. Responding to our comment on the quality of the model validation (and the late availability of more robust Eurostar rail data), the other key change made by the model developer's was to the model structure, moving from an absolute logit model structure to an incremental model structure. Generated trips account for around 70% of the total predicted HS1-HS2 Connections demand in version 5.1 of the model, which we consider is at the high end of the expected range.

8.7. Implications of audit findings

- 8.7.1. It should be noted that the HS1-HS2 Connections Model contributes less than 1% of the total benefits of HS2. Thus the issues noted below should be read as such.
- 8.7.2. The model is well documented and in all cases where we have been able to compare what is in the model to what has been documented, there is commonality.
- 8.7.3. We note that no competitive response from the airlines has been assumed. There is much debate about what a likely competitive response could be (ranging from airlines withdrawing from routes/reducing frequencies to reducing fares and competing heavily on price), but in our opinion a range of competitive response assumptions should be considered.
- 8.7.4. Finally, we note that the model developers state that "there is a concern that some

of the benefits from international passengers may already be captured in PLD and hence would be double counted” as some passengers may buy a separate ticket for their domestic leg and are already included in the PLD. The model developers continue “There is no available data on the extent of this potential double counting, but it is expected to be significant; so to be conservative, although we present in the following section the benefit of HS2 without the link, we propose to exclude this benefit from the eventual HS2 scheme benefit”. Our review of the BCR calculation confirms that this has been done.

9. The Appraisal Spreadsheets

9.1. Introduction and context

- 9.1.1. In the course of the audit, we have reviewed a number of versions of the appraisal spreadsheet which progressively closed out any issues identified in earlier versions. The last fully audited version was 4.2f, with subsequent reviews of the changes implemented to create version 4.3f.
- 9.1.2. The appraisal model is an Excel spreadsheet that consists of a number of worksheets. There is one spreadsheet covering different appraisal time periods for both the London-West Midlands section and the full network to Manchester and Leeds.
- 9.1.3. The economic appraisal spreadsheet uses outputs from Base and Test scenarios run in the PLANET Long Distance (PLD), PLANET South (PS), PLANET Midland (PM) and PLANET North (PN) models and inputs the PLD-EcoOutput file from the appraisal pre-processing program to produce a 60 year appraisal of the economic performance of the Test Scenario relative to the Base.
- 9.1.4. The results from each of the regional models are imported in the same spreadsheet with a macro and then processed in combination with standard economic parameters (such as discount rates, values of time and inflation rates, sourced largely from the DfT's WebTAG guidance) to give the final TEE and Public Accounts tables. The spreadsheet follows this format with the following components:
- input files – the summary output files produced by the PLANET model runs (Do Minimum and Test) for each forecast year, incorporating the results of the macro calculations of economic impacts as described above and the PLD-EcoOutput file from the appraisal pre-processing program;
 - input assumptions – summarising the assumptions used in the calculation process (mostly drawn from WebTAG);
 - monetisation of costs and benefits; including converting time savings to monetary values using values of time (in pence per minute) as set out in WebTAG. This component also accounts for real growth in the value of benefits where appropriate and interpolates benefits between forecast years and extrapolates beyond the final year to cover the full 60 year appraisal period; and
 - conversion to appraisal format involving:
 - discounting to appraisal base year;
 - conversion to appraisal base year prices;
 - conversion to market prices; and
 - summation to TEE/Public Accounts format.
- 9.1.5. The appraisal spreadsheet contains both model runs (Phase 1, i.e. opening of

London to West Midlands section) 60-year and Phase 1 67-year (to link into the 60 years from when the whole network would open) for the full network for each model (PLD, PM, PN and PS). It can also be used to appraise just the Phase 1 or the full network on their own if the user selects the appropriate inputs.

9.2. Structure of the appraisal spreadsheets

- Changes log – only changes since 11/10/2011 onwards are reported
- Instructions – information on how to run the spreadsheet
- Documentation – overview of the process
- RunInputs – control file of the macro
- WebTAG – Standard guidance inputs
- VOT – VOT growth assumptions
- Other assumptions – assumptions including fares, discount rate, and other non-WebTAG assumptions
- Hwy From WebTAG – Marginal external costs and indirect tax assumptions for cars copied from WebTAG
- Hwy – Marginal external costs interpolation from WebTAG
- ImportsDay1C – Data imported with macro from model runs for Phase 1 Network
- ImportsY – Data imported with macro from model runs for the full network
- CalcsY – Processing of inputs imported with macro into annual time savings (full network)
- CalcsDay1C – Processing of inputs imported with macro into annual time savings (Phase 1 network)
- FormattedY – Conversion of time savings into hourly savings (full network)
- Formatted Day1C – Conversion of time savings into hourly savings (Phase 1 network)
- YrBreakdown Y – Monetisation of time savings and discounting (full network)
- YrBreakdown Day1C – Monetisation of time savings and discounting (Phase 1 network)
- PLD Benefits – summarises and calculates total PLD benefits in a user selected output year price base
- PS Benefits – summarises and calculates total PS benefits in a user selected output year price base
- PM Benefits – summarises and calculates total PM benefits in a user selected output year price base
- PN Benefits – summarises and calculates total PN benefits in a user selected output year price base

- Total Benefits – sum of PLD, PM, PN and PS benefits
- Output Sheet – sums appraisal outputs to provide final totals

9.3. Tests and checks undertaken

9.3.1. This section outlines the tests and checks undertaken on each spreadsheet and the results of them. The tests and checks undertaken consisted of the following activities:

- Visual check of spreadsheet structure;
- Use of audit software;
- Line by line audit;
- Check of Macros;
- Scenario testing;
- Model run
- Check update to values of time
- Check and verification of the rule of half calculation in v4.3a, (at the station to station level);
- Use of WITA
- Carbon impacts model implementation; and,
- Operating cost model implementation.

Visual check of spreadsheet structure

9.3.2. The appraisal spreadsheet was reviewed for consistency of structure and content. This included checking sheet names, order and layout of formulae.

9.3.3. The appraisal sheet for the 60-year model has a consistent structure across the PLD, PM, PN and PS models. The same applies for the 67-year model.

9.3.4. The spreadsheet has a complex but logical structure with clearly defined areas for model inputs, user inputs, assumptions, calculations and outputs. Information on the type and duration of model being appraised is entered manually on the RunInputs sheet before data extraction and calculations are performed automatically.

Use of audit software

9.3.5. The appraisal spreadsheet was checked using a specialist auditing tool SpACE (Spreadsheet Auditing for Customs and Excise). SpACE is a risk assessment and audit methodology tool for spreadsheets which was originally developed for and is still used by Her Majesty's Revenue and Customs. It highlights issues that may denote a risk or potential error. For example, length of formulas used (an indication of sophistication and also potential error), number of calculations the results of

which are not used elsewhere in the spreadsheet, where data have been entered or is the output from another calculation, where formulae in columns or rows are not consistent with other formulae in that row or column etc. These issues may not necessarily be errors but they highlight areas where there is a higher risk of a problem and hence priority areas to concentrate the audit on.

- 9.3.6. Each worksheet was also checked using Excel's own internal error checking tool.

Line by line audit

- 9.3.7. Each worksheet in a typical spreadsheet was then checked to ensure formulae were correct for what they were intended to do, that data were correctly linked to calculations in terms of both dependencies and precedents. Any arising issues were logged. This process was repeated for v4.2f.

- 9.3.8. The spreadsheet was then checked to ensure assumptions were consistent with those set out in WebTAG, also undertaken for version 4.2f.

Check of Macros

- 9.3.9. Our check of macros confirmed that they pulled data into the model from the relevant PLANET models and ran the model as programmed to do so.

Scenario testing

- 9.3.10. The values of key assumptions were then changed and the outputs were checked to see if they had moved in the correct direction and to the same extent as would be expected as a result of such changes. An example is assessing the change in benefits arising from an increase in all values of time by 5%. The result from doing this fed through to a 5% change in benefits for the scheme.

Model run

- 9.3.11. Finally we set up a test version of the economic appraisal spreadsheet based on the instructions document provided by the model developer, linking to copies of the output files using the following parameters:

- First forecast Year, and Phase 1 opening year;
- Second forecast Year;
- Phase 2 opening Year; and
- Appraisal period: construction plus 60 years of operation for each phase.

- 9.3.12. We ran the macros which imported data from the selected locations into the relevant sheets. The values produced on the Output Sheet in the test versions matched those found for the same parameters in the original appraisal sheet sent to us.

Updated values of time

- 9.3.13. As part of the updates in the appraisal spreadsheet leading to version 4.3f, values of time were updated in line with a pre-release of the values from the forthcoming October 2013 update to WebTAG Unit 3.5.6.
- 9.3.14. We have reviewed and confirmed the correct implementation of these new values. However, their implementation in the model is unnecessarily complex:
- The forthcoming (October 2013) WebTAG VoTs are input in 2010 prices and values;
 - They are then converted to 2002 prices and values by applying the growth in the Consumer Price Index (CPI growth), the real earnings growth and the difference in Market Price adjustment between pre-2012 advice and current advice (to reflect the higher pre-2012 advice value);
 - These values are then used, but the adjustment of the market price adjustment is reversed out to reflect the lower, later value;
 - All the benefit calculations are then undertaken using these 2002 values; and
 - In the final summary of benefits, they are then uplifted to 2011 prices and values, using CPI and real earnings growth.
- 9.3.15. So the final benefit numbers are based on VoTs in 2010 prices and values from the new (forthcoming) October 2013 WebTAG advice, which are adjusted to 2011 prices and values (but via an adjustment to and from 2002).
- 9.3.16. A similar process is followed for the VoTs used for highway journey time (mostly decongestion) benefits. However, there is an added complexity for the business segment, where an average per-person value of time needs to be derived from separate values for drivers and passengers using an assumption for average car occupancy. An occupancy factor of 1.14 is used which is undocumented. An analysis of data from the National Travel Survey (2002-2010), undertaken by HS2 Ltd, found that the average car occupancy for business and commuting trips was 1.2 persons. This did not vary by trip length or whether weekend days were included or excluded in the analysis. This value coincides with the recommended value in WebTAG unit 3.5.6. We would therefore recommend the use 1.2 as the standard occupancy assumption for business.
- 9.3.17. If the vehicle occupancy factor was changed to the recommended value of 1.2, the per-person VoT for the highway business segment would drop by 1%. A sensitivity test shows that this would reduce overall HS2 scheme benefits by less than 0.01%. In addition, the implementation does not assume a decline in future occupancy rates as recommended by WebTAG. Such a decline would lead to marginally higher per-person VoTs over time and counteract the effect of the low occupancy rate used. Overall we conclude that this is a very minor issue that has a negligible impact on the overall case.

- 9.3.18. For historical reasons, the main benefit calculations have always been based on 2002 prices and values and we understand that the current process stems from a desire not to disturb this main calculation and to keep its results comparable between model versions to allow easier tracing of the effects of different updates. However, this makes the review of the implemented values of time difficult and this complexity can only increase with any future model updates.
- 9.3.19. We recommend that any future updates to the appraisal spreadsheet should include simplifications to allow consistent use of new values of time throughout the calculation.

9.4. Rule of half benefits calculation

- 9.4.1. We have reviewed the pre-processing executable files that take outputs from the Station choice model and prepares them for input to the appraisal to check how the 'rule-of-half' benefits calculation is done during this process.
- 9.4.2. The pre-processor takes inputs and outputs from the Station Choice Model and aggregates them in various ways before outputting them. One of the series of outputs are named EconMatSCMxx, where xx denotes the type and purpose of the output.
- 9.4.3. Firstly, the DM demands are aggregated from PLD-Station-Station-PLD to just PLD O-D (i.e. irrespective of station choice). These are stored in files EconMatSCM1 to EconMatSCM9 where the number represents the purpose:
- 1 = commuting, non car available;
 - 2 = commuting, car available 'from';
 - 3 = commuting, car available 'to';
 - 4 = business, non car available;
 - 5 = business, car available 'from';
 - 6 = business, car available 'to';
 - 7 = leisure, non car available;
 - 8 = leisure, car available 'from'; and
 - 9 = leisure car available 'to'.
- 9.4.4. The DS demands are similarly aggregated and stored in files EconMatSCM10 to 18 where the purposes are in the same order. The demands are extracted from the output of the SCM process.
- 9.4.5. Benefits are then calculated using the station-station demands and the cost inputs to the SCM process. Benefits are calculated as $0.5 * (\text{DM Demand} + \text{DS Demand}) * (\text{DM Cost} - \text{DS Cost})$ for each PLD-Station-Station-PLD combination and then summed to give total benefit for each PLD O-D pair. These are then written to files EconMatSCMxx, where xx is 19-27 for in vehicle time (IVT), 28-36 for walk, 37-45

for wait, 46-54 for boarding penalty, 55-63 for crowding.

- 9.4.6. The pre-processor program also amends the file PLDEcoOutput-16012.prn (output from PFM) in the output folder and renames it as PLDEcoOutput-16012-Amended.prn. The file is changed to add on the total benefit for each individual cost and purpose (i.e. the sum of each of the matrices EconMatSCM19 to 63). The first 17 values in the file deal with the highway and regional model benefits and are unchanged by the pre-processor, but it then adds the matrix totals for each of the benefit matrices. However, the matrix totals are in a different order to the matrix numbering used for the EconMatSCM files. The matrix files are grouped by cost type (e.g. 19-27 are IVT for each purpose), but the totals in this file are grouped by purpose. So the 18th value in the list is IVT for com_nca, the 19th value on the list is walk time for com_nca, etc.
- 9.4.7. We conclude that the rule of half is applied correctly.

9.5. WITA impacts

Overview

- 9.5.1. The wider economic impacts of HS2 are assessed in the WITA (Wider Impacts in Transport Appraisal) module. The estimation process of these impacts has been checked as part of the audit process.
- 9.5.2. WITA is a piece of software that carries out the estimation of wider impacts according to the Department of Transport's guidance (WebTAG 3.5.14). The software has an interface that allows the user to select the inputs (data or .csv files), run the model and view the results. Audit of the DfT's WITA software is beyond the scope of the PFM audit. WITA calculations are hidden and therefore cannot be checked by users. The results can be viewed in a text file once the model is run.
- 9.5.3. WITA needs the following inputs to run successfully:
- Car data
 - Economics data including:
 - Employment data
 - Local authority economics data
 - WebTAG assumptions
 - Commuting Production-Attraction matrix
 - Model outputs (Generalised Journey Time Matrices)
 - Zone correspondences
 - Global data (WebTAG 3.5.14C assumptions)
- 9.5.4. These inputs can be selected manually or automatically through a catalogue file (.WIA). Phase 1 and full networks need to be run separately.

- 9.5.5. WITA produces the following outputs, which can be accessed in the Summary results text file:
- Agglomeration – manufacturing
 - Agglomeration – construction
 - Agglomeration – consumer services
 - Agglomeration – producer services
 - Agglomeration – total
 - Labour Supply impact
- 9.5.6. The results are presented for the years 2026 and 2036 as well as discounted for the appraisal period (2026-2080). Wider economic impacts from “Move to more productive jobs” are not considered in the HS2 economic appraisal and impacts from Imperfect competition are calculated as 10% of transport user benefits in the economic appraisal spreadsheet. A post-processing spreadsheet for each network was received which converts the results from WITA into 2011 prices and adds the results from the years beyond 2080 which are not calculated in WITA.
- Checks undertaken*
- 9.5.7. The main aim of the WITA audit was to reproduce the results obtained from the model development consultants and to confirm the correct application of the WITA process. This was undertaken in two key steps. The first step was to reproduce the results from the same inputs used by the model development consultants. Once this was done successfully, the next step was to reproduce the WITA results using the model outputs obtained in our runs (the rest of the inputs were kept the same). In order to do this, the model outputs needed to be processed with a set of macros to be input into WITA.
- 9.5.8. In addition to this, the WebTAG assumptions contained in the Economics input file and the WebTAG assumptions related to Wider Economic Impacts contained in the Global Data file were checked against the latest WebTAG guidance. The Economics file references the WebTAG units 3.5.6 and 3.3.5 from February 2013, while the Global Data file references WebTAG 3.5.14C. No discrepancies were found.
- 9.5.9. The total value of agglomeration benefits from WITA amount to approximately 25% of total user benefits. This proportion may seem quite high for an inter-urban project, but this is to forget that the agglomeration impacts tend to be dominated by shorter distance trips. This means that the additional shorter distance, released capacity services are responsible for a large share of the WITA benefits.
- 9.5.10. Our review of WITA impacts has concluded that the calculations are implemented as specified. However, the WITA calculations use relatively new DfT software that is only available in a prototype, beta version and whose internal workings cannot easily be verified. However, an examination of the results shows the impacts are concentrated along the route of HS2 as expected.

- 9.5.11. Following the implementation of new values of time pre-released from the forthcoming October 2013 WebTAG update, we have reviewed the WITA calculations again. We reproduced the results obtained by the model developers and analysed the changes from the previous version. In terms of inputs to the process, the differences are:
- 2011 Business VoTs are some 30% lower than previously;
 - 2011 Commuting/Leisure VoTs are some 5% higher than previously; and
 - Commuting/Leisure VoTs now grow at the same rate as business VoTs rather than with an elasticity of 0.8.
- 9.5.12. Our audit of these changes has confirmed the correct implementation of the updates.
- 9.5.13. The resulting overall WITA benefits are now about 27% higher. This implies that it is mostly the future commuting VoTs that drive the benefits (the leisure VoTs are not used in WITA).
- 9.5.14. We understand that the labour supply impacts are only affected by the commuting VoT, so their increase is consistent with the input changes.
- 9.5.15. Agglomeration benefits are by far the largest proportion of WITA benefits. The agglomeration calculation uses purpose-weighted average costs between business and commuting trips (with the weighting determined by the purpose splits for each cell of the matrix, so it will vary from OD to OD). Whether this average cost goes up or down with the new VoTs will therefore depend on the purpose split for a given OD pair.

Issues/Conclusions

- 9.5.16. In summary, the WITA software has been used correctly apart from use of slightly different value of time inputs reflecting an early draft of the forthcoming update to WebTAG Unit 3.5.6, October 2013. Our checks have focussed on verifying the inputs and parameters used and sense-checking the outputs. We recommend further analyses of the wider economic impacts of HS2 to corroborate the model-based WITA benefits.

9.6. Carbon Impacts Model

- 9.6.1. The carbon models for car and diesel train emissions have been reviewed and inputs and calculations have been checked.
- 9.6.2. Both models use assumptions from WebTAG and DECC IAG toolkit tables. The sources are well documented and they have been checked. Only the emission factors from WebTAG Unit 3.3.5 could not be verified because the values are from a forthcoming version not available online, as well as energy consumption by train type which has been calculated in another spreadsheet.

- 9.6.3. The train km inputs have been checked against the train km spreadsheet with no issues found. The car km inputs have not been checked (no car km spreadsheet provided). Both km inputs appear as pasted values.
- 9.6.4. The carbon model spreadsheets use two different car speeds compared to the appraisal spreadsheet which uses only one. These speeds are 'highway long distance' and 'access and 'local'. A source is provided. The speed in the appraisal spreadsheet is 50mph (80.5 km/h) and is used to calculate fuel consumption for cars, which feeds into the car externalities and the government fuel tax revenue calculations.

9.7. Operating Cost Model

Background

- 9.7.1. The operating cost model was checked in terms of inputs, structure and calculations. No documentation was received with the spreadsheet.

Inputs

- 9.7.2. The operating cost model spreadsheet contains a large number of inputs. There is an expectation that some of these inputs may still change in the future. Inputs include:
- Change in train kms and distances
 - Costs separated for classic line and HS2 including:
 - Staff costs
 - Electricity and diesel costs
 - Insurance and Variable Track Access Costs
 - Capacity charges
 - Lease capital and maintenance costs
 - Station maintenance costs
 - Station access charges
 - Rolling stock maintenance, renewal and purchase costs
 - Construction costs
 - Assumptions (average speed, GDP deflator, annualisation factor, discount rate, optimism bias, maintenance cost index, real average earning index)
 - Electricity and Diesel prices
 - HS2 Timetable and trains assumptions
- 9.7.3. The inputs and their sources have been checked.

- 9.7.4. For the GDP deflator input, it was found that this does not exactly match the values in the Carbon model spreadsheet, although the difference is small (0.02).
- 9.7.5. The spreadsheet is structured by type of cost and separates HS2 and classic line costs in different worksheets. Given that some costs are similar, such as staff costs, some inputs are repeated throughout the spreadsheet. In the case of station platforms, it has been found that this data does not match in the “HS2 station costs” and “HS2 station maintenance” tabs. No information on the spreadsheet explains the mismatch.
- 9.7.6. It has also been noticed that most of the inputs are coloured similarly except in some occasion where inputs pasted as values do not have this colour (blue/green). This could be slightly confusing and the colour coding should be explained in a documentation tab to be added in the future.

Results

- 9.7.7. The calculations have been checked and no issues have been found. There is a cell (D34 in the “Classic Line Staff Costs” tab), which has no formula, but this does not affect the results.
- 9.7.8. The streaming, discounting and price and market adjustment calculations have been checked. The annual operating costs are constant over the appraisal period and these are discounted and adjusted by the market price right at the end of the calculation process when they are aggregated. Since most costs are input as 2011 prices into the spreadsheet, little price adjustment is necessary. The price adjustment is applied to the inputs at the beginning before any calculations.
- 9.7.9. Some sense checks and shadow modelling have been undertaken. These involved modifying assumptions such as annualisation factor, discount rate or speed, as well as modifying prices and costs such as electricity and diesel prices. The shadow modelling consisted of replicating the calculation process from start to end for single cost types. All checks produced the expected results.
- 9.7.10. Overall, the spreadsheet is working as expected in terms of its calculation process.

Areas of concern

- 9.7.11. Some minor areas of concern have been identified.
- 9.7.12. Some inputs are repeated throughout the spreadsheet without being linked, sometimes hidden in calculations. A check that these inputs match could be implemented to minimise risk.
- 9.7.13. The sources of some inputs cannot be verified, so these cannot be audited.
- 9.7.14. It is not clear how certain inputs are imported into the spreadsheet such as the change in train km. It has been checked that the current figures for change in train

kms match the train km spreadsheet, but there is a concern that, because the inputs are in a different order, a macro would be a better option to import them as opposed to importing them manually.

9.8. Audit findings

- 9.8.1. Our audit found the appraisal spreadsheets to be implemented in line with documented methodology.
- 9.8.2. We have highlighted a small number of observations below; these are mostly issues of transparency:
- The benefit calculations are based on VoTs in 2010 prices and values from the new (forthcoming) October 2013 WebTAG advice, which are adjusted to 2011 prices and values (but via an adjustment to and from 2002). We recommend that any future updates to the appraisal spreadsheet should include simplifications to allow consistent use of new values of time throughout the calculation.
 - An undocumented vehicle occupancy factor is used for calculating an average per-person value of time for the highway business segment. The impact of this on the overall case for HS2 is negligible but we recommend that future updates be based on latest WebTAG advice or some other source.
 - In the appraisal spreadsheet as well as PFM documentation, the appraisal period is generally referred to as 60 years but it is longer to encompass costs incurred prior to scheme opening. A more accurate description would be “from the first year any costs or benefits are incurred to 60 years after scheme opening.” The appraisal period used in PFM and reflected in the standard case is consistent with WebTAG guidance.
 - In the “Other Assumptions” Tab in the appraisal spreadsheet, fares are described as 2010 prices, 2002 prices, 2026 prices and 2036 prices respectively. As currently set up, this description is not quite correct as the table applies real growth but not inflation to future years. It should be: “2010 values and prices” and “2002 values and prices”, but “2026 values, 2002 prices” and “2036 values, 2002 prices”
 - The CPI assumptions are not consistent with sources in the public domain. They are believed to originate directly from DfT but source not documented.
 - In the “Output Sheet” in the appraisal spreadsheet, the “enhanced table” states benefits are in £m. That should read “£bn”.
 - Our review of WITA benefits has concluded that the calculations are implemented as specified. However, the WITA calculations use relatively new DfT software that is only available in a prototype, beta version and whose internal workings cannot easily be verified. It therefore provides additional reassurance to review the geographical pattern of the benefits. Plots of the WITA benefits using GIS have been provided by the model developers and these show benefits concentrated along the route of HS2 as expected.

- WITA produces outputs in 2010 prices. These are converted to 2011 prices in the post processing spreadsheet. WITA values are then input to the main appraisal spreadsheet in 2002 prices. The conversion of the 2011-based results to 2002 happens outside the formal appraisal spreadsheet process and cannot be audited.
- The car km data is pasted into the calculation sheet as values and the source is not traceable.
- The carbon model uses two different car speeds: 47.9mph for long distance trips, 28.5mph for access trips. The long distance speed assumed is slightly inconsistent with the 50mph used for fuel consumption in the car externalities calculations in the appraisal spreadsheet.

9.9. Implications of audit findings

- 9.9.1. We do not believe that the observations above will have a significant impact on the overall appraisal results.

10. Standard Case Forecast and Appraisal

10.1. Introduction and context

10.1.1. This chapter deals with the inputs that are specific to the standard case forecast and appraisal as opposed to being integral to the model development. This includes both the do minimum and do something rail networks for base and forecast years in all four PLANET models, the highway and air networks in PLD, and the standard case appraisal inputs and results.

10.2. PLD do minimum rail networks

10.2.1. The rail network in the PLD model consists of transit lines and transit line segments coded for each TOC and long distance services. The base year 2010 rail network has been imported to EMME after processing timetable (.CIF files) and formation files (.csv files) from DeltaRAIL, grouped to each service level using a Perl script developed by Arup. The network has also been modified, wherever applicable, prior to importing the transit lines in EMME.

10.2.2. The forecast rail network was developed in a similar fashion using the Perl script from Arup, but in this case using input from MOIRA/MOIRA2 together with forecast timetables (in CIF, PFD and Word formats). The forecast transit network was built incrementally over the base 2010 transit network.

10.2.3. Timetable CIF file (20100616.CIF) and vehicle data files (formation file 20100616.xls) were supplied by the model developers with the base year model as a single data file.

10.2.4. These files were used to check the implementation in the EMME rail network of number of trains per TOC, vehicle mix per TOC, vehicle seating and total capacities etc.

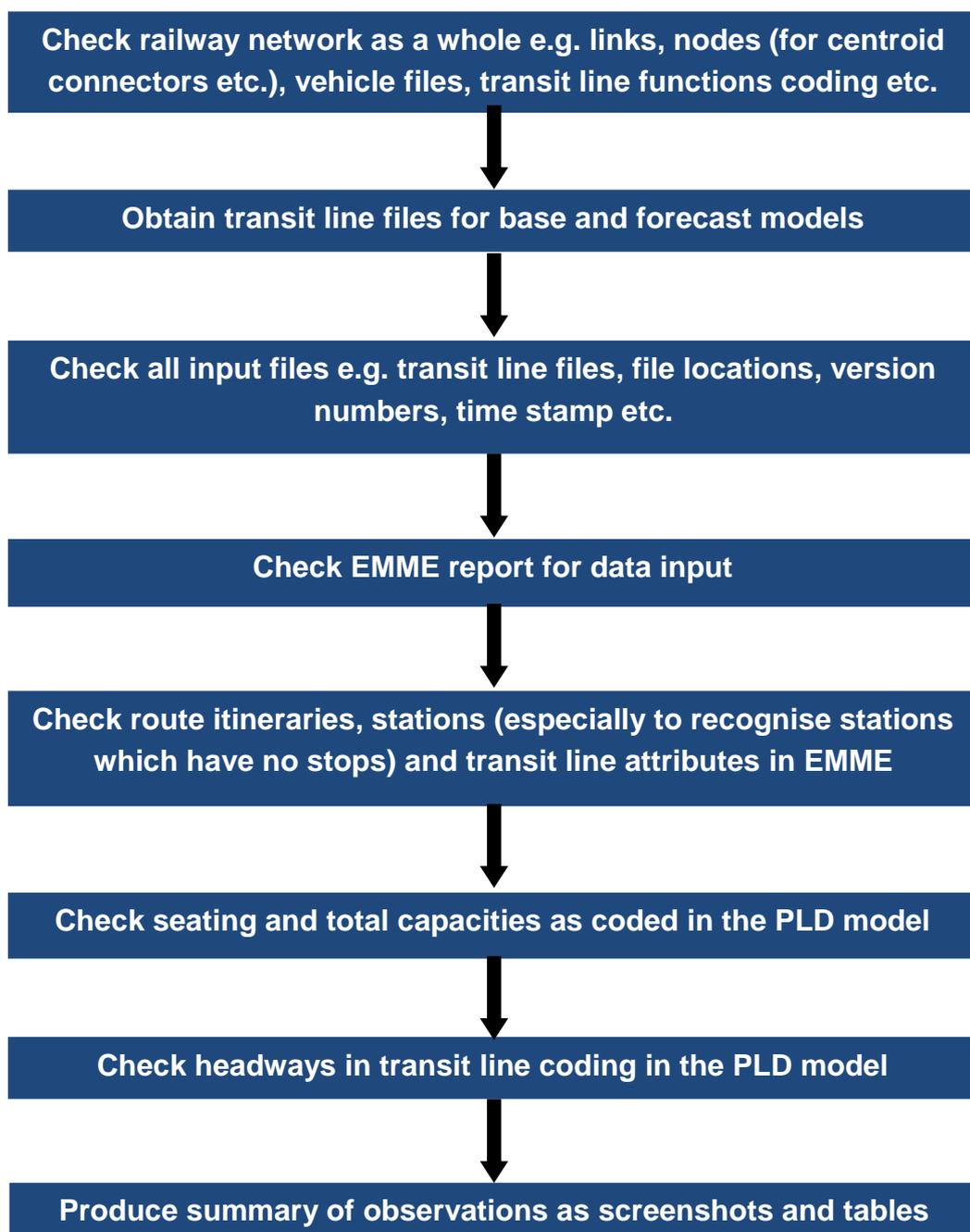
10.2.5. Future year rail network coding was based on forecast network and timetable information from SPG¹³ MOIRA data from DfT/SDG/Atkins, 2011 MOIRA2 data, the East-West rail lines spreadsheet (provided by model developers), pdf and word timetables (Chiltern Railways etc.), the network other schemes network coding e.g. Crossrail, Thameslink and HS2 line network coding information (provided by the model developers).

10.2.6. Due to the unavailability of the PERL script which Arup used to process and group CIF files by each TOC for the base and network rail lines coding, we were unable as part of this audit to fully review the extraction and aggregation process undertaken by the PERL script.

¹³ SPG is the file extension used by the MOIRA software

- 10.2.7. Instead we have based our review on a visual and tabular analysis and used 'sensible' judgments rather than 'absolute' judgments of the rail network coding. Other policy related assumptions were carried forward from previous models.
- 10.2.8. The flowchart in Figure 66 below illustrates the audit process we undertook to review the rail network in the PLD model. This included checking the input rail network data (excluding a review of the original LENNON and CIF data) from the documentation provided by the model developers, coding of the rail network in both the Do minimum and Do Something PLD models, the coding of transit lines headways and attributes and an audit of capacities coded in the PLD rail network.

Figure 66: Audit process



10.3.1. We selected key transit lines on the HS2 corridor to check their implementation against the selected CIF and formation files for the base year network and MOIRA/MOIRA2 and other documented files (in XLS, PDF, DOC formats) for the forecast year network. The key transit lines we selected were as follows:

- East Coast Mainline;
- West Coast Mainline;
- London Midland Line;
- Grand Central Line;
- Chiltern Rail Line;
- Cross Country Rail line; and
- Crossrail.

10.3.2. The above transit lines were checked for their coded TOCs, stops, journey times, headways and vehicle capacities (total and seating capacities). We have checked the coding of these transit lines in the model against the data/documents provided, as listed in the assumption section, and found that except for a few discrepancies, the coding of modelled rail network coding is according to the plans/documents.

10.3.3. We observed that one of the two eastern arms of Crossrail was terminated at Paddington station. Services to and from Shenfield were coded properly in the model whereas the services to and from Abbey Wood terminated at Paddington. This issue has also been discussed with the model developers and we have come to the view that while it would be desirable to correct the Crossrail coding, this would not impact on overall model results as the local accessibility is modelled in PLANET South where Crossrail is correctly and fully coded.

10.3.4. No documentation was available on the walk links coded in the rail network in the PLD model; therefore we were unable to review its implementation.

10.3.5. We also carried out an analysis of stations (used and un-used) and itinerary checks on the HS2 corridor (conventional and high-speed lines). We checked the implementation against maps and data available from HS2 Ltd and model developers' data/documentation and did not find any serious concerns.

10.4. PLD do something rail networks

10.4.1. We received summary spreadsheets of the network coding philosophy for both the HS2 services and the conventional rail services and met with the model developers to discuss this in detail. Subsequent to the meeting, we also received HS2 Ltd's network coding advice and the recommendations to the HS2 Ltd Executive of which service pattern to adopt.

HS2 services audit

10.4.2. The review of HS2 network coding in the PLD model was based on the HS2 lines

specification provided by HS2 Ltd. for both Phase 1 and full network models. The audit task compared the modelled HS2 transit lines coding against the documented service information. The following checks were made to verify the correct implementation of HS2 transit lines coding in the model:

- Headways/Frequencies
- Stopping patterns
- Vehicle types and capacities
- Transit lines coding
- Journey times and dwell times
- Network coding, e.g. links, nodes, modes etc., and connections
- Comparison between Day-1 model HS2 lines coding and Y-network model HS2 lines coding

10.4.3. From the review of the HS2 lines coding, we have identified two issues.

- HS2 services HS10 and HS11 (in both Phase 1 and full network models) from Carstairs to Glasgow and Carstairs to Lockerbie were coded with a return loop in between these stations to adjust dwell times for the non-through passengers from Carstairs. Although it has an intended outcome on the dwell time adjustment, it increases the passenger-km on these services. The same issue arises with the HS2 service coding of HS14 between Sheffield Meadowhall and Leeds stations.
- Node numbers 4001 and 4002 around Meadowhall were added to the PFMv4.2 models for the revised full network allocation. The links are re-aligned in the PFMv4.2 accordingly through these nodes and the original (PFMv4.1) full network links around Meadowhall were deleted. All transit lines in the models were re-allocated to these new links. This correction was made in all the model scenarios in the PFMv4.2 except in the full network model. Since this correction was intended for the Y-network, the omission of this correction in the full network model requires an explanation from the model developers (although we recognise that this has no impact on the current model results).

10.4.4. In response to the first issue, we recommend to use a dummy node with 0 Km distance link to loop the transit lines around for the dwell time adjustments, which will help to keep the passenger-km intact in the model. However, we understand that train kilometres for HS2 are calculated separately in the cost spreadsheet and not extracted from PLD. Therefore this issue does not impact on any modelling results given the current use of PLD.

10.4.5. The second issue is more a housekeeping issue, but it is important both from the point of view of the consistency in between various models and scenarios and to prevent any related potential errors in the model coding in the future PFM versions.

Conventional rail services audit

- 10.4.6. The following checks were made to satisfy the correct implementation of conventional rail services coding in the model:
- Headways/Frequencies
 - Stopping patterns
 - Transit lines coding
 - Journey times and dwell times
 - Network coding, e.g. links, nodes, modes etc., and connections
- 10.4.7. It should be noted that the audit focussed on the DS coding. The DM network model is coded as per the CIF information which is based on DfT timetable data. The model developers have produced a summary of the service patterns found in the CIF files. This is documentation of what has been coded rather than a specification to check the coding against. HS2 Ltd have confirmed that they are satisfied with the service definitions contained in the CIF.
- 10.4.8. It should also be noted that we were unable to check vehicle types and capacities in the DS models due to the lack of documented vehicle types and capacities information for the conventional rail services.
- 10.4.9. One further concern we noted was that the DS coding uses a fundamentally different philosophy from the DM coding (it is not generated as an incremental change on the DM coding). While our audit is concerned with checking the coding against documented service patterns, it will not be possible for us to ascertain whether the differences between DM and DS are in line with intended service changes.
- 10.4.10. However, we have identified 71 coding issues in the DM and DS PLD network used in the standard case analysis. Following discussions with the model developers to distinguish between discrepancies and acceptable coding/cosmetic issues, the impact of the remaining discrepancies between the intended and actual coding used in PFMv4.3 was investigated further through sensitivity tests. We checked that the coding of these sensitivity tests correctly addressed the issues that we had identified and we reviewed the impacts of the sensitivity tests on model results. These results are summarised in section 10.11.1 below.

10.5. PLD Highway network audit

- 10.5.1. The PLD highway network comprises of the GB strategic road network to represent 'long distance' route choice of the car trips. The congestion on these links has been defined by the use of volume delay functions, with preloads to represent local traffic. The definition of strategic roads in the highway network was derived from Highways Agency trunk road network. The link types in the highway network were defined as follows:

- Motorway;
- Dual Carriageway;
- Single Carriageway; and
- Others (e.g. centroid connectors, airport links etc.)

- 10.5.2. The number of lanes in the model was identified by using Ordinance Survey maps and open source mapping data available on the internet.
- 10.5.3. The PLD highway network was derived from HA's Trunk Road Network data, with access links from model zones to the highway network for zone connections. These zone connection links were allocated fixed speeds of 40 km/h. The highway network primarily focussed on the motorways and the strategic route network. In areas where the strategic routes are sparse, the highway network was in-filled with other important routes.
- 10.5.4. The highway network was coded at a link level, i.e. junctions were not coded. Congestion and delays were therefore estimated using the coded volume/delay functions. These were derived from speed-flow curves as defined in DfT's COBA manual.
- 10.5.5. As a part of the audit process of the PLD highway network, we undertook a review of the highway network coding, as received from the model developers, for both DM and DS, Year 2026 and 2036 scenarios.
- 10.5.6. In order to more effectively audit the highway network, we exported the network into the ArcGIS software platform and used this to plot various highway link attributes and characteristics. Plots of attributes such as volume delay function, link type, number of lanes, zone number etc. were constructed for all model scenarios. One of the key advantages of using plots was that it enabled us to compare the highway network for different model scenarios in different forecast years and to review any inconsistencies in the highway network.
- 10.5.7. Number of lanes per link were coded accurately; however, we identified several minor inconsistencies were identified in the coding of the volume delay functions on some links along the M25 orbital and motorways around London, the Midlands and North and around Birmingham. Most motorway links in the model are coded with a VDF code of 11. However, we found links where VDF 16 was allocated. VDF11 and VDF16 currently have exactly the same formulation. We understand that VDF 16 reflects managed motorway schemes, which are currently coded to operate as conventional motorways. However, this does not appear to have been applied consistently.

10.6. PLD air networks audit

- 10.6.1. The base year and future year air networks have been updated for fare and air services using 2010/11 CAA data and DfT's aviation model. The DfT aviation model was also used to derive average route fares which were coded in the PLD model.

- 10.6.2. Our network review of the air base and forecast networks found that all assumptions implied in the model are consistent with the following key documents:
- 2010 Model Development Report (Atkins, 2010); and
 - HS2 model development and baseline report (Atkins, April 2012).
- 10.6.3. Fares were estimated based on the data from CAA (DfT). We observed that 2010 fares were based upon the previous year's fares, adjusted by the average growth factor for all fares. We have audited this process and found that it was correctly implemented in the model. Similarly, CAA data were used to determine the long distance air services and headways in the base network. All these inputs were audited and it was found that these had been implemented correctly.
- 10.6.4. The DfT Aviation Model was used to develop the future year air network. The audit found that the input had also been implemented correctly.
- 10.6.5. All EMME files were checked to ensure that all the desired services and fares were correctly implemented in the air networks. Additional checks were undertaken on the air networks to check the number of seats provided in the forecast 2026 and 2036 air networks compared to the base 2010 air network. The increase of seats in all comparisons was found consistent and sensible.
- 10.6.6. Our audit concluded that the PLD base year and future year networks had been coded correctly.

10.7. PLANET Regional do minimum rail networks

- 10.7.1. The three PLANET Regional Models; PLANET Midlands (PM), PLANET North (PN) and PLANET South (PS) have many features in common with PLD, and thus the audit process is broadly similar.
- 10.7.2. However, they differ from PLD in a number of key characteristics:
- They only cover a three-hour period during the morning peak;
 - They cover a limited geographical area, with a high density of nodes within the primary area of the model, and a limited set of boundary nodes beyond the primary area to facilitate coding of services which extend beyond the model area;
 - Longer distance services are only modelled between nodes included in the model – any extension beyond the boundary node is not modelled, and there is no differentiation between services terminating at the boundary node and those running beyond; and
 - Longer distance services where the first stop is beyond the boundary node limit are not represented.
- 10.7.3. With the exception of PN and PM, which have been split out of a common source, node numbering is unique to each PLANET regional model and PLD thus

geographical locations which exist in two or more models may have different node numbers in each.

- 10.7.4. In addition, the PS model includes transit lines for non-National Rail services, including
- London Underground;
 - Docklands Light Railway;
 - London Tramlink;
 - Selected London bus services; and
 - Selected bus connections to airports.
- 10.7.5. PM, PN and PS use the same input files for rail services as are described for PLD. These are CIF files for the timetable data and separate vehicle data files.
- 10.7.6. No source data were available for non-National Rail services included in PS, although it was reasonably easy to identify London Underground, DLR and Tramlink services for validation against published sources.
- 10.7.7. No source data were available for bus coding included in PS. Bus coding was particularly difficult to verify as the use of several naming conventions for bus transit lines means that they are spread throughout the EMME file, rather than appearing together as a block. Coding was generally for selected London Buses routes, plus RailAir links to Heathrow.
- 10.7.8. As noted above, the PERL scrip used to process CIF files was not available, and it was necessary to base our analysis on visual and tabular comparisons and 'sensible' rather than 'absolute' judgment.
- 10.7.9. Because each of the regional models covers a limited area for a limited time period, in addition to aggregation of services into transit lines, the selection process has first to determine which rail services (or parts of services) fall within the scope of the model.
- 10.7.10. The overall selection process is therefore assumed to include:
- A process to determine whether the individual service (or part of the service) falls within the timescale of the model; and
 - A selection process to determine whether at least two of the stations or stops where the service calls correspond with nodes in the model.
- 10.7.11. Where consecutive station calls are at unlinked nodes, a further process is assumed to determine a plausible route using modelled links which can be combined to connect the calling nodes.
- 10.7.12. Within the CIF files each service is coded individually, whereas the transit lines aggregate individual services and include headway data. Transit lines also include

identification of proxy train operator.

10.7.13. The aggregation process is assumed to operate as follows:

- Services are processed sequentially; with each “new” service allocated a proxy train operator code and a pro-rata number; and
- As further services in the CIF file are processed, those with similar characteristics to transit lines previously created are included by adjustment of the headway in the existing transit line.

10.7.14. However, each time a new or amended CIF file becomes available, the coding process is assumed to be reapplied from scratch.

10.7.15. The audit has concentrated on the following:

- A manual check of the CIF to EMME conversion process, to ensure there is consistent processing of train service data and that the assumed selection process is being consistently applied;
- Cross comparison of the supplied input files with those held within the EMME models after loading and pre-processing;
- Manual comparison of base year service coding with published timetable data; and
- Cross-comparison of base year and future year service coding to identify changes, and validate against supplied assumptions where possible.

10.7.16. In each case the lines files for the do minimum (DM) do something (DS) cases which are included in the inputs folder associated with have been examined.

10.7.17. The CIF to EMME conversion process has been manually checked for all services operated by a sample train operator (First Capital Connect). This check concluded:

- All services in scope were correctly included within a transit line; if necessary as an individual transit line with a 180 minute headway;
- Grouping into transit lines with headway definition was good;
- Only calls at nodes specified in the model were coded;
- Journey times between nodes where services called were pro-rated as necessary for nodes passed through non-stop; and
- Vehicle type definitions and capacities were picked up consistently.

10.7.18. Thus if the same basic conversion process from CIF files has been used for all versions of PLANET, varied only by time period and node list used, then the files could be described as consistent.

10.7.19. However, the selection processes may result in anomalies in the coding of longer distance services between different regional models, and between the regional models and PLD.

- 10.7.20. The duration of end to end transits of longer distance services means that for many services one, other or both ends of the complete journey fall outside the three hour window used for the PLANET regional models. Where long distance services cross the boundaries between regional models, the subset of services which is therefore regarded as “in scope” differs between models.
- 10.7.21. Service coding in PLD is based on the relatively stable pattern of long distance services operated through the main part of the day, with some adjustment to reflect the reduced frequencies and part route operation associated with start and finish of services. In contrast, the regional models only reflect that part of the start of service patterns which fall within the timing window, and may therefore be incomplete or unbalanced when compared with the remainder of the day.
- 10.7.22. If the regional models are primarily designed to reflect the additional capacity which longer distance services can potentially provide in addition to regional and local services during the morning peak, then the longer distance services are fairly represented. The concern relates to any reconciliation which may be attempted between the representation of the longer distance services in the Regional and Long Distance models.
- 10.7.23. No details were supplied of how timescale selection was applied in practice. Where services had origins or destinations at London termini, or similar large cities for PM and PN, this appeared to be the determining point. However, selection was less clear for:
- Services crossing London or other major cities (e.g. Thameslink, Crossrail); and
 - Services not calling at major cities.
- 10.7.24. In particular, the application of the time selection assumption results in:
- Differential selection of which sections of which long-distance services appear in each model; for example services between Plymouth and Aberdeen; and
 - Unbalanced representation of longer distance services; for example, within PS many services extending beyond the boundary nodes leave London termini during the morning peak, whereas fewer early trains from remote origins reach the boundary nodes during the morning peak.
- 10.7.25. These issues could become more important if morning peak data are scaled to synthesise other time periods.
- 10.7.26. The application of the “two or more nodes” assumption results in the inclusion of services which do not actually operate within the model area but call at boundary nodes. Where there is not a direct link between these nodes, such services may be coded to circuitous routes using identifiable links, albeit without stops.
- 10.7.27. The application of the aggregation process to identify transit lines and calculate headways has the following consequences:

- Within a model, even if individual transit lines are unchanged between file versions, they may carry different identifiers depending on differences elsewhere in the source CIF file;
- Between regional models, individual services may be grouped within different transit lines; and
- Within regional models, transit lines may aggregate services wholly within the model area with those sections of longer distance services sharing stopping patterns and journey times.

10.7.28. It is therefore very difficult to determine by subsequent inspection or analysis whether there is consistency between service coding in the regional models and PLD.

10.7.29. Because there is no consistency of transit line or node identification between regional models or between regional models and PLD, the process by which data are passed between models must therefore depend on factors such as cross identification of common nodes. This latter process has been examined as part of the audit of pre-load and wormhole processes in the audit packages covering PLD, PS, PM and PN respectively.

10.7.30. Sample lines files were extracted from two models after inputs had been loaded, and these were compared with the input files before processing. The only difference in the extracted files was the addition of us2 and us3 values at nodes where services called. These values are calculated as part of the model runs and are outside the scope of this part of the audit¹⁴.

10.7.31. Thus all subsequent comparison tests were performed using the input files before loading into the model.

10.7.32. Because do minimum rail service coding was based on CIF files derived from the Train Service Database, it was not considered necessary to compare the input files with published timetables.

10.7.33. Within PLANET South, coding for London Underground, DLR, tram, and bus services has been examined. This has found:

- Underground coding is generally good;

¹⁴ The objective of this part of the audit was to validate the content of the input files prior to processing. These only included us1 values indicating transit times between nodes. However, in several cases, these input files included instructions which both added and deleted specific services or groups of transit lines; thus depending up on the specific order in which files were input to the model, this could affect which transit lines were regarded by the model as active when run. It was therefore considered prudent to check a sample of line files after inputs had been loaded, to ensure that assumptions made regarding active transit lines when examining files prior to loading accorded with the transit lines actually processed by the model. The us2 and us3 values are applied by the model after input.

- DLR and tram coding is generally good; and
- London bus coding shows evidence of at least two different naming conventions for transit lines, with the result that it is scattered through the EMME file. The selection of routes included is outside the strict scope of this audit, but appears to not fully reflect the latest timetable.

10.7.34. No details were supplied to enable an opinion to be given on the completeness or accuracy of bus data, and in particular which routes had been selected for inclusion. Although the audit included several versions of the input file, the bus transit lines remained unchanged between versions.

10.7.35. The layout of the input files was such that separation of the bus transit lines required detailed visual inspection, during which it was possible to identify route numbers which could quickly be checked against published data; hence the comment regarding routes which no longer operate. These include cases where the block of stops served appeared (through comparison with shared sections of other known routes) to be inconsistent with current route numbering. It is therefore possible that other changes such as introduction of new routes and frequency changes have not been coded.

10.7.36. It was anticipated that the DM files within in each model would be the same for 2026 and 2036 – this is confirmed.

10.7.37. It was anticipated that the DM files would be the same for the Phase 1 and full network versions of each model – this is confirmed.

10.8. PLANET Regional do something rail networks

Structure of Do Something transit line input files

10.8.1. For all regional models, there are significant differences between the DS lines files for the Phase 1 and full networks, but within each network the 2026 and 2036 files are the same.

10.8.2. By inspection, it would appear that DS lines files have initially been created for the full network. These are based on the DM files modified as follows:

- Transit lines for services which no longer run or are substantially amended have been removed;
- Transit lines for services which are new, or are substantial amendments to existing services, have been recoded from scratch;

- In most cases blocks of changes been made on an operator by operator basis, with all transit lines appropriate to the particular regional model replaced for operators EC, GW, HT, LM, NT, WC and ZZ¹⁵.

10.8.3. The DS Y lines file has then been further modified to create the DS Phase 1 file. This has typically involved addition of a section at the end of the file, preceded by a comment in the form “Update file to correct Phase n released capacity”. This additional section:

- Deletes blocks of transit lines earlier in the file which are not relevant to Phase 1
- Adds back transit lines which are relevant to Phase 1. In practice, many of these appear to be copied directly from the DM files.

10.8.4. However, modification by deletion and subsequent replacement relies on the input file being compiled and read into the model in the correct order. It is understood that new transit lines which duplicate earlier references are ignored, thus subsequent alterations to a transit line may not be picked up correctly unless the previous transit line has been deleted.

10.8.5. This caused initial problems with validation of Phase 1 DS files in PM, as a large number of transit lines for EC,EM, HT, and XC were initially included in their modified full network version, before inclusion of delete all commands and replacement with the DM version. When comparing the complete file with the DM version, the data were re-sequenced to identify matched blocks, giving the unfortunate impression that the file itself was out of sequence. Subsequent stand-alone examination of the DS file has confirmed that the sequence is correct and that the correct transit lines are input to the model.

10.8.6. The order in which data is presented in PN and PS appears to be correct.

Comparison of Do Something with Do Minimum

10.8.7. For a number of operators, the DS timetable was specified as a set of changes to the DM timetable. Thus the audit process involved cross comparison of the DM and DS input files to identify differences, which were then validated against the specifications supplied. Files have been compared to check the changes against the specification provided by HS2 Ltd.

10.8.8. For those train operators where services are largely unchanged from the DM case, direct comparison has not identified any significant discrepancies in coding.

¹⁵ East Coast, Great Western, Hull Trains, London Midland, Northern Trains, West Coast and (ZZ) Unclassified

- 10.8.9. Where complete blocks of coding for a specific train operator have been changed, it becomes much more difficult to separate those changes made to reflect the specification and any other changes or possible errors. The specification supplied by HS2 Ltd did not include detailed running times for non HS2 services, and information regarding vehicle type was minimal, thus comparison has mainly been confined to headways and stopping pattern.
- 10.8.10. However, spot checks of key service changes show them to be consistent with the specification supplied by HS2 Ltd.

10.9. Standard case appraisal

- 10.9.1. Our final audit findings relate to version 4.3f of the appraisal spreadsheet.
- 10.9.2. We have extracted the results from Mott MacDonald's model run as supplied with the standard case model and populated the appraisal spreadsheets. The import process worked without errors and produced plausible appraisal results on a high level inspection, having compared them with the documented results.
- 10.9.3. We repeated this exercise with the results produced from our own model run. This also worked without errors and input values were identical.
- 10.9.4. We checked and sourced all inputs. With regard to the inputs generated by PFM, we traced back how these are generated within the models and found no issues.
- 10.9.5. With regard to the economic inputs we had a small number of observations as already highlighted in section 9.7.
- 10.9.6. We had one further query regarding the fares used in the spreadsheet model. We observed that the leisure fares are similar in magnitude to the business fares in PS, PM and PN. Atkins explained that a number of factors contribute to the lack of difference between fares for different purposes in the regional models:
- Business journeys are typically longer than those for other purposes which typically lead to a lower fare/km due to the 'taper' effect.
 - The differential between Full and Reduced fares for journeys within PTE areas is considerably lower than the differential for Long Distance journeys to London, e.g. Sutton Coldfield - Birmingham: Anytime £5.20; Off-peak £3.80 (Anytime is 37% more expensive), Birmingham-London: Anytime £158; Off-Peak £49 (Anytime is 222% more expensive).
 - According to PDFH5 factors, half of 'regional' business travellers actually use Reduced price ticketing.
- 10.9.7. In addition to the audit of the appraisal spreadsheet itself, we undertook a number of further checks to verify the appraisal results.
- 10.9.8. We prepared a simple shadow model from scratch in order to check the results. The shadow model replicated the full calculation process from the processing of model

outputs to the estimation of discounted benefits, and produced the same results as the full model.

- 10.9.9. Some sense checks were undertaken by modifying assumptions in different cases. This produced the expected results.

10.10. Assumptions and parameter inputs

10.10.1. Throughout the audit process, we have checked that the parameters and assumptions used in various parts of the modelling suite. We have also compared values and assumptions of relevance to more than one module in the modelling suite and where these are not identical, we have investigated the validity of any discrepancies and the impact these may have on forecasting. In total, over 4,000 values were checked and we have not identified any input errors of significance for the model results.

10.10.2. HS2 Ltd has published an assumptions report which documents the main assumptions used in the model.

10.11. Audit findings

10.11.1. Our overall findings on the standard case forecast and appraisal can be summarised as follows:

- The rail DM and DS networks have been correctly implemented subject to the issues highlighted here.
- It has been difficult to compare the DM and DS codings because they were derived from different sources. The former has been derived from .CIF files and the latter is much more aggregated and has been derived from a timetable plan both of which were supplied from DfT. Thus whilst we have been able to audit the DM and DS transit line services separately, it has not been possible (and was not part of our audit scope) for us to ascertain whether the differences between DM and DS are in line with intended service changes.
- We identified 71 issues with the coding of the DM and DS services in the PLD model. The model developers tested 37 of these issues aggregated (with other issues) in four separate sensitivity tests. The cumulative impact of these tests was a reduction in predicted transport-economic benefits of just under £1bn PV, or 1.5% of the estimated benefits of the full Y network. Furthermore, 15 issues related to the coding of the transit lines and HS2 Ltd have confirmed that the coding has been specified as intended. Of the remaining issues: twelve have a minor impact and seven are cosmetic issues affecting the transparency of the model.
- We have identified a number of minor issues with the coding of a small number of links in the base year highway network in PLD.
- We have been able to conclude that the coding of the base year and future year air networks has been undertaken correctly.

- In the audit of the appraisal, we have highlighted a small number of observations, mostly in connection with transparency and clarity of the way data are used and outputs are presented.

10.12. Implications of audit findings

10.12.1. We believe that the implementation of the standard case scenario in PFMv4.3 has been undertaken in line with its specification, but have a number of outstanding issues on the rail network coding as noted in the preceding paragraph.

10.12.2. With regard to the appraisal, we conclude the estimate of benefits is robust and reliable for the hybrid bill process. We expect that the outstanding observations will only have a minor impact on the resulting benefit calculations.

Appendix A Glossary

| | |
|---------|--|
| AP | Attraction to Production |
| ATOC | Association of Train Operating Companies |
| Biogeme | Software package for the development of discrete choice models by estimating by maximum likelihood |
| CA | Car Available |
| CAA | Civil Aviation Authority |
| CEBR | Centre for Economics and Business Research |
| CIF | Common Interface Format (for network data) |
| CPI | Consumer Prices Framework |
| CR | Car |
| C++ | General-purpose computer programming language |
| DECC | Department of Energy & Climate Change |
| DfT | Department for Transport |
| DM | Do Minimum |
| DS | Do Something |
| EDGE | Endogenous Demand Growth Estimator – Forecasting framework for rail demand growth in Great Britain (DfT) |
| GDP | Gross Domestic Product |
| GIS | Graphical Information System |
| GJT | Generalised Journey Time |
| GJTAE | Generalised Journey Time + Access/Egress |
| HAM | Heathrow Access Model |
| HBEB | Home-Based Employers' Business |
| HBO | Home-Based Other |
| HBW | Home-Based Work (Commuting) |
| HSL | High speed line |
| HSR | High Speed Rail |
| HS2 | High Speed Two (the project) |

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| | |
|-------------|--|
| HS2 Ltd | HS2 project promoter |
| HW | Highway |
| Hybrid bill | Consents process for major projects deemed to be in the national interest that also affect a large number of private interests |
| ICWC | Inter City West Coast |
| IEP | Intercity Express Programme |
| LASAM | London Airports Surface Access Model |
| LOS | Level of Service |
| LUL | London Underground Limited |
| MOIRA | Rail forecasting software and database. Maintained on behalf of ATOC members for rail demand and revenue forecasting. |
| MSOA | Middle Layer Super Output Areas (definition of geographical zones in the national census) |
| NAM | National Accessibility Model |
| NAPALM | National Air Passenger Allocation Model (DfT) |
| NAPDM | National Air Passenger Demand Model (DfT) |
| NCA | Non-car available |
| NHB | Non-Home-Based |
| NHBEB | Non-Home-Based Employers' Business |
| NHBO | Non-Home-Based Other |
| NHBW | Non-Home-Based Work |
| NRTS | National Rail Travel Survey (DfT) |
| NTEM | National Trip End Model (DfT) |
| NTM | National Transport Model (DfT) |
| NTS | National Travel Survey (DfT) |
| OBR | Office for Budget Responsibility |
| OD | Origin-Destination |
| ONS | Office of National Statistics |
| ORR | Office of Rail Regulation |
| P/A | Production/Attraction |

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| | |
|--------|--|
| PDFH | Passenger Demand Forecasting Handbook |
| PFM | PLANET Framework Model |
| PLD | PLANET Long Distance |
| PM | PLANET Midlands |
| PN | PLANET North |
| PS | PLANET South |
| PT | Public Transport |
| R | Software environment for statistical computing and graphics |
| RIFF | Rail Industry Forecasting Framework |
| RPI | Retail Prices Index |
| RTF | Road Traffic Forecasts (DfT) |
| SCM | Station Choice Model |
| TEMPRO | Trip End Model presentation PROgram (DfT) |
| TfL | Transport for London |
| TOC | Train Operating Company |
| TRADS | TRAffic flow Data System (Highways Agency database) |
| TSDB | Network Rail's central Train Service Database |
| WebTAG | DfT's web-based documentation for Transport Appraisal Guidance |