August 2023

HS2

PLANET Framework Model PFMv10a

Model Description Report

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Glossary

AADT	Average Annual Daily Traffic
AAWT	Average Annual Weekday Traffic
ASC	Alternative Specific Constant
AVE	Alta Velocidad Española (Spanish High Speed Rail)
CA	Car Available
CAA	Civil Aviation Authority
CAF	Car Available From
CAT	Car Available To
CBA	Cost Benefit Analysis
CIF	Common Interface Format (for network data)
COA	Census Output Area
COBA	Cost Benefit Analysis (DfT program/methodology)
CP	Crowding Penalty
CSV	Comma-Separated Variables (file format)
CV	Coefficient of variation (standard deviation/mean)
DCF	Discounted Cash Flow
DfT	Department for Transport
FJTS	Frequency and Journey Time Strategy [PT assignment]
FORGE	Fitting On of Regional Growth and Elasticities (NTM)

FY	Financial Year
GIS	Geographical Information System
GJT	Generalised Journey Time
GJTC	Generalised Journey Time including crowding
GJTCAE	Generalised Journey Time including crowding + Access/Egress
GOR	Government Office Region
HBEB	Home-Based Employers' Business
HBEd	Home-Based Education
HBO	Home-Based Other
HBW	Home-Based Work (Commuting)
HSR	High Speed Rail
IEP	Intercity Express Programme (DfT initiative)
ITN	Integrated Transport Network
IVT	in-vehicle time
LASAM	London Airports Surface Access Model
LATS	London Area Travel Survey
LD	Long Distance (> 50 miles one-way)
LDM	Long Distance Model (DfT)
LENNON	Latest Earnings Networked Nationally Over Night (Rail ticket database)
LF	Load Factor (ratio of passengers to seats)
LOS	Level of Service
LSE	London and South-East

MSA	Method of Successive Averages (algorithm)
MSOA	Middle layer Super Output Area
NAM	National Accessibility Model
NAPAM	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
NPS	National Passenger Survey (rail)
NPTDR	National Public Transport Data Repository
NRTS	National Rail Travel Survey
NSE	Network SouthEast
NTEM	National Trip End Model
NTM	National Transport Model (DfT)
NTS	National Travel Survey
OD	Origin-Destination
P/A	Production/Attraction
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
RoH	Rule of a Half (Benefit calculation)
RPI	Retail Prices Index
SCM	Station Choice Model
SNCF	Société Nationale des Chemins de fer Français (French Railways)
SP	Stated Preference
TEMPRO	Trip End Model presentation PROgram
TGV	Train à Grande Vitesse (French High Speed Train)
TOC	Train Operating Company
TRADS	TRAffic flow Data System (Highways Agency database)
TTW	Travel To Work area
TUBA	Transport User Benefit Appraisal (DfT software)
UA	Unitary Authority
VDF	Volume Delay Function (highway assignment)
VoT	Value of Time
TAG	DfT's web-based documentation for Transport Appraisal Guidance

1 Introduction

1.1 Background

1.1.1 The PLANET Framework Model [PFM] has been developed by HS2 Ltd as a tool to forecast the passenger demand and benefits of the HS2 rail network. PFM is subject to a rolling programme of updates and upgrades that uses industry best practice and guidance to establish a "fit for purpose" model. The current version of PFM is version 10a, or PFMv10a.

1.1.2 The aim of this document is to provide a clear account of the PFMv10a model. It is an update of the corresponding documents relating to earlier versions of the modelling suite.

1.1.3 The document does not describe the evolution of the model, but it does discuss in detail those aspects of the model which are unique to PFM. It also attempts to establish a consistent mathematical notation across the disparate elements of the model and to provide a description of all the key calculations.

1.1.4 PFMv10a has been used to produce the HS2 reference case as presented in the Economic Case section of the overall business case. This document, the Model Description Report, does not present the forecasting assumptions used for the HS2 Reference Case, nor the outcomes of the economic assessment, though the methodology both for forecasting and appraisal is described.

Part 1 - An overview of the PLANET Framework Model [PFM]

This part contains a single chapter that provides a high-level overview and introduction to the model.

2 An overview of the PLANET Framework Model [PFM]

2.1 Introduction

2.1.1 This chapter provides a general overview of the PLANET Framework Model [PFM]. The general dimensions of the model are presented first, and then the main model constituents – PLANET Long Distance [PLD], and the Regional PLANETs in outline. Each of these will be discussed in detail in subsequent chapters. The chapter ends with a description of the generalised cost specification used in the various model components.

2.2 Model overview

2.2.1 The PFM has evolved over a number of years and was developed out of existing model components brought together to operate symbiotically. Its aim is to provide forecasts of passenger demand and (generalised) costs to feed into the economic appraisal of the HS2 scheme. As is standard in transport modelling, 'generalised cost' is a combination of monetary costs and travel time components (see box below – Demand and supply in transport models – for more detail).

2.2.2 The crucial elements of the forecasting process may be described as follows:

- derivation of base year passenger demand patterns for rail, air, and highway;
- forecast growth of base year demand to future year(s); and,
- demand response to changes in the provision of future rail services, including both new high-speed rail services and/or changes to rail services on the existing conventional rail network.

2.2.3 The main emphasis of this report is on the third element, though the critical aspects of the other two elements will also be discussed. The derivation of base year demand is described in Chapter 8, while the growth in future year demand is described in Chapter 9.

2.2.4 It may be expected that passenger demand for HS2 will be a mixture of demand transferring (or 'abstracted') from highway and air, as well as additional 'generated' demand. This means that PFM needs to represent the supply and demand for those other modes where demand may transfer to HS2.

2.2.5 PFM is conventional in the sense that it contains a multi-modal supply representation based on networks, together with a multi-modal demand model

which is segmented by different types of travel which responds to changes in generalised cost.

2.2.6   Due to the nature of the HS2 scheme, the emphasis of PFM is mainly on representing longer distance travel. The main area where shorter distance travel needs to be represented is on the rail side. This is in order to reflect the fact that short distance passengers can cause crowding on long distance trains, and also to be able to model the benefits that arise from running additional local services. This is done by making use of regional network models with the generic title of 'PLANET'. Note that Northern Ireland is excluded and as such PFM only models domestic trips within mainland Great Britain.

Demand and supply in transport models

The notions of demand and supply are fundamental to economic theory, but although the terms are indeed widely used within the field of transport economics, there are certain aspects of the transport problem which require that they, and the related concept of an equilibrium system, be defined with some care. In classical economics, it is conventional to treat both supply and demand as functions of (monetary) cost. Since, in addition to costing money, travelling between different locations inevitably involves an expenditure of time, it has become standard in transport economics to deal with so-called 'generalised cost', which explicitly recognises both kinds of expenditure. In its simplest form, generalised cost is a linear combination of cost and (different kinds of) time, the latter being converted to money units by means of the so-called "value of travel time savings".

The notion that demand for travel T is a function of (generalised) cost C presents no difficulties. However, if the predicted travel demand were actually realised, the generalised cost might not stay constant. This is where the 'supply' model comes in. The classical approach defines the supply curve as giving the quantity T which would be produced, given a market price C. However, while certain aspects of the supply function do relate to the cost of providing services (whether it be the cost of highway infrastructure or a public transport service with a specified schedule), the focus of supply relationships in transport has very often been on the non-monetary items, and on time in particular. This is because many of the issues of demand with which transport analysts are concerned impinge on the performance of the transport system rather than on the monetary costs.

It is therefore more straightforward to use the inverse relationship, whereby C is the unit (generalised) cost associated with meeting a demand T. In this sense, the supply function encapsulates both the response of supplying "agencies" and the performance of the system. Note therefore the different "directionality" of the two functions: for demand, the direction is from cost to quantity, whereas for supply the direction is from quantity to cost.

The supply model thus reflects the response of the transport system to a given level of demand. In particular, what would the generalised cost be if the estimated demand were "loaded" onto the system? The most well-known 'supply' effect is the deterioration in highway speeds, as traffic volumes rise. However, there are a number of other important effects, such as the effects of congestion on bus operation, overcrowding on rail modes and increased parking problems as demand approaches capacity. Since both demand and supply curves relate volume of travel with generalised cost, the actual volume of travel must be where the two curves cross – this is known as the 'equilibrium point'. A model with the property that the demand for travel be consistent with the network performance and other supply effects in servicing that level of demand is often referred to as an "equilibrium model".

2.2.7   The main structure of PFM can be envisaged as:

- a multi-modal model of supply and demand for long-distance movements ('PLANET Long Distance' [PLD]); and,
- a set of local rail models ('Regional PLANETs') which deal with the supply implications of the changes brought about by, and associated with, HS2.

2.2.8   Outside of the PFM model – but included within the appraisal of HS2 – there are separate models for valuing the noise impacts of running HS2 trains on the new high-speed line, and the carbon impacts of reduced changes in car and diesel train use. In addition, there is a separate calculation of wider economic benefits. None of these modules are described in this document, but are instead separately reported.

2.2.9   PFM provides an overall 'framework' linking the components in a consistent way, as well as managing the interaction between supply and demand. The PLD demand model deals with three modes of travel: rail, car (either driver or passenger) and air. The coach mode is not explicitly recognised, and is generally considered of low relevance in terms of possible abstraction by HS2, since in most cases coach travellers have explicitly opted for a slower (and cheaper) service. Insofar as such abstraction might occur, it is implicitly treated as part of generation.

2.2.10   Apart from the service characteristics, no special recognition is given to HS2 services. The choice between HS2 and conventional rail services is made as part of the general route choice in the PLD assignment model. The introduction of HS2 leads to improvements for rail in general and increasing overall demand for rail: that portion of rail demand using HS2 services is obtained from the assignment.

2.2.11   In order to carry out an appraisal of a particular HS2 proposal, PFM needs to be deployed for two modelled (forecast) years for each modelled scenario. This produces the required output matrices of demand and generalised cost which feed into the economic appraisal process (discussed in Chapter 11). Both the model and the economic appraisal are compliant with TAG[1] guidance and the most significant aspects of the modelling approach are agreed in collaboration with the DfT.

2.2.12   The full demand-supply functionality of the PFM is applied to both the Do Minimum (without HS2) scenario, as well as the Do Something (with HS2) scenarios. By applying the PFM to the Do Minimum and Do Something, the model takes into account changes in demand and supply between the Do Nothing (validated baseline model) and the forecast future year scenarios. This leads to changes in the rail costs, which in turn operate through the demand model to bring about modal shift and

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[1] TAG is the Department for Transport's web-based documentation for Transport Appraisal Guidance - see
https://www.gov.uk/guidance/transport-analysis-guidance-tag.

generation. This new pattern of demand then leads to further ('second round') changes in cost – largely on the rail network, but to a small extent influencing highway congestion as well. The system is iterated a number of times to reach equilibrium.

2.2.13   Separate networks are maintained for the rail, car and air modes, and these are input into the corresponding assignment procedures. The assignment model takes a modal matrix of travel (as movements from origins to destinations) and assigns (or 'loads') it onto an appropriate network. While the underlying principles are not mode specific, the different characteristics of highway and public transport networks lead in practice to a rather different set of practical problems.

2.2.14   Although assignment is treated as a single 'stage' in the conventional transport model, it in fact relates to a number of separate processes which may be described as:

- choice of route (or path) for each Origin [O]–Destination [D] combination;
- aggregating O–D flows on the links of the chosen paths;
- dealing with supply-side effects (capacity restraint) as a result of the volume of link flows relative to capacity; and,
- obtaining the resulting cost for each O–D combination.

2.2.15   The route-choice process could be considered as a component of demand, but because of its treatment within the assignment it is typically regarded as part of the 'supply' procedures. It should be noted that it is strictly only the implementation of capacity restraint that represents the true supply function. The last process is often referred to as 'skimming' the network.

2.2.16   On the highway side, as only the PLD (long distance) car matrices are assigned, short distance car traffic and freight is represented by highway 'pre-loads' (i.e. traffic which is not included in the matrices to be assigned, but is independently estimated for each link in the network, and assumed to be fixed). Standard equilibrium assignment techniques are employed, and separate user classes are recognised.

2.2.17   By its nature, public transport assignment is considerably more complicated. For the Regional PLANETs, the assignment needs to allow for different access and egress options to and from stations, in addition to the variations between rail services in terms of frequency, in-vehicle time, capacity, and interchange requirements.

2.2.18   For the long-distance movements in PLD, station access is separately modelled by means of a 'Station Choice Model' [SCM]. In this case, therefore, the assignment receives a matrix of station-to-station movements (as opposed to zone-to-zone movements). This results in a more complex version of supply-demand iteration.

2.2.19   By contrast, the air network does not in fact represent any supply constraints: aircraft are not assumed to have any capacity constraint (on the basis that airlines could just run bigger aircraft) and thus, fare and frequency of service do not vary with demand level. The network's main function is to provide matrices of generalised cost.

2.2.20   PFM generally runs on the specialist transport modelling EMME/4[2] software platform developed by INRO, making use of standard procedures and macros. However, the SCM has been developed as a separate module in the C++ language.

2.3   Zoning system, demand segments and scope

2.3.1   The basis of the PLD zoning system is the Local Authority District level, of which there are 406 in mainland Great Britain. To focus on the corridor of interest, aggregation has taken place in the more remote areas, so that the number of zones is reduced to 235 (including a separate zone for Heathrow Airport). The zoning system is shown in Figure 2-1.

2.3.2   The size of the PLD zones means that much of the total travel made within Great Britain is intra-zonal, and therefore not captured by the model. This is not problematic for the HS2 scheme because the emphasis of the PLD model is on long-distance movement.

2.3.3   The PLD demand matrix and network assumptions represent an average weekday. As described in Chapter 12, for economic appraisal purposes, this average weekday demand is converted into an annual demand using 'annualisation factors', to allow for weekend and holiday travel. The Regional PLANETs are AM peak models only, relating to the three-hour period [0700 – 1000] only. Hence an adjustment is required when interfacing demand between the regional peak and PLD all day models.

2.3.4   The impact of local rail demand is modelled in the Regional PLANETs, while that of long distance demand is modelled in PLD. As described in Section 2.5, the Regional PLANETs have a more detailed zoning system in their core areas of interest, generally based on aggregations of Census Output Areas [COAs]. To ensure that no elements of demand appear in two models, PFM makes use of a 'control matrix', which defines which origin-destination movements are held in which of the models. This in turn requires appropriate interfaces to ensure that crowding levels are represented correctly in each of the models. Without further adjustment, this could

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[2] See link to INRO's website and details of EMME software: http://www.inro.ca/en/products/emme/

lead to crowding being understated on long distance services in PLD south of Milton Keynes.

2.3.5   Three purposes are recognised in the modelling: Business, 'Other' (primarily Leisure) and Commuting. The definitions, which are in line with NTS definitions for trip purpose[3], are as follows:

- Commuting: trips between Home and Usual Workplace only;
- Business: trips between Home and 'In course of work', and non-home-based trips with destination in course of work; and,
- Other: all other trips including education.

2.3.6   These trips are further segmented between car available [CA] and non-car available [NCA], though the distinction does not apply in all cases.

2.3.7   In most transport models, the matrices and the model operate on a 'Production/ Attraction' [P/A] basis, distinguishing between home-based trips and non-home-based trips, where the latter are treated on an 'Origin-Destination' [O-D basis][4]. One reason for this is so that the forecasting process can distinguish between factors affecting growth at the home end of the trip (including car availability) and at the 'destination' end of the trip. In addition, this distinction is essential when destination choice is one of the possible responses.

2.3.8   PFM does not explicitly allow for destination choice. This is largely due to the structure of the PFM model and the associated constraints this imposes. Instead, destination choice is reflected indirectly within the 'generation' component of the demand model.

2.3.9   As this removes the most critical reason for moving to a P/A structure, PFM therefore operates on an O-D basis which makes the implementation of the model somewhat simpler. As discussed in Chapter 9, the forecasting procedure is however adjusted to take account of the P/A-based growth. The differential treatment of car availability according to the location of the home is also taken into account at various stages in the model, particularly in connection with the SCM. This is another way in which the advantages of a P/A structure are built into the current model, by distinguishing the direction (from home, to home) in which the journey is being made.

2.3.10   To summarise, the PLD model component operates on a 235-zone level, representing district level spatial resolution in the key areas served by HS2. It models an average weekday, distinguishing three purposes, further segmented by car

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[3] NTS codes the purposes at both ends of the trip: from this, a "trip purpose" can be deduced. The NTS definitions of Commuting and Business are identical to those given above, but NTS makes further distinctions within the 'Other' purpose category.
[4] The differentiation between PA and OD development is discussed further in the box below.

availability, and deals with three modes. The model operates on an OD basis, with some adjustments to reflect P/A format, and deals with assignment (including station choice), and mode choice and generation as demand responses.

Figure 2-1: PLD Zoning System

2.3.11 By contrast, the Regional PLANETs (separate models for South, Midlands and North) operate for rail only, and only allow for demand responses by means of elasticities to changes in rail services (though changes in PLD rail demand are conveyed by interface). They are also weekday models, but relate to the AM peak only.

Alternative formats for transport demand matrices

There are two alternative formats for transport demand matrices, and the distinction is of major importance. The Origin-Destination format relates to trips starting in zone i and ending in zone j, while the Production/Attraction format relates to trips "produced" in zone i and "attracted" to zone j.

An alternative formulation is the "tour", which is a chain of linked trips beginning and ending at the zone of production. In most cases the zone of production is taken as the zone of residence, though some work-related journeys can be "produced" from the zone of workplace.

To see the difference, consider the following simple two-zone example. Zone 1 has 10,000 residents who all work in zone 2, and zone 2 has 2,000 residents who all work in zone 1. Each person travels once to work and back in a day. The total daily volume of travel can thus be represented as:

	Attraction zone				**Destination zone**			
		1	2	Total			1	2	Total
Production zone	1		20,000		Origin zone	1		12,000	
	2	4,000				2	12,000		
	Total			24,000		Total			24,000

O-D matrices when taken over a whole day tend to be symmetric. This is not true of P/A matrices. The totals are the same, but the distribution over cells is quite different.

The full range of demand responses (in particular, the modelling of destination choice) cannot be sensibly modelled on an O-D basis. The matrix structure must be on a P/A basis. A minor exception may be made when modelling the morning peak only, when most journeys will be from home. In addition, when forecasting growth over time, to take account of changes in residences, employment etc., the growth factors need to be applied to P/A matrices.

However, when considering the impact on the network, they are transformed to an O-D basis. This involves recognising the separate directions (outward and return) in the P/A format. The "return" portion of the matrix is transposed and added to the "outward" portion.

2.4 PLANET Long Distance model components [PLD]

2.4.1   The PLANET Long Distance [PLD] model is the core of PFM and is, in effect, a supply-demand equilibrium model for long-distance travel focussed on the HS2 market. An outline of the PLD model structure is shown in Figure 2-2. The figure simplifies by ignoring the different demand 'segments' (purpose and car availability).

Figure 2-2: PLD Model
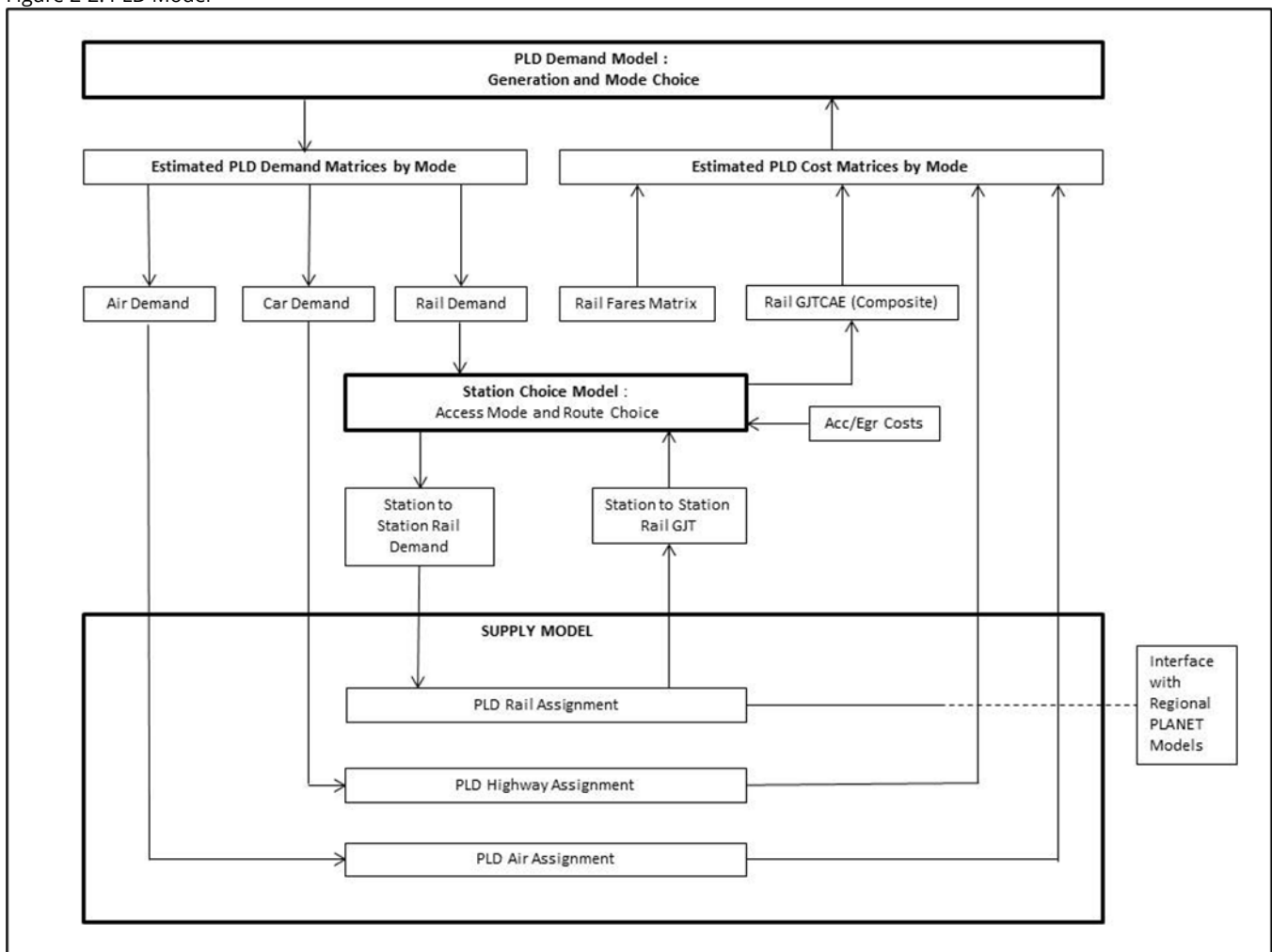
2.4.2   At the top of the structure is the demand model, which deals with mode choice and generated demand, in response to changes in (generalised) cost (and specifically those brought about by the introduction of HS2). At the bottom of the structure are the modal supply models, based on networks: in principle these calculate the changes in cost, as a result of changed demand. For rail there is an intermediate SCM which converts the rail demand matrices from a zone-to-zone basis to a station-to-station basis. The rail assignment then calculates the routes through the network for each pair of stations, allocates the demand and derives the costs (there is also an

interface with the Regional PLANETs). The costs feed back into the demand model and the process iterates until a stable result is obtained.

2.4.3   As is general practice within public transport assignment, the choice of routes within the rail assignment does not make allowance for differential fares. PFM has not been designed to take into account the different fare options generally available to passengers for travelling between an origin and destination using different routes, Train Operating Companies [TOCs] or types of service. It therefore assumes that the cost of travelling by HS2 is the same as travelling by any other conventional rail service.

2.4.4   On this basis, the choice of route reflects only the service characteristics of the route (in-vehicle time – including an allowance for crowding, service frequency/waiting, and the need for interchange). The cost output of the PLD rail assignment is in terms of 'Generalised Journey Time' [GJT][5], but includes an allowance for crowding, so it is denoted as GJTC.

2.4.5   The SCM then introduces the access and egress generalised costs to and from each station, and allows also for choice of access mode (between car and public transport). Because a probabilistic allocation to stations is made in the SCM, the output is in so-called 'composite' GJTCAE [GJTC + Access and Egress] terms, reflecting the cost associated with all possible station pairs. To convert to generalised cost, the fares – divided by the Value of Time – are added prior to returning to the demand model. More discussion is provided in Chapters 5 and 6.

2.4.6   The (revised) estimates of zone-to-zone rail demand (from the demand model) then pick up the station choices obtained from the SCM, thus converting the rail demand to a station-to-station basis.

2.4.7   As noted, allowance is also made for a two-way interface in the rail assignment between the PLD assignment and the Regional PLANETs. This ensures that, for the key 'common' services between PLD and the regional models, the total demand from both long-distance and regional passengers is accurately reflected, ensuring that demand and crowding is correctly assessed in both models.

2.4.8   To achieve this, the demand from relevant short distance rail travellers is transferred as rail 'pre-loads' from the appropriate Regional PLANETs to the PLD assignment. In the opposite direction, for PLANET North [PN] and PLANET Midlands [PM], demand

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[5] GJT is a term widely used in the rail industry, and in PDFH in particular (see Section B4.1 of PDFH5). Unlike the term "generalised cost" which can contain any number of variables depending on the context under investigation, GJT has a very specific meaning in the context of PDFH and contains only the three timetable related service quality attributes: in-vehicle time (strictly speaking, not including allowance for crowding), an allowance for service frequency (effectively, waiting time), and interchange (both as a "penalty" expressed in minutes, and any time taken to make the change). Note that it does not include access and egress costs.

arising from long-distance travellers is again transferred in the form of rail pre-loads, from PLD to the assignment. For PLANET South [PS], PLD demand is transferred by a device known as 'wormholes', both to represent crowding appropriately in PS and to deal with more detailed access/egress options within the local rail system.

2.5 Regional PLANETs

2.5.1 Separate network models are used for local movements in different parts of the country, referred to as PLANET South [PS], PLANET Midlands [PM], and PLANET North [PN]. These are versions of free-standing rail models maintained by the Department for Transport [DfT]. PLANET South [PS] is the oldest and has been used to assess a wide variety of schemes including the Thameslink Upgrade, while the other two were developed more recently. The three regional models operate along generally comparable principles. Their coverage is indicated in Figures 2-3, 2-4, and 2-5.

2.5.2 The primary aim of the Regional PLANETs is to estimate the savings in GJTC associated with new schemes taking advantage of capacity released by HS2 and to ensure that local movements are correctly reflected in the PLD assignment. In addition, they can reflect local crowding benefits associated with classic rail passengers switching to HS2.

Figure 2-3: PLANET North Zoning
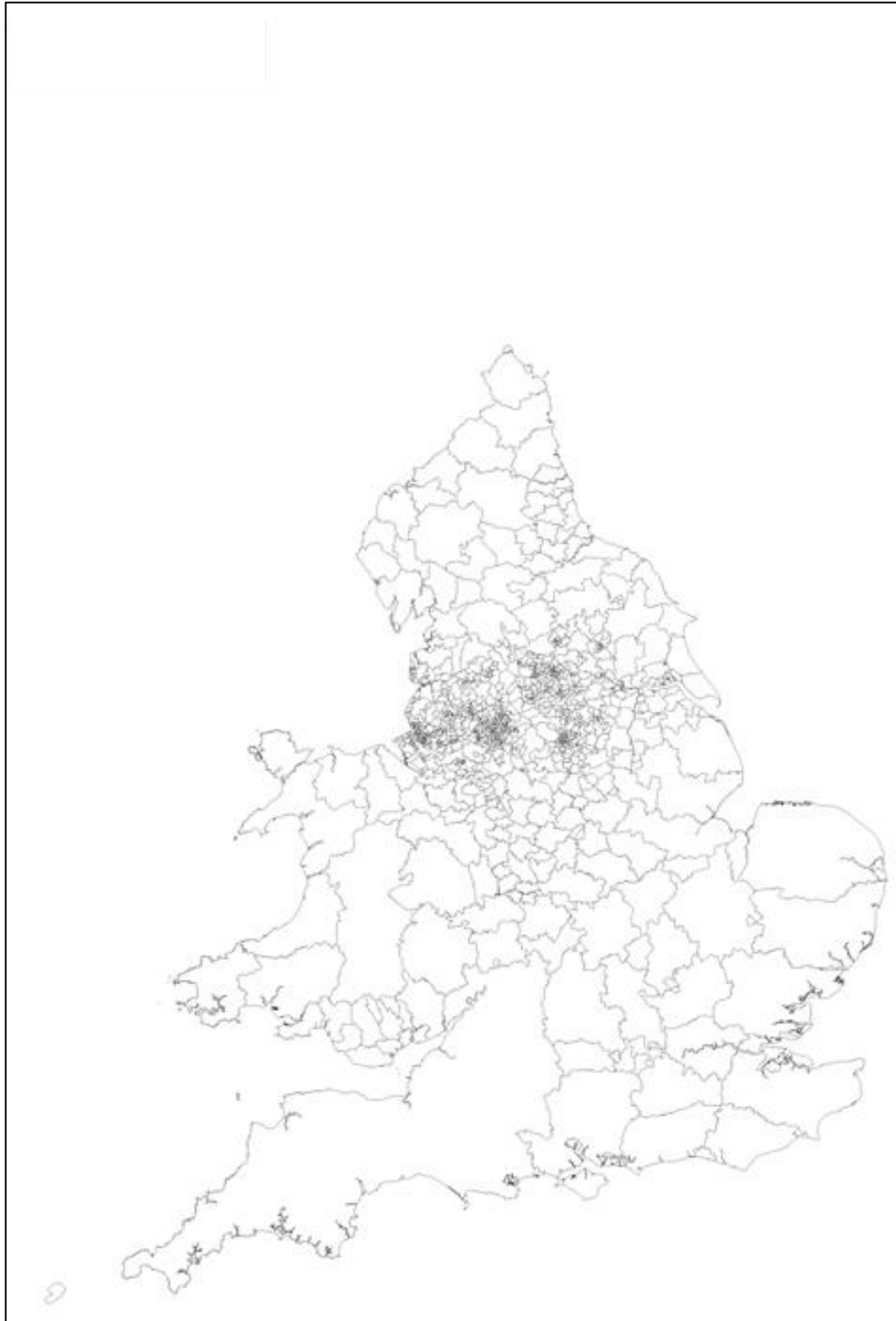
Figure 2-4: PLANET Midlands Zoning
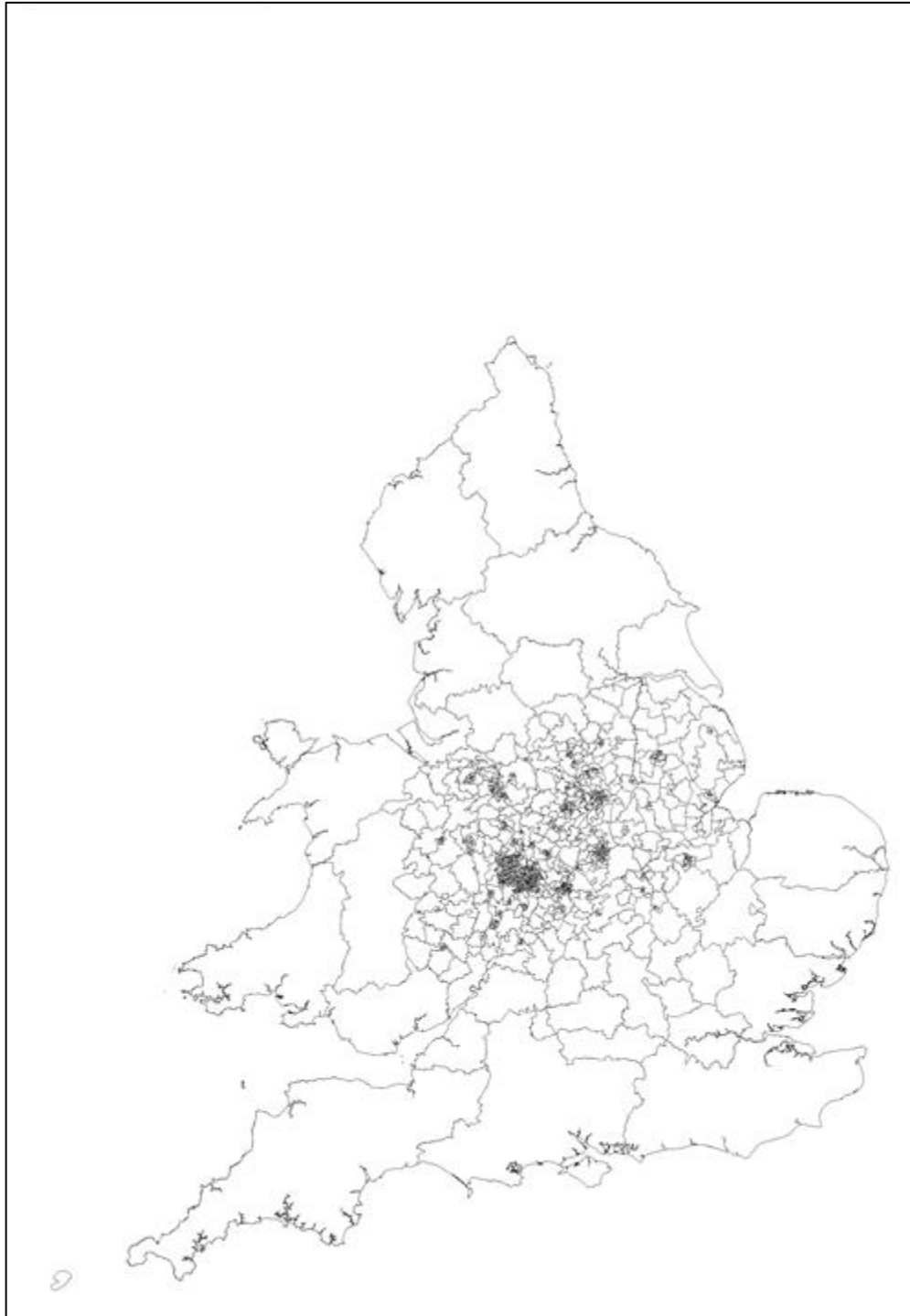
Figure 2-5: PLANET South Zoning

2.6   Other model components

2.6.1   Feeding into the appraisal of HS2 are additional models assessing wider economic benefits and environmental impacts. None of these models form part of the PFM framework and are therefore not described in this report.

2.7   Consistency of generalised cost specification

2.7.1   As was noted in the box at the beginning of this chapter, the demand model makes use of the concept of generalised cost, and in most cases the individual elements are produced from network models. In addition, on the rail side, the SCM allocates demand to stations based on generalised cost[6]. It is important that, as far as possible, the definitions are consistent between all modules in PFM. Note this is not referring to the generalised costs used in appraisal, though these will be discussed in Chapter 11.

2.7.2   All references to 'generalised cost' assume that it is measured in units of in-vehicle time minutes. Thus, generalised cost is defined as: in-vehicle time + $element_a$_* $weight_a$ + $element_b$ * $weight_b$ + ... etc. For example, $element_a$ might be (expected) waiting time, in which case $weight_a$ would represent the equivalent of one minute of waiting time in in-vehicle time units. The actual values are discussed below.

2.7.3   TAG [UnitM2, paragraph 6.5.8] strongly advises that the generalised costs used in both assignment and demand models should be compatible, and the development of PFM has aimed to reduce any inconsistencies to a minimum.

2.7.4   On the highway side, generalised cost relates essentially to in-vehicle time and to monetary costs of travel – these are fuel costs, other operating costs, and 'user charges' such as tolls (and parking). Monetary costs are converted to time units by dividing by the 'Value of Time' [VoT], which may vary with the demand segment. Generalised cost then forms the basis of route choice (within the Highway Assignment) and mode choice (within the demand model). The assignment can impact on zone-to-zone in-vehicle times (via congestion effects) which in turn influence route choice, but the generalised cost weights are consistent between these two models. Over time, generalised costs can change, both to reflect growth in VoT or to reflect other price changes (e.g., fuel costs, highway congestion, rail fares).

2.7.5   On the public transport side (i.e. both rail and air), the specification is more complex. In addition to in-vehicle time (and fares, though these are only used in the demand model), the following need to be taken account of:

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[6] though, as will be seen, rail fares are not included in this instance.

- access and egress time;
- crowding penalties;
- walking time (e.g. between connecting services);
- waiting time; and,
- interchange time.

2.7.6   There is some potential confusion in the way these terms are used in different component models. The main point is that each element of generalised cost needs to be represented in units of in-vehicle time, and the multipliers applied to the elements are referred to as 'element weights'. For example, one minute of waiting time may be considered equivalent to 2 minutes of in-vehicle time, leading to a waiting time weight of 2.0.

2.7.7   In the case of interchange, each interchange is represented by a time penalty[7]. (Expected) Waiting time is derived as a factor applied to the service interval, and is then further weighted to represent the disutility of having to wait.

2.7.8   For air, the assignment is not sensitive to levels of demand, and its main purpose is to provide the appropriate network costs (in-vehicle time, frequency, wait time, access and egress time and fare 'skims' separately for business and other purposes). In fact, as shown in Table 2-1 below, some high element weights have been used in the assignment to ensure that sensible routes are chosen, in terms of the airport pairs used for any zone-to-zone movement.

2.7.9   It should also be noted that element weights for the air mode will only affect the HS2 demand and benefits in situations where the air service level changes between the Do Minimum and the Do Something scenario. For the assessment of HS2, only rail services are assumed to change between Do Minimum and Do Something scenario and hence, the discrepancy in generalised cost definition between the assignment and demand model for the air mode is of no practical significance.

Table 2-1: Generalised cost element weights and other parameters for air in the different models

Air	Assignment model	Demand model
IVT	1.00	1.00
Wait time	2.00	1.00
Access/egress time	10.00	2.00
Board time penalty (minutes)	163.00	n/a

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[7] The convention in the PLANET models is to apply a 'boarding penalty' each time a train is boarded: this means that one more penalty than the actual number of interchanges is included in the GJT. However, this has no impact on the route chosen, nor on the demand model or appraisal. The same convention is maintained for the air assignment.

Air	Assignment model	Demand model
Board time factor	2.00	n/a
Wait time factor applied to service interval	0.10	0.40
Total factor applied to service interval	0.20	0.40

2.7.10   For rail, consistency between the various models is of much greater significance and is discussed in more detail in Chapters 4–6. For PLD, this has been ensured by:

- selecting the assignment model element weights appropriately;
- maintaining the same individual element weights in the SCM; and,
- conveying the 'composite' cost over all the station choice alternatives to the demand model.

2.7.11   There remain some minor inconsistencies between PLD and the Regional PLANETs, as can be seen in Table 2-2. The regional models have a different wait time factor and a different boarding penalty, with PLANET South having a boarding penalty of 3.5 minutes and the other regional models 20 minutes. The PLD assignment model has a boarding penalty of 30 minutes which is, as should be expected, greater for the less frequent travellers on strategic services. It was decided not to alter the values in the regional models, as these reflect different markets to the PLD demand model, and such large differences are also seen in PDFH[8].

2.7.12   The general pattern of recommendations in PDFH is to allow many of the element weights (interchange, walking and waiting time) to vary with overall journey distance: in addition, the treatment of interchange allows for explicit coding of the waiting time for the connecting service. This approach is not really suitable for PLANET network modelling where only the frequency of connecting services is available, and where varying element weights by distance would be a major computational problem[9]. For this reason, the values in the free-standing Regional PLANETs have been accepted as having independent validity.

2.7.13   The wait time factor converts the service interval to the average (expected) waiting time. The factor that is applied in the regional models is 0.5, suggesting random arrivals[10]. This is reduced to 0.4 in the PLD assignment, to acknowledge some of the

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[8] There would also be knock-on consequences for the demand elasticities in the Regional PLANETs.

[9] PLANET assignment does not store path information, so there is no reasonable means of ascertaining the ultimate trip origin when considering passengers boarding a service after interchanging. This applies both to PLD and the Regional PLANETs.

[10] If passengers arrive uniformly in the interval (say, 30 minutes) between two services, then some will just miss the earlier train and wait nearly 30 minutes, while some will arrive just in time for the later train and wait almost 0 minutes, but on average the passengers will wait half the service interval (i.e. 15 minutes). Thus the required factor is one-half.

large service intervals in the model and the fact that passengers will therefore plan their long-distance journeys more, rather than arriving at random; again this is consistent with PDFHv6. Note that having calculated the expected waiting time, it is further weighted to reflect its greater disutility relative to in-vehicle time.

2.7.14 Other than these two differences the regional models and the assignment models have the same set of parameters. It should be noted that these values do not differ by journey purpose: this again is consistent with PDFH.

Table 2-2: Generalised cost element weights and other parameters for rail in the different assignment models

Rail	PLANET long distance	PLANET South	PLANET North	PLANET Midlands
IVT	1.0	1.0	1.0	1.0
Wait time	2.0	2.0	2.0	2.0
Walk time (for connections)	2.0	2.0	2.0	2.0
Access/egress time*	1.0	2.0	1.0	1.0
Board time penalty (minutes)	30.0	3.5	20.0	20.0
Wait time factor applied to service interval	0.4	0.5	0.5	0.5
Total factor applied to service interval	0.8	1.0	1.0	1.0

*As will be seen, access/egress time is dealt with outside the assignment model except in the case of PS.

2.7.15 For the rail modes, fares are only introduced at the demand model level: implicitly it is assumed that the choice of route between stations, as well as the station choice itself, is not influenced by considerations of fare. As noted, PFM has not been designed to deal with the possibility of 'premium fares' for HS2 or any other services.

2.7.16 With the exception of these minor issues noted, a consistent specification of generalised cost has been used throughout. This applies also to VoT, used to convert money costs to IVT units. As far as possible, the individual elements are maintained separately, and conveyed to the appraisal procedure.

2.7.17 As was noted in Section 2.4, the term 'Generalised Journey Time' [GJT] is reserved for the rail mode for the particular combination of IVT, wait time (based on headway) and interchange. It does not include the additional disutility associated with crowding, though the assignment makes use of this as well as GJT. The SCM then introduces further elements relating to access and egress. It is only when the fares are introduced at the demand model stage that a true 'generalised cost' is achieved.

All these generalised cost elements – both separately and in combination – are measured in minutes.

Part 2 – Long Distance model [PLD]

This part of the document describes the core component of PFM, known as PLANET Long Distance [PLD]. There are a number of different components to PLD which are described in separate chapters.

Chapter 3 introduces PLD and discusses key theoretical aspects and notation. The three main components of PLD – the rail assignment, the Station Choice Model [SCM] and the demand model are then discussed in Chapters 4–6. Although PLD is a multi-modal model, most of the emphasis of this report is on the rail mode as this is key to the assessment of the HS2 scheme.

The model inputs, in terms of demand matrices and networks, are not described here, but are described separately in Part 3 alongside those used for the Regional PLANET models.

3 Introduction to PLD

3.1 Overview

3.1.1　The overall structure of PLD was indicated in Figure 2-2. It can be seen that there are three main components: the supply model, the Demand model, and the Station Choice Model which acts as an intermediary step for the rail mode. The purpose of the key PLD modules is to model behavioural responses to changes in rail services in terms of route choice (assignment), Station Choice Model (SCM) and mode and frequency (demand model).

3.1.2　The various modules (the PLD rail assignment, the SCM, the demand model and the Highway and Air[11] Assignment) form part of an iterative system which also includes the Regional PLANETs which are the subjects of Chapter 7. For this reason, a full account of the iterative algorithm is postponed till chapters 9 and 10.

3.1.3　The supply model consists of a network and an assignment routine. These operate independently for the three modes: rail, car and air. The highway network is conventional, and the details will be described later, in Chapter 8. The rail and air networks are also conventional EMME public transport networks, and their details will likewise be described in Chapter 8.

3.1.4　As far as assignment is concerned, the key discussion relates to the rail mode, and it is described in some detail in Chapter 4. For the other two modes, it is convenient to describe the assignment more briefly, in connection with the networks in Chapter 8.

3.1.5　The SCM, described in Chapter 5, is the link (on the rail side) between supply and demand. This converts the matrices of zone-to-zone rail demand, output from the demand model, to matrices of station-to-station demand, taking account of access and egress costs. It also deals with the effect of car availability on the choice of access mode.

3.1.6　Finally, the multi-modal demand model, which deals with modal shift and generation, is described in Chapter 6. As will be discussed there, the PLD demand model is an 'incremental' model, so that it requires a set of (base) Matrices from which to 'pivot'. In Chapter 8, the report describes how the separate modal (rail, car, air) Base Year Matrices, segmented by purpose and car availability, have been obtained. When running the model for future years, the pivot matrices need to take account of demand growth over time, as discussed in Chapter 9. For both rail and car, these future pivot matrices are obtained by applying growth to the Base Year

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[11] as noted earlier, it is not strictly necessary that the Air Assignment is repeated.

Matrices: the air pivot matrices are obtained independently from the DfT Aviation model (see Section 8.4). The resulting pivot matrices represent the Do Minimum forecasts.

3.1.7   The SCM and the demand model have been specially estimated for use in PFM, and both the estimation and application of the models is described in detail. While the rail assignment makes use of available routines in the EMME/4 public transport software suite, some of the aspects are complex. Hence, much of the description in Chapters 4–6 is of a technical nature.

3.1.8   For this reason, the final sections of this chapter set out a notation which will be consistently used for the technical description, together with a discussion of the logit (discrete choice) model, which is the model form which underlies both the SCM and the demand model.

3.1.9   Finally, an important feature of PLD is that it uses a consistent definition of generalised cost throughout.

3.2   Consistent notation

3.2.1   In devising an appropriate notation for the mathematical description of the PLD model, there are three types of item that need to be distinguished:

- quantities, such as travel demand, cost, population;
- arguments/categories, such as zones, stations, purpose, car availability; and,
- parameters, such as generalised cost element weights, values of time.

3.2.2   While it is not possible to be completely consistent, as a general guide quantities are represented by upper case Roman letters, arguments by lower case Roman letters, and parameters by Greek letters. At the end of this section, a table will be set out for reference.

3.2.3   Arguments can be either superscripts or subscripts. Superscripts will be used for fixed categories such as purpose, while subscripts will be used for categories of 'choice', such as zone or mode. An asterisk may be used to denote summation over the relevant argument. To reduce the notational burden, arguments may be omitted when the context is obvious.

3.2.4   The most important symbols are introduced below. Less used symbols are introduced specifically in the text to which they relate.

Quantities

3.2.5   Travel Demand will be denoted by T, and will typically be superscripted by purpose and car availability, and subscripted by zones (usually production and attraction, but sometimes referring to origin and destination) and mode. Pivot or base travel demand is denoted by B.

3.2.6   (Generalised) Cost will be denoted by C, and is measured in time units (minutes). Where necessary, the monetary component is separately denoted by M. The arguments generally reflect those of travel demand. As will be seen in the next section, some of the models are specified in 'utility' rather than cost terms: for this purpose U is used.

3.2.7   Other quantities are Distance (D), Population (P), Workplaces (W) and Income (Y).

Arguments

3.2.8   For fixed categories, p denotes journey purpose and c car availability: in combination these may be represented as 'user classes' and denoted by u. Categories of choice relate to zones (I, J: note that upper case letters are used to distinguish from the lower level 'mzones' used in the SCM, for which i,j are used), modes (m, as well as x for access mode), and stations (R,S).

Parameters

3.2.9   The most important parameters are the 'scale factors' λ on generalised cost (discussed in the next section), which will depend on the 'level' at which the choice is taking place, the structural parameters θ representing the ratio of two λ factors at different levels of choice, other estimated or assumed parameters generally denoted by β (with appropriate description), and α, used to denote the appropriate 'weight' for a generalised cost element. In some cases, specific abbreviations (e.g. VoT for Value of Time) are used for improved legibility.

3.2.10   The following Table 3-1 sets out the symbols used with, where appropriate, an indication of their range (in the case of arguments), and the sections of the report to which they have most relevance. In most cases, upper case letters denote quantities (e.g. demand) and lowercase letters denote arguments/subscripts/superscripts (e.g. mode, purpose). Exceptions are the use of I, J and R,S as arguments, and p as a proportion.

Table 3-1: Table of notation

Symbol	Type *A* = argument *P* = parameter *Q* = quantity	Interpretation	Use	Section
A	*P*	used for crowding calculation	rail assignment	Chapter 4
B	*Q (P)*	base or pivot travel demand (also, parameter used for crowding calculation)	demand model rail assignment	Chapter 6 Chapter 4
C	*Q (P)*	generalised cost (time units) (also, parameter used for crowding calculation)	demand model, appraisal rail assignment	Chapters 6, 10 & 11 Chapter 4
CP	*P*	crowding penalty	rail assignment	Chapter 4
D	*Q (P)*	distance (also, parameter used for crowding calculation)	demand model rail assignment	Chapter 6 Chapter 4
GJT	*Q*	"Generalised Journey Time" (rail)	rail assignment, SCM	Chapter 2, general
GJTC	*Q*	GJT including crowding (rail)	rail assignment, SCM	Chapter 2, general
GJTCAE	*Q*	GJTC with access/egress costs (rail)	SCM, demand model	Chapter 5
G°	*Q*	base or pivot generalised cost	demand model	Chapters 6 & 10
I	*A*	zone (production end)	general	
J	*A*	zone (attraction end)	general	
L	*A*	public transport 'transit line' (or combination of lines)	rail assignment	Chapter 4
LF	*Q*	loading factor (ratio of passengers to seats)	rail assignment	Chapter 4
M	*Q*	monetary cost	demand model	Chapter 6
P	*Q*	population	SCM, growth in demand	Chapters 5 & 10
R	*A*	station (production end)	SCM	Chapter 5
S	*A*	station (attraction end)	SCM	Chapter 5
T	*Q*	travel demand	demand model, appraisal	Chapters 6 & 11
U	*Q*	utility	SCM, demand model (estimation)	Chapters 5 & 6
V	*Q*	estimate of current demand in MSA procedure	assignment, supply demand loop	Chapter 4 Chapter 10

Symbol	Type *A* = argument *P* = parameter *Q* = quantity	Interpretation	Use	Section
VoT	*P*	Value of Time	demand model (SCM)	Chapters 5 & 6
W	*Q*	High level Managerial jobs	SCM	Chapter 5
		(also used for estimate of 'auxiliary' demand in MSA procedure)	assignment, supply-demand loop	Chapters 4 & 10
Y	*Q*	income	SCM, demand model	Chapters 5 & 6
Z	*Q*	Choice set for station pairs	SCM (and Regional PLANETs)	Chapter 5 Chapter 7
a	*A*	link	assignment	Chapter 4
c	*A*	car availability segment (CA, NCA)	SCM, demand model	Chapters 5 & 6
d	*A*	direction (outward, return)	SCM, demand model	Chapters 5 & 6
i	*A*	mzone (production end) within I	SCM	Chapter 5
j	*A*	mzone (attraction end) within J	SCM	Chapter 5
k	*A*	generalised cost element	appraisal	Chapter 11
m	*A*	main mode (rail, car, air)	demand model	Chapter 6
n	*A*	iteration no.	assignment, supply demand loop	Chapter 4 Chapter 10
p	*A (Q)*	purpose (superscript) (commute, business, other); proportion (quantity)	general SCM, demand model	General Chapters 5 & 6
u	*A*	user class	assignment	Chapter 4
x	*A*	access mode (highway, PT)	SCM	Chapter 5
y	*A*	year	demand model	Chapter 6
a	*P*	lower bound for crowding penalty	rail assignment	Chapter 4
β	*P*	estimated parameter	SCM, demand model	Chapters 5 & 6
δ	*Q*	dummy (0,1) variable	SCM, demand model	Chapters 5 & 6
ε	*Q*	random term in logit model	SCM, demand model	Chapters 3, 5 & 6
η	*P*	distance elasticity for VoT	demand model	Annex B
θ	*P*	structural parameter for logit hierarchy	SCM, demand model	Chapters 3, 5 & 6
λ	*P*	coefficient on generalised cost	SCM, demand model	Chapters 3, 5 & 6
μ	*Q*	average loading factor for rail link	rail assignment	Chapter 4

Symbol	Type *A* = argument *P* = parameter *Q* = quantity	Interpretation	Use	Section
π	*P*	proportionate allocation of zone between mzones	SCM	Chapter 5
σ	*Q*	standard deviation of loading factor for rail link	rail assignment	Chapter 4
ω	*P*	proportion of auxiliary demand used in MSA averaging	assignment, supply demand loop	Chapter 4 Chapter 10

3.3 Some notes on logit models

3.3.1   There are many texts which establish these properties, but chapter 3 of Kenneth Train's 'Discrete Choice Methods with Simulation' (2002) which is downloadable (free)[12] is particularly accessible.

3.3.2   The logit model is a 'discrete choice' model widely used in transport demand models to allocate demand among different ('discrete') alternatives, such as modes or destinations. In the classic description, the relative appeal of each alternative i, taking into account all its salient characteristics including cost, is denoted as 'utility'. Individuals are assumed to choose the option which has maximum utility. Alternative i is assumed to have a 'representative' utility U_i which is subject to an additive 'random term' ε_i, which allows for those elements in individual choice which are unknown to the modeller. When these random terms for the alternatives are independently and identically distributed ('IID') with a type I extreme value (or Gumbel) distribution[13], the logit model is obtained, whereby the proportion (probability) choosing alternative i is given by:

Equation 3-1:

$$p_i = \frac{\exp(U_i)}{\sum_{i'} \exp(U_{i'})}$$

where the summation in the denominator ranges over all the possible alternatives.

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[12] http://elsa.berkeley.edu/books/choice2.html
[13] see the cited work by Train for an explanation.

3.3.3   In transport models it is conventional to re-specify the model in terms of 'generalised cost' C, rather than utility, yielding:

Equation 3-2:

$$p_i = \frac{\exp(-\lambda.C_i)}{\sum\limits_{j \in Z} \exp(-\lambda.C_j)}$$

where λ is a positive 'scale factor', and the negative sign accounts represents costs or 'disutility'.

3.3.4   Given that each individual is choosing the option with maximum utility, it is of interest to see what the expected maximum utility derived from the choice process is, allowing for the random term. This can be shown to be given by the natural logarithm of the denominator in Equation 3-1, in other words:

Equation 3-3:

$$U* = E[\max(U_i + \varepsilon_i)]_i = \ln\left(\sum\limits_{i'} \exp(U_{i'})\right)$$

because the formula is the logarithm of a summation, it is colloquially referred to as the 'logsum'.

3.3.5   The formula can also be cast in generalised cost terms, where its interpretation is the expected minimum generalised cost derived from the choice process. This is normally referred to as the 'composite cost', given by the equivalent 'logsum' formulation but converted to cost units:

Equation 3-4:

$$C* = \frac{-1}{\lambda}.\ln \sum\limits_{i'} \exp(-\lambda.C_{i'})$$

3.3.6   The composite cost plays an important role in the 'nested (or hierarchical) logit' model, where the choice set is partitioned between different levels. These levels relate to different degrees of sensitivity to generalised cost. For example, a difference of 10 minutes may have a greater effect on station choice than (main) mode choice. In such a case, the more sensitive choice ('station') is carried out at a lower level, and 'nested' within the mode choice. The model for station choice would then be 'conditional' on the mode used, making use of the formulation in Equation 3-2. However, the choice between modes would make use of the composite cost Equation 3-4 calculated separately for each mode. In such models the scale factor (λ)

is different at each level, and it is a requirement that at any given level it may not be greater than the value for the next level down. For more discussion in the context of transport models, see TAG Unit M2, §3.2.

3.3.7   When estimating logit models, it is conventional to use the method of Maximum Likelihood[14], and to report the value of the maximum log-likelihood, as well as the value when all parameters are set to zero (the 'null' value). In assessing two alternative models where one of them can be viewed as a restricted version of the other (for example, by constraining certain parameters to have the same value), twice the difference in log-likelihood is distributed as a chi-squared statistic with degrees of freedom equal to the number of restrictions. Another statistic commonly reported is the "rho squared" value [ρ^2], which is an approximate measure of goodness of fit with a range between 0 and 1, though it should not be considered analogous to the R^2 statistic used in regression analysis. For further discussion, see the cited reference by Train, chapter 3.

3.3.8   As noted, for nested (hierarchical) models, the scale factors λ must not decrease as the 'tree' is descended. Thus if station choice is conditional on access mode, the λ relating to station choice cannot be smaller than the λ relating to access mode, otherwise the model is mis-specified. The estimation conventions are to some extent software-dependent, but can all be put on a consistent basis.

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[14] This is a statistical method of fitting the parameters of a model to data which attempts to maximise the probability that – assuming the model form is correct – the data would be that which is actually observed.

4 Rail (PLD) assignment

4.1 Introduction

4.1.1 The function of the PLD assignment is to take matrices of station-to-station passenger demand and assign them to appropriate routes through the PLD Network. This then allows the components of GJTC (in-vehicle time, interchange and an allowance for frequency – see Section 2.4, as well as crowding) plus other generalised cost elements to be 'skimmed' from the network and passed to the SCM. As discussed later, the station-to-station demand is provided by the SCM.

4.1.2 In addition, the impact of relevant demand from the Regional PLANETs on crowding in PLD is included, by means of rail 'pre-loads'. PLD loadings on specified services relevant to the Regional PLANETs are also provided as output. The interfaces between PLD and the Regional PLANETS are described in Chapter 7.

4.2 Discussion of assignment

4.2.1 Since public transport assignment is a relatively specialised topic, it is worth providing some description. The problem is that between any two stations there are a number of different routes or services that passengers can choose to travel on, each of which will have different stopping patterns, journey times, frequencies, and crowding levels. Groups of services that have similar characteristics are for the purpose of this discussion referred to as 'transit lines'[15]. Each 'transit line' that is coded will have an associated in-vehicle time [IVT] for all pairs of stations 'served', together with a specified frequency or headway. In practice, there may be some judgment in classifying the services actually available according to these criteria (e.g. there may be marginal differences during the course of the day in IVT, or in the stations actually served, which are considered insufficient to justify defining a separate 'transit line').

4.2.2 Based on appropriate assumptions to convert between frequency and (expected) waiting time (see Section 2.7), it is possible to calculate, for each station-to-station pair, the transit line with lowest GJT[16] (including an allowance for interchanges). But it would be inappropriate to allocate all the demand to this transit line. In particular, passengers arriving at random may find that another transit line will get them to their destination station faster, so that in practice they would not choose the minimum GJT service. For these and other reasons, public transport assignment

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[15] This is the terminology used within the EMME software.
[16] As we shall see in Section 4.3, in practice the assignment also takes account of crowding, so GJT should be written GJTC. For the moment we ignore this complication.

methods use the notion of an 'attractive set' of transit lines, with the aim of defining those transit lines which in practice are likely to receive some of the demand.

4.2.3   The attractive set is normally defined by first identifying the transit line with the fastest GJT excluding the allowance for the service interval (i.e. 'waiting time'), and then considering what other transit lines offer a connection which under some circumstances could be worth taking. The rules in respect of how the 'attractive set' is defined may vary, and in particular according to software implementations. Having decided the attractive set, the standard ('frequency-based') approach is to allocate the demand across all attractive transit lines in proportion to their frequency.

4.2.4   The EMME software offers two options for undertaking assignment known as conventional and alternative methodologies, both of which are used in the PFM framework and discussed below.

4.2.5   In conventional EMME methodology, as used by the Regional PLANET models, this standard approach is referred to as 'Optimum Strategy Algorithm' and may be described[17] along the following lines:

A: define 'attractive set' of transit lines:

- order transit lines in terms of increasing (generalised) journey time (excluding waiting); and,
- proceed through transit lines adding to attractive set as long as the (generalised) journey time excluding waiting for the next transit line is less than or equal to the expected total time (including waiting) from the current attractive set.

B: allocate demand to transit lines:

- at any stage in the definition of the attractive set, the allocation of demand to a transit line is directly proportional to the frequency of that transit line; and,
- thus the calculation of expected total time is based on this allocation.

4.2.6   Waiting time is calculated as a user-supplied proportion of headway (the 'wait time factor'). In PLD, the wait time factor is 0.4, so that waiting time is calculated as 0.4 * headway, and further weighted by a factor of 2 (see Section 2.7)[18].

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[17] A more detailed description, based on EMME documentation, is provided in Annex A.

[18] According to TAG Unit M3.2, paragraph 3.2.1 "The simplest assumption for the calculation of the mean wait time is to assume that it is half the headway. This assumes that passengers arrive randomly at the stop and that the service is reliable. This may be a reasonable assumption for services with short headways but for long headways it is more realistic to assume that passengers will try to time their arrival at the stop to minimise waiting time." See also the discussion in paragraph 2.7.13 of this Report.

4.2.7   Figure 4-1 below gives an indication of how this process operates, for an illustrative example[19]. In this example, the best transit line takes 91 minutes and has a frequency of 12 trains over the 16-hour day, with an implied waiting time of 62.3 minutes: these values correspond to the case where the attractive set contains only the best transit line. It is now shown what happens as further transit lines are considered for addition to the attractive set.

4.2.8   Concentrating firstly on the solid lines, the top (blue) line [av_t] shows how the average in-vehicle time (including possible allowance for interchange) increases (because 'later candidates' have higher IVT) as further transit lines are added to the attractive set. This is compensated for by an increase in frequency which reduces expected waiting time. The mauve line [f], to which the right hand axis applies, shows how the total frequency (in terms of services per 16 hour period) of attractive transit lines increases, from 12 (in the case where the attractive set contains only the transit line with lowest IVT) to 36 when the process ends (because no more transit lines are worth adding): the brown line [wait] shows the corresponding reductions in expected waiting time. In this example, 15 attractive transit lines have been found: thereafter the reduction in effective waiting time is outweighed by the increase in mean IVT.

Figure 4-1: Definition of attractive transit lines (the dashed lines refer to the FJTS)

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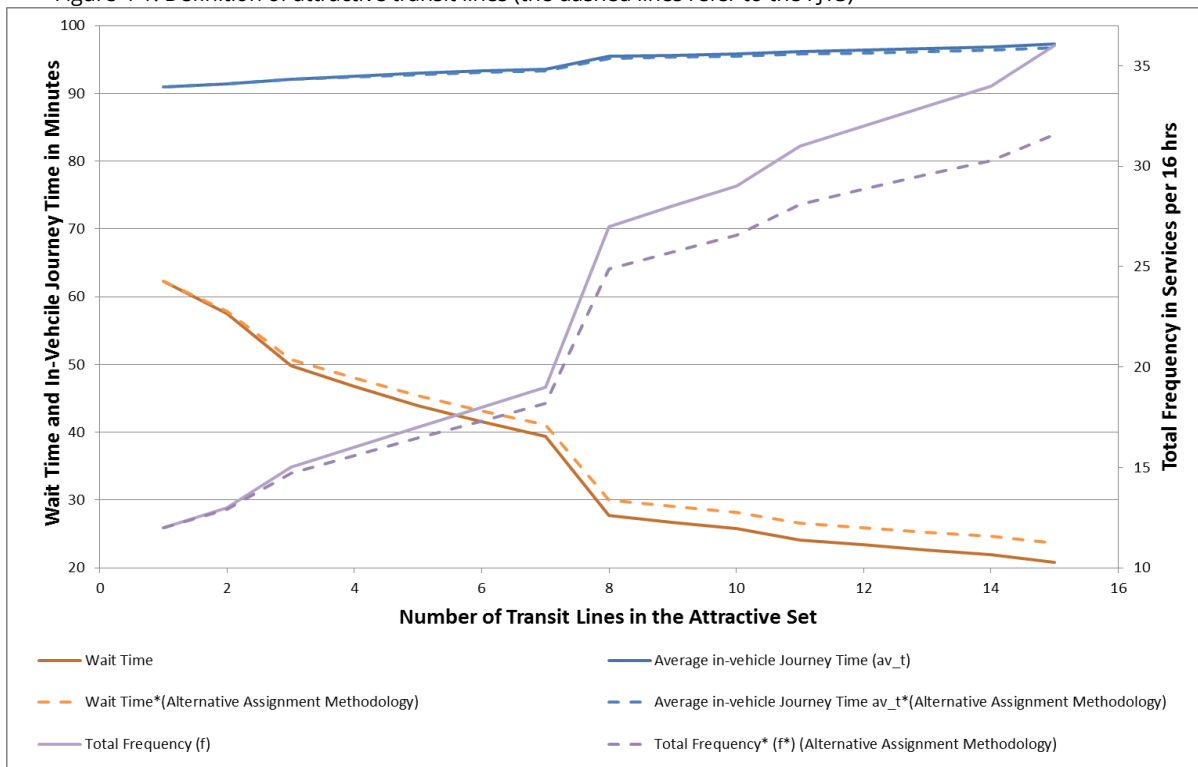
[19] For the sake of clarity, options requiring interchange have been excluded from this example. Note that the values of 'wait' in Figure 4-1 reflect the PLD assumptions noted above.

4.2.9   This standard version of public transport assignment, using the Optimum Strategy
           Algorithm, is widely used, and has been adopted for the Regional PLANETs described
           in Chapter 7. However, an acknowledged concern with the frequency-based
           approach is that, once they are in the attractive set, two transit lines with the same
           frequency will get the same demand allocation, even though there may be a non-
           trivial distinction in their IVTs (in the example given, there was a difference of 14
           minutes between the first and last transit lines in the attractive set). For this reason,
           it is of interest to consider how the frequency-based assumption might be relaxed,
           particularly in the context of long distance travel.

4.2.10   In the current version of the software being used for PFM, an alternative algorithm is
           offered and this is used in the PLD model. In place of adding in the complete
           frequency for each new transit line accepted into the attractive set, the frequency is
           factored down by an amount proportional to the difference in IVT between the new
           transit line (t) and the mean IVT $\bar{t}$ for the current attractive set. The factor (p′) is given
           as:

Equation 4-1:

$$p' = \left(1 - \frac{t - \bar{t}}{w}\right) < 1,$$

where w is the expected wait time for the current attractive set.

4.2.11   In general, the difference between p′ and 1 can be expected to be quite small, since
           longer distance services tend to have wider headways, so that the average waiting
           time will be relatively large (as the graph suggests). It can also be noted that because
           of its impact on the mean IVT, this approach can lead to a different (larger) attractive
           set. This revised 'strategy' is referred to as the Frequency and Journey Time Strategy
           [FJTS]: further details are provided in Annex A.

4.2.12   The dashed lines in Figure 4-1 show the corresponding effects when this method is
           used. It can be seen that, in this example, there is a very slight reduction in average
           IVT [av_t*], and correspondingly less of a reduction in expected wait time [wait*].
           Thus, as expected, the allocation of demand is more towards those transit lines in
           the attractive set with lower IVT. Overall, the changes are not very large. In this
           example, the attractive set is the same for both methods.

4.2.13   Nonetheless, the impact of the FJTS can be expected to be greater when high-speed
           services are introduced. It will be clear that the impacts of HS2 will be most keenly
           felt when there is a significant IVT improvement, and it is this which will test the
           assignment model to the greatest extent. Remaining with the previous example, but
           introduce an illustrative high-speed service as an additional 'transit line' ('H'). In the
           example, the H service has 16 trains (over a 16 hour day) with IVT of 53.2 minutes:

with the fastest service had 12 trains with IVT of 91.3 minutes. As H is the fastest transit line, it now becomes the first transit line in the attractive set, and corresponds to the case in Figure 4-2 where there is only one transit line in the attractive set.

4.2.14   With the traditional 'frequency' allocation, only two other transit lines enter the attractive set in this example[20]. For the faster of these, there is still a 38 minute difference in IVT with respect to H, and for the next fastest, the difference is 43 minutes. Thereafter it turns out that the improvement in waiting time from including further services in the attractive set is outweighed by the increase in mean IVT. The results are shown in the solid lines in Figure 4-1. According to the frequency-based allocation, the new service H gets only 55% of the overall demand.

4.2.15   It is worth studying the inclusion of the second transit line in more detail. As noted, the H service in the example has 16 trains with IVT of 53.2 minutes and the next fastest service has 12 trains with IVT of 91.3 minutes. If for convenience it is assumed there are in fact 16 of the next fastest service and that it operates exactly between the H schedule, in other words 30 minutes later, then it will be clear that those catching the next fastest service will actually arrive later than they would if they waited another 30 minutes and took service H. On this reasoning, it seems unlikely that the next fastest service should take 41% of the demand as the frequency-based algorithm predicts (if there were indeed 16 rather than 12 trains it would take 50%).

4.2.16   Now considering the alternative FJTS assignment method, shown by the dashed lines in Figure 4-2, it can be seen that the attractive set has increased relative to the frequency-only allocation: however, the additional 5 transit lines are all low frequency transit lines, with only 1 or 2 services per day, so that their impact is small. The essential difference between the two assignment methods occurs because of the 'down-grading' of the next fastest service, owing to its 38 minutes of additional IVT. As a result its share of total demand falls from 41% to 13%, while that of H rises from 55% to 85%. At least with this example, this appears a more reasonable outcome.

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[20] These are of course the first two transit lines In Figure 4-1, corresponding to the attractive set of 2 transit lines.

Figure 4-2: Definition of attractive transit lines with HS2 included (the dashed lines refer to the FJTS)
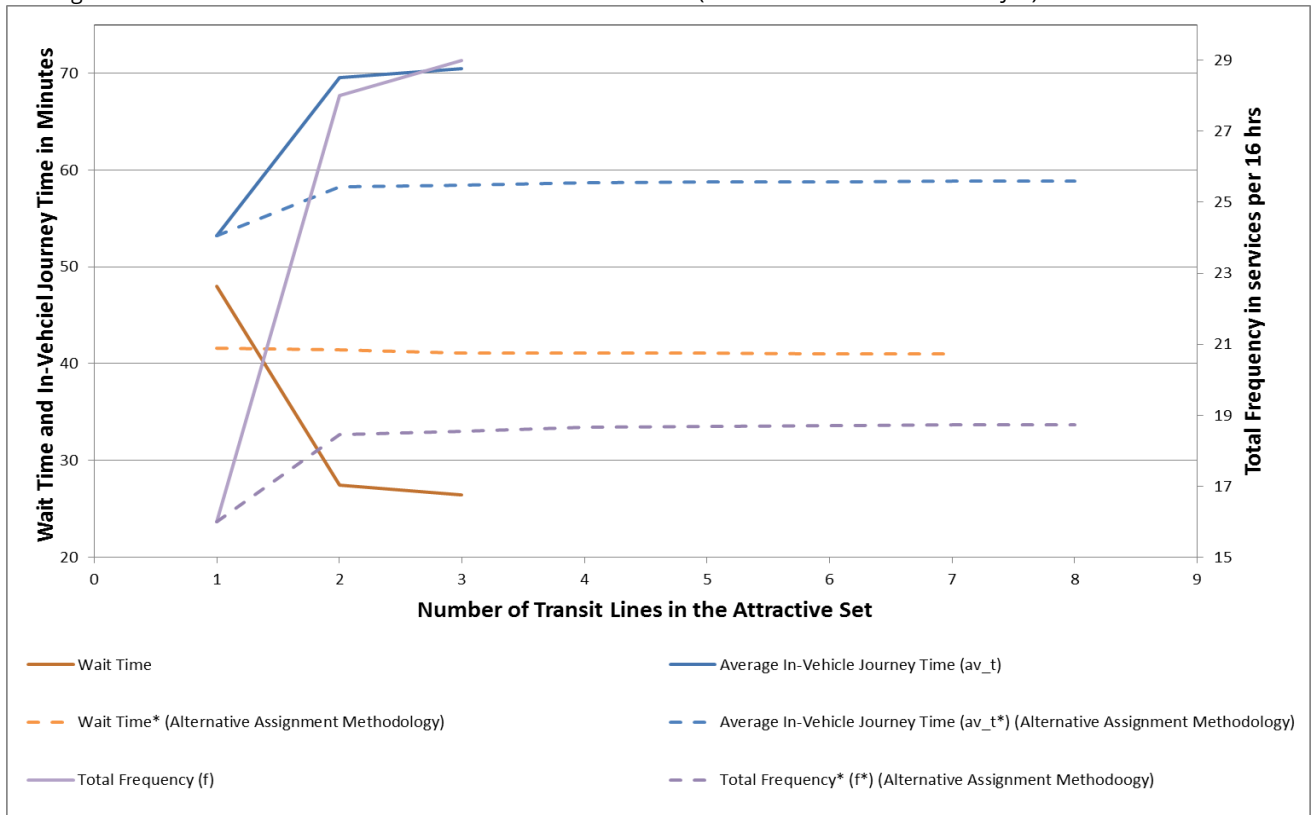
4.2.17   Hence, while the effect of the alternative assignment method is slight in the absence of the high-speed service H, it plays a much more important (and more in line with intuition) role when H is introduced. On this basis, the FJTS assignment approach has been used for PLD. This approach is also more consistent with other models in the rail industry: the ORCATS (Operating Revenue Computer Allocation System, a data source maintained for ATOC as part of the work of Rail Settlement Plan) model for allocating Rail revenues between TOCs is based on a combination of frequency and journey time, and MOIRA[21] has used a frequency and journey time assignment for many years. However, as already noted, the standard (frequency-based) algorithm has been retained for the Regional PLANETs.

4.3   Modelling reliability

Background

4.3.1   The transit lines for all trains that are coded into the PFM represent the level of timetabled train services and thus the assumption is that rail services will arrive

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[21] MOIRA is a uni-modal rail demand model which uses the deterministic rooftop algorithm to assign passengers to trains using the full detail of the timetable and elasticities to increase/decrease demand after timetable changes as measured by the composite Generalised Journey Time measure.

when they are scheduled to do so. However, in reality trains do not always run on time, and passengers are often subject to delays for any combination of reasons.

4.3.2   As such, it is necessary to model reliability in the modelling of train services, and in particular of the proposed high-speed services where it is assumed these will be more reliable than conventional rail services.

Methodology

4.3.3   The methodology can be described by the following steps:

- PEARS[22] data, supplied by the DfT, was used to determine an average delay per kilometre (km) value for each TOC. Analysis of the PEARS data over the past 10 years shows no clear trend in these values changing over time and so the same values are assumed for future years;
- Each conventional TOC has its own delay per km value which is applied in the model assignment (both Do Minimum and Do Something). This is calculated by link and train service and is weighted by 3[23] for the purposes of assignment and added to the IVT;
- HS2 is assumed to have 0.003 mins delay per km on dedicated running sections and delay per km equal to West Coast Main Line [WCML]/East Coast Main Line [ECML] where it runs on the conventional rail sections. This is also factored by 3 and added to the IVTs; and,
- The IVT skims from the assignments (with delay per km added) are then fed through the demand model.

4.3.4   Essentially, the model increases journey times for all services (conventional and high-speed) using a calculated delay per km penalty.

4.4   The treatment of crowding

4.4.1   The rail assignment is further complicated by the need to take account of crowding. The initial allocations to services ('transit lines') produced by the algorithms just discussed assume IVT in line with scheduled times. However, the result of this allocation may be that some services receive a loading which, relative to their capacity, implies a level of crowding between one station and the next[24]. The way this is dealt with is, in essence, to weight the IVT for that section by a factor greater than 1: this may be viewed as an additional amount of 'disutility' measured in units

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[22] Paladin Data Extract and Reporting System (PEARS) is used by Network Rail for monitoring train performance and delay.

[23] The weighting of reliability time by 3 relates to research from PDFH which showed that passengers perceive each minute of delay time as equivalent to 3 minutes of travel time.

[24] Note that passengers are assumed to experience a level of discomfort from crowding before all the seats are taken up and they are required to stand (see Figure 4-3).

of IVT to account for the discomfort associated with crowding[25]. In practice, the algorithm maintains IVT at its scheduled value, but introduces a further element to GJT referred to as 'crowded time'.

4.4.2 PDFH6[26] specifies (Table B6.1) 'Recommended Value of Time Multipliers' under conditions of crowding. The multipliers depend on the level of demand relative to capacity, whether the passenger is seated or standing, and the broad spatial categories of NSE[27], Regional and Intercity services: they relate to the loading on a specific train. The multipliers are close to 1 as long as the loading (demand per train) is at or below the train's seating capacity. Thereafter they rise quite rapidly, in line with passengers per square metre of standing room. This latter measure allows the procedure to take account of different rolling stock configurations in which seating capacity is traded against standing space.

4.4.3 For each rolling stock type, the standing capacity for passengers at a density of 2.5 per metre squared [m^2] is input into the model to be consistent with input crowding parameters from PDFH.

4.4.4 Figure 4-3 illustrates how the multiplier for the per train crowding penalty varies with demand, for the intercity case. Up to seating capacity, the demand is measured as 'load factor' [LF] calculated as the ratio of passengers to seats, and it is assumed that there is no standing. Thereafter, demand is measured as (standing) passengers per m^2 of standing room. The blue line indicates how the seated penalty rises and the pink line shows the standing penalty, which only begins at LF = 1. The red line indicates the proportion of passengers who are seated[28], which is 100% up to LF = 1, thereafter falling: this is used to estimate the average penalty, shown in yellow. It can be seen that this rises more or less linearly from the point at which LF = 1 and standing pass/m^2 = 0.

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[25] An alternative interpretation, in line with PDFH, is that the "value of time" (more strictly, the value of travel time savings) is increased under conditions of crowding.

[26] The latest version of PDFH is now v6 (issued May 2018); however, crowding factors have not changed from v5.

[27] Network South East

[28] This calculation requires an explicit assumption about the intercity configuration (in terms of standing room and seats): for this purpose the "IEP 8 car" stock has been assumed. Thus, while the standing and seating penalty curves apply to all intercity configurations, the average penalty curve is stock-dependent.

Figure 4-3: Illustrative crowding penalties (intercity example)
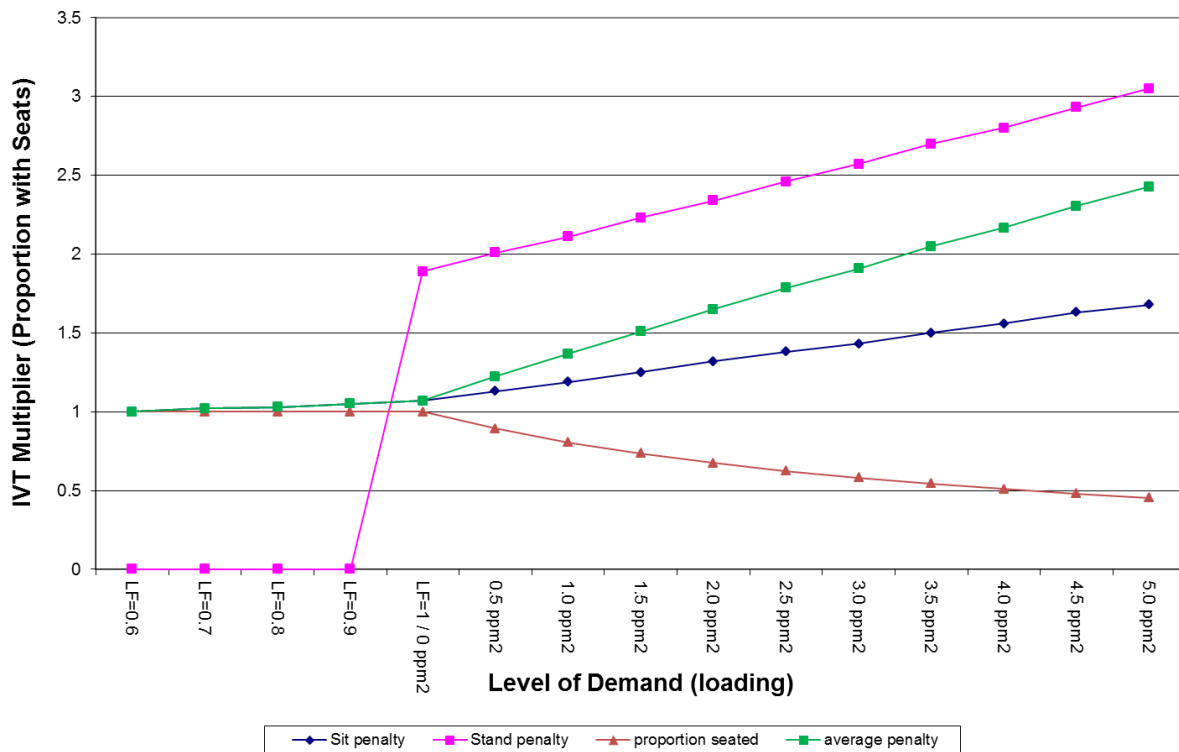
4.4.5   These crowding penalties are for a particular train with a given loading on a particular section of the line. The assignment model produces the loading for an average train on each section, and it can be expected that loadings vary over the course of the period modelled (for PLD this is the 16 hour day). Since the overall pattern is not linear over the whole range of loading, it is necessary to take account of these variations. For this purpose, the average crowding penalty function, as calculated for each rolling stock type, is approximated by a piece-wise linear formulation, as a function of the load factor [LF], as follows (where α is the value of the load factor at which crowding penalties commence, A and C are intercepts, and B and D are slope parameters for the fitted lines):

Equation 4-2:

    If LF $\leq \alpha$, then Crowding Penalty CP = 1

    If $\alpha <$ LF ≤ 1, then CP = A + B·LF

    If $1 <$ LF, then CP = C + D·LF

4.4.6   In other words, up to a certain load (where demand = α times the seating capacity), there is no effect due to crowding: thereafter there is a modest, assumed linear, effect until seating capacity is reached [LF = 1], and then there is a different relationship (again assumed linear) beyond seating capacity.

4.4.7   The key parameter D, which gives the slope of the penalty function above the point where all seats are occupied, is obtained by determining the value of LF at 'Total Capacity' (corresponding to standing density of 2.5 passengers per m^2), and using the PDFH6 recommendations to calculate the crowding penalty both at that level and at the point where all seats are occupied (LF = 1).

4.4.8   It is then further assumed that, for a predicted average loading factor μ on a specific section of a line, the variation in LF over the course of the day can be approximated by a normal distribution with mean μ and an appropriately chosen standard deviation σ. On this basis, the average crowding factor $\bar{C}\bar{P}$ can be calculated by the following formula, where X (the variable of integration) represents the loading factor LF:

Equation 4-3: Average crowding factor

$$\bar{C}\bar{P}_r(\mu) = \frac{1}{\sqrt{2\pi\sigma_r^2}}\int_{-\infty}^{\alpha_r} e^{\frac{-(X-\mu)^2}{2\sigma_r^2}}\,dX + \frac{1}{\sqrt{2\pi\sigma_r^2}}\int_{\alpha_r}^{1}(A_r + B_r X)\cdot e^{\frac{-(X-\mu)^2}{2\sigma_r^2}}\,dX$$
$$+ \frac{1}{\sqrt{2\pi\sigma_r^2}}\int_{1}^{\infty}(C_r + D_r X)\cdot e^{\frac{-(X-\mu)^2}{2\sigma_r^2}}\,dX$$

The formula is implemented by means of an EMME macro.

4.4.9   In this equation, r represents a particular 'TOC' group, and is thus associated with the rolling stock. Both the crowding function[29] parameters and the σ parameter representing the variation in loading over the course of the day are specific to 'r'. The values of the coefficient of variation [CV, = σ/μ] for each TOC group have been obtained by analysis of guard counts on arrival and departure from key stations.

4.4.10   This average crowding factor is then applied as a multiplier to the IVT for the section of line to which it relates and the difference between the result and (unweighted) IVT is defined as 'crowding time'.

4.5   The implications of crowding for the assignment

4.5.1   Starting with an assumption of no crowding, the EMME assignment procedure constructs the attractive set for each station to station pair, and allocates the demand for that station to station pair among the transit lines in the attractive set. Doing this for every station-to-station pair provides the total loading on every section of every transit line, and hence allows the average load factor μ per section to be calculated. Since the CV for the transit line is known, this allows the value of σ to be

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[29] In previous versions of PDFH, the crowding function parameters also varied with purpose: however, since PDFH5 this is no longer the case.

inferred. These values (μ, σ) are then used, via Equation 4-3 above, to obtain the average crowding penalty for each section.

4.5.2   Because of the crowding penalty, the values of GJT(C) for affected routes will change, and this will have impact on the construction of the attractive sets and hence the allocation of demand. This therefore requires an iterative process to achieve convergence.

4.5.3   In order to control the iterations, a damping method known as the Method of Successive Averages [MSA] is used. Suppose V^n is the section loading in iteration n, and W^n is the implied revised loading taking account of the changed crowding levels. If just W^n is used as the next estimate of V for iteration n+1, the procedure may 'oscillate' without reaching a stable solution. Using MSA, before calculating the average loading factors μ, the loadings are averaged according to the following formula:

Equation 4-4:

$$V^{n+1} = \omega \cdot W^n + (1 - \omega) \cdot V^n$$

where ω takes the value 1/n.

4.5.4   The number of iterations is set at 10 and the following assignment statistics are output to monitor convergence:

- The overall network wide passenger kilometres is calculated for each iteration, and the percentage and absolute changes between iterations are compared.
- The segment with the minimum and maximum flow difference between each iteration is identified. (A segment is a specific transit line on a specific link.)
- The total network GJTC is calculated for each iteration (on a matrix basis) and the percentage and absolute changes between iterations are compared.

4.6   Dealing with user classes

4.6.1   As noted in Section 2.3, PFM recognises different categories of demand. Insofar as these need to be recognised within the assignment, this is done by means of the concept of 'user classes'.

4.6.2   Section 2.2 noted the four key procedures within an assignment model. Two of these – the choice of path, and the supply response – are potentially different by user class. Separate demand matrices are needed for each user class, and are treated independently in the assignment, though the contribution to section loading (and hence the level of crowding) is calculated by adding across all user classes.

4.6.3   The choice of path may differ by user class because the generalised cost specification is different. However, in the current version of PLD assignment, the generalised cost weights do not vary by demand segment (except for the value of time, but this is not used in PLD assignment). In addition, while in previous versions of PDFH the supply response (which here relates to crowding) was different by purpose, the PDFHv6 based crowding response no longer varies by purpose. Hence there is in fact no requirement for different user classes: the demand matrices should be aggregated prior to the assignment.

4.6.4   In practice, for historic reasons, this is not currently done: nine user classes are used, corresponding to the different segments in the SCM, as described in Chapter 5. Although computationally wasteful, this will have no impact on the outcome.

4.6.5   Hence, for the sake of completeness and to allow easier updating, the overall summary in the next section makes allowance for the possibility of user classes [denoted by the symbol 'u'].

4.7   Overview of PLD assignment

4.7.1   As will have been seen, the PLD assignment is highly complex. Because of the impact of crowding on the choice of transit lines, it involves an iterative structure with MSA damping. The crowding function itself needs to take account of the different rolling stock used on the various transit lines, and to convert between an average loading to take account of variation over the course of a 16-hour day.

4.7.2   Finally, the route choice is achieved by means of an "attractive set" of transit lines definition: for this purpose, a recently developed algorithm has been used referred to as the "Frequency and Journey Time Strategy" [FJTS]. This is considered more appropriate than the standard frequency-based approach to deal with the special circumstances of HS2.

4.7.3   At the end of the assignment, the algorithm produces the number of passengers (by user class) on each section of each transit line, and also, by the process known as "skimming", the average GJT(C) values (also by user class) for each station-to-station movement, to be used in the SCM.

5 Station Choice Model [SCM]

5.1 Introduction

5.1.1 As has been seen, the PLD assignment requires a matrix of station-to-station demands T_{uRS}. However, the demand model (see Chapter 6) works in terms of zone-to-zone movements.

5.1.2 The function of the SCM is to act as a 'bridge' between these two modules, by taking account of the access and egress possibilities between zones and stations. The SCM models passengers' combined choice of access mode and station. More precisely, it represents passengers' choice of access mode, first station and last station. Access mode is either by car or public transport[30].

5.1.3 Thus it takes a matrix of rail demand (from the demand model described in Chapter 6) and, taking account of the different times between different stations (GJTC, obtained from the assignment model described in Chapter 4) as well as access and egress, allocates the demand to a pair of stations, which is then passed to the assignment model. The choice model is of the nested logit form and has been specifically estimated for PFM.

5.1.4 The model is run separately for each purpose (Business, Other, Commuting). In addition, to allow for possibilities of car access, a distinction is made between car-available [CA] and non-car available [NCA] segments within each purpose. In what follows 'p' is used to denote purpose and 'c' to denote car availability.

5.1.5 As noted in Section 2.3, PFM works with matrices in OD, rather than P/A format. This causes some issues in relation to car availability since the car would only be expected to be available at the home ('production') end of the trip. For this reason, additional segments CAF, CAT are defined for CA travellers, in line with the rail matrices described in Section 8.2. Direction (outward/return, or F/T) is denoted by 'd'. This distinction is not required for NCA travellers since they have no choice of access mode.

5.1.6 The result is that the SCM works with the following 9 segments[31] (based on arguments pcd):

- business car available from origin (thus origin is the production end) [CAF];
- business car available to destination (thus destination is the production end) [CAT];

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[30] Those reporting use of taxi are treated as having access by car.
[31] The combination of p, c and d is equivalent to the 'user classes' discussed in the previous chapter (Section 4.5).

- business car not available [NCA][32];
- other car available from origin [CAF];
- other car available to destination [CAT];
- other car not available [NCA];
- commuting car available from origin [CAF];
- commuting car available to destination [CAT]; and
- commuting car not available [NCA].

5.1.7   There is potential confusion, when working with OD matrices, in the terms 'access' and 'egress'. These therefore are defined on a P/A basis, so that 'access' always relates to the production end, where there is an issue of car availability, and 'egress' always relates to the attraction end, where it is assumed there is no mode choice to the final destination.

5.1.8   Section 5.2 contains discussion on the detailed level of zoning which is required for the SCM. This then leads on, in Section 5.3, to a discussion of catchment areas, and the way that the access and egress to and from stations possibilities are specified (Section 5.4). In the remainder of the chapter it is discussed both how the model has been estimated and how it is applied within PFM. Beginning with the model estimation details (Section 5.5). Different models have been estimated for production zones in London and those outside London. As the non-London model is more complex, it is presented first. The models make extensive use of data from the National Rail Travel Survey[33] (NRTS).

5.1.9   Because of the more detailed zonal system, a procedure is required whereby the PLD zonal demand matrices can be disaggregated. This is described as a 'gravity model' and has been estimated as a separate model, discussed in Section 5.6. Finally, the model application is described (Section 5.7) and an overall summary of the calculations is given.

5.2   Zonal detail

5.2.1   In the context of station choice, a particular problem is caused by the size of the PLD zones (Section 2.3). For this reason, the SCM considers the same geographic area as PLD but adopts a finer zoning system ('mzones') for what is defined as the core area of interest for HS2, broadly covering North West England, Yorkshire, West Midlands, East Midlands and Greater London. Figure 5-1 below shows the SCM's mzone coverage, corresponding with the core area.

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[32] It is currently assumed that all business rail travellers have car available, so this segment is in fact empty.
[33] See paragraph 5.5.4 for further details of the survey.

5.2.2   For the core area outside London, the SCM operates at the Middle layer Super Output Area (MSOA) level, whereas Transport for London's Railplan[34] zoning system is used for the Greater London area. For the rest of Britain, the PLD zoning system is retained.

5.2.3   The above zonal disaggregation results in 3,962 mzones, comprising 2,608 MSOA zones, 1,211 Railplan zones and 143 PLD zones. A link between the 3,962 mzones and the 235 PLD zones is maintained such that data at mzone level can be aggregated to provide outputs at PLD zone level.

5.2.4   In what follows, I and J are used to denote PLD zones, and i within I, j within J to denote the mzones.

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[34] Railplan is Transport for London [TfL]'s standard public transport assignment model.

Figure 5-1: SCM zone coverage
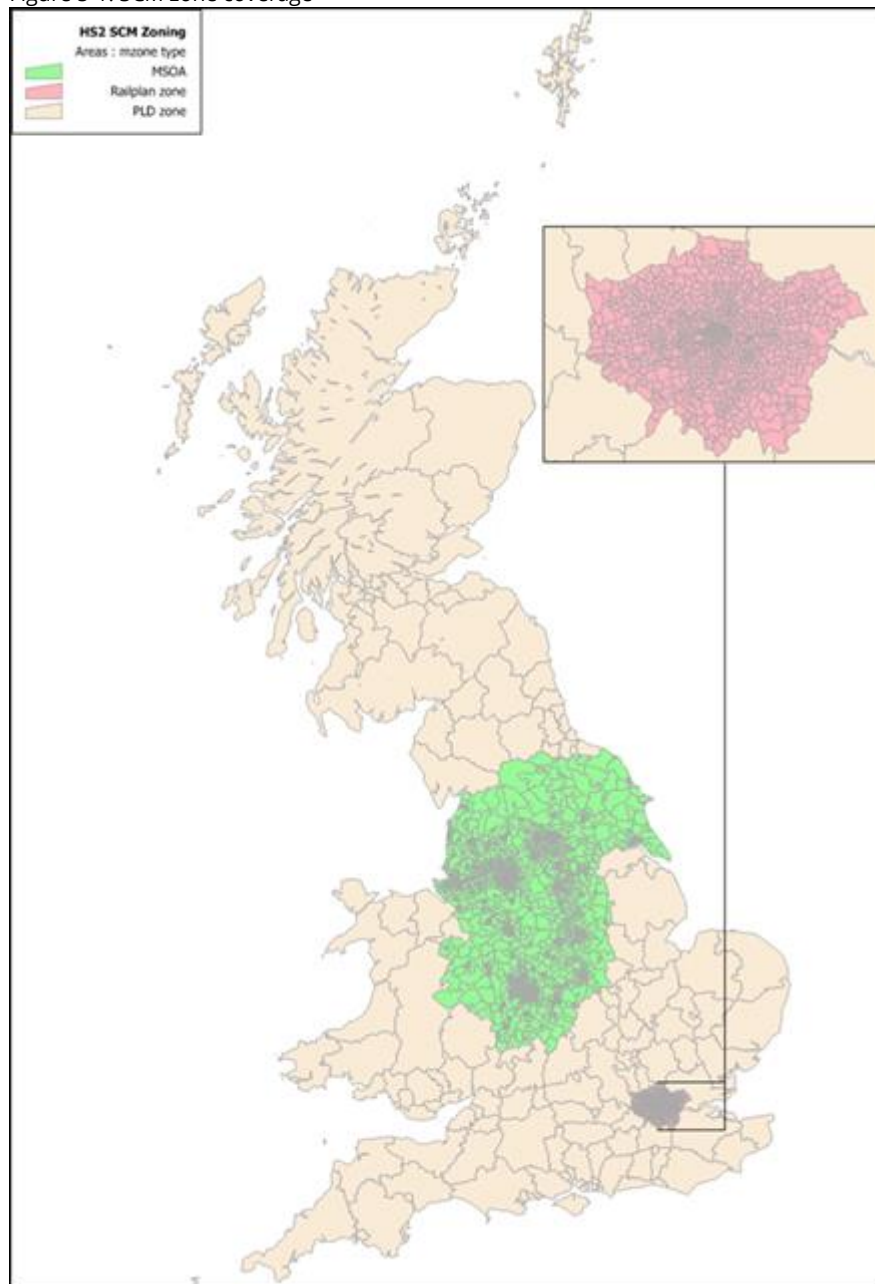
5.2.5 Although it is straightforward to aggregate the mzones up to PLD zones, an additional procedure is required whereby the PLD zonal IJ demand matrices can be disaggregated to the mzone ij level. The 'gravity model' developed for this purpose is discussed separately in Section 5.6.

5.3 Definitions of 'catchment areas'

5.3.1 An important assumption for the model is to define the realistic choice set of station pairs [RS] for any i-j movement. Although it might be proposed that the SCM could

model station use without any such constraint, this would have a serious impact on model run time.

5.3.2   In standard terminology, the catchment area of a station is the set of zones from which it derives potential demand. With PFM it is used in the inverse sense – for any mzone, it is the set of stations that might be accessed (on the production side), or which might serve as the alighting station for the final destination (on the attraction side).

5.3.3   In addition, the SCM does not aim to represent rail as an access mode, except where a local rail station is not represented in the PLD rail assignment[35] (described in the previous section). In other words, if a station [R or S] is included in the PLD rail assignment, it cannot be used in the SCM as an access point to another station. The only public transport [PT] access trips permitted in the SCM are:

- rail trips from a local station not in PLD rail assignment; and,
- other non-rail trips.

5.3.4   As a result of this restriction the 'catchment area' for PT in the SCM is generally smaller than that for highway. However, highway access is not allowed for London zones.

5.3.5   The following general principles were followed in determining catchment areas, though in key areas, particularly where HS2 Ltd are considering alternative station locations, catchment areas were examined individually to best match observed behaviour. The source of the access and egress cost data is discussed in Section 5.4 below.

5.3.6   For highway access (NB for zones outside London only) the set of stations is the same for all mzones i within a given PLD zone I, and all PLD stations within 60 minutes of the zone centroid are potentially included. Not more than 20 stations are allowed in application, and in practice the number is usually much smaller. Where there is a potential need to restrict the number, this is done in favour of:

- nearer stations; and,
- stations with a larger number of services.

5.3.7   For estimation purposes, the set is limited to those stations where there are observed NRTS flows between the station and the PLD zone.

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[35] As described in Chapter 9, the PLD rail network is intended to be a strategic network, and therefore does not include all possible stations.

5.3.8   Note that new HS2 stations are set up using these same principles. In this case consideration is given to the dominance of a station in connection with the other HS2 stations in the area.

5.3.9   Public transport 'catchment areas' are typically a subset of those for highway. In principle PT passengers are assumed to access the PLD rail network via their local station, and where the local station is within the PLD model this forms the focus for PT access trips, using bus or light rail, as well as walking.

5.3.10   PT access by classic rail is generally only used where the local station is not in PLD. Because of these considerations, it is possible for the actual choice set to vary across mzones within the PLD zone. However, every mzone will always have at least one PLD station to which PT access is permitted.

5.3.11   In the SCM model estimation, there are never more than 10 first/last station pairs available for a given PLD zone: hence, taking into account the two access modes, passengers have at most 20 alternatives to choose from. The situation is different in the application of the SCM, where more stations are taken into account and where the catchment areas can have up to 20 stations.

5.3.12   The catchment areas have been re-assessed in the light of the application of the SCM, to ensure that no unlikely choices are being made.

5.4   Defining access and egress

London station access costs

5.4.1   For London stations, cost skims have been obtained from the latest version of Transport for London's (TfL) Railplan model (v7.2). Previously the complete GJT cost skims have been used. However, within EMME it is now possible to extract these skims by journey component. As such, Walk, Wait-Time, and in-vehicle time have been exported so that access cost components are consistent between London and non-London stations.

5.4.2   Skims from TfL's Base (2016) model and Reference Case (2031) models have been used to obtain Base/Do Nothing access costs and Future Year access costs. This is in order to capture the inclusion of Crossrail in the Future Year costs only.

5.4.3   Although the Railplan model years do not exactly match with those in PFM this is not expected to have a material impact as these cost skims do not include demand-dependent crowding penalties. In addition, there are known significant schemes between the two base and future years that would materially impact access costs.

Non-London station access costs

5.4.4   For non-London stations, Basemap's TRACC software has been used. This is the industry standard for accessibility analysis, particularly public transport or mixed mode analyses. This has been used to obtain:

- Highway Distance;
- Highway Time;
- Public Transport Distance; and,
- Public Transport Time (by component).

5.4.5   Therefore, current-day access costs have been obtained for non-London stations. Unlike London stations, no future year changes to access costs have been explicitly accounted for based on the TRACC data however it may be necessary to take account of any future infrastructure schemes that would significantly impact upon station access costs.

5.5   SCM estimation

5.5.1   The SCM is a choice model based on a nested logit formulation. The estimation of a choice model requires data about the choices actually made, and explanatory variables (times, costs, etc.) relating to each possible option. Both access/egress costs/times and times (GJT, including crowding) within the rail network are required. Separate model parameters are estimated for the three journey purposes: Commute, Business and Other. In addition, as is standard, Alternative Specific Constants (ASC) are used in some places to proxy for intrinsic preferences for some of the options.

5.5.2   Model estimation for the station choice at the London end was carried out separately (as it was expected that travel behaviour in London would be notably different from the rest of Britain). Beginning with the choice of station at the non-London end, and then consider the choice at the London end.

Non-London SCM

5.5.3   For station choice at the non-London end, the estimation is confined to trips that have London as one of the trip ends (i.e. attraction). For persons with no car available at the non-London end, access mode choice is not dealt with – for these records, only the station choice is relevant. For "car available" journeys where the production zone is not London, the estimation involves both station choice and access mode.

5.5.4   The choice data was taken from the NRTS[36] and represents 2004/05 demand. NRTS is an on-mode paper-based survey, designed to obtain the pattern of rail passenger travel. Raw survey data has been expanded to match station counts. A subset of the data relating to long-distance rail journeys (>50 miles) where there is a choice of station/route to use for a particular zone, travelling to/from London, was used.

5.5.5   Because the model relates to station and access mode choice outside London, egress at the London station is ignored in the generalised cost specification. The access costs used in the calibration were obtained from the National Accessibility Model (NAM) at the time that the SCM was developed and calibrated.

5.5.6   The following weights have been used:

- walk time [β_{wk}]: 2.0
- wait time [β_{wt}]: 2.0
- PT in-vehicle time [β_{PT}]: 1.0
- HW in-vehicle time [β_{HW}]: 2.0

5.5.7   All stations in the catchment area of a PLD Zone are considered available by car, whereas (as noted) some stations may not be considered accessible by public transport. Passengers that do not own a car can only choose between the stations that are accessible by PT.

5.5.8   Although long-distance rail fares are not included in the SCM, the monetary cost of access and egress is. For highway access, this is petrol cost and notional parking cost, while for PT access it is fixed and variable components of fare. These were 2005 values (consistent with the NRTS demand data) in 2010 prices (consistent with TAG and other components of PFM).

5.5.9   Petrol cost is calculated using TAG formulae from Unit 3.5.6 (October 2012 version)[37] based on fuel price, car efficiency, petrol/diesel car proportions and inflation rates (see Table 5-1). It was impossible to obtain sufficiently accurate data for parking charges in 2005 for each station, and a fixed parking cost was set to a notional amount of £13 (2009 prices), converted to 2010 prices. As a consequence, parking charge does not have any impact on people's choices, and merely affects the ASC for the highway access mode in the model formulation.

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[36] https://www.gov.uk/government/statistics/national-rail-travel-survey-overview-report
[37] The latest values are now in Table A1.3.8 of the TAG data book: the model estimation has not been updated.

5.5.10   Public transport fares were calculated using a simple distance-related formula applied to an analysis of 2008 fares data, with a basic fare (fixfare) and an additional amount per kilometre:

Equation 5-1:

$$PT\_fare = pt\_fixfare + pt\_fare \cdot Distance$$

5.5.11   These are 2005 values in 2010 prices using the DfT's local bus fares index[23] and the Retail Prices Index (RPI)[38]. The values are given in Table 5-1 below.

5.5.12   To convert the monetary costs of access/egress to time units, Values of Time (VoT) are required. These are consistent with the assumptions made in the PLD demand model at the time of SCM estimation, values were calculated at the mean distances for each purpose, taken from the NTS LD data.

5.5.13   The assumptions made for all monetary elements of access/egress are shown in Table 5-1.

Table 5-1: Assumptions for monetary elements of generalised time

Parameters	2005 values/2010 prices
Highway cost parameters	
hw_petrol (pence/km)	7.72
hw_parking (pence)	1359.80
PT cost parameters	
pt_fixfare (pence)	109.606
pt_fare (pence/km)	13.63
Value of Time	
VoT Business (pence/min)	73.31
VoT Leisure (pence/min)	19.35
VoT Commute (pence/min)	26.41

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[38] Annual average of the CHAW index: The CHAW index is the Retail Prices Index which relates to all items, available from www.ons.gov.uk/.

5.5.15   Finally, for the rail GJTCs, skims were extracted from a base year (2010 at time of calibration) run of the PLD assignment model. The skims relate to the following elements:

- in-vehicle time ['IVT'];
- additional GJT due to crowding ['Crowd', in IVT units];
- walk time ['Walk'];
- wait time ['Wait']; and,
- boarding/interchange ['Board', average number].

Note that, in the context of PLD rail assignment, 'Walk' relates only to walking associated with interchange (which, in some cases, means moving between stations).

5.5.16   To ensure consistency with the GJTC weights used in the assignment, these are combined into a single quantity GJTC as follows:

Equation 5-2:

$$GJTC = IVT + Crowd + 2 \cdot Walk + 2 \cdot Wait + 30 \cdot Board$$

It will be seen that the element weights are consistent with those used in the PLD assignment.

5.5.17   Prior to model estimation, directional differences in these costs are accounted for by averaging the costs for each direction.

5.5.18   For the three journey purposes, the utilities associated with the choice of a station pair RS for a journey[39] between mzones i and j are specified as follows (note that egress – at the London end – is omitted):

- Highway access

Equation 5-3:

$$U^p{}_{RS,Hwy|ij} = -\lambda^{Acc}{}_p \cdot \left(\text{HWTime}_{iR} \cdot \beta_{HW} + Petrol\frac{\text{Dist}_{iR}}{\text{VoT}^p} + \frac{Parking}{VoT^p} + GJTC_{RS} \right) + City_p$$
$$\cdot \, \delta_{R=city} + Pway_p \cdot \delta_{R=Pway} + Other_p \cdot \delta_{R=Oth}$$

---

[39] As noted, I is treated as the production zone and j as the attraction, so that the "i–R'" leg is "access'" and the "S–j'" leg is "egress".

- PT access

Equation 5-4:

$$U_{RS,PT|ij} = -\lambda^{Acc}{}_p$$
$$\cdot \left(\text{PTTime}_{iR} \cdot \beta_{PT} + \text{Walk}_{iR} \cdot \beta_{wk} + \text{Wait}_{iR} \cdot \beta_{wt} + Fare \frac{\text{Dist}_{iR}}{\text{VoT}^p} + \frac{FixedFare}{VoT^p} \right.$$
$$\left. + GJTC_{RS} \right)$$

where:
- λ^{Acc} is the scaling parameter on generalised cost for access mode choice (utils/min);
- GJTC is the rail Generalised Journey Time including crowding between the first and last stations (min);
- VoT is the trip-purpose-specific value of time (pence/min);
- Dist is the distance to the station (km);
- HWTime is the highway access time (min);
- Petrol is the price of petrol (pence/km);
- Parking is the parking charge at the station (pence);
- City, Pway and Other are the alternative specific constants (ASCs) for city, parkway and other stations (utils);
- δ_{City}, δ_{Pway} and δ_{Oth} are dummy variables (=1 for station types 'City', 'Parkway' and 'Other' station types respectively);
- PTTime is the public transport access time (min);
- Walk is the average walk time to the station (min);
- Wait is the average wait time en-route to/from the station (km);
- Fare is the average public transport fare per km (pence/km);
- FixedFare is the fixed component of the public transport fare (pence);
- β_{HW} is the highway access time coefficient;
- β_{PT} is the public transport access time coefficient;
- β_{wk} is the walk time coefficient; and
- β_{wt} is the public transport wait time coefficient.

5.5.19 ASCs have been used only for the car mode, and they are station-type-specific. Three station types were defined for the model calibration: 'City', 'Parkway' and 'Other', for city centre stations, parkway stations, and other stations, respectively. These ASCs and station definitions capture the components of the car access costs not included in travel time, notably parking cost and congestion in city centres. Where a station type was not clear, then the type was determined as that which gave the best fit to the observed choice of access mode.

5.5.20 For all purposes, the preferred nesting structure is for the choice of station pair [RS] to be nested below access mode choice [Highway vs PT], as shown in Figure 5-2.

Figure 5-2: Station choice structure
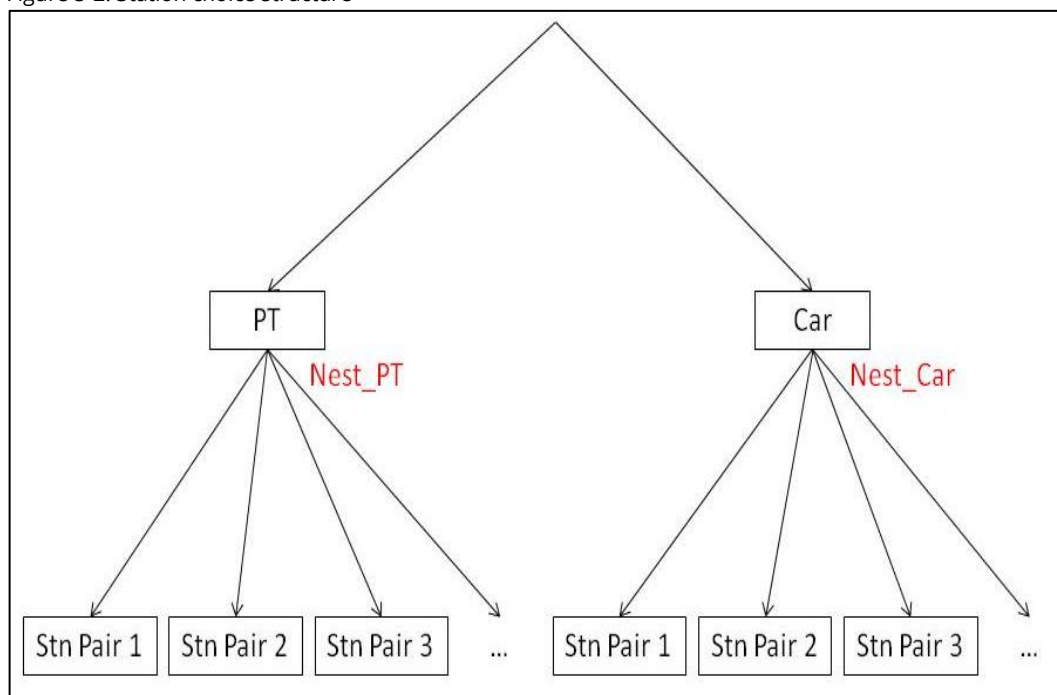
5.5.21   The parameters to be estimated are λ^{Acc}, City, Pway and Other, as well as the nesting parameter "Nest", which was constrained to be the same for both nests. Model estimations were carried out separately for the three purposes using the statistical estimation software Biogeme v1.8[40].The results are set out in Table 5-2.

Table 5-2: Estimated coefficients for Station Choice Model, by purpose

	Business	**Other**	**Commute**
Null log-likelihood	-10,873.1	-4,151.07	-5,131.42
Final log-likelihood	-5348.8	-2021.26	-2,297.86
Adj. rho square	0.508	0.512	0.551
Parameters (t-stat)			
City (utils)	0.772 (9.99)	0.527 (3.41)	1.74 (6.06)
Other (utils)	1.15 (24.9)	1.16 (11.76)	1.73 (21.32)
Pway (utils)	2.01 (13.85)	1.84 (7.73)	2.41 (13.83)
λ^{Acc} (utils/min)	0.0247 (14.7)	0.0156 (7.82)	0.0359 (15.3)
Nest = $1/\theta$ [t-stat w.r.t 1]	2.6 (8.69)	3.86 (5.62)	1.61 (5.33)

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[40] http://transport.epfl.ch/transport (Bierlaire, 2003). Accessed 1 October 2013.

5.5.22   Note that according to the conventions of Biogeme, the scaling parameter λ^{Acc} relates to the upper nest (i.e. the choice of access mode). The scaling parameter for the lower nest (choice of station pair RS) is obtained by multiplying λ^{Acc} by the "Nest" parameter[41]. With this convention, the Nest parameter must be greater than 1.0, and the t-statistics in the table measure its significance relative to 1.0 rather than zero, from which it is clear that the parameter in all cases is significantly greater than 1. This implies that the choice of station pair is considerably less random (lower error variance) than the choice of access mode.

London SCM

5.5.23   For station choice within London, estimation was carried out separately using observed demand data of movements to/from London where station choice exists at the London end. Unfortunately, there are no Intercity flows where there is a choice of station that is not also significantly affected by the train service or fare; it was therefore necessary to use South East flows from NRTS. The following three key movements were chosen:

- London to/from East Croydon/Brighton (choice of London Bridge, Victoria, etc.);
- London to/from south-west London (choice of Waterloo or Vauxhall); and
- London to/from the South East (choice of Charing Cross, Cannon Street, etc.).

These are all relatively short-distance journeys.

5.5.24   For the three key movements identified above, Railplan was used to provide generalised cost of access, with, as noted earlier, a modification to the weighting factor for wait time, while NRTS was used to provide the demand. For example, for a respondent reporting a journey from Waterloo to Wimbledon, the utilities associated with the two station alternatives (Waterloo or Vauxhall) for this respondent would be:

Equation 5-5:

$$U = \alpha \cdot access\ time + \beta \cdot IVT$$

where α is the parameter associated with the access times, and β is the parameter associated with rail IVT. Note that for London station choice, there is assumed to be no choice of access mode, so nesting is not required.

5.5.25   Model estimations were carried out by journey purpose (Business, Leisure and Commuting) and also for all purposes combined. The estimations produced access

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[41] An alternative convention, used in the demand model estimation (Chapter 6), scales the parameters at the lowest level, and uses nesting or structural parameters θ (where 0 ≤θ≤ 1) for higher levels. The Biogeme estimates of the "Nest" parameters are equivalent to 1/θ in this case.

time parameters α ranging between -0.13 and -0.17, depending on journey purpose. For all purposes combined, the parameter was estimated at -0.157. The estimated value by journey purpose, taking into account +/- two standard errors, did not appear to be significantly different from the overall value of -0.157. The resulting model, for all purposes combined, is shown in Table 5-3.

Table 5-3: SCM logit model for the London end – all purposes

	All purposes	**All purposes**
Null Log-Likelihood	-174555	
Final Log-Likelihood	-105648	
Adjusted rho-square	0.395	
Parameter	Value	t-test
α (access)	-0.157	-27.89
β (rail in-vehicle-time)	-0.0287	-3.26

5.5.26　Due to the characteristics of the short-distance rail journeys used in the calibration, it was felt that the estimated parameter β for the rail in-vehicle time component was not directly applicable for the long-distance rail journeys to be modelled in SCM. Hence it was decided that only the London parameter on access time should be used, and that in other respects the SCM should be the same as that estimated for non-London zones. In the case of London access times, therefore, a "London correction factor" is introduced to re-weight the PT access time so that the effective coefficient is equal to -0.157.

5.5.27　For the non-London model, the implied coefficient on PT access time (at the lower, station choice, level) is $-\lambda^{Acc}$ .Nest.β_{PT} (where β_{PT} = 1). Hence, for each purpose this coefficient needs to be further weighted in the London case so that it has the value of 0.157. Taking the example of the commute model (see Table 5-2), the unadjusted coefficient has the value -0.0359 *1.61 = -.0578. In this case, a further weight of 2.72 is therefore applied to PT access time.

5.6　SCM zonal disaggregation

5.6.1　It is necessary to disaggregate the PLD demand to the mzone level for the purpose of operating the SCM. The aim is, for each IJ movement, to produce fractions $\pi_{ij}[IJ]$ which allocate the total zone to zone demand T^{pcd}_{IJ} to movements between the constituent mzones T^{pcd}_{ij}. The approach assumes that $\pi_{ij}[IJ]$ is modelled as $f^{ipcd}.g_j^{pcd}$ (where f, g, are proportionate sub-zone allocations of the production and attraction zones, respectively). The calculation of f_i and g_j is done in various ways.

5.6.2   For zones outside the defined core area (see Figure 5-1), no disaggregation is carried out (PLD zones are used). For zones in London, Railplan demand matrices are used to apportion the total PLD zonal demand across all purposes (including Heathrow and Hillingdon) to the corresponding Railplan zones. For "key HS2 locations" (defined as PLD zones: Birmingham, Leicester, Derby, Nottingham, Sheffield, Leeds, Macclesfield, Stockport, Manchester and Warrington), the mzone distribution of productions and attractions is based on observed long-distance (over 50km) trips by purpose in NRTS.

5.6.3   For the remainder of the core area, the NRTS data is insufficient to allow observed factors to be used directly; hence "gravity" models are calibrated separately for the production [f_i^{pcd}] and the attraction [g_j^{pcd}] ends, and for each purpose, again using NRTS data for long-distance travel. The calibration dataset was restricted to those zones where the model is to be used. Calibration was undertaken using the 'R' software package[42].

5.6.4   In carrying out the disaggregation, there are two separate effects which need to be taken into account. The first, and most straightforward, is the 'size' effect due to the composition of the mzone relative to the PLD zone which contains it: this relates to the selection of appropriate zonal variables such as population, employment etc. However, because the SCM is only disaggregating rail demand, there will be a tendency for the demand to be concentrated – other things being equal – in zones with better access to the network. In order to take this into account, an intermediate model was estimated which also took account of station use by zone.

5.6.5   From NRTS, for all stations considered to be within the catchment area of a particular PLD zone, the proportion of demand at a given station associated with each mzone was used as the dependent variable. Thus, considering for example the production end, it should be first noted, for each PLD zone I, the ("catchment area") set of stations {R[I]}, and then for each station R, the NRTS weighted sample flow Q_{iR} originating from each mzone I is obtained. These flows were then taken as the dependent variable in a constrained regression on a set of zonal attributes for i, including the access time between i and station R, taken from NAM. For this purpose, the minimum of highway time and public transport weighted total time was used. The model was estimated separately for each purpose, with the total number of trips in each PLD zone constrained to match the observed. This requires a set of (PLD) zonal constants to be estimated.

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[42] 'R' is a free software environment for statistical computing and graphics (www.r-project.org).

5.6.6　For productions, the rail demand between a given mzone and station was found to be dependent on the population, income or number of high-level managerial jobs in the mzone, and access time to the station. The following model was estimated:

Equation 5-6:

$$\hat{Q}_{iR} = K_I \, P_i \, Y_i^{\beta_Y} \, W_i^{\beta_W} \, AT_{iR}^{\beta_{AT}} \quad \text{subject to} \quad \sum_{i \in I} \sum_{R \in \{R[I]\}} \hat{Q}_{iR} = Q_I$$

where, as usual,

- R relates to a station
- i relates to an mzone
- I relates to a 'PLD zone'
  and
- P is the population at MSOA from ONS 2008 mid-year population estimates
- Y is the income at MSOA from ONS 2007/8 model-based income estimates
- AT is the access time from NAM
- W are the number of high-level managerial jobs from ONS 2001 Census data
- K_s are constants specific to each "PLD zone"
- β_Y is the elasticity with respect to income
- β_{AT} is the elasticity with respect to access time
- β_W is the elasticity with respect to high-level managerial jobs

5.6.7　For business and commuting, it was found that income and access time gave the best fit in estimating the distribution of trips.

5.6.8　The Other purpose was split between home-based and non-home-based. For home-based Other, it was again found that income and access time gave the best fit; however, for non-home-based Other, the best model consisted of the number of high-level managerial jobs and access time, and the population variable was removed. The estimation results are provided in Table 5-4.

Table 5-4: Gravity model for Productions – t-statistics in brackets

	Business	Home-based Other	Non-home-based Other	Commuting
Elasticity to income β_Y	1.651 (34.9)	1.489 (28.2)		2.294 (49.2)
Elasticity to number of high-level managerial jobs β_W			0.9276 (103.5)	
Elasticity to access time β_{AT}	-1.831 (-60.0)	-1.578 (-51.5)	-0.7694 (-32.4)	-2.023 (-65.1)

5.6.9　It would be expected that a positive relationship exists to income and high-level managerial jobs as well as also expecting to have a negative relationship to

access/egress time – people are more likely to travel long distances by train if they have a short access time to the station. The model estimates are therefore of the expected sign and magnitude. They are statistically significant at the 95% level (t-stats well above 2.0).

5.6.10   For the attraction end, the rail demand between a given mzone and station was found to be dependent on the number of high-level managerial jobs, and access time. Along similar lines, the following model was estimated:

Equation 5-7:

$$\hat{Q}_{jS} = K_J W_j^{\beta_W} ET_{jS}^{\beta_{ET}} \quad \text{subject to}$$

$$\sum_{j \in J} \sum_{S \in \{S[J]\}} \hat{Q}_{jS} = Q_J$$

where, as usual,
- S relates to a station
- j relates to an mzone
- J relates to a "PLD zone"

and
- W are the high-level managerial jobs from 2001 Census
- ET is the egress time from NAM
- K_S are constants specific to each "PLD zone"
- β_W is the elasticity with respect to high-level managerial jobs
- β_{ET} is the elasticity with respect to egress time

5.6.11   Calibration was again carried out by journey purpose. Table 5-5 shows the model estimates. All estimates are of the expected sign and the ordering of the elasticities to managerial jobs being lowest for Other and highest for Business seems reasonable, as most business trips are made by those in high-level managerial jobs.

Table 5-5: Gravity model for Attractions – t-statistics in brackets

	Business	Other	Commuting
Elasticity to number of high managerial jobs β_W	1.744 (70.7)	0.6799 (79.2)	0.9726 (99.9)
Elasticity to access time β_{ET}	-0.3389 (-8.9)	-1.197 (-38.2)	-2.167 (-54.0)

5.6.12   Ignoring the zonal constants (K in Equations 5-6 and 5-7) and the access time element AT, the model form can be viewed as giving an index of attractiveness for each mzone i, separately for each purpose p. The access time element then modifies this, separately for each station for PLD zone i. In order to produce an overall index H, the access time contributions were weighted by the contribution r of each station

to the zone (also from NRTS). In other words, taking the production side as an example:

Equation 5-8:

$$H_i^{prod,p} = P_i Y_i^{\beta_Y^p} W_i^{\beta_W^p} \sum_R r_{R|i} . AT_{iR}^{\beta_{AT}^p}$$

where the summation is over those stations R in the catchment area of PLD zone I, and rR|i is the proportion of demand from zone i which uses station R. Note that for the productions this quantity $r_{R|i}$ is taken as the same for all purposes, but for the attractions it is calculated separately for each purpose.

5.6.13   For the Other purpose, the separate "indices of attractiveness" for home and non-home were simply added, implying the formula:

Equation 5-9:

$$H_i^{prod,p=oth} = \sum_R r_{R|i} . \left(P_i Y_i^{\beta_Y^{p=oth(home)}} AT_{iR}^{\beta_{AT}^{p=oth(home)}} + W_i^{\beta_W^{p=oth(nh)}} AT_{iR}^{\beta_{AT}^{p=oth(nh)}} \right)$$

5.6.14   The proportionate allocation f_i is then given as:

Equation 5-10:

$$f_i \quad = \frac{H_i^{prod}}{\sum_{i \in I} H_i^{prod}}$$

5.6.15   Corresponding calculations for H^{att} are carried out at the attraction end to obtain the proportionate allocation g_j.

5.6.16   These "gravity model" allocations f_i and g_j are applied once for each purpose (separately for production and attraction ends) for the [core area] non-key PLD zones, to obtain the required proportions $\pi_{ij}[IJ]$ of mzone level demand. These proportions are then retained as static inputs to the SCM: thus any changes resulting from population changes or new jobs over time are not taken into account in the disaggregation process.

5.7   Model application

5.7.1   The operation of the model is described in Figure 5-3. It should be read from bottom to top, going up the right-hand side and down the left, though in practice the interface with the other models means that there is an element of iteration. Figure 5-3 ignores demand segments, but in practice the model needs to be run separately for the 9 [pcd] segments described earlier.

5.7.2   Note that while the figure describes the essential logic of the model, the overall model algorithm incorporates an additional loop between the SCM and the rail assignment, as will be described in Chapters 9 and 10.

5.7.3   The model operates at the mzone level (i.e. for a movement between i and j). For any such movement, the set of available station pairs[43] {RS} for access mode x is defined as Z^x_{ij}. For the lower choice in the model, separately for each access mode, the total generalised cost, apart from the rail fare, for getting from i to j via R and S is needed.

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[43] Note that although the set is notated as if it relates to the mzone movement i-j, the same set is actually used for all $i \in I$ and $j \in J$, for a given PLD zone to zone movement I-J.

Figure 5-3: The SCM within the Rail Demand and Supply system
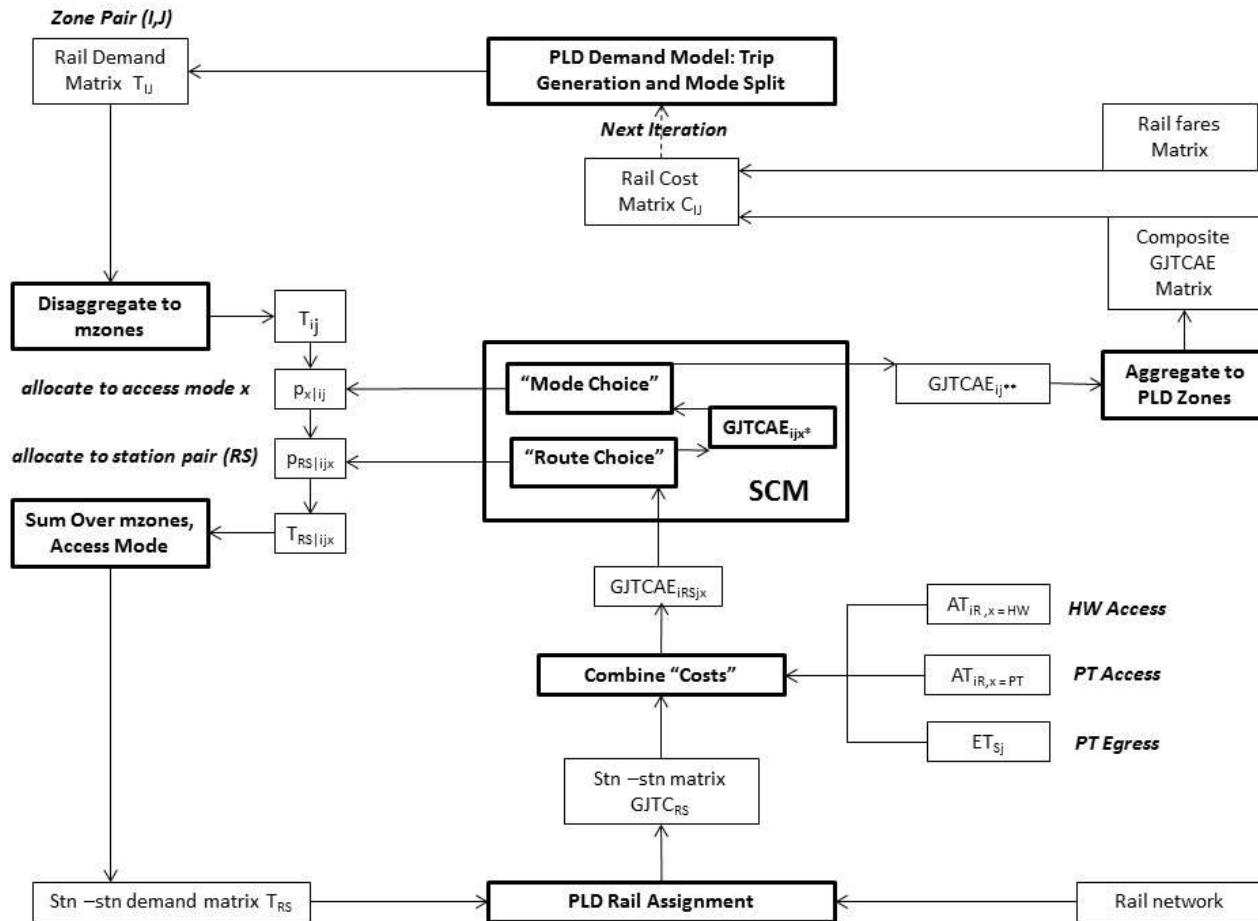
5.7.4   The diagram should be read from the bottom up, starting with the rail assignment. When the demand model is reached, the direction changes to come down the left-hand side.

5.7.5   Given the station-to-station GJTC, the first stage is to introduce the access and egress costs. For CAF travellers, access is defined as the movement from mzone i to station R, and egress as the movement from station S to mzone j. Conceived on a P/A basis, it is assumed that there is no mode choice for egress – public transport must be used. At the 'production' [home] end, access mode choice is available to those who have a car. For CAT travellers, access and egress are effectively reversed. Since NCA travellers have no mode choice, it is immaterial which end is which.

5.7.6   In point of fact, most long-distance rail journeys will be round trips. The cost skims from the PLD assignment can vary significantly with direction, in part due to the definition of the 'attractive set', but also because for some movements the scheduled journey time can be significantly different by direction (up to ten minutes).

For these reasons the SCM uses the average of the PLD rail GJTC in the two directions.

5.7.7   For reasons of computational efficiency, the calculations are carried out only when the demand matrix cell is non-zero.

5.7.8   Hence, using the same terminology as in the previous section, but now introducing egress costs explicitly, the weighted time GJTCAE (in units of IVT minutes) of a CAF movement i-R-S-j can be written as:

- for the highway nest

Equation 5-11:

$$GJTCAE_{iRSj,Hwy}^{p[c=CA][d=F]}\bigg| = \text{HWTime}_{iR} \cdot \beta_{HW} + Petrol\frac{\text{Dist}_{iR}}{\text{VoT}^p} + \frac{Parking}{VoT^p} + \text{½}\,(GJTC_{RS} + GJTC_{SR})$$

$$+\text{PTTime}_{Sj} \cdot \beta_{PT} + \text{Walk}_{Sj} \cdot \beta_{wk} + \text{Wait}_{Sj} \cdot \beta_{wt} + Fare\frac{\text{dist}_{Sj}}{\text{VoT}^p} + \frac{FixedFare}{VoT^p}$$

$$+\frac{1}{\lambda^{Acc}_{\;p}}\left(City_p \cdot \delta_{R=city} + Pway_p \cdot \delta_{R=Pway} + Other_p \cdot \delta_{R=Oth}\right)$$

- and for the PT nest

Equation 5-12:

$$GJTCAE\bigg|_{iRSj,PT}^{p[c=CA][d=F]}$$

$$= \text{PTTime}_{iR} \cdot \beta_{PT} + \text{Walk}_{iR} \cdot \beta_{wk} + \text{Wait}_{iR} \cdot \beta_{wt} + Fare\frac{\text{dist}_{iR}}{\text{VoT}^p} + \frac{FixedFare}{VoT^p}$$

$$+ \text{½}\,(GJTC_{RS} + GJTC_{SR})$$

$$+\text{PTTime}_{Sj} \cdot \beta_{PT} + \text{Walk}_{Sj} \cdot \beta_{wk} + \text{Wait}_{Sj} \cdot \beta_{wt} + Fare\frac{\text{dist}_{Sj}}{\text{VoT}^p} + \frac{FixedFare}{VoT^p}$$

5.7.9   The choice of station pair RS (notated "Route Choice" in Figure 5-3) for access mode x (= Hwy or PT) is then given by the logit model form:

Equation 5-13:

$$p_{RS|ij,x}^{pcd} = \frac{exp(\,[\lambda^{Acc}_{\;p}/\theta_p].\,GJTCAE_{iRSj,x}^{pcd})}{\sum_{[R'S']\in Z_{ij}^x} exp(\,[\lambda^{Acc}_{\;p}/\theta_p].\,GJTCAE_{iR'S'j,x}^{pcd})}$$

where $p_{RS|ij,x}$ is the proportion of those travelling from i to j and using access mode x who choose station pair [RS].

5.7.10   By the standard properties of the nested logit model, this yields a 'composite GJTCAE' ['logsum'][44] over all available [RS] pairs, separately for the two access modes (where available):

Equation 5-14:

$$GJTCAE_{ijx*}^{pcd} = \frac{1}{[\lambda^{Acc}{}_p/\theta_p]} ln \left(\sum_{[R'S']\in Z_{ij}^x} exp([\lambda^{Acc}{}_p/\theta_p] \cdot GJTCAE_{iR'S'j,x}^{pcd}) \right)$$

5.7.11   This composite GJTCAE is then used in the higher-level choice between highway and PT access[45] (notated "Mode Choice" in Figure 5-3), again using the logit form:

Equation 5-15:

$$p_{x|ij}^{pcd} = \frac{exp(\lambda^{Acc}{}_p \cdot GJTCAE_{ijx*}^{pcd})}{\sum_{x'\in\{Hwy,PT\}} exp(\lambda^{Acc}{}_p \cdot GJTCAE_{ijx'*}^{pcd})}$$

where $p_{x|ij}$ is the proportion of those travelling from i to j who use access mode x.

5.7.12   Again, this yields a 'composite GJTCAE' ['logsum'], this time over the two access modes:

Equation 5-16:

$$GJTCAE_{ij**}^{pcd} = \frac{1}{\lambda^{Acc}{}_p} ln \left(\sum_{x'\in\{Hwy,PT\}} exp(\lambda^{Acc}{}_p \cdot GJTCAE_{ijx'*}^{pcd}) \right)$$

5.7.13   This is therefore the composite cost (ignoring fares) of rail travel between mzones i and j, allowing for choice of access mode and station pair. Note that for NCA segments, GJTCAE_{ij**} = GJTCAE_{ij(PT)*}, as derived in Equation 5-14.

5.7.14   However, since the PLD demand model (see Chapter 6) operates on PLD zones rather than mzones, we need to average over all i ∈ I, j ∈ J. This is done by weighting by the demand proportions π_ij[IJ] between mzones i and j and summing over all relevant mzones. Hence the composite GJTCAE matrix (GJTC plus access and egress costs) at the PLD zone level is obtained as follows:

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[44] see Section 3.3 for an explanation.
[45] This model is not needed for the NCA segments, since they are assumed "captive" to public transport access.

Equation 5-17:

$$GJTCAE_{IJ}^{pcd} = \sum_{i \in I, j \in J} \pi_{ij}^{pd}[IJ]GJTCAE_{ij**}^{pcd}$$

5.7.15   Since the demand model does not recognise the 'directional' segment (To/From), which exists only for the rail mode, the result is averaged over the two directions to give:

Equation 5-18:

$$GJTCAE_{IJ}^{pc*} = \tfrac{1}{2}\left(GJTCAE_{IJ}^{pc[d=F]} + GJTCAE_{IJ}^{pc[d=T]}\right)$$

5.7.16   After adding in the fares matrix divided by VoT, this is passed as generalised cost to the PLD demand model (Chapter 6).

5.7.17   The demand calculations now begin at the top of Figure 5-3, starting with an estimate $T_{IJ,rail}{}^{pc}$ of total PLD zone to PLD zone rail movements (by segment pc) from the demand model. For CA travellers, this needs to be split by direction, and this is done on the basis of the pivot[46] Matrices B, so that:

Equation 5-19:

$$GJTCAE_{IJ}^{pc*} = \tfrac{1}{2}\left(GJTCAE_{IJ}^{pc[d=F]} + GJTCAE_{IJ}^{pc[d=T]}\right)$$

5.7.18   The first step is to disaggregate this demand to the mzone level, giving the demand matrix[47] for the SCM as:

Equation 5-20:

$$T_{ij}^{pcd} = \pi_{ij}^{pd}[IJ] \cdot T_{IJ}^{pcd}$$

5.7.19   Using the choice proportions previously calculated (Equation 5-15 and 5-13), this demand is then allocated, first to access mode:

Equation 5-21:

$$T_{ijx}^{pcd} = p_{x|ij}^{pcd} \cdot T_{ij}^{pcd}$$

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[46] See Section 6.4 for further explanation.
[47] Henceforth in this section we drop the "rail" subscript since all quantities are now for the rail mode.

and then to station pairs:

Equation 5-22:

$$T_{RS|ijx}^{pcd} = p_{RS|ij,x}^{pcd} \cdot T_{ijx}^{pcd}$$

5.7.20   The required station-to-station matrix TRS by user class [u = pcd] for the PLD rail assignment is obtained by summing over mzones and access modes:

Equation 5-23:

$$T_{RS}^{pcd} = \sum_{I} \sum_{J} \sum_{i \in I} \sum_{j \in J} \sum_{x} T_{RS|ijx}^{pcd}$$

5.7.21   This completes the description of the SCM. As noted above, within the overall iterative system some of the steps may be omitted. This is further discussed in Chapters 10 and 11.

6 PLD demand model (mode split and generation)

6.1 Introduction

6.1.1 The function of the PLD demand model is to predict the demand for long distance [LD] travel as a result of changes in costs. It is constructed as a hierarchical (nested) logit model dealing with mode choice (between car, air, and rail) and generated (new) travel. Note that, in this context, 'new' travel refers not just to wholly new trips but also those that might have been abstracted from other destinations (since destination choice is not explicitly represented in the model).

6.1.2 The model has been specially constructed for PFM and is estimated using observed data on respondents' long-distance[48] travel choices from the 2011–2019 NTS surveys, using adjustments to take account of changes in travel costs over the period.

6.1.3 An important aim of the model is to determine the relative sensitivity to generalised cost of mode choice and generation. In application, it 'pivots' off a base estimate of demand in response to changes in generalised cost delivered from the modal networks and, in the case of rail, from the SCM.

6.1.4 This chapter describes how the model was estimated and then how it is applied within PFMv10a.

6.2 Inputs to demand model parameter estimation

Choice data

6.2.1 As with the SCM, the estimation of a choice model requires data about the choices actually made – in this case, mode choice and the frequency of LD trip making, and explanatory variables (times, costs, etc.) relating to each possible option.

6.2.2 The LD data is provided by both the standard one-week diary survey used in the NTS to record information on trips of all lengths, and trips collected from the dedicated LD travel 'recall' survey[49]. Both the recall and diary data are used to estimate the models.

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[48] Trips with a one-way distance of at least 50 miles.

[49] The National Travel Survey (NTS) contains two sources of LD travel – diary data and "recall" data. The diary data is collected as part of the overall week's travel diary completed in respect of trips of all length by all respondents. In addition, "recall" data is collected, in which respondents are asked to recall any trips of over 50 miles they had made in the previous week.

6.2.3   The modelling unit for the PLD demand model estimation is the full LD home-based 'tour', defined as a series of linked long-distance journeys starting and finishing at the same home-location. Each individual trip has to be over 50 miles in length to be recorded in the NTS LD data. A primary destination is identified for each tour which defines the purpose of the most distant destination visited.

6.2.4   The detailed purpose codes recorded in the NTS data have been aggregated into the three model purposes as follows:

- Commute tours are tours made to work primary destinations;
- Business tours are tours made to primary destinations visited in the course of work; and,
- Other travel tours are tours made to all other primary destinations (including education).

6.2.5   To determine the 'main' mode used for tour legs involving two or more LD trips, the following mode hierarchy has been applied across the modes used for each of the LD trips made during the tour leg:

- air;
- rail;
- bus/coach;
- car; and
- other.

6.2.6   Thus, if car is used to access a public transport mode (for example, driving to an airport to catch a flight), the public transport mode is represented as the main mode. Tours with main mode 'bus/coach' and 'other' are excluded from both the frequency and mode choice models.

Level-of-Service (LOS) data

6.2.7   The LOS data reflect travel conditions in the base year (2018/19 UK financial year). Note however that all costs within the PFM are defined in 2010/11[50] UK financial year prices.

6.2.8   The choice data in the model estimations spans the 2011 to 2019 period. There have not been any significant changes in journey times for LD travel over this period. Nonetheless we have estimated separate mode specific constants for earlier years of data (2011 to 2016) and the more recent years (2017 to 2019) to allow the model specification to capture any changes in mode share that follow from differences

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[50] Prices are converted to 2015/16 for the economic appraisal process outside of the PFM.

between the 2018/19 LOS and travel conditions actually faced by travellers in earlier years of data.

6.2.9   For rail, logsum composite Generalised Journey Time (GJT) measures were supplied from the Station Choice Model (SCM) (see Chapter 5), defined at the 235 PLD zone level. The LOS components included in the composite GJT are rail IVT, crowding, access and egress time, walk time, wait time, and boardings. By using the composite GJT directly in the estimation of the demand models, consistency in the relative weightings of the rail GJT components is ensured between the SCM and demand models. Separate sets of rail LOS were provided for commute, business, and other travel purposes.

6.2.10   For car, distance and time skims have been supplied from the PLD highway assignment model separately for business, other and commute purposes. No information on tolls, such as for travel on the M6 Toll or one of the Dartford crossings, is available from the skims.

6.2.11   For air, IVT, frequency, wait time, access and egress time and fare skims have been supplied from the PLD air assignment model separately for business and other purposes. Air is not modelled for commute travel and, as noted, all air trips are assumed to be in the 'car available' segment.

6.2.12   In most cases, the coding of the NTS destination permitted the direct use of the LOS data, however in some cases it was necessary to use a mapping process between NTS and PLD zoning systems. For the 'one-to-many' cases, the LOS for the more aggregate PLD zone in which each UA-County zone lies was used for all the coded destinations. For the 'many-to-one' cases, LOS to the UA-County zone was calculated as a weighted average of the LOS to each PLD zone that lies within the UA-County zone, using as weights total employment for commute and business, and total population for the other travel purpose. The population and employment data used for this averaging process was supplied based on the data used for generating the PFM forecast matrices. The data is defined using the PFM zoning system and represents 2018/19 conditions.

Monetary costs - car costs

6.2.13   Fuel costs for car were calculated using the distances and times from the highway LOS. The distances and times were used to calculate the average speed for the chosen OD pair using the formulae for calculating costs given on tabs A1.3.11 (commute and other) and A1.3.12 (business) of the DfT's TAG Databook (February 2021). The TAG Databook provides values for input into the formulae going back to 2010 and this means that car costs have been calculated using year specific values for the consumption formulae.

6.2.14   In terms of non-fuel costs the guidance in TAG Unit M2.1 Variable Demand Modelling
          is that these should be included for travel made in the course of work, whereas for
          private travel only fuel costs should be included. Therefore non-fuel costs have only
          been included in the car costs for business.

6.2.15   The car costs calculated from the TAG Databook refer to an average car. To convert
          costs per vehicle to per person costs for the modelling average LD party size values
          have been used.

Monetary costs - rail fares

6.2.16   Rail and air fare matrices were supplied for the estimation work. Consistent with
          other PFM costs these matrices are in 2018 values and 2010/11 financial year prices.
          To account for real terms changes in rail fares over time data was sourced from the
          Office of Road and Rail (ORR). This database provides annual rail fare indices by the
          following flow types: London and South East; Long Distance; Regional. For each of
          these flow types the indices are also broken down by ticket type: Advance; Anytime;
          Off-Peak; Season; Super Off-Peak; Other; and All Tickets. For commute indices for
          long distance flows were used for season tickets whereas for business and other
          indices for long distance flows for all tickets were used.

Values of Time

6.2.17   The PFM models work with a generalised time formation in which monetary costs
          are converted to equivalent in-vehicle time minutes using VoT functions. The VOT
          functions used to make this conversion are an important input to the model
          estimation process. Paragraphs 3.3.6 to 3.3.9 of TAG Unit M2.1 provides VOT
          functions that vary by distance which are specified as follows:

Equation 6-1:

$$VOT_{2010}^{D,I,y} = k^y \, VOT_{2014}^{D0,I0} \left(\frac{D}{D_0}\right)^{\wedge} E_d$$

where:
$VOT_{2010}^{D,I,y}$ is the VOT in 2010 prices (the price year used in TAG) for value year y

k^y is a price and value year adjustment for year y used to adjust 1) from 2014 prices to 2010
prices and 2) from 2014 values specific to the year of NTS data (2011 to 2019).

$VOT_{2014}^{D0,I0}$ is the national average VOT in 2014 prices and values.

D is the trip distance in km.

D_0 is the average distance used in the VOT function in km.

E_d is the distance elasticity.

6.2.18   The parameter values provided in TAG for the distance only function (as opposed to a distance and income function) are given in Table 6-1.

Table 6-1: TAG all-distances VOT function parameters (VOTs in 2014 prices)

Parameter	Commuting	Other non-work	Business – car	Business – rail
$VOT_{2014}^{D,I}$	8.44 £/hr	2.80 £/hr	9.15 £/hr	17.25 £/hr
D_0	16.40 km	13.1 km	31.9 km	88.3 km
E_d	0.248	0.315	0.387	0.435

6.2.19   The parameters provided in TAG were derived from NTS data across trips of all journey lengths including short-distance trips. Since the PLD demand model concerns long-distance trips it was necessary to derive parameter estimations for long-distance trips only.

6.2.20   The long-distance VOT function parameters were obtained using the same regressions used in the derivation of the TAG all-distance VOT function parameters, but instead filtering the NTS sample to only include long distance trips, specifically trips of 50 miles and above. This ensures consistency with the long distance trip definition used in the PFM mode choice and frequency estimations. The long-distance regressions do not include income as a variable because the PFM does not allow an income segmentation to be implemented within the demand model.

Table 6-2: Long distance VOT function parameters (VOTs in 2014 prices

Parameter	Commuting	Other non-work	Business – car	Business – rail
$VOT_{2014}^{D,I}$	16.51 £/hr	7.93 £/hr	20.65 £/hr	28.35 £/hr
D_0	116.8 km	165.9 km	158.8 km	192.4 km
E_d	0.276	0.249	0.392	0.594

6.3   Estimating demand model parameters

Model scope

6.3.1   PFM is an average weekday model. The base year in PFMv10a is 2018/19, monetary costs for the base year are 2018 values but in 2010/11 UK financial year prices. The PFM demand model predicts two choices:

- Long-distance travel frequency; and,
- Mode choice.

6.3.2   Destination choice is not explicitly modelled. Three travel purposes are represented: commute; business; and other travel. Education travel forms part of the other travel purpose. When the PFM demand models are applied they are segmented into car available (CA) and non-car available (NCA) segments.

Estimation approach

6.3.3   Models were estimated separately for commute, business, and other travel purposes. The PFM model structure represents frequency and mode choice responses, destination choice is not explicitly modelled. The main objective of the mode choice estimations is to estimate the sensitivities to generalised time at the lowest level in the mode choice structure – the lambda values – and then to estimate structural parameters (theta) that define the relative sensitivity of higher-level choices.

6.3.4   Figure 6-1 illustrates the frequency and mode choice model structure, and highlights how the theta parameters are used to define the sensitivities to generalised cost (the lambda values) at each level in the choice structure. It is noted that the mode choice and frequency models are estimated sequentially, not simultaneously.

Figure 6-1: Frequency and mode choice model structure
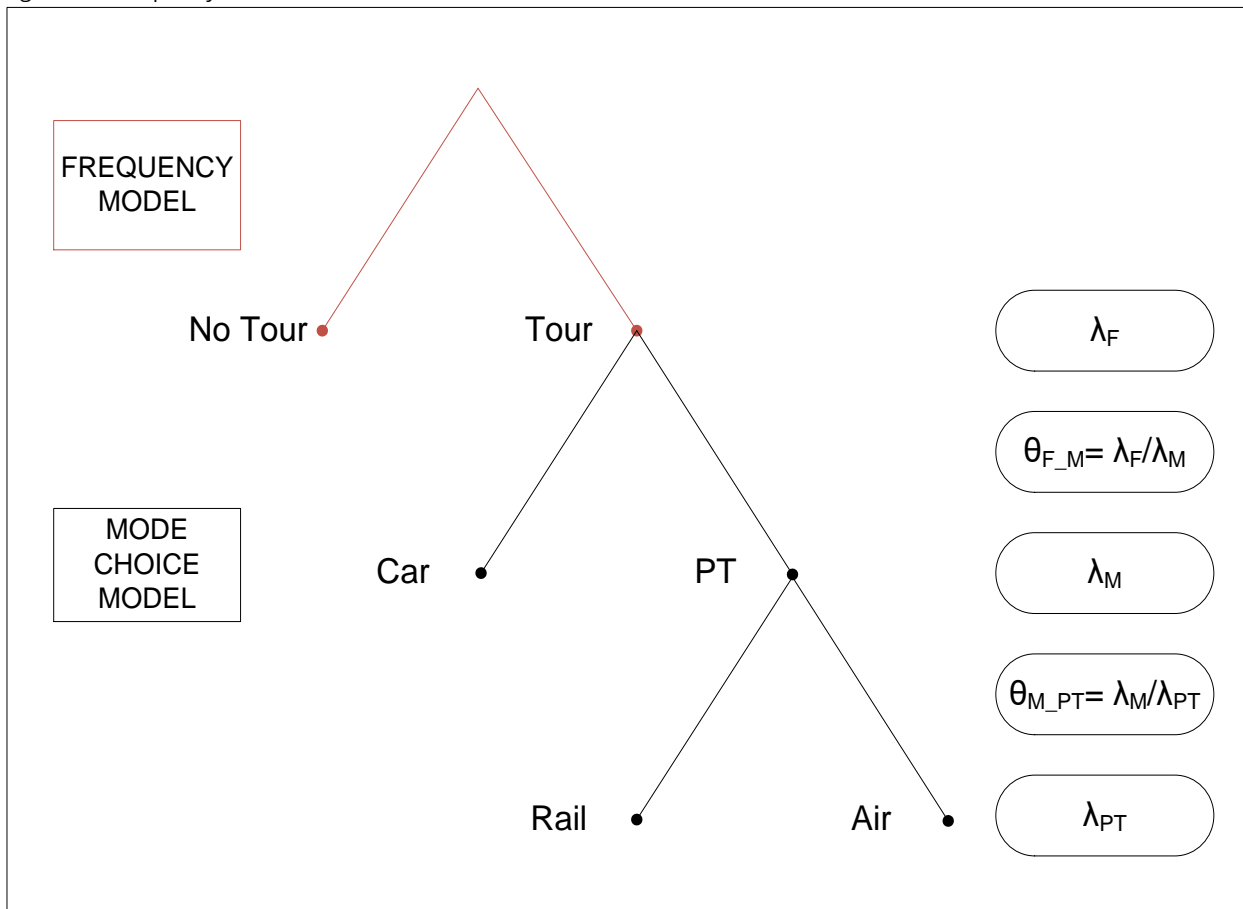
6.3.5   The sensitivity to generalised cost is estimated at the lowest level in the structure. The generalised time parameter between rail and air defines λ_{PT}. We can calculate the sensitivities to generalised time for the car versus public transport choice λ_M, and for the no tour versus tour choice λ_F, using the structural parameters θ_{M_PT} and θ_{F_M} that are output from the model estimation. Note that for commute, there is no rail versus air choice and therefore the generalised time parameter estimated in the model defines λ_M directly.

6.3.6   In addition to the generalised time parameters, the mode choice models incorporate mode-specific and other constants:

Equation 6-2:

$$GT_m = GJT_m + \frac{cost_m[Y]}{VOT\,[Y,D]}$$

where:

GT_m is the generalised time for mode m (minutes).

GJT_m is the Generalised Journey Time for mode m, including both in-vehicle time and out-of-vehicle time components with appropriate weightings (minutes).

$cost_m$ is the monetary cost of the mode (pence in 2010/11 prices) in year Y.

$VOT [Y, D]$ is the value of time (pence/minute in 2010/11 prices) in year Y, for a trip of distance D (Km).

Estimating the mode choice models

6.3.7 The mode choice model predicts the choice between car and public transport, and for business and other travel, the choice between rail and air. Consistent with the frequency model, only weekday tours are included in the model estimation procedure. If a tour is made where one leg is made on weekday, and the other leg on the weekend, then it is included with a weight of 0.5.

Estimating the frequency models

6.3.8 The frequency model predicts the binary choice between not travelling and making a long-distance tour on an average weekday. The NTS LD data (recall plus diary) cover a two-week period, hence a period of 10 weekdays. On each weekday, if an individual does not travel, they contribute a 'no tour' observation.

6.3.9 If a tour is made where one leg is made on a weekday, and the other leg on a weekend, then it is included in the counts of weekday tours made with a weight of 0.5. Tours where both legs are made on a weekend are excluded from the tour counts.

6.3.10 Ideally, the frequency models would be developed using all the NTS data, including tours made on weekends, as HS2 services will operate at weekends as well as during the week, and for leisure travel a significant proportion of total travel takes place at weekends. The PFM network models have been setup as average weekday models and it is not currently planned to establish a separate weekend model.

6.3.11 The key output from the frequency model estimation is the structural parameter that defines the relative sensitivity of the frequency and car versus PT choices. This structural parameter allows the frequency choice lambda to be calculated, which determines the sensitivity of travel frequency to changes in generalised time.

6.4 PLD demand model application

6.4.1 The combined mode choice and frequency model is applied incrementally, pivoting from 'Base Matrices'. 'B' is used to denote these, regardless of the year to which they apply. Associated with the pivot matrices in any given year will be a set of generalised cost matrices. These matrices are denoted by G_0.

6.4.2   The demand model works with generalised cost, and the specification is compatible with Equation 6-2 except that for the application, everything is on a trip – rather than a tour – basis. Therefore:

Equation 6-3:

$$C_{mIJ,y}^{pc} = GT_{mIJ,y}^{pc} + M_{mIJ,y}^{p}/VoT_{y}^{p}(D_{IJ})$$

where:

$C_{mIJ,y}^{pc}$ is the generalised cost for mode m (minutes) for each purpose and car availability of a trip from I to J in year Y.

$GT_{mIJ,y}^{pc}$ is the Generalised Journey Time for mode m, including both in-vehicle time and out-of-vehicle time components with appropriate weightings (minutes) for each purpose and car availability of a trip from I to J in year Y.

$M_{mIJ,y}^{p}$ is the monetary cost of the mode (pence in 2010/11 prices) for each purpose of a trip from I to J in year Y.

$VoT_{y}^{p}(D_{IJ})$ is the value of time (pence/minute in 2010/11 prices) in year Y, for each purpose of a trip of distance D *(Km)* from I to J in year Y.

6.4.3   The cost elements are calculated for the year y to which they relate. In the case of rail, GT is obtained as GJTCAE from the SCM, while for car and air, GT is derived from the corresponding networks.

6.4.4   The first requirement is to calculate the difference ΔC between C and the pivot costs G$_0$:

Equation 6-4:

$$\Delta C_{mIJ,y}^{pc} = C_{mIJ,y}^{pc} - G^{0\,pc}_{mIJ,y}\,\forall I,J,p,c,m$$

where:

$C_{mIJ,y}^{pc}$ is the generalised cost for mode m for each purpose and car availability of a trip from I to J in year Y.

$G^{0\,pc}_{mIJ,y}$ is the generalised pivot costs for mode m for each purpose and car availability of a trip from I to J in year Y.

$\Delta C_{mIJ,y}^{pc}$ is the difference of generalised cost and pivot costs for mode m for each purpose and car availability of a trip from I to J in year Y.

6.4.5   In typical model tests, the fares for rail and air will be the same in the 'Do Minimum' [DM] and 'Do Something' [DS] scenarios, and therefore fares have no impact on the generalised cost differences. Nevertheless, for consistency the fares are still included

as part of the generalised cost calculation. Similar considerations apply to all the elements of GT for the air mode. In most circumstances, ΔC will be zero for the air mode because air supply is not changed between the Do Minimum and Do Something scenarios.

6.4.6   In calculating C for highway, it was noted in Section 6.2 that the TAG formulae for fuel consumption were applied using the actual network speed for each IJ movement. In model application, however, it was considered that implementing this detailed procedure would introduce significant complexity and, after further investigation, it was considered acceptable to work with a single average speed across the network. Hence overall average car cost per kilometre values (on a per-person basis) are calculated using these average speed values, together with the advice given in TAG A1.3 for forecasting changes in car costs over time, and divided by occupancy.

6.4.7   The detailed calculations for the application of the demand model are now set out, with the operation summarised in Figure 6-2. This should be read from bottom to top, going up the right-hand side and down the left, though in practice the interface with the other models means that there is an element of iteration. Figure 6-2 ignores demand segments, but in fact the model needs to be run independently for each purpose and car availability [pc] combination.

6.4.8   At the lowest level, starting from the input of the SCM and the Air assignment, there is a 'PT choice' between rail and air (for Commute, this choice does not apply, since the air mode is not considered available).

Figure 6-2: The demand model

PT choice

6.4.9   To calculate the choice between rail and air, the following calculations are made:

Equation 6-5:

$$p_{m|IJ}^{pc} = \frac{B_{mIJ}^{pc} \cdot exp(\lambda^p{}_{PT} \cdot \Delta C_{mIJ}^{pc})}{\sum_{m' \in \{rail,air\}} B_{m'IJ}^{pc} \cdot exp(\lambda^p{}_{PT} \cdot \Delta C_{m'IJ}^{pc})}$$

where:

$p_{m|IJ}^{pc}$ is the choice probability for mode m (air or rail) for each purpose and car availability of a trip from I to J.

B_{mIJ}^{pc} is the pivot matrices for mode m for each purpose and car availability of a trip from I to J.

ΔC_{mIJ}^{pc} is the difference of generalised cost for mode m for each purpose and car availability of a trip from I to J.

$\lambda^p{}_{PT}$. is the estimated generalised time parameter between rail and air for each purpose.

6.4.10   By the properties of the incremental logit model, this allows the calculation of the incremental 'composite' cost $\Delta C_{[PT]IJ}$ while the specification is compatible with Equation 6-5.

Equation 6-6:

$$\Delta C^{pc}_{[PT]IJ} = \frac{1}{\lambda^p{}_{PT}} ln \left(\frac{\sum_{m'\in\{rail,air\}} B^{pc}_{m'IJ} \cdot exp(\lambda^p{}_{PT} \cdot \Delta C^{pc}_{m'IJ})}{\sum_{m'\in\{rail,air\}} B^{pc}_{m'IJ}} \right)$$

This is then passed up to the next choice level – 'mode choice' between car and PT.

Mode choice

6.4.11   The choice between car and public transport is calculated by:

Equation 6-7:

$$p^{pc}_{m|IJ} = \frac{B^{pc}_{mIJ} \cdot exp(\lambda^p{}_M \cdot \Delta C^{pc}_{mIJ})}{\sum_{m'\in\{PT,car\}} B^{pc}_{m'IJ} \cdot exp(\lambda^p{}_M \cdot \Delta C^{pc}_{m'IJ})}$$

where:

$p^{pc}_{m|IJ}$ is the choice probability for mode m (PT or car) for each purpose and car availability of a trip from I to J.

B^{pc}_{mIJ} is the pivot matrices for mode m for each purpose and car availability of a trip from I to J.

ΔC^{pc}_{mIJ} is the difference of generalised cost for mode m for each purpose and car availability of a trip from I to J.

$\lambda^p{}_M$. is the estimated sensitivities to generalised time for the car versus public transport choice for each purpose.

Again, this allows the calculation of the incremental 'composite' cost $\Delta C_{[M]IJ}$ while the specification is compatible with Equation 6-7.

Equation 6-8:

$$\Delta C^{pc}_{[M]IJ} = \frac{1}{\lambda^p{}_M} ln \left(\frac{\sum_{m'\in\{PT,car\}} B^{pc}_{m'IJ} \cdot exp(\lambda^p{}_M \cdot \Delta C^{pc}_{m'IJ})}{\sum_{m'\in\{PT,car\}} B^{pc}_{m'IJ}} \right)$$

6.4.12   This is then used in the Frequency model, where a slightly different formula is applied to provide an estimate of revised total travel (by all modes) between I and J for segment pc:

Equation 6-9:

$$T_{*IJ}^{pc} = B_{*IJ}^{pc} \cdot exp(\lambda_F^p \cdot \Delta C_{[M]IJ}^{pc})$$

where the asterisk indicates summation over all three modes.

where:

T_{*IJ}^{pc} is the revised total trip between I and J for each purpose and car availability by all modes.

B_{IJ}^{pc} is the pivot matrices for each purpose and car availability of a trip from I to J.

$\Delta C_{[M]IJ}^{pc}$ is the incremental composite cost from mode choice between car and public transport for each purpose and car availability.

λ_F^p. is the estimated sensitivities to generalised time for no tour versus tour choice.

Revised demand calculations

6.4.13 Given the mode choice probabilities, the revised demands T are now calculated by 'going down the tree':

Equation 6-10:

$$T_{mIJ}^{pc} = T_{*IJ}^{pc} \cdot p_{m|IJ}^{pc}, m' \in \{PT, car\}$$

where:

T_{mIJ}^{pc} is the revised trip between I and J for each mode (PT or car), purpose and car availability.

T_{*IJ}^{pc} is the revised total trip between I and J for each purpose and car availability by all modes.

$p_{m|IJ}^{pc}$ is the choice probability for mode m (PT or car) for each purpose and car availability of a trip from I to J.

and

Equation 6-11:

$$T_{mIJ}^{pc} = T_{[PT]IJ}^{pc} \cdot p_{m|IJ}^{pc}, m' \in \{rail, air\}$$

where:

T_{mIJ}^{pc} is the revised trip between I and J for each mode (rail or air), purpose and car availability.

$T_{[PT]IJ}^{pc}$ is the revised total public transport trip between I and J for each purpose and car availability.

$p_{m|IJ}^{pc}$ is the choice probability for mode m (rail or air) for each purpose and car availability of a trip from I to J.

6.4.14   In this way, the output demand for each mode is derived, which can be passed, in the case of car, to the highway network, and in the case of rail, to the SCM. Note that the air network is not sensitive to demand, so further assignment is not strictly required for this mode[51].

6.4.15   It can be seen that apart from the pivot demand matrices and the generalised cost matrices, the only other requirement for the model is the set of λ values. These are derived from the model whose estimation was described in the previous section.

6.4.16   Note that the values presented in this section are applied to both NCA and CA segments. The λ values define the model sensitivities to generalised cost changes in minutes, and are presented here in trip units as required for the PFM implementation. This requires the estimated λ_{PT} values to be multiplied by 2[52], and then to be multiplied by the estimated values of θ_{M_PT} and θ_{F_M} in order to calculate λ_M and λ_F. Table 6-3 summarises the lambda values used to implement the frequency and mode choice models in incremental form.

Table 6-3: λ values for demand model application

Choice	Commute	Other	Business
Frequency	λ_F	-0.0029	-0.0027
Car v PT	λ_M	-0.0051	-0.0046
Rail v air	λ_{PT}	n/a	-0.0064

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[51] Although, as will be seen in Chapter 10, it is in fact carried out.

[52] The models estimated using tour level-of-service, so the sum of outward and return legs. However, the models are implemented using trip level-of-service, calculated as the average of outward and return legs. To convert the lambdas from the estimations that are in tour units into trip units they are multiplied by two in order to ensure the product of the lambda and the level-of-service is the same in trip and tour unit.

Part 3 – Other component models

In this part we discuss the three Regional PLANETs (PLANET South, Midland, and North) in Chapter 7.

7 Regional PLANETs

7.1 Introduction

7.1.1 This chapter describes the three Regional PLANET models - PLANET South (PS), PLANET Midlands (PM), and PLANET North (PN), noting their general similarities and the specific aspects where they are different. These models complement the PLD rail network and ensure that all rail services are represented in key areas of interest. By means of the 'control matrices', it is ensured that any one PLD zone-to-zone movement is represented in only one of the four PLANET models.

7.1.2 PLD has priority as the representation of strategic rail, and the control matrices have been devised with this in mind. However, to represent crowding properly, the overlaps between the models need to be carefully handled. This is generally done with rail "preloads", but a different method, referred to as 'wormholes', is used for representing the impact of PLD flows on the PS network.

7.1.3 The Regional PLANETs are important not only for the representation of potential crowding relief on local services brought about by HS2, but also for allowing a representation of revised local services to take account of released capacity.

7.2 Overview of Regional PLANET models

7.2.1 The Regional PLANET models (South, Midlands, North) are all AM peak period rail passenger models covering the full three-hour period between 07:00 and 10:00 on a typical weekday. The zoning systems were described in Section 2.5.

7.2.2 PLANET South is the oldest, and differs in some respects from the other two, which share development history, functionality and data sources. Within PFM, all three models use the EMME network and assignment platform. The 'transit lines' are built using the same approach as for PLD (this is described in Section 8.5). The assignment uses the standard (frequency-based) Optimum Strategy[53] algorithm, and the MSA damping method to control convergence, as described in Chapter 4.

7.2.3 There is a full representation of National Rail services within the area covered by each model, which implies that this includes some services within the region also represented in the PLD model. However, whether OD movements are dealt with in one of the Regional PLANETs or in PLD demand is indicated by means of a "Control Matrix". Demand matrices for each model are initially provided covering all

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[53] Given that the emphasis of these regional AM models is more on high frequency peak services than on fast services, there is no significant value in considering the FJTS version of the algorithm.

movements, and then the control matrices remove demand for non-selected movements.

7.2.4   Interfaces are required:

a) to export to the PLD Assignment the level of passenger loadings from intra-Regional demand forecast on longer distance services; and,

b) to import to the Regional PLANETs the level of passenger loadings from PLD demand forecast on Regional services.

7.2.5   The general approach to the interface makes use of rail 'preloads', but in the case of b) for PS, the 'wormholes' method is used to import demand from PLD. The interfaces are a key aspect of PFM, and are described in Section 7.6.

7.2.6   Unlike the PLD assignment, which is strictly station-to-station, the Regional PLANETs deal with zone-to-zone movements, so that access and egress are explicitly modelled: again, there are some differences in this respect between PS and PM/PN.

7.2.7   In addition, the models use an elasticity-based approach to represent the change in demand at the OD level caused by changes in service specification, crowding or fares. For the purpose of applying elasticities, based on PDFH guidance, changes in generalised time are calculated by comparing two scenarios or cases: a "Do Minimum" (base) and a "Do Something" (test). While the elasticities generate changes in rail demand, there is no capability to understand where that demand has come from or identify modal shift or the impact of changes in competing modes, such as the use of the private car, as there is no comparable representation of the costs of car travel.

7.2.8   The Base Year Demand is compatible with MOIRA station-to-station data for 2018/19. Demand is split by the three purposes – Business, Other, Commute – and, for PM/PN, further by car availability [CA/NCA]. This is described in detail in Section 8.2.

7.2.9   The models offer:

- rail route choice where reasonable route choices exist;
- demand responses (elasticities) varying with travel purpose (business, other (leisure) and commuting);
- response to congestion on the rail modes (crowding);
- a range of outputs to inform scheme development and decision making;
- statistics on passenger flows – such as number of passengers, travel time and distance travelled;

- passenger flows by route;
- levels of train passenger crowding anticipated;
- fare revenue by operator group; and,
- economic benefit calculations.

7.2.10   The network models do not take into account the fare paid by the passenger and it is considered that their route choice is unaffected by the fare paid. In terms of demand responses, the elasticities applied have been calibrated to GJT, without any fare term. The impact of changes in fares is captured exogenously using EDGE, as described in Chapter 9.

7.2.11   In the following three sections, the individual models are described in somewhat more detail.

7.3   PLANET South

7.3.1   The PS model has been in use since the 1990s for modelling forecast crowding on the London and South East rail network and associated impacts on London Underground lines. The model represents morning peak period rail movements within an area which covers the former Network South East area, with less detailed representation beyond those areas: it is a three-hour period assignment. PS was adapted for PFM to include only trips within London, South East and South West areas.

7.3.2   In addition to National Rail services, the London Underground (LUL) and light rail (DLR) services are represented, based on data provided by Transport for London (TfL). This is less detailed than for the National Rail system, but ensures the model is able to adequately represent the role of LUL services as a feeder for longer distance travel, or as a competitor where appropriate. Similarly, but to a lower level of detail, it includes a representation of the feeder system provided by London Bus services within Greater London. This additional network representation ensures passenger dispersal within Greater London is adequately represented and evaluated.

7.3.3   Demand data is presented on a zone-to-zone basis, and each zone centroid is connected to one or more appropriate stations. There are 1,372 zones.

7.3.4   For each station pair (average) GJTC is calculated using the frequency-based (optimal strategy) described in Chapter 4, and then for any zone-to-zone pair, the minimum cost route, including access/egress, is calculated over all possible station pairs available to the zone pair. As a result of MSA damping, this may in practice lead to multiple station allocations for any one zone pair. The base year network for PS is shown in Figure 7-1 below.

Figure 7-1: PLANET South Base Year Network
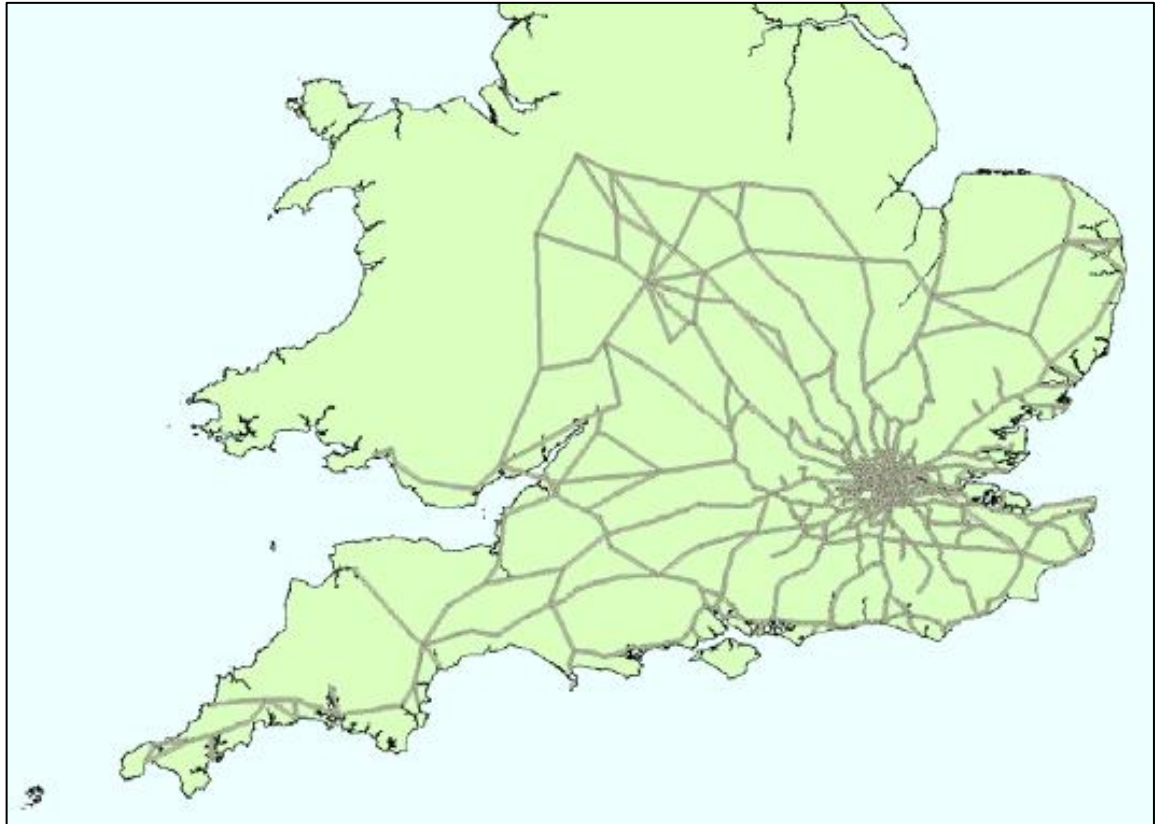
7.4   PLANET Midlands

7.4.1   Together with PN, this was developed in 2009 and is centred on Birmingham with the East Midlands (Derby, Nottingham, and Leicester) also within the core area. The zoning system is based on aggregations of MSOA zones. PM has 1146 zones (59 of them external), and 259 stations. The network for PM is shown in Figure 7-2 below.

Figure 7-2: PLANET Midlands Network
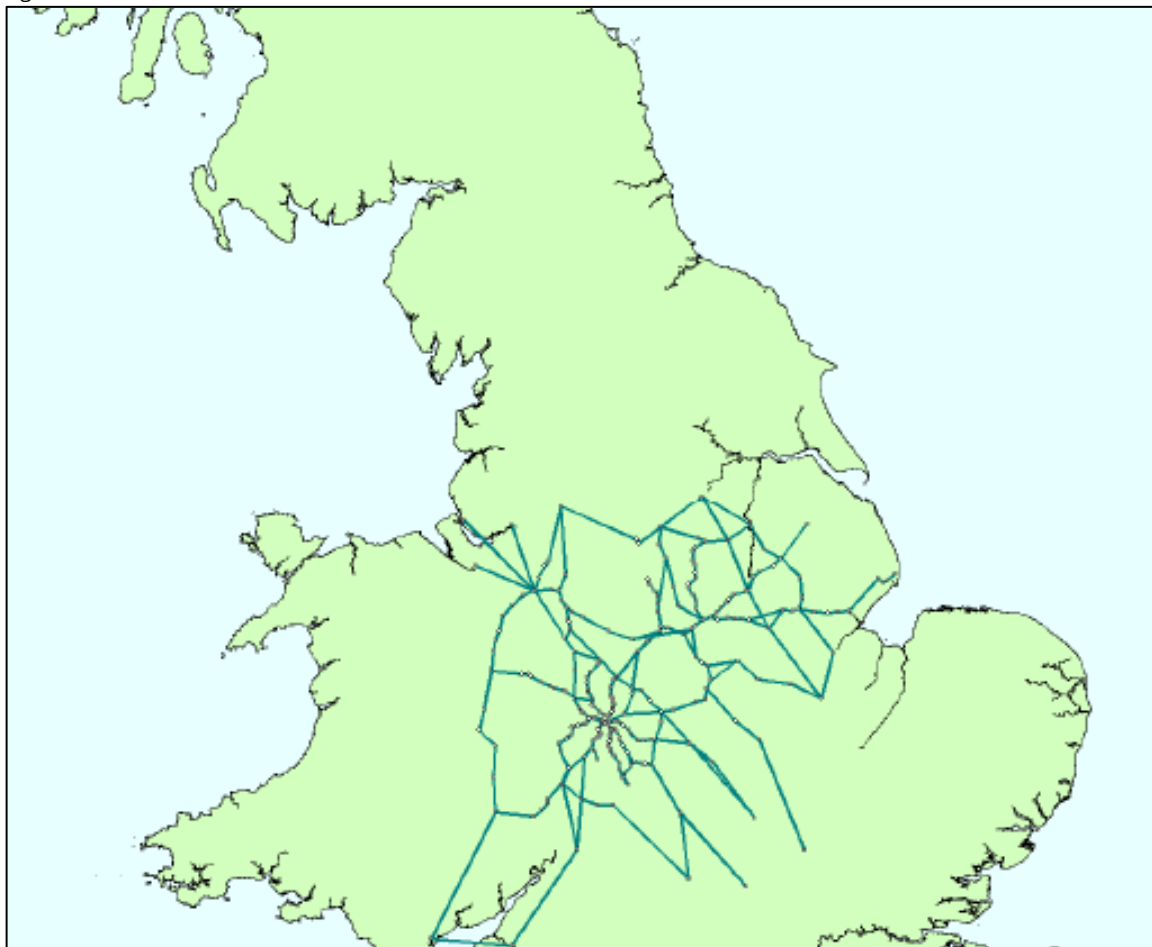
7.4.2   In contrast to PS, PM has the zone-to-zone demand matrix for the three purposes further segmented by CA/NCA. There is then a simplified version of the PLD SCM to allocate to stations.

7.4.3   For each zone, a maximum of 5 origin stations and 5 destination stations (i.e. a matrix of 25 possible routes) is allowed. In addition, zone-station-station-zone combinations with less than 0.1 journeys per AM peak (or less than one journey per fortnight) are excluded. The result is that there is a pre-allocation of zone-to-zone movements to a station-to-station matrix, which is then assigned. Access times to rail stations are based on the National Accessibility Model (NAM), which calculates the travel time from each Census Output Area [COA] population centroid to each of the five nearest stations (in terms of travel time) for car available and non-car available households. The following assumptions have been made:

- Only one time of day has been modelled, with arrival at the station for 08:00 hours. Early arrival of up to 30 minutes is allowed without a time penalty so that the choice of this single time can be representative of AM peak journey times.

- Car available (CA) journeys assume that the car driver can park adjacent to the station without a time penalty searching for a car park space.
- Non-car available (NCA) journeys use walk and bus but exclude rail and cycle.
- Access times are capped at 90 minutes.

7.4.4   The Station Choice Model then makes use of the incremental logit formulation, where the allocation of station-station journeys between origin and destination zones pivots off NRTS data, with separation of CA and NCA access and egress.

7.4.5   For each zone pair [IJ], the model predicts the allocation between up to 25 (5*5) RS routeings (the set denoted as Z^c_{IJ}) when rail service interventions, or changes to access/egress, affect the relative attractiveness of alternative stations/routes.

7.4.6   The model has the following structure:

Equation 7-1:

$$p^{pc}_{RS|IJ} = \frac{q^{pc}_{RS|IJ} \cdot exp(\lambda.\Delta GT^{pc}_{IRSJ})}{\sum_{R's' \in Z^c_{IJ}} q^{pc}_{R'S'|IJ} \cdot exp(\lambda.\Delta GT^{pc}_{IR'S'J})}$$

where:
- p_{RS} is the proportion of people choosing to travel via stations R and S in the test scenario;
- q_{RS} is the proportion of people choosing to travel via stations R and S in the base scenario;
- Z^c_{IJ} is the choice set (dependent on car availability) of station pairs for those travelling between zones I and J;
- λ is the logit dispersion parameter. For PM this took the value -0.1
- $\Delta GT_{RS} = GT_{RS} - GT^0_{RS}$; where
  - GT_{RS} is the Generalised Time of travelling via stations R and S in the test scenario;
  - GT^0_{RS} is the Generalised Time of travelling via stations R and S in the base case.

7.4.7   To obtain a first approximation of the AM peak journeys that would be abstracted from other stations by the opening of a new station, a hybrid logit is used. For each affected flow, the hybrid logit uses a standard multinomial formulation to estimate the shares of trips attracted and produced by the new station, and then reallocates the remaining demand between the existing stations using the incremental formulation.

7.4.8   To reduce run times, the code limits these calculations to zone-zone flows where the new station would be closer than the fifth most popular CA/NCA station (according to the NRTS input), and also prevents access/egress above a threshold distance set to 10km.

7.5 PLANET North

7.5.1 As with PM, this was developed in 2009 and is centred on the M62 Liverpool/Manchester–Leeds/Sheffield corridor. The zoning system is based on aggregations of MSOA zones, and the base year demand matrix is derived in the same way. PN has 961 zones, and 511 stations. The demand data is compatible with that for PM, as are the generalised cost parameters.

7.5.2 The network for PN is shown in Figure 7-3 below.

Figure 7-3: PLANT North Network
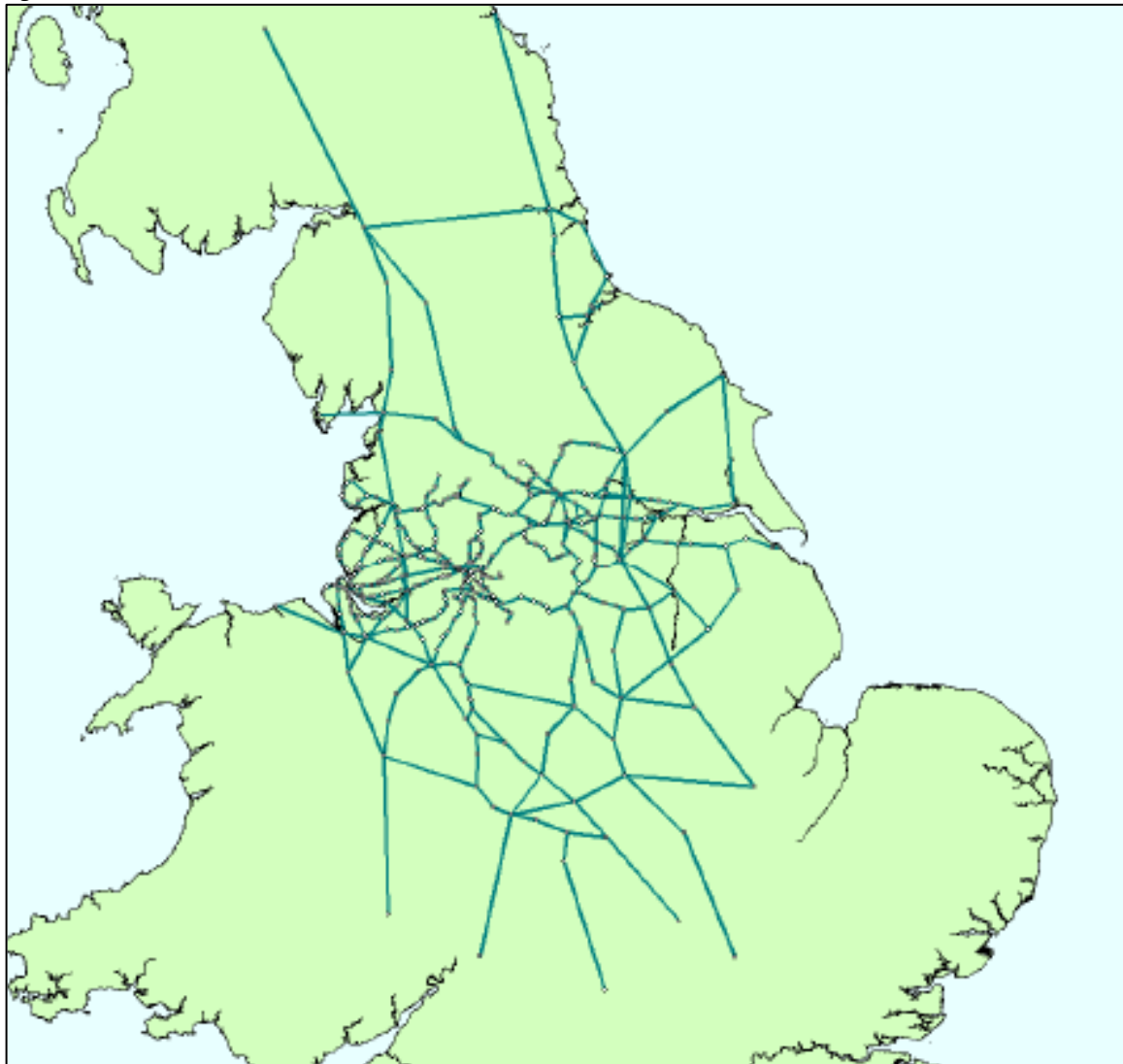
7.5.3 PN has an identical station choice procedure to that in PM, except that λ takes the value of -0.03 rather than the -0.1 for PM.

7.6 Interface with PLD

Introduction

7.6.1   It was noted in Section 7.2 that the interfaces between PLD and the Regional PLANETs are in two directions:

- to export to the PLD Assignment the level of passenger loadings from intra-Regional demand forecast on longer distance services; and,
- to import to the Regional PLANETs the level of passenger loadings from PLD demand forecast on Regional services.

7.6.2   Figure 7-4 aims to illustrate the general requirements schematically. The top part of the figure illustrates, on the left-hand side, the 'Control Matrix' (see below), assuming that zones are generally numbered from north to south, with journey length increasing away from the main diagonal. According to this, each OD pair is uniquely assigned to one of the four PLANET models (PLD and the Regional PLANETs). Note that within the zonal range of PN and PM, some of the movements are in fact handled in PLD, as discussed below.

7.6.3   However, as the right-hand side shows, there is an overlap between the services represented in PLD and those in the Regional PLANETs. If the demand matrix allocated to each PLANET model were simply assigned to all services in that model, the contribution of the other demand to those services would be missed, with potential consequences for the modelling of crowding. The aim of the interface is to deal with this problem, in the manner suggested in the bottom part of the figure.

Figure 7-4: Schematic representation of interfaces between PLD and Regional PLANETs
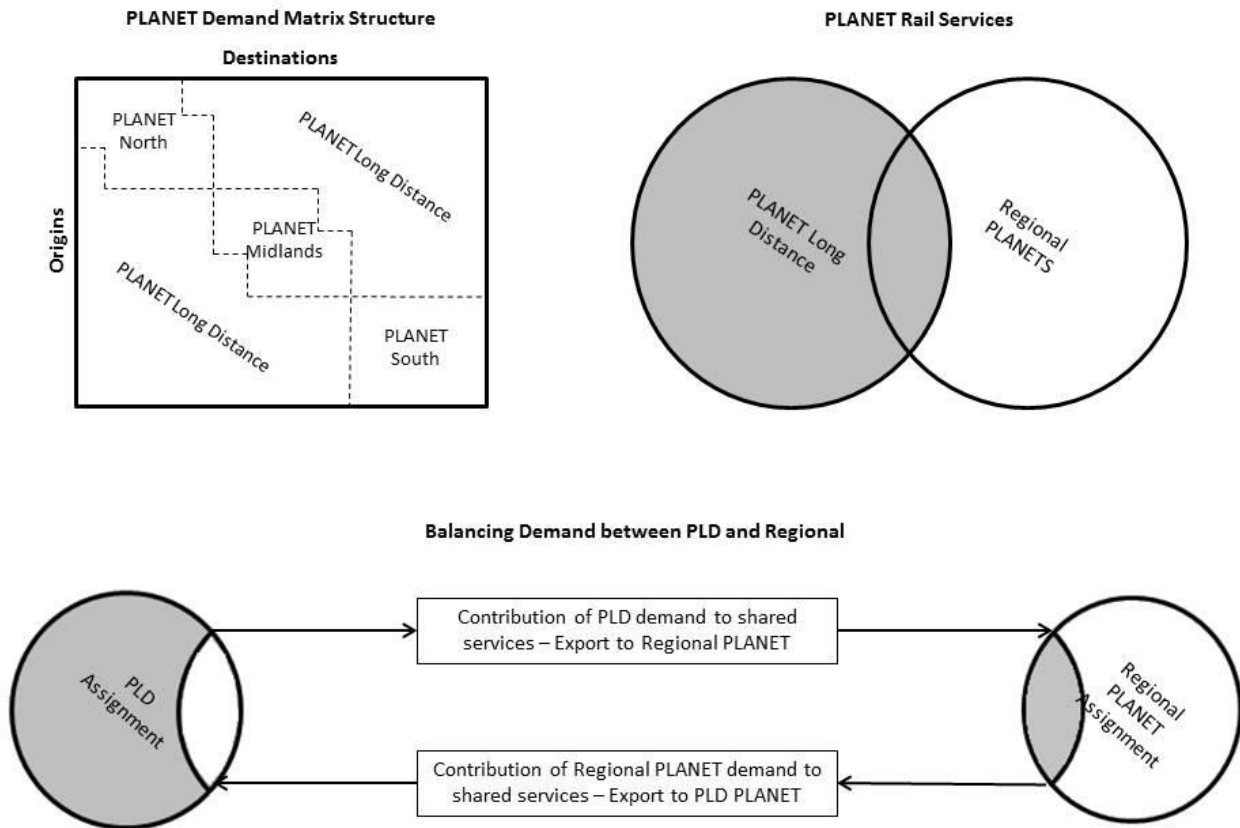
Control matrices

7.6.4　The PLANET models have initially been developed as free-standing models, so that their scope is to deal with all relevant services. Careful consideration is required in order to determine how best to use the 'strategic' PLD model and the more detailed Regional PLANETs in combination.

7.6.5　Beginning with the definition of strategic services as represented in PLD, the Control Matrix takes into account what elements of rail demand at a zone-to-zone level are best represented in PLD, bearing in mind the scope of the Regional PLANETs and the focus on the HS2 corridor, with the proposed distribution of stations. This is most straightforward in the case of PS, since apart from the London stations, there are no HS2 stations within the detailed area covered. Hence, all movements within an area bounded approximately by a line from the Severn Estuary to The Wash can be removed from PLD.

7.6.6　The Control Matrix was initially developed for the PLD zoning system. The PLD zones were then linked to their corresponding zones in PM and PN to derive control

matrices for these Regional models. This approach ensures that there is no demand represented in both PLD and a regional model and ensures that all movements have a defined model within which to reside.

7.6.7   With respect to PM and PN, there are two elements to consider where the demand for a particular movement should reside – the travel to work [TTW] area for the major conurbations of interest, and local trips using key strategic corridors.

7.6.8   It is important that movements within each TTW area are represented within the appropriate regional model. The TTW areas used in the model are based on the DfT TTW area definitions that aim to reflect areas where the bulk of the resident population also work within the same area. Figure 7-5 shows the TTW areas diagrammatically. Trips wholly within each individual TTW area are modelled within the appropriate Regional PLANET model, i.e. Birmingham and East Midlands in PM, the remainder in PN.

7.6.9   Figure 7-5 shows that a number of the TTW areas overlap. For example, zones in the eastern section of the Liverpool TTW area are also in the western section of the Manchester TTW area. This necessitates building the control matrix carefully, to ensure that only those origin-destination zone pairs that constitute local trips are excluded from the PLD demand matrices.

Figure 7-5: PLD travel to work areas
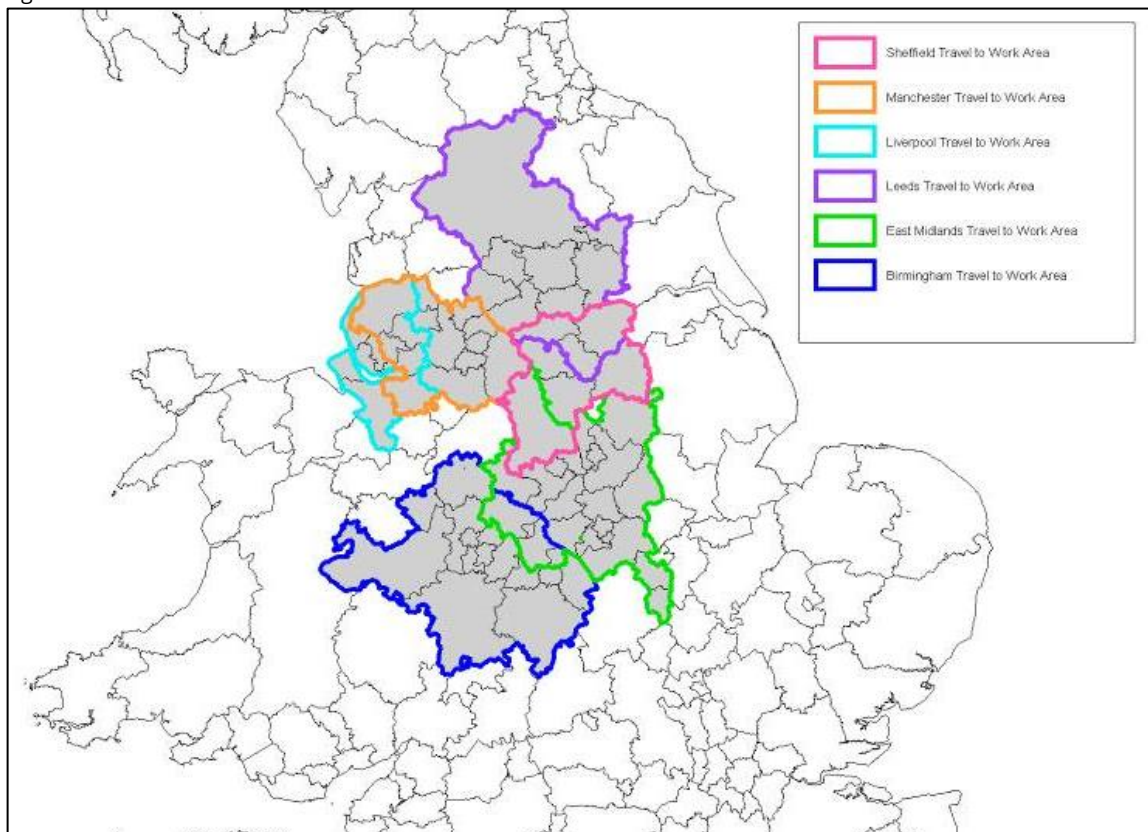
7.6.10   It is also important to ensure that local trips along the key rail corridors affected by HS2 are captured and modelled in the regional models. The three key corridors are the West Coast Main Line [WCML] (Blue), Midland Main Line [MML] (Green) and East Coast Main Line [ECML] (Red), shown in Figure 7-6. Along each of these rail corridors the control matrix ensures that local trips are modelled in PM or PN (as appropriate). Note that the Cross Country route between Birmingham and Sheffield is dealt with in the Regional PLANETs since all adjacent OD pairs through which the line runs are within JTW areas (Birmingham, East Midlands or Sheffield).

Figure 7-6: Key corridors
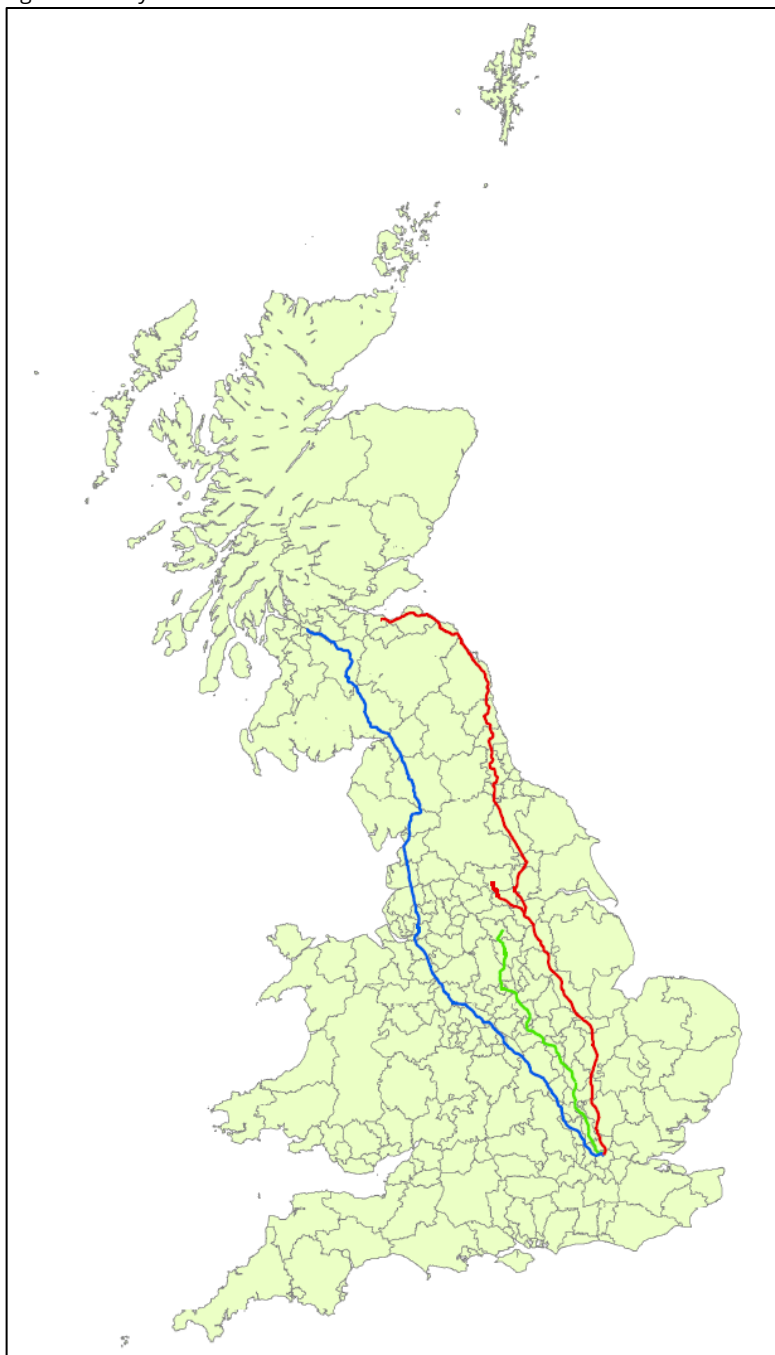
7.6.11   Local trips have been defined as trips between adjacent zones along the key corridors. This ensures that, for example, demand from Crewe to Warrington is included in PN, but demand from Crewe to Preston is modelled in PLD.

7.6.12   The control matrix removes the following trips from the scope of PLD:

- all trips wholly within defined journey to work areas for Birmingham, the East Midlands, Liverpool, Manchester, Sheffield and Leeds;
- trips between neighbouring PLD zones within key sections of the WCML, MML and ECML;
- all trips internal to the PLANET South model area; and,
- all trips internal to Scotland and internal to part of Wales.

7.6.13   Consequently, these movements are all catered for in the appropriate Regional PLANETs, while those movements which remain in the scope of PLD are removed from the Regional PLANETs.

Classification of services

7.6.14   In respect of transferring loadings from the Regional PLANETs to PLD, the basic process is to identify the local demand in the regional model which has been assigned to long distance services, and calculate the level of that local demand in units of passenger demand per train per hour. These rail pre-loads are then exported from the regional model and imported into PLD.

7.6.15   The scope of the Regional PLANETs can be conceived in terms of boundaries or "cordons". A service is considered as long distance for a Regional PLANET model if it has at least two stops within the cordon and proceeds beyond the cordon.

7.6.16   The initial step in the process is to define a series of "dummy" services to represent the corridors of interest; then relevant services in those corridors are "flagged" and, finally, the local demand rail preload values are calculated and exported.

7.6.17   In respect of transferring loadings from PLD to the Regional PLANETs, for PM and PN the demand is transferred from PLD as a passenger preload on selected services. This is done in terms of passengers/train/hour and represents those PLD passengers assigned to use services classified as long distance within the Regional PLANET, thus interacting with local passengers.

Rail preloads

7.6.18   In simple terms, the process for identifying and transferring pre-loads between the models relies upon two manual processes. First, the identification of the sections of train tracks (links) where pre-loads are required and, second, the identification of the

train services (transit lines) which carry both 'local' and long-distance demand on those track section (links). This process enables these transit lines to be included in the pre-load process only on the applicable links, even if the transit lines traverse more than one pre-load area. This becomes even more crucial as pre-loads are included for short distance movements along strategic corridors as well as in urban areas.

7.6.19   Technically, it is feasible to match individual services in PLD and the regional models in order to directly pass actual demand to the correct service in the other model. However, the services modelled in PLD and the regional models are not necessarily consistent. For example, services may run only outside the AM peak period and therefore would not be included in the regional models. Conversely, service patterns and utilisation may be different in the AM peak when compared to an all-day model. As a result, such a detailed approach is complex and labour intensive.

7.6.20   The process of producing the transit lines from SPG files for PLD and the regional models leads to a number of distinct service specifications within the PLANET models, many of which are slight variations in stopping pattern or timings rather than being substantially different services. For this reason, when transferring from the Regional PLANETs to PLD, similar transit lines are grouped into "packets", so that pre-load demand is passed between similar services in the local models and PLD. Each packet is given a unique code that is present in both the local model and PLD, and pre-load transfer occurs between these sets of transit lines at a packet level.

7.6.21   Before the process can take place, certain manual tasks need to be undertaken, namely:

- defining which services are eligible for pre-load transfer in the Regional PLANETs and PLD;
- defining which packet to each of these services belongs; and,
- defining the AM peak to all-day factor for each TOC.

7.6.22   Note that HS2 services do not fall into the category of "eligible for pre-load transfer" due to the restriction on travel between Old Oak Common, Heathrow and Euston.

7.6.23   First, the links that are within the core areas of the regional models are identified. In PM and PN these are largely within the TTW areas (for example Manchester to Stoke-on-Trent). Links in PS are defined as those on strategic corridors (for example, the WCML). This is because services that are not on strategic corridors will not be carrying long-distance demand. This shows that choice of links and services are inter-related.

7.6.24   Second, the subset of services which are eligible to be used in the pre-load process are defined. These services necessarily need to be able to transport strategic demand and local demand. Therefore, the service needs to have rail service origin and rail service destination in different TTW areas (for strategic demand criteria, i.e. if they were both in the same area, then the control matrix would mean all demand would be modelled in the designated regional model); and have at least two stops in a given TTW area (for local demand included in regional model to be able to make use of service).

7.6.25   Services are then grouped together into 'packets' in PLD and regional models if they are similar in terms of the stations they call at and the markets they cater for. This enables pre-load allocations to take account of journey times, stopping patterns and individual services. To remove the directionality of AM peak demand, the demand is averaged between the outward and the reverse link in the Regional PLANETs.

7.6.26   As PLD is an all-day (0700–2300) model and the regional models are all AM peak period (0700–1000) models, factors (F) are required to convert between time periods, both AM Peak period to all-day and all-day to peak period, to provide a representation of crowding impacts over the appropriate time periods. To transform peak flows to all-day and vice versa, demand profiles from MOIRA have been used to create suitably robust factors.

7.6.27   Factoring demand is important, as demand profiles vary considerably over the course of a day. For example, consider demand on long-distance West Coast services to and from Manchester. Long-distance demand on the WCML is heavily skewed towards London in the early morning and a corresponding return peak in the late afternoon/early evening. Demand on these services modelled in PLD is balanced in both directions as the PLD model is an all-day model. When transferring long distance demand on these services from PLD to the regional model (PN in this case), demand profiles become important because in the AM peak period covered by PN, long-distance demand on services to London is much higher than on services from London.

7.6.28   Conversely, local demand using the same long-distance services also requires factoring when transferred from a Regional PLANET to PLD. For example, AM peak flows modelled in PN (such as Stockport to Manchester or Macclesfield to Manchester) are heavily biased towards Manchester in the AM peak, but for inclusion in the all-day PLD such flows are directionally balanced and should be factored before transfer to PLD.

Pre-load factors from Regional PLANETs to PLD

7.6.29   The following equation is used to calculate the pre-load factors from Regional PLANET to PLD:

Equation 7-2:

$$X_{PLD} = \frac{X_{RP} + X_{RP}{}^{r}}{2} \cdot F \cdot \frac{T_S}{T_P}$$

where:
- X_{PLD} = Pre-load in PLD
- X_{RP} = Regional PLANET packet flow
- X_{RPr} = Regional PLANET reverse packet flow
- F = AM peak – all-day factor
- T_S = Trains per day
- T_P = Trains per day in PLD packet

7.6.30   The factoring mechanism allows for factors converting PM, PN, and PS AM peak demand (local short-distance flows) to PLD all-day demand to be disaggregated by TOC. However, analysis of local demand using MOIRA data suggests that there is little variation between TOCs. Therefore a factor of 2.67 is applied to all TOCs in the PM and PN areas, while in the PS area a factor of 3.2 was found to be more appropriate. This factor converts two-way AM peak segment flows on a link for a specific service to an all-day flow (thereby ensuring pre-loads in PLD are directionally balanced).

From PLD to Regional PLANETs

7.6.31   The factor to convert PLD demand to regional model demand varies by the type of movement of the transit line, as there are strong tidal flows into London in the AM peak. As such, factors are provided for Non-London, To London and From London services, as shown in Table 7-1. These factors are used to apply directionality to the PLD to PM and PN regional model pre-loads. An alternative 'wormhole' approach is used in the PS area, as discussed below.

Table 7-1: All-day to peak period conversion factors

Direction	Factor
Non-London	0.22
To London	0.27
From London	0.10

Source: MOIRA demand profiles

Wormholes

7.6.32   "Wormholes"[54] are effectively dummy zones at or near the PS cordon: there are 10 of them related to existing services, and a further three to deal with HS2. By means of a "select link" analysis[55] at each cordon point in PLD, origin-destination matrices of demand passing through the point are established. After scaling from all-day to peak-only levels, these are converted to PS zones.

7.6.33   The demand data for each cordon point is then accumulated into a single matrix for all the cordon points, and the resulting demand is assigned onto long-distance services in PS, with the PS assignment routines allowing the demand to reach their final destinations within the PS area using any other rail or underground services.

7.6.34   This has the advantage of enabling the long-distance demand to be assigned in a realistic manner on the more detailed PS network. The 'wormhole-based' demand is allocated to a separate 'user class', and is not subject to the standard demand (elasticity) responses in PS. In addition, it is not evaluated in the economics, as it is already included in PLD, and is purely included in PS to provide suitable crowding levels in the model, and to enable the patterns of long distance demand dispersal to be better represented and understood. It will, however, through the crowding mechanism, affect the demand responses for "local" trips within PS.

7.6.35   The PS cordon is shown in Figure 7-7. For existing services, 10 links crossing this cordon are identified in PLD: Newport – Cardiff, Newport – Hereford, Gloucester – Cheltenham, Moreton – Evesham, Banbury – Leamington, Wolverton – Rugby, Wolverton – Northampton, Bedford – Wellingborough, Peterborough – Leicester, Peterborough – Grantham. A wormhole zone for PS is associated with each link: note that the links are bi-directional.

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[54] The wormhole terminology is used to represent the process of the artificial demand transfer from PLD to PS.
[55] A 'select link analysis' is an option within an assignment procedure which allows the demand matrix contributions to the load on a specified link to be identified.

Figure 7-7: Location of PS cordon

7.6.36　For HS2 there is a further wormhole, but in the output this is split into three matrices – one for Euston trip ends, one for Old Oak Common trip ends, and one for all others. Provision can also be made for a possible HS2 link to Heathrow.

7.6.37　For each of these links, in both directions, a select link analysis is performed in PLD assignment – separately by user class. So for link a, user class u, a (sub-)matrix $T_{a,}{}^{u}{}_{RS}$ between PLD stations R and S is obtained, representing all the movements using link a, in either direction.

7.6.38　These PLD matrices needs to be factored to allow for the fact that PS is only for AM peak. This is done using MOIRA2 profiles by departure time – there are 240 of these, defined on:

- 3 journey purposes (business, commute, leisure);
- 5 flow categories (To London, From London, To Blue[56], From Blue, Other);
- 2 journey legs (Outward, Return); and
- 8 journey time bands (0–20, 21–50, 51–100,101–140, 141–180, 181–270, 271–360 and 361–999 minutes).

Each profile implies a specific factor to convert from full day to AM peak.

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[56] In MOIRA, 'Blue' refers to a major commuting destination station excluding London.

7.6.39   For PFM purposes, some of these are combined. Given that for PS the majority of demand is to/from London, the distinction between To and From 'Blue' has been dropped. Since the MOIRA2 profiles are based on departure times, they can be used directly for the 'From London' movements, but for the 'To London' movements an adjustment has to be made to determine which trips arrive in London within the AM peak period, using the average journey time to London for the given journey time band.

7.6.40   Separately by purpose and direction, each RS pair is allocated to one of the profiles[57], and hence the relevant factor t^{pd}_{RS} is obtained: these factors multiply the select link matrices $T_{a,}{}^{u}{}_{RS}$.

7.6.41   In the standard case, one of R or S will be within the remit of PS: in some cases, however, neither station is (e.g., South Wales to North East England). In principle, the end which is outside PS will be converted to the corresponding wormhole zone 'a', while the end within PS needs to be disaggregated to a PS zone, as the zone systems differ between PLD and PS. This is done by aggregation correspondence lists held within EMME. The aggregation correspondence lists associates PLD stations with their PLD geographic zones, so that the select matrices are output from PLD in geographic zone format. These are then disaggregated into PLANET South zones where appropriate by another ensemble.

7.6.42   For non-London zones, the disaggregation was simply based on what proportion of trips in PS made up each PLD zone, making allowances for where PS zones cut across PLD zone boundaries. For London zones, the Railplan distribution (based on the distribution at the London end of trips to Manchester) was found to be much more suitable, and this distribution was conveyed to the Greater London zones in PS via a simple correspondence.

7.6.43   Note also that where R and S are both outside PLANET South, trip ends are re-aggregated to the wormhole zones by an automated spreadsheet process which uses the distribution of select demand flows across the PS cordon to distribute trips across the wormhole zones. This effectively replicates the assignment of the select demand but truncated at the PS cordon.

7.6.44   The resulting factored matrices can be combined (by direction, user class and wormhole) and passed as input to PS assignment.

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[57] NB because the profiles are defined on journey time (defined as in-vehicle time plus the Number of Interchanges multiplied by 30 minutes, derived from PLD model skims for IVT and Number of Boardings minus 1.), it is possible that the allocation could be scheme-dependent, though this will not normally be the case.

Implementation

7.6.45   The way in which the interfaces are achieved within the overall PFM structure is described in Chapters 9 and 10.

Part 4 – PFM model assembly and forecasting

In this part, a description of how the networks and the base demand matrices were built up is provided. Following this, in two steps the use of the model for forecasting is explored. The first step relates to the "Do Minimum" case, where the growth of demand over time, as well as the expected changes to the networks is described. The second step relates to the introduction of HS2 and other associated changes to the rail network.

8 Base year demand and networks

8.1 Introduction

8.1.1 The Base Matrices represent the demand in the base year (2018/19), and, with the exception of the air mode[58], are used as the foundation for forecasting the future year demand in specific years. Thus, they represent an essential component in the overall PFM.

8.1.2 Extensive work has been carried out to derive consistent and reliable Base Year Matrices. The emphasis of the work relates to the scope of the PLD matrices. The three modes (rail, car, and air) were derived independently, but cross-checks have been carried out to ensure modal consistency.

8.1.3 Separate matrices are required for the three purposes (Commuting, Business and Other), and as noted in Section 2.3, they are segmented between car available and non-car available (though for both the car and air modes the matrices are assumed to relate only to car available travellers).

8.1.4 The following three sections provide an overview of how the matrices were developed. As was noted in Section 2.2, the matrices have generally been prepared on an OD basis, though the methodology has been designed to provide them on a P/A basis as well. They relate to average weekdays. To convert to total annual demand (for the purposes of appraisal) a set of mode-specific annualisation factors are used, reported in Chapter 11.

8.1.5 Section 8.5 then describes how the base year rail network was derived, both for PLD and the Regional PLANETs. PLD Rail Assignment was described in detail in Chapter 4, and this applies – with some minor modifications noted in Chapter 7 – to the Regional PLANETs. Section 8.6 describes how the base year rail fares were derived. For the remaining two modes (car and air), the base networks and assignment methods are discussed together (Sections 8.7 and 8.8).

8.1.6 As a result, this chapter presents all the necessary input to the base year models. The way in which the demand matrices are modified for future growth is described in Chapter 9, where changes to the Do Minimum networks are also described. The additional network changes for the Do Something case are described in Chapter 10.

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[58] The air mode demand forecasts are taken from DfT's Aviation Model rather than forecasting from an input base year demand matrix as in the case of rail and highway.

8.2   Base year rail matrices

8.2.1   In this section it is described how the base year rail matrices have been derived. In contrast with the car and air modes, where only long-distance movements are needed, base rail matrices are required not only for PLD but also for the three Regional PLANETs. While general principles are followed, there are some differences in approach which reflect both the context and the stage within the modelling at which the work was done.

8.2.2   Note that in model application, not all the elements in these matrices are in fact used because of the need to ensure that each flow is only represented once. This is managed by means of the 'control matrices' (see Section 7.6).

8.2.3   The primary source of data is the MOIRA revenue and journeys matrix for 2018/19, which provides total annual ticket sales (by ticket type) and revenues, for every combination of origin-destination stations. However, this data does not provide a journey purpose breakdown, so National Rail Travel Survey [NRTS], described in Section 5.3, is used. In addition, it should be noted that for trips to (and within) Travelcard areas such as London many of the trips in the MOIRA journeys matrix will be to Travelcard zones and will not identify individual stations.

8.2.4   The MOIRA journeys matrix relates to all trips during the year, while PFM only models travel choices/patterns within a single weekday (or, in the case of the Regional PLANETs, the weekday AM peak). Hence, the production of PFM rail demand matrices requires the MOIRA journeys matrix to be 'deannualised', removing travel at weekends, and, in the case of the Regional PLANETs, estimating the proportion of weekday trips occurring in the AM peak[59]. Factors are dependent on flow distance and based on ORCATS (Operating Revenue Computer Allocation System, a data source maintained for ATOC as part of the work of Rail Settlement Plan) assumptions for season tickets.

PLD rail matrices

8.2.5   The first stage in constructing the PLD Base Matrices distributed the de-annualised weekday MOIRA 2018/19 station-to-station data between zones of origin and destination depending on the location of the stations used.

8.2.6   The purpose splits were controlled to the NRTS data at a regional level, without making use of ticket types. On the basis of careful testing, it was concluded that this was a more appropriate method than using the most recent PDFH recommendations on ticket type to purpose conversion. Note that the definitions of purpose are compatible with those used for highway trips: the PDFH definitions are

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[59] As shown in chapter 12, allowance for these "missing" trips is made within the appraisal, by means of the "annualisation factors".

slightly different in terms of the treatment of longer distance commuting and education trips.

8.2.7   The NRTS was also used to segment passengers between car available and non-car available, but incorporating an allowance for the growth in car ownership over time to the 2018/19 base year.

8.2.8   The outcome is a set of matrices which in aggregate correspond to the MOIRA journeys matrix, but which have incorporated additional data and analysis to produce a best estimate of zone-to-zone rail demand by purpose and car availability.

8.2.9   Primarily to inform the access possibilities in the SCM, car available matrices are split between outward movements (CAF – 'Car Available From', where a car is available at the origin) and return movements (CAT – 'Car Available To', where a car is available at the destination).

8.2.10   Apart from intra-zonal movements, the PLD matrices have been constructed for all possible movements, regardless of journey length. However, by means of the "control matrices" (Section 7.2), many of the cells are masked out in the model application.

PLANET Midland (PM) and PLANET North (PN) rail matrices

8.2.11   The PM and PN rail matrices were derived from the same MOIRA 2018/19 journey matrix as the PLD rail demand matrices. The PM and PN matrices use a similar process as the PLD matrices whereby the MOIRA station to station movements are mapped to zone-to-zone movements, segmented by journey purpose. The main difference in the development process is that the PM and PN demand is deannualised to the AM peak period, whereas PLD represents a 16-hour "all-day" period.

PLANET South (PS) rail matrices

8.2.12   The PS model has a highly detailed zoning system, being based on earlier versions of Transport for London's (TfL's) Railplan model. Because the level of zonal detail contained within MOIRA for movements within London is far less than is contained within the PS model, MOIRA is not the most suitable data source. As such, a version of TfL's Railplan is used to map directly to the PS zone system, as the zoning systems are more comparable and Railplan has a more detailed representation of movements within London.

8.2.13   The 2016 Railplan matrices were used to derive PS matrices for the 2018/19 base year. The RRP zoning system is mapped to the PS zone system using a Geographic Information System (GIS) process. The journeys matrix is then segmented into

journey purposes and production/attraction format specifically for the PS model. The data were then uplifted from 2016 to 2018/19 using sectoral uplift factors derived from interpolated MOIRA data for 2014/15 and 2018/19. As previously mentioned, the journeys matrix is then masked using a control matrix to ensure that long-distance movements are excluded from the PS journey matrix.

8.3 Base year highway matrices

8.3.1 Highway trips are only represented in PLD, which captures longer distance movements, generally following the alignment of the HS2 scheme. There is no highway representation in any of the Regional Planet models.

Source data

8.3.2 The PLD highway demand matrices were developed using demand matrices from Highways England (HE) highway models that included March 2015[60] demand matrices for the following regions: North, Midlands, South East, South West and TransPennine South. Highway movements internal to Scotland and Wales are not included in the HE models, hence the internal highway movements for these devolved nations were retained from earlier versions of the PLD base model.

8.3.3 The HE car matrices (Light and Heavy Goods Vehicles were excluded) represent the best available representation of the highway demand in England. They are derived from an observed data set using mobile phone data with very high sample sizes.

Zone mapping

8.3.4 To transform HE demand matrices to the PLD zone system, the HE trips are modified in all matrices based on the overlapping area between HE and PLD zones. There are a small number of HE zones that overlap several PLD zones, but the vast majority exactly fit within the PLD zones. Where HE zones overlap several PLD zones, the number of HE trips to be allocated to each PLD zone is pro-rated by the relative size of the overlapping areas.

8.3.5 There are more than 9,000 zones in total in all of the HE highway models, where each model includes 3 journey purposes (Business, Leisure, and Commute) and 4 time periods (AM peak, PM peak, Inter-peak, and Off-peak). This dataset is managed in a SQL database that brings together the individual RTMs into a national matrix for PLD.

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[60] The 2015 HE highway demand matrices are converted to PLD demand matrices and then growthed to 2018/19 using TEMPRO growth forecasts.

8.4 Base year air matrices

8.4.1 The PLD model contains domestic airport-airport non-transfer movements, thus the geographical scope of movements is confined exclusively to mainland Great Britain and excludes:

- movements to/from Northern Ireland, Isle of Man, etc.; and,
- interlining trips (i.e. those movements with two or more legs, where the first leg is within Great Britain but the second and any subsequent legs are international; similarly for inbound journeys, only legs wholly within Great Britain are included).

8.4.2 The matrix of air passenger movements is derived from outputs from the DfT's Aviation Model forecasts. It should be noted that the focus of the DfT aviation model is more on the international than the domestic air market sector. The main source of data for the DfT aviation model is the Civil Aviation Authority passenger survey, which provides information about the ultimate origin and destination of (departing) passengers, together with total passenger data which allows the data to be expanded.

8.4.3 This has been analysed to provide an airport choice model, separately for business and leisure passengers (commuting is not a significant purpose for this mode). It is assumed that all air travellers have car availability[61], so the matrices are not split between car available and non-car available. The matrices are produced on an annual basis, but converted to average weekday by means of the annualisation factors discussed in Chapter 11.

8.5 Base rail (PLD) network

8.5.1 The PLD rail network represents "strategic" corridors, such as the main trunk lines across Britain (for example, the West Coast Main Line (WCML), East Coast Main Line (ECML), Midland Main Line (MML), Great Western Main Line and Cross-Country and Trans-Pennine routes). The rail network in PLD (which derives from an earlier version known as the 'Planet Strategic Model' developed for the Strategic Rail Authority [SRA] in 2002) does not cover all local commuter rail lines, unless they are part of a strategic corridor[62]. Key features of the rail model include:

- strategic route choice for rail trips across mainland Britain;
- the all-day service frequency and stopping patterns of trains;

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[61] There is little evidence on the car availability of air passengers (the standard CAA questionnaire does not ask about it). A very small proportion (0.02%) of all trips in the NTS (2002-2010) are coded as having main mode air, and of these, 91% are from car owning households. Thus, the assumption is probably slightly conservative (since non-car available travellers are probably more inclined to switch to rail).

[62] For instance, the majority of the London, Birmingham, Manchester or Glasgow rail commuter networks are excluded from the model, but those services sharing tracks with the various strategic routes would be included.

- representations of wait time and interchange time; and,
- "shadow services" incorporated to absorb local trips in the demand matrices.

8.5.2   The original network was defined by the following criteria for inclusion of services:

- Existing rail links that link the 30 largest conurbations within England, Scotland and Wales, together with Gatwick, Stansted and Manchester Airports;
- Routes that form an integral part of the principal long-distance lines (including ECML, WCML, MML); and,
- Passenger rail routes included in the Trans-European Network.

8.5.3   It was developed in order to forecast the impact of rail network improvements on strategic passenger rail movements, defined as passenger rail movements between major traffic generators (including large cities, airports and international rail termini) of over around 100 km in distance.

8.5.4   Train service patterns for the base year model are sourced from available timetable information. This is typically via MOIRA2 software[63], which contains service patterns for all TOCs for the base year. These timetables are converted into EMME format transit lines for inclusion in the PLD and regional sub-models. For consistency, MOIRA is also used as the source of the majority of train capacities by different stock type.

8.5.5   The starting point for rolling stock capacities is MOIRA2. This uses the total seating capacity and standard class standing capacity (defined as at 2.5 passengers per square metre). In a few cases there were concerns over the MOIRA2 values (for example, the ratios of seating to standing capacity), and these were then revised based on discussions with DfT and comparison against similar rolling stock types (e.g. 45% for intercity stock based on advice from DfT and independent measurement of the rolling stock layout on, for example, Pendolinos). Note that where no capacity data exists in MOIRA2 for a rolling stock type (and no similar type of rolling stock is listed), the currently used capacity data in PFM (derived from DfT's National Modelling Framework) [NMF]) is retained.

8.5.6   The key fields for matching in the formation and capacities data are illustrated in Table 8-1. The "Total capacity" minus the number of seats gives a notional figure for the number of standing places available. In practice, it is assumed that this figure relates to a standing density of 2.5 passengers per square metre. Further information is given in Section 4.4 on crowding.

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[63] Timetables for specific TOCs and years can also be supplied directly by DfT.

Table 8-1: Example of train formation CSV data

Field	Example
Unique Identifier (UID)	L12455
Formation	1*TL (12-car)
Seats	659
Total capacity	1770

8.5.7   London Underground transit line data were supplied by TfL in the form of an extraction of all transit lines for the Underground from Railplan[64], and was combined with vehicle type data extracted from Railplan.

8.5.8   The PLD Rail Network is shown in Figure 8-1.

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[64] Railplan is Transport for London (TfL)'s standard public transport assignment model.

Figure 8-1: PLD Rail Network
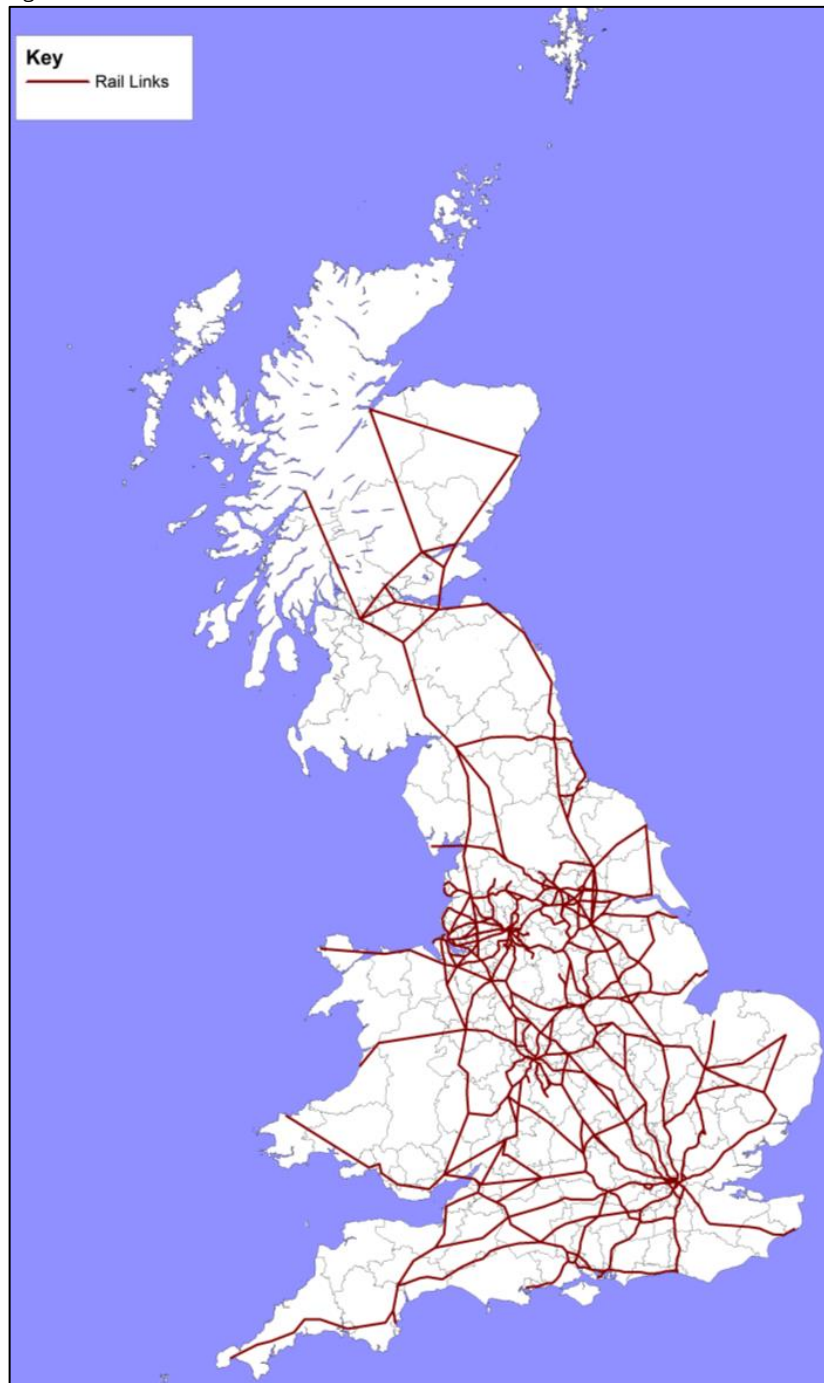
8.6 Base year rail fares

8.6.1   Although fares are not used in the rail network assignment, they are used in the demand and appraisal modules, and it is therefore convenient to describe them here.

8.6.2   While ideally the approaches taken to develop the trip and fares matrices would be consistent, the approach of defining purpose for the trip matrices without recourse to ticket type means that total trips between a zone pair are split into commuting, business and leisure. If the revenues were processed using the same set of proportions, the ratio of revenue to trips would be the same for each purpose – so there would be no fares differentiation by purpose. Much of the differentiation by purpose is expected to be due to the different mix of purposes travelling at weekends and in the peak and off-peak periods and is thus related to ticket type.

8.6.3   Accordingly, it was decided to use the revised mapping of ticket type to journey purpose adopted in PDFHv6 to derive the fares matrices. Section B1 of PDFH6 (version dated May 2018) was used to obtain the ticket type to purpose conversions for the geographic areas covered by PLD.

8.6.4   The appropriate purpose splits were applied to each zone-to-zone movement, taking into account combinations of origin/destination and trip length, to both the numbers of journeys and the total revenue for each ticket type (full/reduced/season) and zone pair for the CA trips[65]. The results were aggregated to give the total revenue and total trips by purpose for each zone pair.

8.6.5   For each zone-to-zone movement, the fares for a single journey are calculated by dividing the total MOIRA revenue by the total number of MOIRA trips. In cases where there are insufficient observations or the implied fare is significantly different from the average, a series of checks and adjustments are made to avoid extreme fares, along the following lines.

8.6.6   The average yield per kilometre (total revenue/total trips/distance) is calculated for each zone pair and trip purpose. These are used to give an average and acceptable range (minimum/maximum) for the yield per kilometre for each purpose as follows:

- Average: median yield per kilometre for purpose across all zone pairs for purpose; and,
- Minimum/maximum yield per kilometre: median ± standard deviation of yields per kilometre across all zone pairs for purpose.

8.6.7   A series of thresholds were also defined:

- Small flows <0.05 trips per weekday for zone pair (summed across all trip purposes);

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[65] The processing of the trip matrix is carried out for car owners and non-car owners separately. To use the same processing tools, the car owning stage (being the majority of the trips) is run for revenue as well as trips to derive the fares for all trips whatever their car ownership.

- Large flows >50 trips per weekday for zone pair (summed across all trip purposes); and,
- Minimum fare: £2.00

8.6.8   The fares were then calculated as shown below:

- For zone pairs with large flows (>50 trips/weekday) and intra-regional flows (wholly within GORs): Fare = Maximum [Total revenue/total trips, £2.00].
- For all other zone pairs (inter-regional with flows ⩽ 50 trips per weekday):

  - If average yield per kilometre not within defined range, or volume of trips is small or initial fare is less than minimum (£2.00): Fare = Maximum [average yield per kilometre * distance for OD, £2.00].
  - Otherwise: Fare = Maximum [Total revenue / total trips, £2.00]

8.7   Base highway network and assignment

8.7.1   The highway network represents the UK strategic road network, with notional access links (centroid connectors) from model zones. Generally, the model includes motorways and the primary route network, with infill in certain areas where the primary route network is sparse. Key features of the highway model include:

- strategic route choice for car trips across mainland Britain;
- all-day representation of demand, converted to hourly demand to be compatible with hourly speed/flow relationships, based upon COBA[66] contained within TAG Unit M3.1 Appendix D;
- strategic demand only, supplemented by local pre-loads; and,
- three trip purposes (user classes), plus a single pre-load for goods vehicles and local car trips.

8.7.2   Road types were identified using Ordnance Survey [OS] mapping and verified for the UK trunk road network. Once the road type was identified, the relevant speed/flow relationship code was added to the link information. The number of lanes on motorway links were checked using internet available imagery and on other link types using OS mapping.

8.7.3   Highway network link types are defined as follows:

- motorway;
- dual carriageway;
- single carriageway; and,

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[66] The Cost Benefit Analysis programme developed by DfT/HA for road schemes.

- other (reserved for centroid connectors and airport links only).

8.7.4   The road types are shown in Figure 8-2.

Figure 8-2: Link types in the highway network
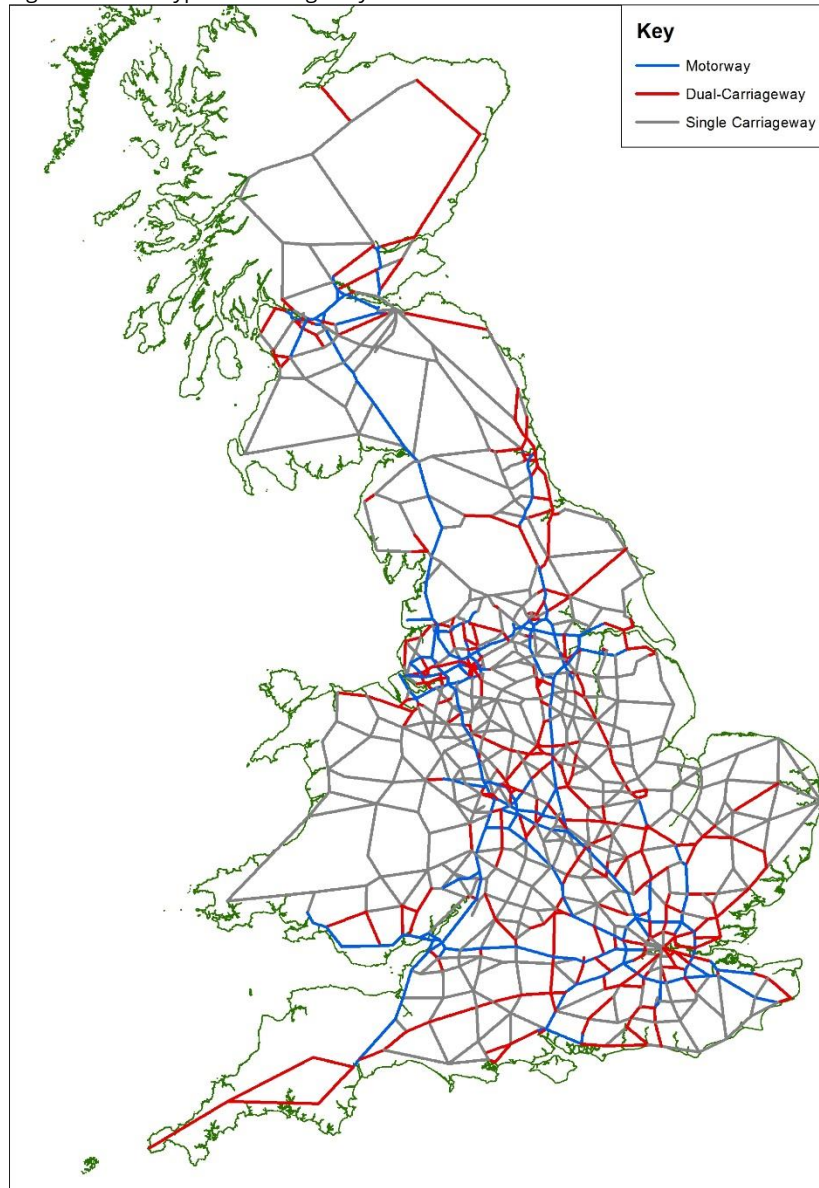
8.7.5   The majority of highway links have been assigned as motorway, dual carriageway and single carriageway speed/flow relationships; with centroid connectors and airport links assigned fixed speeds. The speed/flow relationships for these link types match TAG Unit M3.1 curves, as shown in Table 8-2. They allow the speed to be calculated for different levels of flow on different carriageways. According to standard practice for rural roads, three sections are recognised (see TAG M3.1): in the first section, the speed of vehicles reduces slightly as flow increases until a critical flow level "break point" (Q_B) is reached, after which we move to the second

section in which the rate of speed reduction becomes greater until capacity (Q_C) is reached. The third section (above capacity) employs a formula based on queuing theory. These are compatible with the recommendations in TAG M3.1: note that the speeds for flows over capacity are given by the Advice Note 1A relationship.

Table 8-2: Speed/flow parameters for PLD Highway Network

	Motorway		Dual carriageway		Single carriageway	
Flow level	**Flow/lane /hour (F)**	**Speed (km/h)**	**Flow/lane/ hour (F)**	**Speed (km/h)**	**Flow/lane/ hour (F)**	**Speed (km/h)**
less than Q_B	<1200	116-0.006*(F)	<1080	116-0.006*(F)	<1280	72.1 - (0.015+0.00027*5) *(F)
> Q_B, < Q_C	>1200, <2250	105-0.033*(F-1200)	>1080, <2180	101.5 -0.033*(F-1080)	>1280, <1600	51.2-0.05*(F -1280)
> Q_C	>=2250	70.4/(1+70.4*(F-2250) / (8*length*2250))	>=2180	65.2/(1+65.2*(F - 2180) / (8*length*2180))	>=1600	35.2/(1+35.2*(F - 1600) / (8*length*1600))

where:
- Q_B is the flow at which the speed/flow slope of light vehicles changes (veh/hour/lane);
- Q_C is the maximum capacity (veh/hour/lane); and,
- Length is the link length in km.

8.7.6   The PLD highway demand only contains long distance movements, as discussed in Section 8.3. As such, assigned traffic volumes on the highway network should be lower than observed counts and the difference between the two sets of traffic volumes is assumed to be "local traffic".

8.7.7   Highway "pre-loads" are calculated in the base year and represent the difference between count data and the assigned flows from the PLD demand matrices. These are attached to links to reflect local traffic. These highway pre-loads include all vehicle types (LGVs, HGVs, Public Service Vehicles (PSVs) as well as cars).

8.7.8   The highway pre-loads were derived from the DfT's traffic counts, which have the benefit of being split by vehicle type, requiring no further processing and full road coverage for the UK. The dis-benefit is that they are undertaken using manual counts once every five years, and are therefore less accurate, but for the purpose of the highway model in PLANET this was deemed to be satisfactory.

8.7.9   Count data were obtained from the DfT's major roads two-way flow count set[67]. The full data set was downloaded and the values used for comparison to the modelled flows (the latest year available at the time of the exercise).

8.7.10   In addition, an initial base year PFM model run was undertaken using the new matrices with the highway preloads set to zero. This provided flows from a pure un-congested assignment to be compared against the DfT counts.

8.7.11   The counts and the flows were matched with the PLD links through use of GIS software. All the counts and the base year PLD highway network were plotted in ArcGIS and each count was then assigned to any link within 300 metres.

8.7.12   This meant that some links were connected to multiple counts and in rare occasions counts were connected to multiple links. However, when rationalised, this resulted in a correspondence list between PFM links and DfT count site identifiers.

8.7.13   This correspondence list was used to connect the count data, GIS data and the flow data from the assignment and calculate the pre-loads. The stages below provide an overview of the process adopted:

- for each link in the model the road name(s) and two-way count data were collated;
- the average flow by vehicle type is then calculated, and combined with GIS outputs to bring together the link flow from the base year assignment and the count data; and,
- the differences are then calculated as the preload value.

8.7.14   The DfT Transport Statistics data are available in Average Annual Daily Traffic (AADT) form. AADT was converted to Average Annual Weekday Traffic flows [AAWT] by applying a factor of 1.07, derived by comparing the AAWT and AADT flows from the existing TRADS counts in year 2010.

8.7.15   A summary of the conversion factors by road type is given in Table 8-3. The counts were then allocated to their appropriate link and applied equally to both directions. In total, over 900 TRADS counts and a further 1,950 DfT counts were used.

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[67] DfT GB Road Traffic Counts: https://data.gov.uk/dataset/208c0e7b-353f-4e2d-8b7a-1a7118467acc/gb-road-traffic-counts

Table 8-3: AADT to AADW Factors in 2010

Road type	AADT to AAWT factor	Count of site
Motorway	1.08	257
Dual carriageway	1.08	153
Single carriageway	1.07	161
Total	**1.07**	**571**

8.7.16   Whereas longer distance traffic is an output of the demand model, local traffic is assumed not to be responsive. Traffic volume has an impact on modelled journey times, which are governed by the speed/flow parameters described above. If traffic volume is reduced (due to mode shift to HS2 for example), less delay occurs, adding to the HS2 scheme de-congestion benefits. Local road congestion is not included in the model (as the nodes and links and detailed zone structure do not exist): the model is only concerned with change in journey times on the strategic leg of the highway journeys.

8.7.17   Of the included strategic roads, junction delays are not modelled due to the relatively low proportion of delay attributable to junctions for long distance trips. Since the mode choice model is incremental, the main function of the highway network is to provide robust strategic journey times.

8.7.18   The model uses a multiclass (business, other and commuting) generalised cost assignment algorithm. It uses the standard EMME highway equilibrium assignment algorithm to achieve convergence, with up to 50 iterations permitted. Convergence is reached at 0.01% best relative gap or 0.01 mins normalised gap[68].

8.8   Base air network and assignment

8.8.1   The air model covers most domestic air services in mainland Britain. Key features of the air model are:

- demand data for domestic UK, non-interlining trips;
- two journey purposes (business and other, not commuting);

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[68] from the EMME user manual, these terms are defined as follows:
"The best relative gap is an estimate of the difference between the current assignment and a perfect equilibrium assignment, in which all paths used for a given O-D pair would have exactly the same time. The relative gap is the difference between the total travel time on the network and the total travel time on the shortest paths for the current iteration, divided by the total travel time on the network.
"The normalized gap, or trip time difference, is the difference between the mean trip time of the current assignment and the mean minimal trip time. The mean trip time is the average trip time on the paths used in the previous iteration; the mean minimal trip time is the average time computed using the shortest paths of the current iteration. The relative gap decreases strictly from one iteration to the next, whereas the trip time difference does not necessarily have this property. In a perfect equilibrium assignment, both the relative gap and the normalized gap are zero."

- a network that represents the timetabled paths for a particular year supplemented by a transit line timetable file that provides the routes and number of flights;
- representation of fare, service frequency, wait and journey time;
- "unconstrained" (i.e. no congestion); and,
- car access and egress assumed to and from airports. The choice of airport is partly related to the air service characteristics, such as price and frequency, but also to the access and egress.

8.8.2   Air services are represented on a simple basis, with individual "transit lines" representing flights operating between different UK airports, as shown in Figure 8-3. Congestion is not modelled on air routes, as congestion on the air network is less about aircraft seating capacity than a shortage of runway slots at congested airports. If there is no congestion, then the airline response will be to increase frequency or the size of plane. This is not a problem in practice, as air services are more able to respond to demand with pricing mechanisms in the short term, and re-allocation of aircraft and routes in the medium term. There is also no allowance for reliability.

8.8.3   Air passengers are assumed to have car access at both ends of their air trip. This is consistent with airports outside London, where public transport access is often poor, and the strategic network represents very few actual airport rail links. In addition, air passengers tend to have a higher value of time and are more likely to use taxi if a car is not available for that leg. Interliners[69] are not covered by the PLD air model.

8.8.4   The supply data for air has been provided by DfT Aviation. The base year domestic air fare matrix, from the DfT Aviation Model, provides air fares between all modelled airports in 2008 prices and values. These are adjusted to the base year. The fare matrix is based on a distance function, which has been developed for each individual airport with domestic flights.

8.8.5   The air assignment is a 2 user class assignment (business and other), with no crowding process, for the reasons given earlier. It should be noted that the air model exists to provide the PLD mode choice model with the generalised costs of air travel, as a competitor to rail.

8.8.6   Because the assignment operates on a zone-to-zone basis, rather than airport-to-airport, airport choice is implicitly accounted for, using the mechanism of the 'attractive sets' and frequency allocation (see Section 4.2 for a more detailed discussion in the rail context). In most cases it may be expected that the nearest

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[69] These are international air passengers using domestic air services for part of their journey.

airports will be used for any given movement between PLD zones (subject to a service being available).

Figure 8-3: Air Network
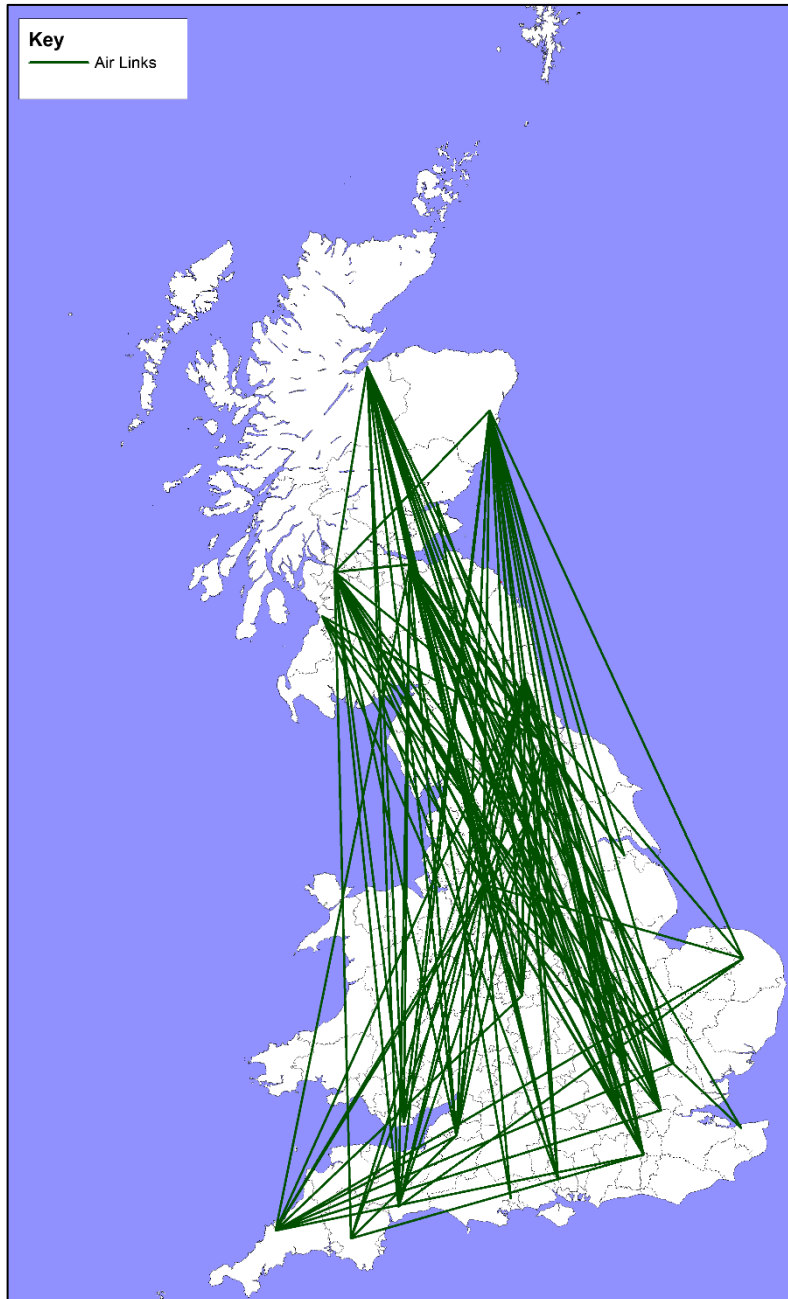
9 Forecasting the 'Do Minimum'

9.1 Introduction

9.1.1 To construct the Do Minimum [DM] forecast for a given future year Y, PFM requires forecasts of exogenous growth from external sources. These are obtained for each mode separately, but using a consistent set of "drivers", common forecasts of population and GDP.

9.1.2 In the case of car and rail, growth factors are obtained which can be applied to the Base Year Matrices described in Chapter 8. For the air mode, use is made directly of the DfT aviation model, described in Section 9.5. The resulting multi-modal matrices of demand TY are used as the "pivot" for predicting the impact of the Do Something case, as discussed in Chapter 10.

9.1.3 Both for the purposes of operating the demand model and for appraisal, the costs associated with the DM are also needed. To obtain these, the forecast T_Y is assigned to the (future) network and the resulting costs (C_Y) are taken as representative of the DM for that year. The principles for constructing the future year networks are set out in Section 9.6.

9.1.4 The rest of the chapter describes the detail of the growth forecasts.

9.2 Economic assumptions

9.2.1 As is explained in the following three sections, forecasts are made separately for the three modes (rail, car, air), and the required input variables ("demand drivers") vary between them, with the rail forecasts being the most detailed. Common to all three modes is a consistent set of assumptions relating to socio-economic drivers:

- Population;
- Employment; and,
- GDP per capita.

9.2.2 In addition, because the car ownership forecasts are based on household income growth, there is a need for a consistent set of demographic data relating to Households. In line with this, both rail and car forecasts are sensitive to Car Availability.

9.2.3 There are then the specific drivers related to Intermodal competition, both relating to prices (fuel costs, fares) and level of service, as follows:

Intermodal competition drivers[70]:

- National Rail fares;
- London Underground fares;
- Car time;
- Fuel cost;
- Bus cost;
- Bus time;
- Bus headway;
- Air cost;
- Air headway; and,
- Air passengers.

9.3 Forecasting 'Do Minimum' rail demand

9.3.1 The rail demand forecasting process is undertaken using the DfT's Exogenous Demand Growth Estimation Tool (EDGE). This is an implementation of the elasticity model recommended in PDFH6. Four separate elements are considered: External Environment, Inter-modal Competition, Fares and Journey Time, Frequency, and Interchange. PDFH makes a distinction between the rail-specific components [Fares (F) and Journey Time, Frequency and Interchange (J)] and "external" components (E). The latter include both the socio-economic drivers ("External Environment") and the drivers for other modes ("Inter-modal Competition").

9.3.2 For the external components, the model is:

Equation 9-1:

$$I_E = \left(\frac{GVA\ per.cap._{new}}{GVA\ per.cap._{base}}\right)^g \cdot GJT_{Trend}{}^j \cdot \left(\frac{POP_{index_{new}}}{POP_{index_{base}}}\right)^p \cdot \left(\frac{EMP_{index_{new}}}{EMP_{index_{base}}}\right)^e \cdot Exp[u(Particpn)] \cdot$$
$$\left(\frac{Car\ Cost_{new}}{Car\ Cost_{base}}\right)^f \cdot \left(\frac{Car\ Time_{new}}{Car\ Time_{base}}\right)^c \cdot \left(\frac{Bus\ Cost_{new}}{Bus\ Cost_{base}}\right)^b \cdot \left(\frac{Bus\ Time_{new}}{Bus\ Time_{base}}\right)^t \cdot \left(\frac{Bus\ Head_{new}}{Bus\ Head_{base}}\right)^t$$

where:
- I_E is the external factors index for the change in volume between the base and the new periods; and,
- The parameters are all elasticities, with the exception of n that determines the non-car-ownership elasticity.

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[70] Note that in the documentation of the EDGE model used for rail forecasting, the terms "Bus cost" and "Air cost" are used, and these are maintained here. However, it is clear from PDFH Section B1.4 that these are in fact Fare variables.

9.3.3　　These growth factors are then further multiplied by the growth brought about by changes in rail fares.

Equation 9-2:

For a uniform change in all fares or a change in the average fare, the formula used is:

$$I_F = \left(\frac{F_{new}}{F_{base}} \right)^{f_t}$$

where:

- I_F is the index for the change in volume due to changes in fare and fare related factors

- F_{new} is the new average fare and F_{base} is the base average fare, and the ratio of the two is the uniform fare change

- Both F_{base} and F_{new} should be expressed in real terms (see Chapter D1)

- f_t is the overall fares elasticity.

9.3.4　　Hence the overall zone to zone growth factor is the product $I_E . I_F$.

9.3.5　　The latest guidance from TAG (unit M4, Table 1) recommends that PDFH6 elasticities are used for all demand drivers. PDFH6 provides elasticities for the remaining 'external' components separately for season tickets and other ticket types, by general types of journey:

- London Travelcard Area [LTA];
- London Travelcard Area to/from South East;
- Rest of Country to and from LTA;
- Non-London to/from 'Core Cities' and 'Major Centres' with/without PTE;
- Non-London other flows; and,
- Airport Access.

9.3.6　　There are separate elasticities for each flow category and in some instances they vary by trip distance. The fares elasticities can vary by ticket type (full, reduced, season), and journey purpose depending on the flows and categories.

9.3.7　　EDGE is applied both to the base year PLD demand matrices and to the corresponding Regional PLANET matrices for the two modelled years.

9.3.8   As noted in Section 8.2, although base rail PLD matrices have been produced in P/A format, they have been converted to OD for use in the assignment model. For the car available segments, the P/A-based forecasts from EDGE are applied directly to the base CAF matrices and, in transposed form, to the base CAT matrices. For NCA, the forecasts produced by EDGE have been averaged over the two directions and then applied to the base NCA (OD) matrices to produce the required PLD forecast matrices. Thus, as far as possible, the directional variation in the growth factors is maintained.

9.3.9   In PLANET South the matrices are held separately by direction ("PA" and "AP"), and subsequently summed to form a full OD matrix before assignment. This means that the growth from EDGE can be applied directly (transposing for the AP direction). In PLANET Midlands and North, only OD matrices are available, so an average growth from EDGE over the two directions is used.

9.4   Forecasting 'Do Minimum' highway demand

9.4.1   The forecasting of the PLD DM car matrices relies generally on TEMPRO/NTEM methodology, as recommended in TAG M4 §7. The TEMPRO forecasts assume no changes in highway generalised cost and provide growth factors by Production and Attraction zones (and also by Origin and Destination).

9.4.2   The starting point was the set of 2018/19 Base Year Matrices described in Section 8.3. Although PLD works with OD matrices, for the explicit purpose of forecasting, the basic three purposes were expanded to the following:

- Home-based work (HBW) daily person P/A matrix;
- Home-based employers' business (HBEB) daily person P/A matrix;
- Home-based other (HBO) daily person P/A matrix;
- Non-home-based work (NHBW) daily person P/A matrix;
- Non-home -based employers' business (NHBEB) daily person P/A matrix;
- Non-home -based other (NHBO) daily person P/A matrix; and,
- The purposes of these matrices are compatible with the purposes present in TEMPRO.

9.4.3   P/A growth factors for the following purposes were then derived from TEMPRO, where the non-home based (NHB) factors were used for all disaggregated non-home based matrices (NHBW, NHBEB and NHBO):

- Home-based work (HBW);
- Home-based employers' business (HBEB);
- Home-based other (HBO); and,
- Non-home-based (NHB).

9.4.4   These growth factors are then applied using the Furness[71] procedure until a stable (P/A) matrix is obtained for each purpose. A further elasticity-based adjustment is made to allow for any difference between the economic forecasts being used for PFM and those implicit in TEMPRO.

9.4.5   Finally, the future year DM matrices are converted back to OD format using the derived P/A to OD factors (Section 9.3). For non-home-based matrices P/A and OD matrices are identical.

9.4.6   In the following sub-sections these various procedures are described in more detail.

Derivation of Furness targets from TEMPRO

9.4.7   Version 7.2 of the TEMPRO dataset was used to derive factors to 'Furness' the 2018/19 daily highway P/A base matrices to the two forecast years. The TEMPRO options chosen were to calculate Trip Ends (on a P/A basis) for an Average Weekday for all areas and sub-areas, for all individual purposes, and for the two modes 'Car driver' and 'Car passenger'. A correspondence list was applied to aggregate the combined car driver and car passenger modes data from TEMPRO unitary authorities to the 25 zone sector system shown in Figure 9-1. Finally, the 15 TEMPRO purposes were aggregated to HBE, HBEB, HBO and NHB.

9.4.8   This process was undertaken for both Production and Attraction totals and for the base year and forecast year data separately. The final stage was to divide the forecast year aggregated totals by the base year to produce a set of eight (four purposes by Production and Attraction) Row and Column factors to apply to the base year P/A matrix to produce Furness targets.

Furness calculations

9.4.9   The 2018/19 daily highway P/A base matrices in the model are factored by the row and column P/A factors, which are summed to row and column totals to produce Furness targets. The Furness calculations are then implemented, scaling to origin totals. This step produces P/A matrices for the six purposes (HBW, HBEB, HBO, NHBW, NHBEB and NHBW).

Application of GDP elasticity

9.4.10   A derived GDP elasticity (global factor) is applied to the output Business, Other and Commuting matrices to correct for the GDP discrepancy between TEMPRO and the latest OBR forecasts that have been used in the forecasting of rail demand.

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[71] This refers to the procedure for successively multiplying a matrix by a series of row and column factors until a converged solution is obtained (see for example Ortúzar & Willumsen, Modelling Transport, 2011).

9.4.11   There are two ways in which a change in GDP over time will affect the forecasts of car traffic: one is through a change in car ownership and therefore a change in the total number of trips by car, and the other is through a change in the VoT which will change the value of the money cost component of generalised cost, potentially affecting both the number and length of trips by car.

9.4.12   The elasticity of car trips to GDP was derived from earlier work[72] for HS2 Ltd , and the elasticities are shown in Table 9-1. These were derived by running alternative sets of GDP forecasts through the DfT's NTEM procedure (both car ownership and trip ends). The work suggests that the elasticity is very low (in the order of 0.125), and lower than the 0.16 vehicle kilometres value specified in TAG M4 para 7.4.14 that also includes the VoT effects just noted.

Table 9-1: Implied elasticity of highway demand to GDP derived from NTEM outputs

Purpose	Business	Other	Commute
Implied elasticity	0.151	0.147	0.087

9.4.13   The elasticities shown in Table 9-1 were applied to the relative growth in GDP and the resulting factors were applied globally to the forecast P/A matrices to correct for the change in GDP forecast.

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[72] PLANET Long Distance and Long Distance Model Comparison, Phase Zero Report, High Speed Two Ltd., March 2012.

Figure 9-1: 25 sector system
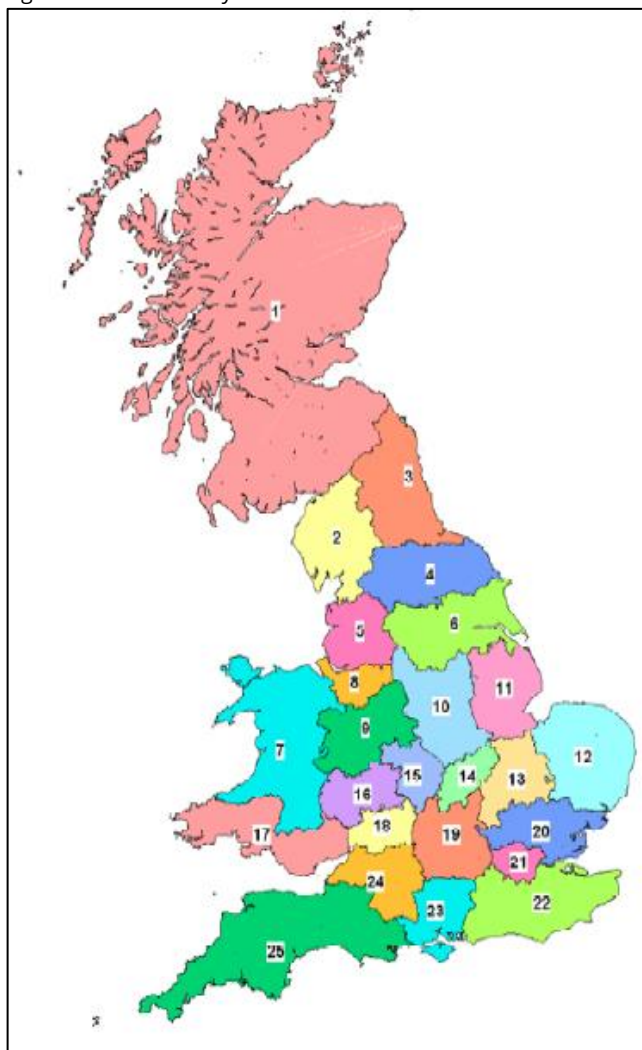
PA to OD conversion

9.4.14   The final process to create the future daily highway OD matrices uses the P/A to OD factors noted earlier. These were input to the process at the 25 sector level, and applied to the home based purposes to convert them to OD format. The required PLD purposes were then obtained by aggregating the 6 OD purposes.

Factoring 2018/19 pre-loads to future years

9.4.15   In addition to the forecast car matrices it is also necessary to adjust the highway pre-loads in the Highway Assignment model (Section 8.7). The pre-loads are calculated for the model forecast years using the NTM traffic forecast component of the Road Transport Forecasts 2015 (RTF15)[73]. The key input assumptions to RTF15 are the following:

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[73] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/411471/road-traffic-forecasts-2015.pdf

- Population and employment data – based on the NTEM dataset which incorporates ONS and OBR projections;
- GDP Forecasts – based on the OBR short and long run GDP forecasts between 2010 and 2040; and,
- Fuel Prices – taken from the DfT's Fuel Price Forecasting Model, which uses DECC oil price projections, planned VAT and fuel duty, and the OBR predicted GDP deflator.

9.4.16　NTEM forecasts traffic levels by region and road type, and the flows for the years required were derived using interpolation and extrapolation from Table 4.3 from Road Transport Forecasts 2015, as shown in Table 9-2. The link pre-loads were uplifted using the following assumptions:

- As the projections from the National Transport Model have a broad order of magnitude they possess a significant range of uncertainty. As this uncertainty is likely to be greater for more disaggregate results, a single factor was calculated to be applied globally to all regions;
- The values calculated apply to England only; it is assumed that Wales and Scotland have the same growth factors; and,
- As the nature of the network modelled is predominantly major roads, the only road types to be considered in the calculation of the growth factors are Motorway, Trunk and Principal.

Table 9-2: Road Transport Forecast

Bn Vehicle miles	Year	Motorway	Trunk	Principal	Other roads	All roads
Car	2010	39	24.2	67.8	77.6	208.6
	2035	55.6	33.9	91.6	104.7	285.8
LGV	2010	6.7	4.1	10.9	14.2	35.9
	2035	12.6	7.7	20.4	26.7	67.3
HGV	2010	6	2.8	3.5	1.8	14.1
	2035	8.7	4	4.9	2.5	20.1
Bus and coach	2010	0.2	0.2	0.9	1.4	2.7
	2035	0.2	0.1	0.8	1.3	2.4
All traffic	2010	51.9	31.3	83.1	94.9	261.2
	2035	77.1	45.7	117.7	135.1	375.6

9.5　Forecasting 'Do Minimum' air demand

9.5.1　The approach for base year and forecast year air demand is to adopt the DfT Aviation Model forecasts of supply and demand. This approach ensures a consistent

approach to forecasting domestic air passenger demand and aviation supply between the base and forecast years.

9.5.2 The domestic air passenger demand provided by the DfT came from the DfT Aviation Model forecasts October 2017. The data provides future year unconstrained end-to-end, non-transfer demand by trip purpose (employers business and other).

9.5.3 This section includes a brief summary of the DfT Aviation Model, more details of which can be found in the DfT publication of UK Aviation Forecasts, October 2017, before presenting the forecast data.

DfT Aviation Model

9.5.4 The DfT Aviation Model forecasts the number of passengers passing through UK airports ('terminal passengers') each year. This covers UK and foreign residents travelling to, from or within the UK. The PLD model covers only those trips made exclusively within Great Britain and therefore excludes movements to/from Northern Ireland, Isle of Man etc. and excludes interlining trips (international movements where, for outbound journeys, the first leg of the trip is within Great Britain but the second and any subsequent legs are international). Within this context of the wider aviation model it should be noted the internal domestic market sector accounts for approximately 15% of the passengers in the model, although the proportion varies over time.

9.5.5 The DfT's aviation forecasts are primarily prepared to inform long-term strategic aviation policy rather than provide detailed forecasts at every individual airport. The airport and specific market sector level forecasts, such as those used in PLD, are therefore only generated as an intermediate output of the forecasting approach.

9.5.6 Passenger forecasts are generated for each forecast year in two steps:

- The first step is the 'Unconstrained' national air passenger demand forecasts which are generated using the National Air Passenger Demand Model (NAPDM). This combines time-series econometric models with projections of key driving variables, to forecast national air travel demand assuming no UK airport capacity constraints.
- The second step includes the likely impact of future UK airport capacity constraints, allocation of passengers to airports and translation of passengers into air transport movements is modelled with the National Air Passenger Allocation Model (NAPAM).

9.5.7 The 'unconstrained' demand forecasts from the NAPDM can also be converted to airport-level 'unconstrained' passenger demand forecasts using NAPAM. This is

achieved by switching off the airport capacity constraints used in NAPAM, showing how UK air passenger numbers would grow if there were no UK airport capacity constraints. It is these unconstrained forecasts that have been used in the PLD model.

9.5.8   Figure 9-2 provides an overview of the framework used to produce forecasts of UK air passengers.

National unconstrained demand forecasts

9.5.9   NAPDM combines a set of time-series econometric models of past UK air travel demand with projections of key driving variables and assumptions about how the relationship between UK air travel and its key drivers change into the future. The key drivers vary by market sector. In the leisure sector consumer spending and air fares have been identified as the key drivers, whilst in the (domestic) business sectors GDP and fares were shown to be the main drivers. While it is capable of producing forecasts to 2080, only the forecasts up to 2050 have been used for the unconstrained demand forecasts input to NAPAM.

9.5.10   The domestic air passenger demand provided by the DfT came from the DfT Aviation Model's October 2017 forecasts. The data contained future year unconstrained end-to-end, non-transfer demand by trip purpose (employers business and other) and accompanying aviation supply from the DfT Aviation Model. These matrices are in origin to destination (OD) form.

9.5.11   The DfT Aviation Model matrices represent average annual demand. As such, the assumption is that over the course of a year demand should have similar levels of origin and destination trip totals. Any asymmetry found between origins and destinations as a result of the production of exportable matrices from the DfT Aviation Model was removed by creating a transpose of the matrix and averaging the two matrices.

Figure 9-2: Overview of the framework used to produce forecasts of UK air passengers
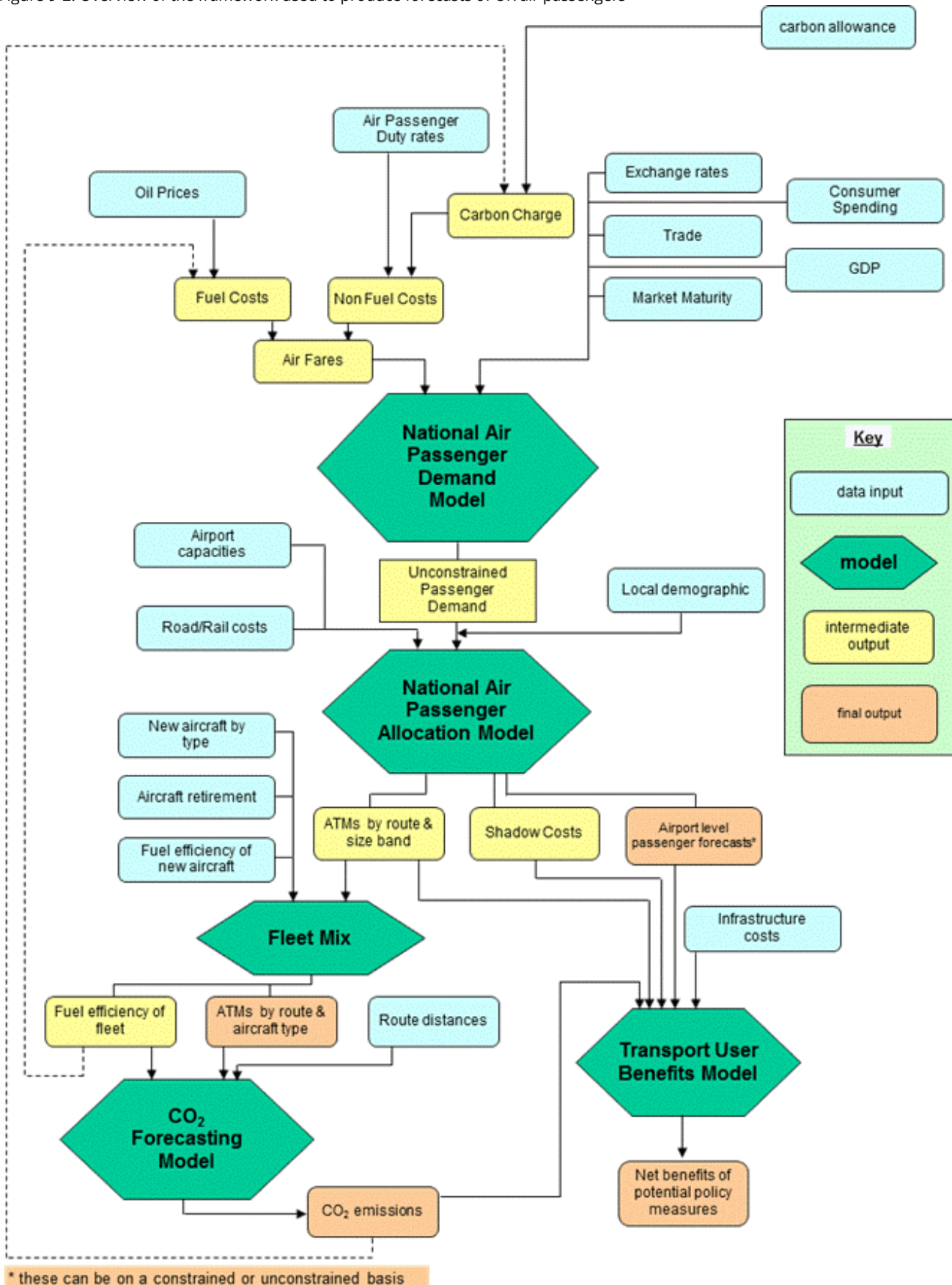
National Air Passenger Allocation Model (NAPAM)

9.5.12 NAPAM comprises several sub-models and routines which are used in combination and iteratively:

- the Passenger Airport Choice Model forecasts how passenger demand will split between UK airports;
- the Air Transport Movement (ATM) Demand Model translates the passenger demand forecasts for each airport into air traffic movements; and,
- the Demand Allocation Routine accounts for the likely impact of future UK airport capacity constraints on air transport movements (and thus passengers) at UK airports.

9.5.13 One of the key features of the model is the ability of the ATM Demand Model to project the availability of routes from each modelled airport. The model assumes that, in line with mainstream economic theory, supply will respond to demand as long as the market is commercially viable. The ATM Demand Model simulates the introduction of new routes by testing in each forecast year whether sufficient demand exists to make new routes viable from each airport. The test is two-way, so routes can be both opened and withdrawn. Also, airports are tested jointly for new routes, allowing them to compete with each other. This is one of the reasons why the air supply is updated as the same time as the demand in the PLD model using the adopted DfT forecasts of supply and demand.

9.6 Future networks for 'Do Minimum'

Rail

9.6.1 In addition to the pure network changes regarding future services, it is also necessary to make provision for future HS2 stations in the DM network. This is for reasons of appraisal, rather than demand forecasting, and is discussed in more detail in Chapter 11. While it has little impact on the DM demand, the actual procedure is briefly described below.

9.6.2 In general, the assumptions made for the future networks are in line with DfT assumptions for timetables and stock. Note that network changes are required for both PLD and the Regional PLANETs. No changes are assumed between the first and the second forecast years.

New HS2 stations

9.6.3 In connection with the appraisal of the DS, any proposed new stations associated with the scheme need to be included in the DM as well. This is a technical requirement for the appraisal in connection with the SCM, and is discussed in some detail in Chapter 11. These new stations will, of course, not have any direct services

associated with them in the DM, but it must nonetheless still be possible to reach the desired destination, so they need to be connected into the DM rail network. In cases where the new station is close to an existing station, this could be done by means of a walk link, but in other cases a transit link will be required. These links should be realistic rather than merely notional.

9.6.4   The proportion of passengers allocated to these 'new stations' in the DM has always been very small.

9.6.5   As an indication of what is required for a particular version of the HS2 scheme, we note in Table 9-3 how this has been done for the HS2 stations Old Oak Common, Birmingham Interchange, Birmingham Curzon Street, East Midlands Interchange, Manchester Interchange, and Leeds.

Table 9-3: Summary of DM connections to new HS2 stations

HS2 Station	Do Minimum connection to network
Old Oak Common	Transit Link to Paddington
Birmingham Interchange	Walk Link to Birmingham International
Birmingham Curzon Street	Walk Link to Birmingham New Street Walk Link to Birmingham Moor Street
East Midlands Interchange	Tram Link to Nottingham
Manchester Interchange	Walk Link to Manchester Airport
Leeds	Walk Link to Leeds

Highway

9.6.6   Information relating to the proposed enhancements to the highway network between the base year and the forecast years has been provided by the DfT; which was reviewed against lists of road projects from National Highways (and Welsh and Scottish equivalents) and also included in the National Infrastructure Plan and subsequent DfT announcements.

9.6.7   The update to the future year HS2 PLD highway network follows TAG Unit M4 guidance on scheme uncertainty. The guidance states that an uncertainty log should be created that includes an assessment of the uncertainty of each individual input by placing it into one of the four categories Near Certain, More than Likely, Reasonably Foreseeable, and Hypothetical.

9.6.8   The starting point for the creation of the uncertainty log was the DfT's National Transport Model's list of schemes. The list was reviewed against lists of road projects from National Highways (and Welsh and Scottish equivalents) and also included in

the National Infrastructure Plan 2011 and subsequent DfT announcements since then. The schemes were then assigned an uncertainty criterion, which was reviewed by DfT.

9.6.9   TAG Unit M4 guidance states that all the inputs categorised as 'Near Certain' will be included in the core scenario, it is also expected that those inputs categorised as 'More than Likely' will be included. This approach is consistent with that adopted for rail forecasting.

9.6.10   The list of schemes provided and subsequently reviewed by the DfT included schemes marked as open since 2010 and also on site and these were included in the future year PLD highway networks. Following the TAG Unit M4 guidance, only schemes considered as near certain and reasonably foreseeable were included in the future year DM HS2 PLD highway networks.

9.6.11   A number of schemes in the reviewed DfT list were not included. Reasons for excluding schemes were:

- maintenance or structural schemes;
- junction schemes (not applicable in the PLD link only highway network);
- small scale improvements that would affect only a fraction of the modelled link;
- safety schemes; and,
- schemes on the fringes of the network.

9.6.12   The majority of the schemes included in the model amount to improvements to existing links, so no additional links were required for those schemes. However, the number of lanes and VDF were amended accordingly.

Air

9.6.13   The forecast yearly number of flights is kept the same between the Base year and the forecast years. In previous versions of the PFM (pre-PFMv9) forecast demand and supply were taken from the DfT's Aviation Model to create inputs to PFM. However, in the interests of transparency and robustness of inputs, the base air supply is now retained for the forecast years, and the forecast demand is derived by growing the base air demand matrix using published aviation growth forecasts from the DfT's website.

9.6.14   The base Fares matrices described in Section 8.8 are factored to forecast year values.

9.7 Treatment of demand cap

9.7.1 In accordance with TAG Unit A5.3 Section 2.3, the PFM operates a 20-year forecast period, meaning that the second forecast year is 20-years from the point/year of appraisal:

"models using the standard approach should be used to ensure that one of the modelled years is forecast twenty years from the appraisal year (e.g. an appraisal carried out in 2017/18 would be on the basis of a 2037/38 forecast). Beyond this point, and for the remainder of the appraisal period, the magnitude of impacts associated with the level of demand may be extrapolated using a simple forecast model, in line with projected population growth (applied to all ticket types and journey purposes)".

9.8 Future year 'Do Minimum' costs

9.8.1 Key to the successful economic assessment of the HS2 scheme in the 'Do Something' scenario, is to ensure accurate costs and demand in the 'Do Minimum' scenario from which to "pivot". Pivot-point modelling is described in TAG Unit M2 "Variable Demand Modelling" and essentially involves forecasting the change in demand patterns based on cost changes from a reference case scenario. In previous releases of the PFM (PFMv7.1 and earlier), the Do Minimum scenario essentially involved an assignment of demand to supply for all modes in order to generate a set of 'Do Minimum' costs against which to pivot the Do Something scenario.

9.8.2 This methodology was a legacy of the PFM and did not take account of changes in costs from the Base scenario to the forecast 'Do Minimum' scenario. It also does not account for any demand response due to the schemes included in the forecast year network. The implication of this is that forecast demand growth could in theory not be constrained by over-capacity trains, but could also not adequately reflect improvements in infrastructure between the Base and forecast 'Do Minimum' scenario.

9.8.3 In response, an approach was developed that effectively creates a 'Do Nothing' scenario that models demand and supply from the base scenario but with future year prices. The cost skims from the 'Do Nothing' scenario are then used in the forecast 'Do Minimum' scenario in order to model a demand response to cost changes from the 'Do Nothing' to the 'Do Minimum' (using much the same process as described in Chapter 10 when forecasting the impact of HS2). This process allows a constraint of forecast demand growth and/or a demand response to improvements in infrastructure assumptions.

9.8.4   The costs and demand from the 'Do Minimum' are then used to pivot the demand response to the 'Do Something' scenario. As well as providing the demand response to the change in costs from the 'Do Nothing' scenario, the new methodology also results in a higher level of model convergence in the 'Do Minimum' scenario.

9.8.5   Whilst not a new concept, this approach has only recently been applied in the PFM due to previously being constrained by the hierarchy of the model structure which is not readily flexible to significant changes such as this. This methodological update provides a more robust set of 'Do Minimum' costs on which to pivot the demand response to the 'Do Something', as well as providing more realistic forecast demand flows.

9.8.6   During testing of the new methodology, at an aggregate level the impact on the overall levels of demand was modest, however at a more disaggregate level there was demand constraint along corridors of known crowding effects, and increases in demand along corridors where infrastructure schemes are due to improve the modelled scenario.

10   Forecasting the impact of HS2

10.1   Introduction

10.1.1   As with the DM, any version of the HS2 scheme ("Do Something") needs to be run for at least two years – the opening year and the second forecast year. In this chapter, we describe how this is carried out. For illustrative purposes, some scheme details are noted, but it should be kept in mind that the procedure is appropriate for any version of the scheme.

10.1.2   As described in Chapter 6, this is an 'incremental' model which pivots off the DM demand matrices, according to the predicted change in costs relative to the DM costs. The change in costs is, as would be expected, predominantly seen on the rail side. In fact, the air costs are assumed not to change, while changes in PLD highway demand will have only a small effect on generalised cost. In addition, rail fares are assumed not to change, so that it is only rail service patterns (including times, frequency and seating capacity) that impact on costs, and hence on demand.

10.2   Specifying the 'Do Something' scheme

10.2.1   The Do Something [DS] scheme involves changing the Do Minimum network to represent the scheme to be tested. In the case of HS2 this requires not only coding the high-speed service patterns, but also the changes in the conventional rail service specification in the rest of the network to take account of released capacity.

10.2.2   As a result, the coding of the DS rail network is a substantial task, and extends to the Regional PLANETs as well as the PLD network. No changes are made to the air and highway networks.

10.2.3   As noted in the previous chapter, any new stations associated with HS2 need to have been included in the DM network. In the DS network, these now become properly connected to the rest of the network by high-speed services.

10.3   Predicting the impact of the scheme

10.3.1   In essence, the changes in the rail network - with the introduction of new services - impact firstly on the station-to-station GJTC values, and this leads to changes in the station choice allocation as well as the zone-to-zone GJTCAE. This in turn leads to new rail demand (both generated and abstracted from other modes), which is then assigned with consequent "second round" effects on crowding (and, to a limited extent, highway congestion, though not air). To obtain an "equilibrium" result, iteration is necessary, subject to convergence measures discussed in Section 10.4.

10.3.2   Additional complexity is introduced by the need to interface with the Regional
PLANETs. The required outputs are the DS demand and the DS costs, separately by
mode and demand segment. The operation of the algorithm for producing this
output is outlined in the box below, with particular attention to rail costs. Iteration 0
is carried out to produce a first estimate of the necessary pre-loads: the demand
model is not invoked at this stage.

10.3.3   For historical reasons, 'assignment' within PLD refers to a process which carries out a
separate assignment for each of the three modes every time it is called. While this is
computationally inefficient, it does not impact on the final results.

10.3.4   At the end of this process, the DS generalised cost matrices C^{pc}_{mIJ} and demand
matrices T^{pc}_{mIJ} are produced for each mode m (the rail matrices are also produced
for the three Regional PLANETs). Note that for the purposes of appraisal, the cost
matrices need to be split into separate elements, and the way this is done is
described in Chapter 11.

Outline of Algorithm for DS

(Iteration 0)

Assign Unit PLD rail matrix to generate uncrowded Rail GJTs on DS network

Read PLD DM demand matrices $T^{0\ pc}_{ij}$, Reg PLANET demand matrices

Run SCM to produce PLD station-to-station demand

PLD Assignment:

       Highway/Air

       Rail (10 iterations) to update Rail GJTCs

Run SCM to produce PLD station-to-station demand

PLD Assignment:

       Highway/Air

       Rail (10 iterations) to update Rail GJTCs and impacts on Regional PLANETs

Run Regional PLANETs including PLD loads: produce pre-loads for PLD Rail

Apply station-to-station proportions to DM PLD rail demand matrices

(Iterations 1&2)

PLD Assignment:

       Highway/Air

       Rail (10 iterations) with pre-loads to update Rail GJTCs

Run SCM to produce PLD station-to-station demand

PLD Assignment:

       Highway/Air

       Rail (10 iterations) to update Rail GJTCs

Run SCM to produce PLD station-to-station proportions and rail GJTCAE*

Run Demand Model based on cost changes: produce revised PLD demand matrices

Apply station-to-station proportions to revised PLD rail demand matrices

(Iteration 3)

PLD Assignment:

       Highway/Air

       Rail (10 iterations) with pre-loads to update Rail GJTCs

Run SCM to produce PLD station-to-station demand

PLD Assignment:

       Highway/Air

       Rail (10 iterations) to update Rail GJTCs and impacts on Regional PLANETs

Run SCM to produce PLD station-to-station proportions and rail GJTCAE*

Run Demand Model based on cost changes: produce revised PLD demand matrices

Apply station-to-station proportions to revised PLD rail demand matrices

Run Regional PLANETs including PLD loads: produce updated pre-loads for PLD Rail

(Iterations 4-6 as Iterations 1-3)

(Iterations 7-12 as Iterations 1,2)

(Iteration 13)

PLD Assignment:

       Highway/Air

       Rail (10 iterations) with pre-loads to update Rail GJTCs

Run SCM to produce PLD station-to-station demand

PLD Assignment:

       Highway/Air   Skim Costs

       Rail (10 iterations) to update Rail GJTCs

Run SCM to produce PLD DS station-to-station demand and DS GJTCAE*

Output DS costs C (including Rail Fares)

Output DS demand T

10.4 Model convergence

Theoretical MSA approaches

10.4.1 To achieve an equilibrium between supply and demand, an averaging process is required. For this purpose, the method of successive averages (MSA) has been used, whereby at each iteration the latest result is combined with the "rolling average", such that oscillation will be reduced.

10.4.2 The averaging can be applied to either the cost skims input to the demand model, or to the output demand from the demand model. The equations below show an example of each of these two options.

Type 1: Demand Averaging

10.4.3 Averaged Demand is given as follows:

Equation 10-1:

$$X_{ijcm}^{n+1} = \omega^n \cdot D\left(C\left(X_{ijcm}^n\right)\right) + (1 - \omega^n) \cdot X_{ijcm}^n$$

where:
- X_{ijcm} Current Demand (Averaged);
- $C(X_{ijcm})$ is Cost for Current Demand;
- $D(C(X_{ijcm}))$ is New Demand resulting from Cost for Current Demand; and,
- i is Origin, j is Destination, c is User Class, m is Mode, and n is the iteration number.

10.4.4 This implies that each new iteration of demand to be passed to the assignment is a proportion (ω^n) of the current iteration's demand as output from the demand model, added to the complement proportion ($1 - \omega^n$) of the rolling average of the previous iteration's demand.

Type 2: Cost Averaging

10.4.5 Averaged Cost is given as follows:

Equation 10-2:

$$C_{ijcm}^{n+1} = \omega^n \cdot Y\left(D\left(C_{ijcm}^n\right)\right) + (1 - \omega^n) \cdot C_{ijcm}^n$$

where:

- C_{ijcm} is Current Cost (Averaged)
- $D(C_{ijcm})$ is Demand resulting from Current Cost
- $Y(D(C_{ijcm}))$ is New Cost for Demand resulting from Current Cost

10.4.6   This implies that each new iteration of the assignment costs to be passed to the demand model is a proportion (ω^n) of the current iteration's costs as output from the assignment, added to the complement proportion (1-ω^n) of the rolling average of the previous iteration' s costs.

10.4.7   In both cases ω^n, described as the Step Length at iteration 'n', is calculated as $\omega_n = \frac{1}{n}$ (though a constant weight of ½ was also tested, with only marginally worse results).

10.4.8   Cost Averaging (Type 2) was preferred because it could be implemented easily into the PLD model whilst maintaining the general structure and functionality of the model.

Measurement of demand and supply convergence

10.4.9   TAG M2.1 Section 6.3 sets out that the recommended criterion for measuring convergence between demand and supply models is the demand/supply gap defined by:

Equation 10-3:

$$\frac{\Sigma_a C(X_a{}^n) \left| D\left(C(X_a{}^n)\right) - X_a{}^n \right|}{\Sigma_a C(X_a{}^n) X_a{}^n} * 100$$

where:
- $X_a{}^n$ is cell *a* in the previous assignment matrix for iteration *n*
- $C(X_a{}^n)$ is cell *a* in the generalised costs resulting from assigning that matrix
- $D(C(X_a{}^n))$ is cell a in the matrix output by the demand model based on costs $C(X_a{}^n)$. In models where the matrix output by the demand model is used directly as the assignment matrix (as will usually be the case in variable demand models), this will be equal to $X_a{}^{n+1}$.
- *a* represents every combination of origin, destination, demand segment/user class, time period and mode.

10.4.10   TAG suggests 0.1% is an achievable target, though in some cases a value of 0.2% would be acceptable in problematic systems. The adjustments made to the model as part of this process allows us to measure this easily, therefore making the PFM model convergence more readily measured and transparent.

Practical implementation of MSA into PLD

10.4.11   The basic approach is to undertake the following operations within the PLD process:

- store the 'rolling average' set of costs prior to assignment and skimming;
- assign and skim all modes; and,
- weight the resultant costs from (step 2) with (step 1) using MSA.

10.4.12   This ensures the appropriate averaging of costs before the next input to the mode choice model, thereby ensuring better convergence in line with TAG criterion.

10.5   Assessment

10.5.1   The various model components discussed in earlier chapters have all been brought together in a single algorithm which allows for route and station choice, demand effects (mode shifts and generation), and the impact on the various networks (including the Regional PLANETs). The interactions between the different rail networks, as well as those between demand and supply in general, are all allowed for.

10.5.2   The algorithm has been developed in a heuristic way, rather than using more complex optimisation methods. While it could probably be streamlined, it is not likely that this would have any impact on the results. The convergence monitoring is in line with TAG recommendations, and the level of convergence at the end of the fixed set of iterations meets the TAG criteria.

Part 5 – Using the model for appraisal

In this part we discuss how the model has been used to produce the necessary inputs for the appraisal of HS2 and describe the calculations that are then carried out.

11 Economic appraisal

11.1 Introduction

11.1.1 The aim of the economic appraisal is to compare key quantities (in monetary terms) with and without the HS2 scheme. Cost-Benefit Analysis (CBA) is the mainstay of project appraisal for the Department for Transport (DfT) and other Government departments and agencies, although other elements also form part of the overall appraisal. An essential component of CBA is discounted cost flow (DCF) analysis, which calculates a 'Present Value' of both Benefits (PVB) and Costs (PVC), using an agreed Discount Rate, in order to obtain a Net Present Value, as well as other indicators such as Benefit-Cost Ratios (BCR).

11.1.2 The focus in this chapter is on describing the economic benefit and revenue calculations. Guidance on CBA in appraisal can be found in TAG units A1.1, A1 3 and A5.3 and PFM follows these.

11.1.3 The following sections concentrate on the main items of benefit and revenue and describes the input data and calculations.

11.2 Inputs and outline of calculations

11.2.1 To carry out an economic appraisal of a single phase of the scheme, four model runs are required as a minimum although more can be used for a more detailed assessment: As a minimum the Do Minimum and Do Something are required for two forecast years.

11.2.2 For each of these, the segmented demand matrices T^{pc}_{mIJ} from both from PLD and the Regional PLANETs are required. We also require the corresponding generalised cost matrices C^{pc}_{mIJ}, further split by elements "k".

11.2.3 The DfT CBA procedures are standardised according to the rules set out in TAG Unit A1.3, along with the tabular presentation of the "Transport Economic Efficiency" results (TEE table), and the TUBA Manual[74]. This section focuses on the calculation of the main elements in the TEE table of relevance for modelling – User Benefits [S] and Revenues [R]. For notational simplicity the following mathematical description ignores distinctions of purpose and other possible "segmentations", but in practice they need to be made.

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[74] Transport User Benefit Appraisal program. This incorporates the principles outlined in TAG A1.3. However, it is not compulsory to use it, and given the complexity of the HS2 appraisal, custom-built appraisal software has been developed.

11.2.4   In terms of user benefit there are a number of generalised cost elements that need to be distinguished. In particular the TEE table identifies the following items: travel time, vehicle operating costs, user charges (including fares) and operator revenues: we denote these by k. The contribution of element k to the overall user benefit associated with mode m in year Y is given as:

Equation 11-1:

$$S_{m,k}^Y = -\tfrac{1}{2} \sum_{IJ} \left(T'^{Y}_{IJm} + T^{Y}_{IJm} \right) \cdot \left(C'^{Yk}_{IJm} - C^{Yk}_{IJm} \right)$$

where:
- T is demand, C is (generalised) cost in money terms, and the prime (') denotes the with scheme case;
- I and J are zones; and,
- m is mode.

11.2.5   This calculation, generally referred to as the 'Rule of a Half' [RoH], is a very widely used approximation to the true 'Consumer Surplus'. However, as is noted in the TUBA Manual, the approximation deteriorates when the cost changes become large. In these circumstances, a better approximation, referred to in the TUBA Manual as "Numerical Integration" [NI], is recommended. Because there are some large changes in cost associated with the HS2 scheme, NI has been used throughout. To avoid notational complexity, the formulae in this section make use of the standard RoH methodology, but the approach to NI is set out in Annex B.

11.2.6   The following generalised cost elements [k] (varying by mode) are required:

Table 11-1: Breakdown of user benefits for appraisal reporting

Generalised cost elements for rail	Generalised cost elements for highway
Uncrowded Journey Time	Journey Time
Crowded Journey Time	Vehicle Operating Costs (Fuel)
Access/Egress Times	Vehicle Operating Costs (Non-Fuel)
Wait Time	
Walk Time (for interchange)	
Boarding Penalty	

11.2.7   Note that although corresponding cost elements for the air mode are available, they do not change between the DM and DS cases, and hence – they are not calculated and do not contribute to the benefit calculations.

11.2.8   For the most part, the calculations can be carried out at the zonal level (e.g. for PLD at the "IJ" level). For the rail mode, however, the calculations are undertaken at station to station level using outputs from the Station Choice Model [SCM]. This is because the guidance states that the appraisal should be undertaken at the lowest level of choice. In this case this is the outputs from the SCM which are at a zone-to-station to station-to-zone level. The dimensions of this are too big to calculate in a sensible amount of processing time, so the zone-to-station costs are kept constant and the appraisal then undertaken at the station-to-station level.

11.2.9   The weightings applied to the rail components of cost in the various models were set out in Section 2.7: they do not vary by purpose. Table 11-2 repeats this information and also includes the appraisal values, which have been agreed with DfT as being consistent with TAG.

Table 11-2: Generalised cost element weights for rail.

Rail	Modelled and Appraisal values (all purposes)		
	PLD	**PS**	**PM & PN**
IVT (uncrowded)	1.0	1.0	1.0
IVT (crowded)	1.0	1.0	1.0
Wait time	2.0	2.0	2.0
Walk time	2.0	2.0	2.0
Board Time Penalty[75] (mins)	30.0	3.5	20.0

11.2.10   Slightly different formulae apply to the revenue calculations, this is calculated as follows:

Equation 11-2:

$$R_{m,k}^{Y} = \sum_{IJ} \left(T'^{Y}_{IJm} \cdot C'^{Yk}_{IJm} - T^{Y}_{IJm} \cdot C^{Yk}_{IJm} \right)$$

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[75] These are the additional minutes of GJT accrued per boarding to reflect the perceived disutility of boarding a train service.

11.3 Annualisation

11.3.1   The demand variables relate, in the case of PLD, to an average weekday, and in the case of the Regional PLANETs, to the AM peak of an average weekday. To convert them to an annual basis, annualisation factors are required, and the following values are used for PLD:

Table 11-3: PLD annualisation factors

	Rail	Air	Highway
Business	255	313	275
Leisure	428	313	361
Commuting	264	n/a	282

11.3.2   These factors were derived by applying NTS-derived journey purpose splits for non-weekday long-distance rail demand to estimates of total non-weekday demand derived from the deannualisation process used in developing the PLD matrices. The NTS long-distance data from 2010-2019 was used at a national level giving the following results:

Table 11-4: Proportion of total weekly rail demand over 50 miles by journey purpose and weekday/non-weekday from NTS data

	Weekday	Weekend
Business	20%	1%
Leisure	33%	21%
Commuting	24%	0%

11.3.3   It is assumed that, on average, there are 245 working week days per year based on 260 calendar weekdays per year, 8 bank holidays and an additional reduction to account for atypical, reduced demand in the Christmas and New Year period, particularly in the week between the two. This factor was used in the approach used to deannualise LENNON data by ticket type and has been confirmed to be appropriate through analysis of available data such as guard counts and MOIRA data.

11.3.4   On this basis, the equation used was:

Equation 11-3:

$$A^p = 245 * \frac{T^{wd} \cdot s^{p,wd} + T^{we} \cdot s^{p,we}}{T^{wd} \cdot s^{p,wd}}$$

where:

- T^{wd} = Total weekday demand for all purposes derived from LENNON deannualisation
- T^{we} = Total non-weekday demand for all purposes derived from LENNON deannualisation
- $s_{p,wd}$ = Share of weekday demand for journey purpose p (derived from NRTS data as part of PLANET matrix development)
- $s^{p,we}$ = Share of non-weekday demand for journey purpose p (derived from NTS)

11.3.5   Using these annualisation factors, the sum of annualised demand will equal the total demand reported in the MOIRA journeys matrix. In carrying out the calculations, the demand from MOIRA was restricted to all trips over 50 miles excluding those covered by the Regional PLANETs. This is more consistent with the NTS data used in generating the factors, and with the main benefits of HS2 (which applies to long distance flows).

11.3.6   Separate factors are derived for PLANET South/Midlands/North.

Table 11-5: Annualisation factors for Regional PLANETs

	User benefits	Crowding
Business	1,376	557
Leisure	697	490
Commuting	2,562	756

11.4   Interpolation for non-modelled years

11.4.1   Ideally, the model would be run for every year Y of the benefit stream, but in practice it is not feasible. For this reason assumptions are required about the path of benefits for those years when explicit model runs are not carried out. As we have seen, the PFM is run for at least two years, which we denote as A and B, where A is the opening year and B is the second forecast year.

11.4.2   Running the transport model in years A and B allows the calculation of the quantities S_k^Y for these two years (from now on these terms are assumed to include the annualisation factors). It is clear from the definition of these quantities that they require both demand estimates (T) and (generalised) cost estimates (C), separately for the DM and the DS. Changes in the demand estimates over time are partly exogenous to the transport model (through population changes and income changes, the latter also affecting car ownership), and partly endogenous, due to supply-side effects. Similarly, changes in the cost estimates over time are also partly exogenous (e.g. fuel prices/efficiency, fares), and partly endogenous (supply-side effects such as congestion and crowding).

11.4.3 Given only a limited number of years with model runs, the approach taken used in the purpose-built appraisal software developed for PFM, which is in line with TUBA, is as follows[76]. Keeping the benefits in their natural units (i.e. time for all elements apart from the money costs), for A < Y < B linear interpolation is carried out between S_k^A and S_k^B to get a value of S_k^Y.

Equation 11-4:

$$S_k^Y = S_k^A + \frac{Y-A}{B-A} \cdot (S_k^B - S_k^A) \qquad \text{for A<Y<B}$$

11.4.4 After the cap year (B) a zero growth assumption in the volume of benefits is made. Hence the implied formula is:

Equation 11-5:

$$S_k^Y = S_k^B \qquad \text{for Y>B}$$

11.4.5 This produces an estimate of annual benefits for each generalised cost element for every year. At this point the values are converted to monetary values so they can be combined and included in the right format in the TEE table.

11.5 Weighting the elements

11.5.1 The various time elements now need to be weighted (to take account of the different weights α_k set out in Table 11-2, which vary by purpose) and then converted to money terms by multiplying the weighted time elements by an appropriate Value of Time [VoT]. VoT varies by purpose and by year, in line with TAG Unit A1.3. This can be written as:

Equation 11-6:

$$B_k^Y = VoT^Y \cdot \alpha_k S_k^Y$$

for all time elements k

11.5.2 To give an estimate of total user benefits in any one year, the elements need to be summed over all elements k. However, for presentational purposes the breakdown by elements is retained as well.

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[76] Note that this is not intended as a description of the actual calculations in TUBA, but rather of the underlying principles.

11.7 Calculating the Present Value of Benefits

11.7.1 If the benefits in year Y are written as BY, then the present value of benefits (PVB) is given as:

Equation 11-7:

$$PVB = \sum_Y \frac{B^Y}{(1+r)^{Y-W}}$$

where r is the discount rate (in line with TAG Unit A1.1, para 2.7.5), and W is the base year.

11.7.2 While in theory the calculation could be summed over an infinite number of years into the future, in practice this is limited to a finite 'appraisal period'. This raises the question as to whether any unaccounted benefits at the end of the appraisal period (technically referred to as the 'residual value') need to be taken into account. TAG A1.1 also provides guidance on this.

11.7.3 Of course, benefits cannot be generated before the opening year of the scheme. According to TAG A1., Y should range over 60 years starting with the scheme opening year. Because the opening years are different for each phase, the appraisal includes the benefits between the opening years, as well as the 60 years from the opening of the final phase.

11.7.4 A three-year "ramp-up" period is included for both Phases. Prior to applying the discounting, the benefits associated with each phase are reduced by 20% in the opening year, 10% in the next year, and 5% in the following year. This is done to reflect the fact that in the system will not be a mature market until a number of years after opening.

11.8 Closing remarks

11.8.1 The foregoing discussion relates to the general calculation of the user benefit elements, with special attention to the rail mode. In addition, the appraisal spreadsheet requires the calculation of revenue (separately by purpose), indirect tax (business/non-business), and highway externalities (congestion, accident, local air quality, noise), as well as benefits from reduced carbon emissions.

11.8.2 Additional Wider Economic Impact Benefits are calculated in line with TAG A2. 1. The factors taken into account are: Agglomeration benefits (WB1), Imperfect competition (WB3) and Labour Market Impacts (Exchequer consequences of increased GDP (WB4) due to Increase in labour force participation (GP1)).

11.8.3   All the calculations are done separately for PLD and the three Regional PLANETs, in line with the "control matrices". The highway externality and indirect taxation calculations are in line with the requirements of TAG A5.4, based on changes in car-Km. Revenue calculations are straightforward, using Equation 11-2 given earlier. All these elements are linearly interpolated as described in above between the modelled years.

11.8.4   The calculations are carried out partly by means of EMME macros and partly within a purpose-built spreadsheet, which has a pre-processing step written in VB.net and uses outputs from the SCM (i.e. the correct level at which the data is used for the appraisal). Data is imported for each model runs, separately for each phase of the scheme, for the two modelled years. Interpolation and extrapolation are carried out following the principles embodied in TUBA. Generalised cost element weights and values of time all derive from TAG.

11.8.5   The outcome is that the output from the various PFM model components is all brought together in a series of appraisal tables which represent best CBA practice following the principles of TAG.

12 Annexes

12.1 Annex A: EMME documentation of transit assignment strategies

12.1.1 The standard transit assignment algorithm implemented in EMME is a multi-path algorithm based on the concept of strategies and optimal strategies. In EMME a strategy is a set of rules that allows a traveller to reach their destination. Due to the waiting time at stops in a transit network, a traveller may select from a more complex choice set than just a simple path toward a destination, so this strategy could constitute a single path using a single transit line or a number of paths each involving one or more transit lines. In a strategy, the traveller chooses a set of paths before embarking on the trip, and at each node where there is waiting, boards the first vehicle to arrive from any of the attractive lines. On boarding a vehicle the traveller knows where he will get off.

12.1.2 The optimal strategy between each origin and destination zone is the one that has the least overall travel time (including access, waiting, in-vehicle time etc.). Therefore the optimal strategy will only include that combination of paths and related transit lines that result in the least overall travel time. It follows that if any other paths are considered as part of the strategy they would increase the overall travel time. Those transit lines included in the optimal strategy are called the attractive lines.

12.1.3 The assignment process operates in two stages:

- Calculate the optimal strategy i.e. the set of attractive routes and lines that minimises the overall journey time.
- Assign demand according to that strategy.

12.1.4 In calculating the optimal strategy and assigning demand according to that strategy, the following rules apply:

- Waiting time at a node is related to the combined frequency of all attractive transit lines at that node (combined linearly).
- It is assumed that a traveller's path is determined by the transit line that first arrives at each node.

12.1.5 At a node, the probability of a particular transit line arriving first and the proportion of passengers assigned to each attractive route is based on the service frequency of each transit line in relation to the combined frequency of all attractive transit lines at that node.

12.1.6   As the wait time is calculated based on the combined frequency of all attractive transit lines at a node, it is possible that including a transit line that is slower than the current attractive lines could reduce the overall journey time i.e. the wait time saving as a result of the change in combined frequency outweighs the additional journey time of the slower service.

12.1.7   Note that the travel time includes all journey time elements e.g. access time, wait time, in-vehicle time, boarding time, and their associated assignment weights e.g. wait time factor, wait time weight, boarding penalty etc. The way that the overall journey time is calculated taking into account multiple paths and combined service frequencies is outlined below.

12.1.8   The algorithm used for the optimal strategy is shown in Table A1 and a working example is included below. The algorithm is applied to each origin destination pair. It is applied from the destination zone working back towards the origin zone. The algorithm starts from the nearest node connected to the destination zone.

- Firstly it determines attractive transit lines outgoing from that node to the destination.
- Then it looks at services incoming to that node (this helps determine whether alighting at the node are attractive options compared to remaining on a service).
- It then looks at the next nearest node.

Table A1: Optimum strategy algorithm

Determination of attractive lines in optimal strategy
A. Lines outgoing from node Y - Processing of the line with smallest time to destination, t1
A1. Calculate combined frequency: f = f1
A2. Calculate waiting time: wait = headway fraction / f
A3. Calculate average time to destination: average_t = t1
A4. Calculate expected total time to destination: u = wait + average_t
B. For each line, in increasing order of time to destination, tl If tl > u line l and the following are not attractive If tl $\leqslant$ u line l is attractive
B1 Calculate combined frequency: f = f + fl
B2. Proportion of demand for each attractive line: pl' = fl' / f
Proportion using Blue
B3. Calculate waiting time: wait = headway fraction / f
B4 Calculate average time to destination: average_t = Sum pl' * tl'

Determination of attractive lines in optimal strategy
B5. Calculate expected total time to destination: u = wait + average_t
C. Repeat for Lines Incoming to node Y
D. Repeat for other nodes in increasing order of travel time

12.1.9   The process of determining attractive lines and hence the optimal strategy, using a simple example based on a path between two nodes is outlined below.

- Starting with the transit line with the smallest travel time, assuming it arrives immediately (i.e. ignoring wait time).
- Calculates the total journey time (including wait time).
- Select the next fastest transit line, assuming it arrives immediately (i.e. ignoring wait time).
- Compares travel time of this line with the total journey time using the fastest transit line.
- If the travel time it is less than total travel time, then the line is considered attractive as it will reduce the overall total travel time.
- If the travel time it is less than total travel time, the total travel time is recalculated taking into account the combined frequency and the proportion of demand using each of the attractive transit lines.
- The process is repeated using the next fastest transit line.

12.1.10   At any point in the process if the next fastest path is slower than the exiting total travel time then this line and any slower lines are not attractive and the set of attractive lines has been identified.

12.1.11   The next step is to load demand on to the attractive transit lines according to that strategy. The proportion of demand is allocated to each transit line based on the frequency of individual transit lines in relation to the overall combined frequency. Demand is loaded on starting from the origin zone working towards the destination zone.

12.1.12   The assignment algorithm based on frequency and journey time is an alternative public transport assignment algorithm that provides the facility to distribute flow between attractive lines based on a combination of frequency and travel time. The weighting of frequency may be modified on a global, node (stop) or transit line (rail service) basis.

12.1.13   The assignment algorithm for this option works in a similar way to the optimal strategy, with a few key differences. These relate to the calculation of combined frequency, overall travel time and the allocation of demand to each transit line.

12.1.14   In calculating the combined frequency, an adjustment is made to the frequency of the next fastest transit line being considered to reflect the difference in journey time between it and the current attractive lines. Modification to the calculation of combined frequency has a knock on impact on the calculation of journey time and the allocation of demand to individual services.

12.1.15   The assignment algorithm is presented below; a worked example is given at the end of this Annex.

Table A2: Assignment algorithm based on frequency and journey time

Determination of attractive lines
A. Lines outgoing from node Y - Processing of the line with smallest time to destination, t1
A1. Calculate combined frequency: f = f1
A2. Calculate waiting time: wait = headway fraction / f
A3. Calculate average time to destination: average_t = t1
A4. Calculate expected total time to destination: u = wait + average_t
B For each line, in increasing order of time to destination, tl If tl > u line l and the following are not attractive If tl ≤ u line l is attractive
B2 Calculate p_adj, where p_adjl = 1 – (t1 - average_t)/wait
B3 Calculate combined frequency: f = f + p_adjl * fl
B4 Calculate Proportion of demand for each attractive line: pl' = p_adjl' * fl' / f
B5. Calculate waiting time: wait = headway fraction / f
B6 Calculate average time to destination: average_t = Sum pl' * tl'
B7. Calculate expected total time to destination: u = wait + average_t
C. Repeat for Lines Incoming to node Y
D. Repeat for other nodes in increasing order of travel time

12.1.16   The initial steps of the algorithm are identical to the optimal strategy. When a second line is identified as being attractive the calculation of the combined frequency is different to that in the optimal strategy. In the optimal strategy the combined frequency is simply the sum of the frequency of the individual services. In the frequency and journey time assignment an adjustment factor is calculated for the line to be added to the set of attractive lines. The adjustment factor effectively reduces the frequency of the next fastest transit line by the proportion of additional journey time compared to the frequency of the existing attractive lines. This adjustment factor is applied to the frequency of the next fastest transit line when

calculating the combined frequency, reducing the frequency of the transit line and effectively increasing headway and wait time. This reduces the combined frequency and increases the headway and wait time compared to the optimal strategy.

12.1.17   As the combined frequency is used to calculate the wait time, and the wait time makes up part of the overall journey time, the overall journey time is different to that calculated in the optimal strategy. The adjustment factor is also to service frequency in the calculation of demand by services effectively reducing the proportion of demand allocated to the slower service.

12.1.18   Note that compared to the optimal strategy, the frequency and time based strategy is sub optimal, i.e. the calculation of minimum costs results in greater minimal costs than the optimal solution. This is because during the calculation of combined frequency the frequency of the next quickest route which is being looked at is factored to reflect the increased journey time compared to the optimal solution. For an identical network this can change the number of attractive lines.

## 12.2 Annex B: Benefit calculation by numerical integation

12.2.1   When calculating benefits at the station to station level we can encounter large changes in costs and demand between the Do Minimum and the Do Something situation. This can result in a breakdown of the rule of a half [RoH], which assumes that the demand curve can be treated as a straight line between the two points: in practice the assumption of linearity may not be justified for large changes, implying that the RoH may be overestimating the benefits.

12.2.2   A better estimate of the benefits can be made using a numerical integration approach (i.e. calculating the area under the demand curve between the Do Minimum and the Do Something). This method involves creating a series of steps between the two points, and requires only the calculation of the demand at each intermediate cost point, with the RoH then applied separately to each step. The distribution of steps need not be even between the end points, and in particular there may need to be a higher density of stages near the Do Minimum as we expect the demand curve to be less linear at this point (i.e. the error from a linear approximation to the curve will be at its greatest). The sum of the benefits for all of these steps gives the most reliable estimate of benefits and revenue.

12.2.3   The theory behind the rule of half is set out in section 3 of the TUBA guidance note[77]. The following graphs from the TUBA guidance illustrate the principle. The figure below shows a demand curve and a supply curve that shifts between the Do Minimum and Do Something as a result of implementing a transport scheme. The shaded area represents the change in the quantity known as the consumer surplus. If we approximate the demand curve as a straight line then this area can be calculated using the rule of a half:

$$Benefit = \frac{1}{2}(T^0 + T1)(C^0 - C^1)$$

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[77] https://www.gov.uk/government/publications/tuba-downloads-and-user-manuals
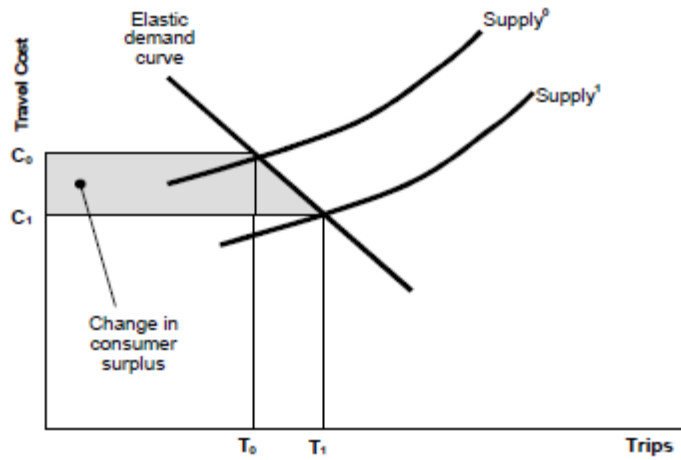
12.2.4   The figure below from the TUBA Guidance shows what can happen to the standard benefit calculation when cost changes are large:
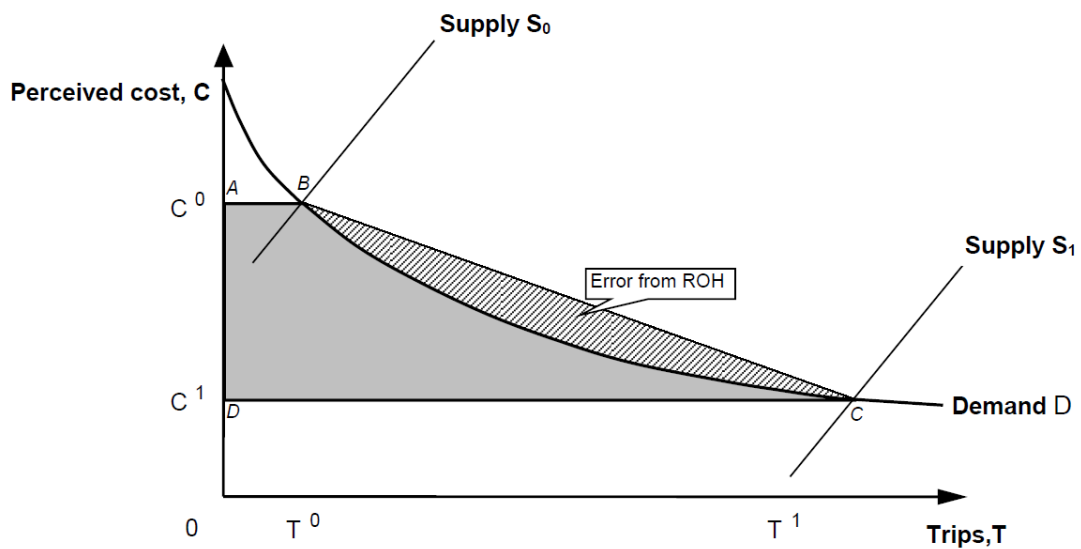
12.2.5   The solution recommended in the guidance to deal with large cost changes is to create a series of intermediate points between the Do Minimum and Do Something and apply the rule of a half to each pair of points in sequence. In effect, this is approximating the demand curve as a sequence of straight lines rather than a single straight line, as shown in the figure below:
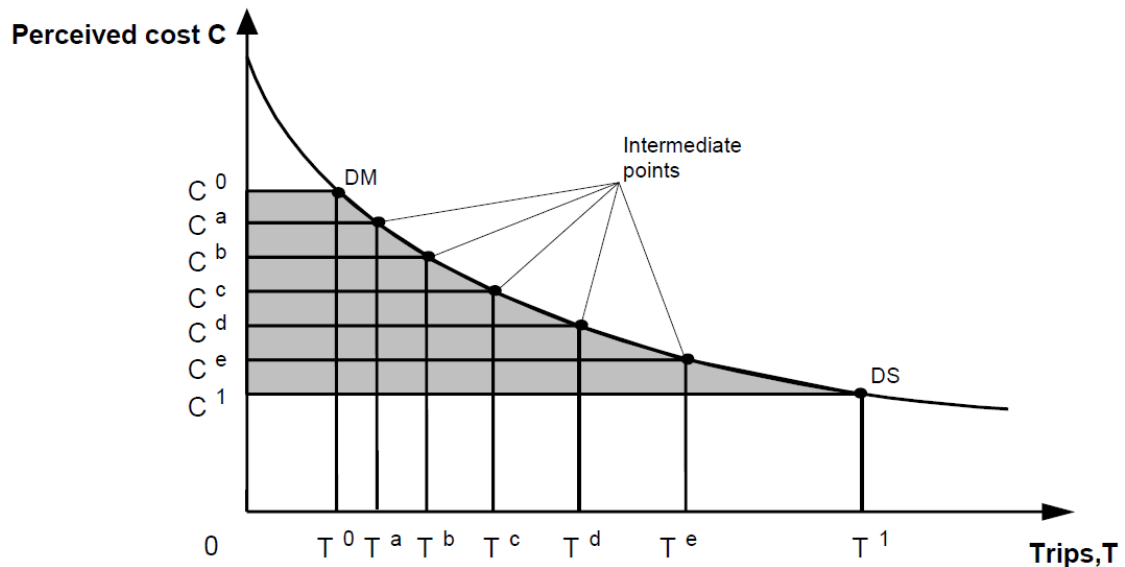
12.2.6   For the intermediate points we are only interested in what comes out of the demand model for a given set of costs, i.e. we are trying to understand the shape of the demand curve. There is no need to run any assignments, and therefore no need to code fictitious network scenarios for these points.

12.2.7   The Numerical Integration Process macro consists of the following steps:

- Run the Station Choice Model with a pre-determined set of costs based on the appraisal Do Minimum demand for the step;
- Transfer the output costs skims to the demand model;
- Run the demand model with the new cost skims to get a new set of demand;
- Run the SCM to get the Do Something station-to-station demand based on the new Do Something PLD to PLD demand;
- Run the pre-processing step for the appraisal.

12.2.8   The macro is then run for each intermediate point of the numerical integration process and each of the forecast years.

12.2.9   The points chosen for the final Numerical Integration results are:

- Do Minimum
- 85% of Do Minimum, 15% of Do Something costs ie is $C_{dm} + 0.15 (C_{ds}-C_{dm})$
- 67% of Do Minimum, 33% of Do Something costs ie is $C_{dm} + 0.33 (C_{ds}-C_{dm})$
- 50% of Do Minimum, 50% of Do Something costs ie is $C_{dm} + 0.50 (C_{ds}-C_{dm})$
- 34% of Do Minimum, 66% of Do Something costs ie is $C_{dm} + 0.66 (C_{ds}-C_{dm})$
- 20% of Do Minimum, 80% of Do Something costs ie is $C_{dm} + 0.80 (C_{ds}-C_{dm})$
- 10% of Do Minimum, 90% of Do Something costs ie is $C_{dm} + 0.90 (C_{ds}-C_{dm})$

- Do Something