Department for Transport

UK Aviation Forecasts

August 2011

Contents

Tables

Figures

1 Introduction and Key Results

1.1 Introduction

1.1 The Government has committed to produce a sustainable framework for UK aviation to replace the previous administration's *The Future of Air Transport* White Paper published in 2003 (the 2003 White Paper). The first step towards the adoption of a new policy framework was the publication of a scoping document in March 2011 to initiate a dialogue with a wide range of stakeholders on the future direction of aviation policy[1].

1.2 The scoping document committed the Department for Transport (DfT) to publish updated forecasts of UK air passengers and UK aviation carbon dioxide (CO_2) emissions. This document meets that commitment. The deadline for responding to the scoping document is 30 September 2011. A six month period has been allowed to enable responses to take into account these updated forecasts and the new evidence being published as part of the Government's response to the Committee on Climate Change (CCC) report on options for reducing CO_2 emissions from UK aviation (the CCC report)[2]. The Government's response to the CCC report will also include the results of Aviation CO_2 Marginal Abatement Cost (MAC) curve analysis[3]. The MAC curve analysis assesses the potential CO_2 emissions savings and costs associated with a range of possible policy levers.

1.3 The updated forecasts presented in this report represent the DfT's assessment of how activity at UK airports and the associated CO_2 emissions are likely to change into the future, given existing policy commitments. Their primary purpose is to inform long term strategic aviation policy. The updated CO_2 forecasts have been central to the MAC curve analysis, forming the baseline against which a range of policy options for reducing CO_2 emissions from UK aviation have been assessed. The forecasts will also inform the development of other aspects of policy, including, for example, wider Government policy on tackling climate change.

1.4 This report updates *UK Air Passenger Demand and CO_2 Forecasts, 2009,* published under the previous administration alongside the announcement of its decision to confirm support for a third runway at Heathrow airport. As well as presenting the DfT's latest aviation

---

[1] *Developing a sustainable framework for UK aviation: Scoping document*, Department for Transport, March 2011 (available at http://www.dft.gov.uk/consultations/open/2011-09/consultationdocument.pdf.)

[2] *Meeting the UK aviation target – options for reducing emissions to 2050,* Committee on Climate Change, December 2009

[3] *A Marginal Abatement Cost Curve Model for the UK Aviation Sector, Technical Report* EMRC/AEA, August 2011

forecasts, it explains in detail the forecasting methods and assumptions used to produce them[4].

1.5 The updated forecasts reflect several key developments since 2009. They are explained in more detail elsewhere in the report and include:

- the Government's policy not to support new runways at Heathrow, Gatwick or Stansted;
- the decision to include aviation in the EU Emissions Trading System (ETS) from 2012;[5]
- the Government's policy to support the development of a high speed rail route running from London to Birmingham, Manchester and Leeds[6];
- changes to Air Passenger Duty rates;
- changes to projections of economic growth and oil prices; and
- developments to the forecasting methodology resulting from a process of continual development

1.6 The forecasts are presented as ranges to reflect the inherent uncertainty involved in forecasting to 2050. Low and high forecasts have been defined to represent either end of a range of reasonably likely outcomes, and a central forecast has been defined to lie broadly in the middle of the range. The results of a series of sensitivity tests, in which the key inputs to the forecasts are varied, are also reported.

1.7 All aspects of the DfT's forecasting methods used to produce the updated forecasts have been subject to independent peer review. A series of peer review reports, assessing different aspects of the updated models, and a covering letter from the main peer reviewer summarising the conclusions of the review, are being published alongside this report on the DfT website.

1.2 Key results

UK Air Passengers and Air Transport Movements

1.8 The approach taken to produce UK air passenger and air transport movement (ATM) forecasts remains broadly the same as that reported in *UK Air Passenger Demand and CO_2 Forecasts 2009*. However, while the structure of the forecasting framework remains broadly the same, the updated passenger and ATM forecasts reflect an extensive programme

---

[4] Please note that unlike *UK Air Passenger Demand and CO_2 Forecasts, 2009* this report does not present DfT's aviation appraisal methods. These are being published separately as part of the Department's transport analysis guidance (see www.dft.gov.uk/webtag/)

[5] A legal challenge to the Aviation EU ETS Directive is currently the subject of a legal challenge. The Government is working with the rest of the EU in robustly defending the Directive and believes the Directive to be fully compatible with international law.

[6] This remains subject to the current public consultation and, in due, course parliamentary approval.

of model updates and enhancements. In addition to the developments highlighted in paragraph 1.5, these include:

- re-estimation of models using the latest data on UK airport activity and its key drivers;
- the updating of the model base year to 2008 from 2004;
- extension of modelling range so that detailed forecasts can be produced to 2050; and
- improvements to the way market maturity is reflected in the forecasts

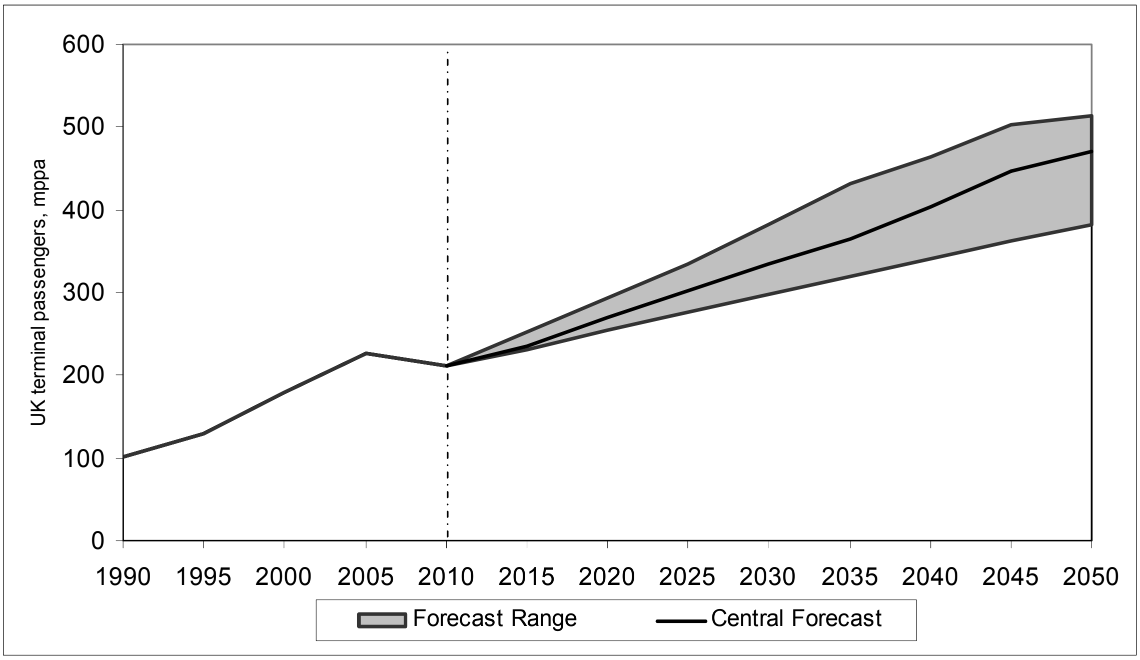
1.9 Chapter 2 and Annexes A to D provide full details of the methodology and assumptions underpinning the updated air passenger forecasts. Annex E explains the changes to the forecasting methodology introduced since 2009.

1.10 Figure 1.1 shows the DfT's updated forecasts of UK air passengers measured as numbers of terminal passengers. These forecasts are based on the assumption that there will be no new runways in the UK, with only incremental developments to airport terminals to make maximum use of existing runways. The upper and lower bounds of the range of forecasts are derived by combining sensitivity tests in which the projections of the key drivers of air passenger demand are varied. The central forecasts are based on central projections for each driver.

1.11 The main factors driving the range in passenger forecasts are different assumptions about future economic growth, growth in oil and EU ETS carbon allowance prices, the effects of market maturity on air travel demand and the extent to which there will be a 'bounce-back' of demand following the significant reductions observed as a result of the financial crisis.

1.12 The number of air passengers using UK airports is forecast to recover from the recent downturn, rising from 211 million passengers per annum (mppa) in 2010 to 335mppa in 2030 (within the range 300mppa to 380 mppa), and to 470mppa in 2050 (within the range 380mppa to 515 mppa). These forecasts imply average annual growth in passenger numbers to 2050 of 2.0% (within the range 1.5-2.3%) significantly lower than the 3.7% average seen over the past twenty years.

Figure 1.1: UK terminal passengers (constrained – 'max use') - historic with central, low, and high forecasts

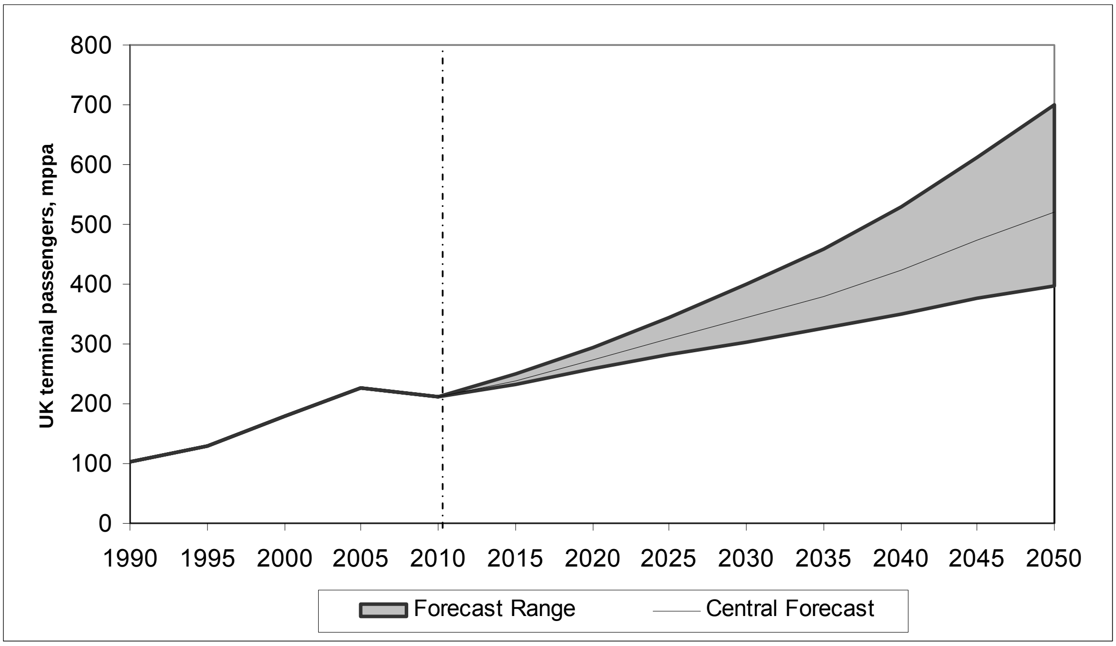


1.13 As an intermediate step in producing the air passenger forecasts presented in Figure 1.1 'unconstrained forecasts' are produced, which show how the number of UK air passengers would grow if all UK airports were able to grow to meet demand, i.e. if there were no airport capacity constraints.

1.14 The national unconstrained forecasts are shown in Figure 1.2. These forecasts suggest that, if there were no airport capacity constraints, UK air travel demand would rise from 211 million passengers per annum (mppa) in 2010 to 345mppa in 2030 under the central forecast, within the range 305mppa to 400mppa. By 2050 the central forecast is for 520mppa within the range of 400mppa to 700mppa.

1.15 A comparison of the forecasts in Figure 1.1 with the unconstrained forecasts in Figure 1.2 shows that the number of UK air passengers is forecast to be constrained by airport capacity. If there are no new runways in future, by 2050 the number of passengers is forecast to be 50mppa (within the range 20mppa to 185mppa) lower than it would have been if there were no airport capacity constraints. Capacity constraints have a greater effect at the airport level. For example, the central forecasts suggest that without new runways the three largest London airports will be at capacity by 2030, and all growth beyond 2040 will occur at regional airports.

Figure 1.2: UK unconstrained demand - historic with central, low, and high forecasts



UK aviation CO_2 emissions

1.16 The forecasts of UK aviation CO_2 emissions cover emissions produced by all flights departing UK airports to 2050, adjusted to match the DECC published estimate of outturn aviation CO_2 emissions in the base year[7]. The forecasts therefore include CO_2 emitted from all domestic and international flights departing UK airports, irrespective of the nationality of passengers or carriers and include all freighter traffic.

1.17 The approach taken to producing UK aviation CO_2 forecasts remains broadly the same as that reported in *UK Air Passenger Demand and* CO_2 *Forecasts 2009*. However, like the air passenger and ATM forecasts, the updated forecasts reflect an extensive programme of model updates and enhancements. The key developments include:

- updated ATM forecasts (see above);
- modification of assumed aircraft fuel burn rates to reflect advice from independent experts; and
- extension of fleet turnover model to operate to 2050 and to expand maximum number of aircraft types to 150 (from 70 previously)

---

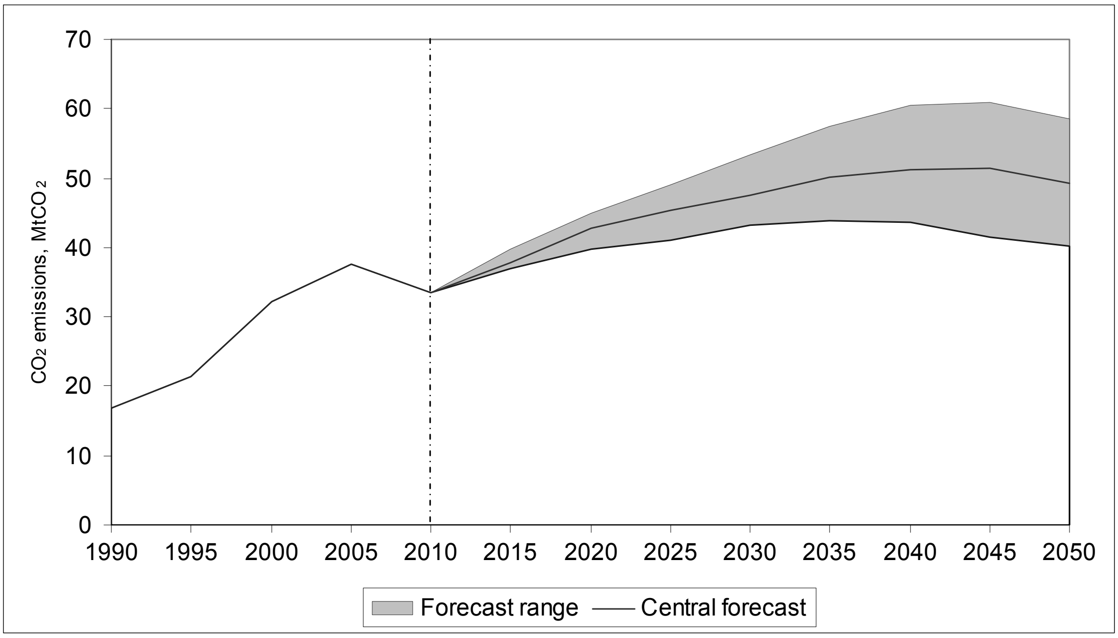
[7] This covers the 31 largest airports in the UK. Emissions from the other minor airports are unlikely to be significant as they offer only short range services. DECC's estimates of outturn CO_2 emissions from aviation are based on the amount of aviation fuel uplifted from bunkers at all UK airports. The 'forecast' for 2008 is about 0.5 $MtCO_2$ (1%) below the latest revised DECC estimate for that year.

1.18 Chapter 3 and Annex C provide full details of the methodology and assumptions underpinning the updated aviation CO_2 forecasts. Annex E explains the changes made to the forecasting methodology since 2009.

1.19 Figure 1.3 below presents the updated UK aviation CO_2 forecasts. The upper and lower bounds of the range are defined by combining the range of ATM forecasts with ranges of assumptions about fuel efficiency improvements and penetration of alternative fuels in the fleet of aircraft using UK airports.

1.20 Following the drop in emissions associated with the impact of the recent financial crisis and global economic slowdown on aviation activity, UK aviation CO_2 emissions are forecast to grow steadily without further government intervention over the next twenty years. They grow from 34 $MtCO_2$ in 2010 to 48 $MtCO_2$ in 2030 in the central forecasts. Post 2030, the effects of market maturity and airport capacity constraints cause the growth of activity at UK airports to slow. Improvements in aircraft fuel efficiency are expected to continue beyond 2030 and, in the central and high forecasts, biofuels are expected to penetrate the aircraft fleet as kerosene and EU ETS allowance prices increase. By 2040, the balance of these two effects causes emissions to stabilise, before starting to fall by 2050.

Figure 1.3: UK aviation CO_2 forecasts to 2050



1.21 Aviation's entry into the EU ETS from 2012 will mean that CO_2 emissions in the aviation sector will be capped. Airlines operating flights into, within and out of the EU will be required to surrender allowances and credits to cover their annual CO_2 emissions. Therefore, although CO_2 emissions from aviation are forecast to continue to grow in the UK and other EU countries, this growth will not result in any overall increase in the total CO_2 emissions from sectors included in the ETS, because the aviation sector will have to pay for reductions to be made elsewhere.

The overall result will be that the net contribution of the aviation sector to CO_2 emissions will not exceed the level of the cap.

2 Air Passenger and Air Transport Movement Forecasts

- There has been a strong upwards trend in UK air passenger travel for several decades with frequent deviations from the long term trend driven by economic recessions and other wider shocks. The recent financial crisis and associated recession caused the biggest fall in activity at UK airports since 1950.
- The UK air passenger forecasts are generated in two stages. First, national demand unconstrained by airport capacities is forecast, using the econometric models in the National Air Passenger Demand Model. The likely impact of future airport capacity constraints and split of passengers between airports is then forecast using the National Air Passenger Allocation Model.
- The models used for the updated forecasts are based on the latest available data on activity at UK airports.
- The updated forecasts also incorporate the latest economic growth forecasts, the latest oil price projections, reflect the entry of aviation into the EU Emissions Trading System (ETS) and the Government's policy not to support new runways at Heathrow, Gatwick and Stansted.
- The number of air passengers using UK airports is forecast to recover from the recent downturn, rising from 211mppa in 2010 to 335mppa in 2030 (within the range 300mppa to 380mppa), and to 470mppa in 2050 (within the range 380mppa to 515mppa).
- The central forecasts indicate that, with no new runways, the three largest London airports will be at capacity by 2030, and that all further growth beyond 2040 will occur at regional airports.

2.1 This chapter comprises three sections that set out:

- in section 2.1, an overview, including the nature and purpose of the UK air passenger and air transport movement (ATM) forecasts;
- in section 2.2, the methodology, assumptions and validation of the models used to forecast UK air passengers and ATMs; and
- in section 2.3, the updated UK air passenger and ATM forecasts.

2.1 Overview

Nature and purpose of forecasts

2.2 The DfT 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. As part of the process to account for the impacts of airport capacity on passenger demand, the number of air transport movements (ATMs) is also forecast. Box 2.1 explains the definition of terminal passengers and ATMs that are used.

2.3 These forecasts are used to inform and monitor long term strategic aviation policy. They are inputs to the forecasts of UK aviation CO_2 emissions, which are described in chapter 3.

Box 2.1: Terminal passengers and air transport movements

The Civil Aviation Authority (CAA) records the number of passengers, and the number of aircraft take-offs and landings, at UK airports each year.

The CAA defines a 'terminal passenger' as a person joining or leaving an aircraft at a reporting airport, as part of an air transport movement (ATM). This includes passengers 'interlining' (transferring between connecting services), but excludes those ’transiting' (arriving and departing on the same aircraft without entering the terminal) at a reporting UK airport.

The CAA further defines an ATM as a landing or take-off of an aircraft engaged on the transport of passengers, cargo or mail on commercial terms (excluding 'air taxi' movements, and empty positioning flights). As it does not include non-commercial movements, it also excludes private, aero-club, and military movements.

The number of terminal passengers is related to, but not the same as, the number of trips by air to and from the UK. For example, a passenger making:

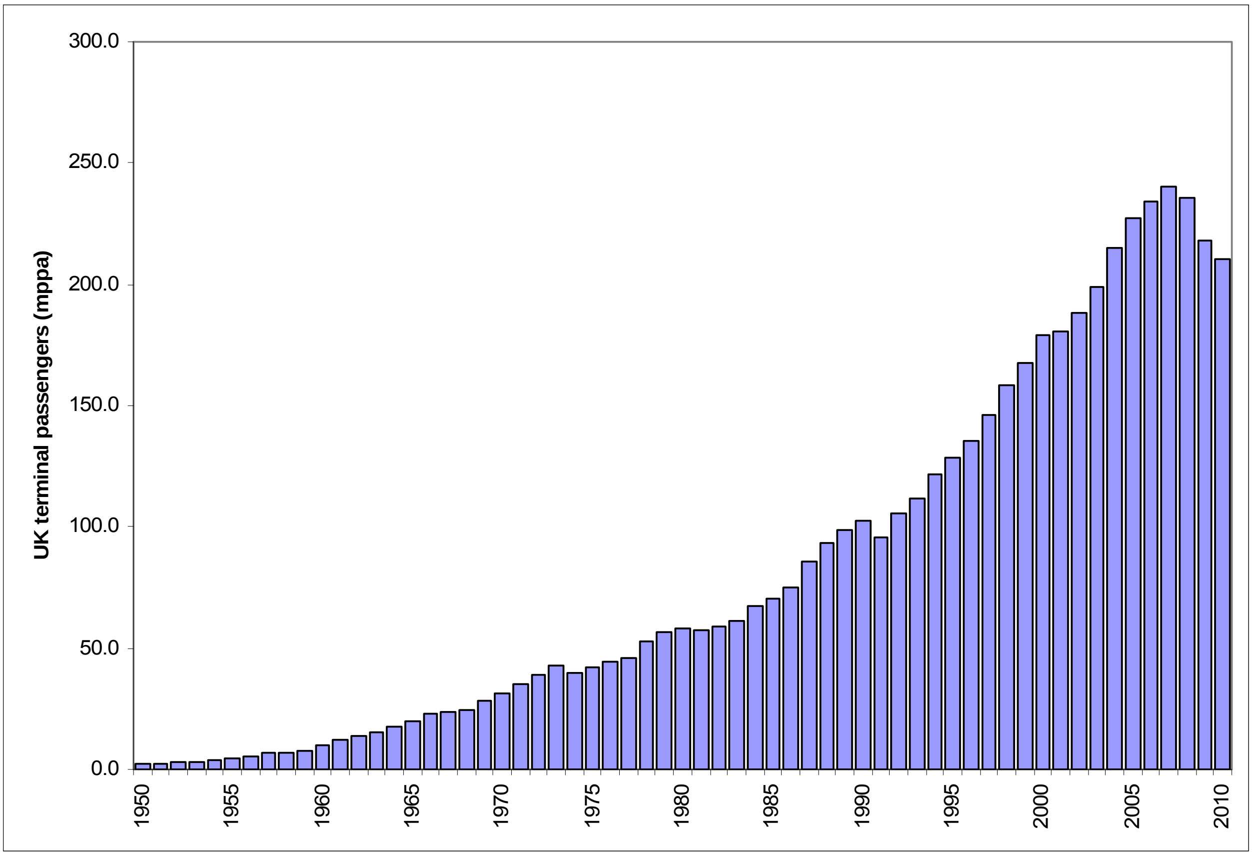
- a direct, one way trip from the UK to an overseas destination would count as one terminal passenger;
- a domestic, direct, one way trip would count as two terminal passengers;
- a one way trip from the UK to an overseas destination, via a UK connection (or transfer) would count as three terminal passengers; and,
- a one way trip between two overseas countries via a connection in the UK would count as two terminal passengers.

A round trip would involve double the terminal passengers of a one-way trip. The full definitions of terminal passengers and air transport movements is available on the CAA website at: www.caa.co.uk/docs/80/airport_data/2006Annual/Foreward.pdf

Context and interpretation of passenger forecasts

2.4 Figure 2.1 shows the growth of UK air passenger travel since 1950. The frequent deviations from the long term trend have been driven by economic factors, such as recessions or oil price shocks, or by wider conditions, such as military conflicts, terrorism, fears of global pandemic or volcanic ash episodes. The recent financial crisis and associated economic downturn caused the largest fall in activity at UK airports since the end of the Second World War. It is reasonable to expect that activity at UK airports will continue to be affected by such less predictable short term fluctuations in future.

Figure 2.1: UK terminal passengers 1950-2010



2.5 The primary purpose of the passenger forecasts is to inform long term, strategic aviation policy, for which the longer term trend is more relevant than the short term fluctuations around it. However, the forecasts are capable of capturing the effects of some short term fluctuations (such as economic growth and oil prices), to the extent that accurate forecasts of them are available. In the longer term, such fluctuations are rarely predictable, and so do not feature in the forecasts. Hence, while the forecasts are primarily intended for longer term purposes, they should be able to capture some, though not all, shorter term influences.

2.2 Methodology, Assumptions and Validation

2.6 This section describes the methodology and assumptions used to produce UK air passenger and air transport movement (ATM) forecasts. Chapter 3 describes the methodology and key assumptions used in producing UK aviation CO_2 forecasts.

2.7 In broad terms, the passenger forecasts are generated in two steps.

1. 'Unconstrained' national air passenger demand forecasts are generated using the National Air Passenger Demand Model. This combines time-series econometric models with projections of key driving variables, to forecast national air travel demand assuming no UK airport capacity constraints.

2. 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.

2.8 The 'unconstrained' demand forecasts from the National Air Passenger Demand Model can also be converted to airport-level 'unconstrained' passenger demand forecasts using the National Air Passenger Allocation Model. This is achieved by switching off the airport capacity constraints used in the National Air Passenger Allocation Model.

2.9 The 'unconstrained' demand forecasts produced by the National Air Passenger Demand Model are only an intermediate step in the forecasting process. The 'unconstrained' passenger demand forecasts from the National Air Passenger Allocation are, in contrast, an alternative output to constrained passenger forecasts, showing how UK air passenger numbers would grow if there were no UK airport capacity constraints.

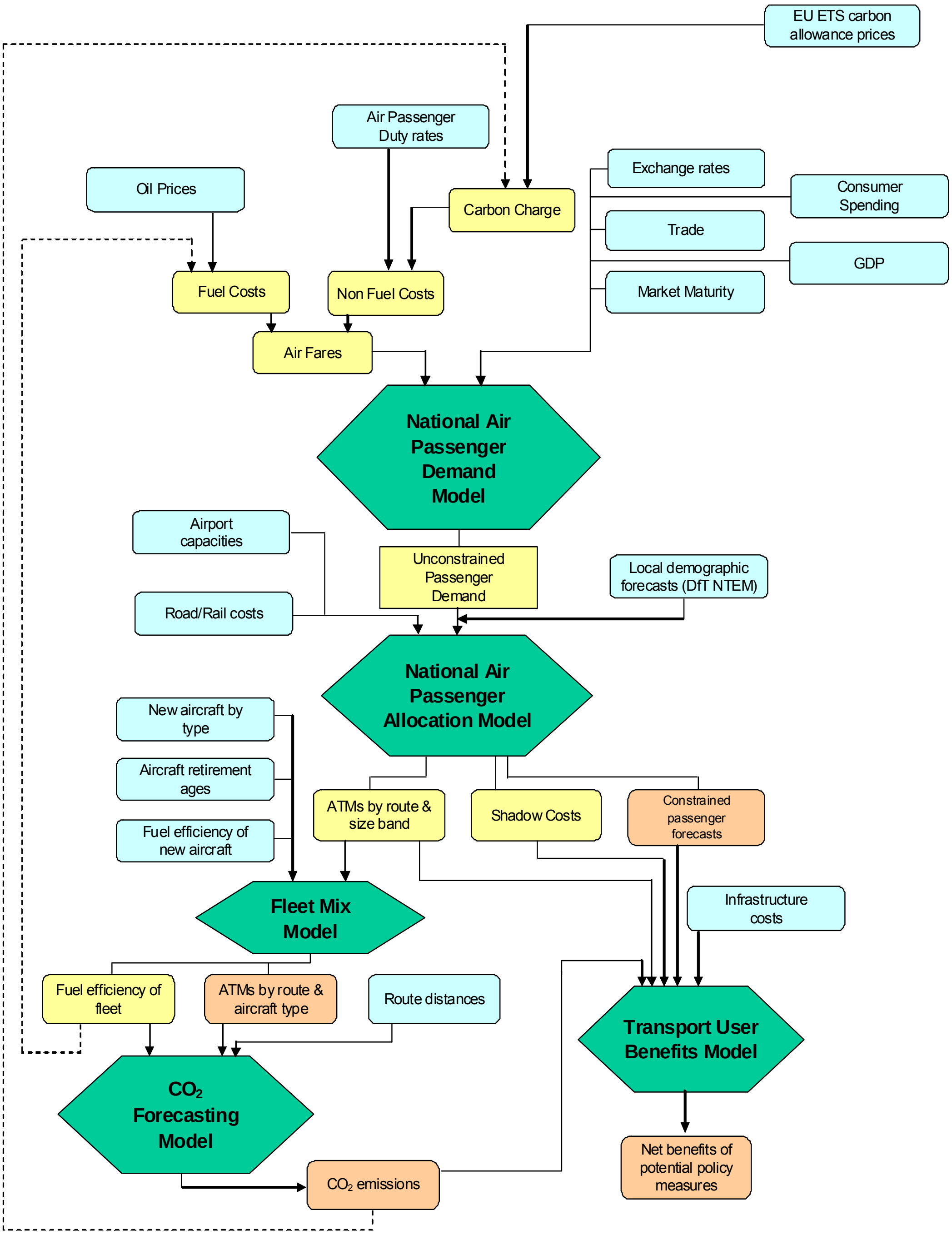
2.10 Figure 2.2 provides an overview of the framework used to produce forecasts of UK air passenger and aviation CO_2 emissions. The diagram shows the key inputs (in blue), models (in green), intermediate outputs (in yellow), and final outputs (in orange). It illustrates the case where the National Air Passenger Allocation Model is being used to produce constrained UK air passenger forecasts. The same diagram can be used to illustrate the case where unconstrained UK air passenger forecasts are produced by the National Air Passenger Allocation Model, by replacing the orange field "constrained passenger forecasts" with an orange field called "unconstrained passenger forecasts", and deleting the blue field "Airport capacities" that points to the National Air Passenger Allocation Model.

2.11 All the forecasting methods are described in chapters 2 and 3 of this document. The appraisal methods employed in the Transport User Benefits Model are described in TAG Unit 3.18 *Aviation Appraisal.*[8]

---

[8] www.dft.gov.uk/webtag/

Figure 2.2: UK aviation forecasting framework



National Air Passenger Demand Model forecasts to 2080

Methodology

2.12 The National Air Passenger Demand Model is used to forecast the number of UK air passengers assuming no UK airport capacity constraints. It does this by combining 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 National Air Passenger Demand Model is capable of producing forecasts to 2080; it has been used up to 2050 to produce the forecasts presented in this document.

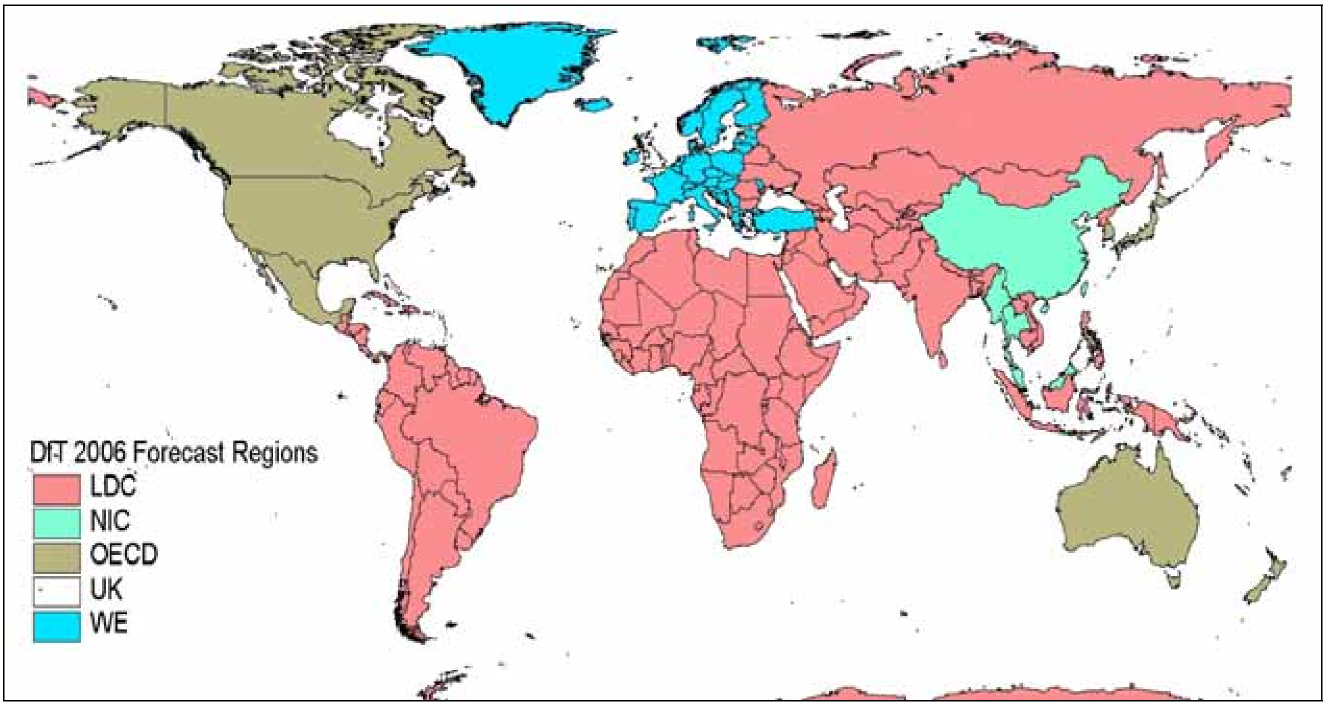
2.13 A time-series econometric model is a statistically estimated equation which quantifies how, historically, key driving factors have caused the variable of interest (in this case UK air passengers) to move over time.

2.14 The market for passenger air travel through UK airports has been split into separate sub-markets reflecting different trends, strength of driving forces and availability of data. One might expect that the demand for leisure trips would be driven by consumer spending, and to some extent affected by air fares; while travel for business purposes might be expected to be driven by total GDP and international trade, and less affected by air fares at the aggregate national level. Similarly, one might expect the strength of the causal factors to vary between global regions, reflecting a range of factors including each region's stage of economic development, the maturity of the air travel market to and from the UK and the availability of alternative modes of travel.

2.15 The market for passenger air travel is therefore split according to:

- the global region the passenger is travelling to or from (see Figure 2.3);
- whether the passenger is a UK or overseas resident;
- the passenger's journey purpose (leisure or business);
- whether the passenger is on an international or domestic flight; and
- whether the passenger is making an international to international connection at a UK airport (as part of a journey between two other nations).

Figure 2.3: Global regions used in the National Air Passenger Demand Model



2.16 Overall, this gives nineteen market sectors for which separate econometric models are estimated and used to forecast demand. Box 2.2 sets out some detail of the econometric modelling approach, and annex A gives more detail on the econometric models and the work to re-estimate the models undertaken since *UK Air Passenger Demand and* CO_2 *forecasts, 2009* was published.

Econometric analysis

2.17 The econometric analysis confirmed that the key variables determining UK air travel varied by market segment, but in general included measures of economic activity, air fares, and exchange rates. In the leisure sectors, consumer spending and air fares were identified as the key drivers. In the business sectors, GDP and international trade were shown to be the main drivers, with more limited price effects identified.

2.18 Table 2.1 below summarises the estimated long run elasticities of air passengers with respect to income and fares that have been used in producing the updated forecasts[9]. This shows that income is a strong driver in the domestic and UK markets, with the estimated income elasticity of demand ranging from 1.2 to 1.7. This falls to 1.0 for the foreign markets, and 0.5 for the international to international interliners market. The overall average income elasticity is strong at 1.3. Air fare elasticities are more variable. A strong price elasticity of -0.7 is used for

---

[9] The elasticity of demand with respect to another variable shows the percentage change in demand that would result from a 1% change in the other variable.

the UK leisure sector, while a slightly lower value of -0.6 is used for the foreign leisure market. The fare elasticity for the domestic market is lower still at -0.5, although this elasticity combines the relatively price elastic (-0.7) domestic leisure sector, with the more price inelastic (-0.3) domestic business sector. Lower air fare elasticities of -0.2 are used for both the UK and foreign business markets.

Box 2.2: Econometric analysis of UK air passengers

The purpose of the time series modelling is to quantify the relationship between the number of passengers using UK airports and the variables which cause it to change. Economic theory and analysis of data from earlier years suggests that income, consumer spending, international trade, exchange rates and air fares were all likely to be driving variables.

Most of the markets display strongly trended variables. There are upward trends in traffic, but also in the driving variables such as consumer spending, GDP, exports and imports. Similarly there is typically a downwards trend in air fares. Estimating the relationship between strongly trended variables like this could suffer from the problem of 'spurious regression', where the statistical significance of the estimated relationship appears stronger than it really is. However, if there exists a relationship to which the variables tend to revert in the long run, the variables are said to be 'co-integrated' and there are a range of time series techniques available that avoid the problem of spurious regression.

The Unrestricted Error Correction Model (UECM) approach has been applied to estimate co-integrated relationships. All the models take the general form:

$$\Delta Q_{it} = \alpha_i + \beta_i \Delta Z_{it} + \delta_i Q_{it-1} + \gamma_i Z_{it-1} + \varepsilon_{it}$$

where
Q_{it} = log of passenger demand in market i at time t
Z_{it} = log of driving variables in market i at time t
ε_{it} = error in prediction in market i at time t
$\alpha_i,\beta_i,\gamma_i,\delta_i$ = parameters to be estimated
Δ = change between period t and period t-1

The models were estimated over different time periods, depending on the availability of data. The earliest sample period began in 1984, but all models used data up to 2008.

The results show a good fit to the data in most markets with statistically significant parameters of the expected sign and magnitude. The R^2 values (which show the proportion of the past variation in the dependent variable the models explain) for most of the market models are in the region of 0.6-0.9. This indicates that the models are successful in explaining past movements in the number of UK passengers, and therefore provide a level of confidence in using them as a starting point for projecting UK air passengers in future.

Table 2.1: Long run price and income elasticities of UK terminal passenger demand

		Elasticity of demand with respect to	
Sector	Share of Passenger demand 2008	Income	Air Fares
UK Business	8%	1.2	-0.2
UK Leisure	45%	1.4	-0.7
Foreign Business	7%	1.0	-0.2
Foreign Leisure	14%	1.0	-0.6
International to International Interliners	10%	0.5	-0.7
Domestic	15%	1.7	-0.5
Overall	100%	1.3	-0.6

Notes:

Income variable depends on sector

Price and income elasticities are point estimates.

Results are elasticity of terminal passengers to income or fares

2.19 The resulting overall air fare elasticity is -0.6. It is intuitive that this is some way below unity, given that passengers may have options beyond not travelling in their response to an increase in fare. For example, they might reduce the cost of their trip by travelling to a less expensive destination, or by using a less expensive class of travel or airline. This overall fare elasticity is also in keeping with the findings for other modes that UK transport demand is price inelastic (i.e. has a price elasticity below -1). Furthermore, Box 2.3 explains that the elasticities presented in Table 2.1 are broadly consistent with other relevant published studies.

Box 2.3: National aviation demand price and income elasticities comparisons

In assessing the results of the econometric modelling, the price and income elasticities have been compared with those found in the literature. In choosing elasticities for comparison, it is essential to focus on studies which are relevant to the UK national passenger demand. For example, it would not be accurate to compare a national level price elasticity to that of a sub-national market, or an individual airline. As shown by CAA (2005), price effects at the sub-national level could be stronger, reflecting greater substitution possibilities, but substitution between routes or airlines would not affect the total market size. Also, comparisons with markets in other countries or regions of the world are complicated by their different population distribution, geography and transport systems, and market structures.

A literature review revealed that while there is a large number of studies of aviation price and income elasticities, relatively few are relevant to UK national demand. Key studies which are directly comparable are Graham (2000)[1], Dargay & Hanley (2001)[2], CAA (2005)[3] and Dargay, Menaz & Cairns (2006)[4]. None of these studies covers all the market sectors modelled and used for forecasting, but where they coincide they find price elasticities broadly comparable to those presented in this report.

The price elasticity of UK leisure travel is found to be -0.6 by Dargay & Hanley, in the range of -0.7 to -0.8 (outbound) by CAA, -1.0 for short haul and 0.4 for long haul by Dargay, Menaz & Cairns. The estimated price elasticity of UK Leisure travel used for the updated forecasts (-0.7) therefore sits in the middle of the estimates in the literature. Dargay, Menaz and Cairns could not find significant fare effects for UK business travel, while Dargay & Hanley found a small price effect of -0.3, slightly above the elasticity underpinning the updated forecast of -0.2. Dargay and Hanley also estimated a price elasticity of -0.3 for the foreign business and leisure markets, which is close to the elasticities of -0.2 and -0.6 used for these sectors in the updated forecasts.

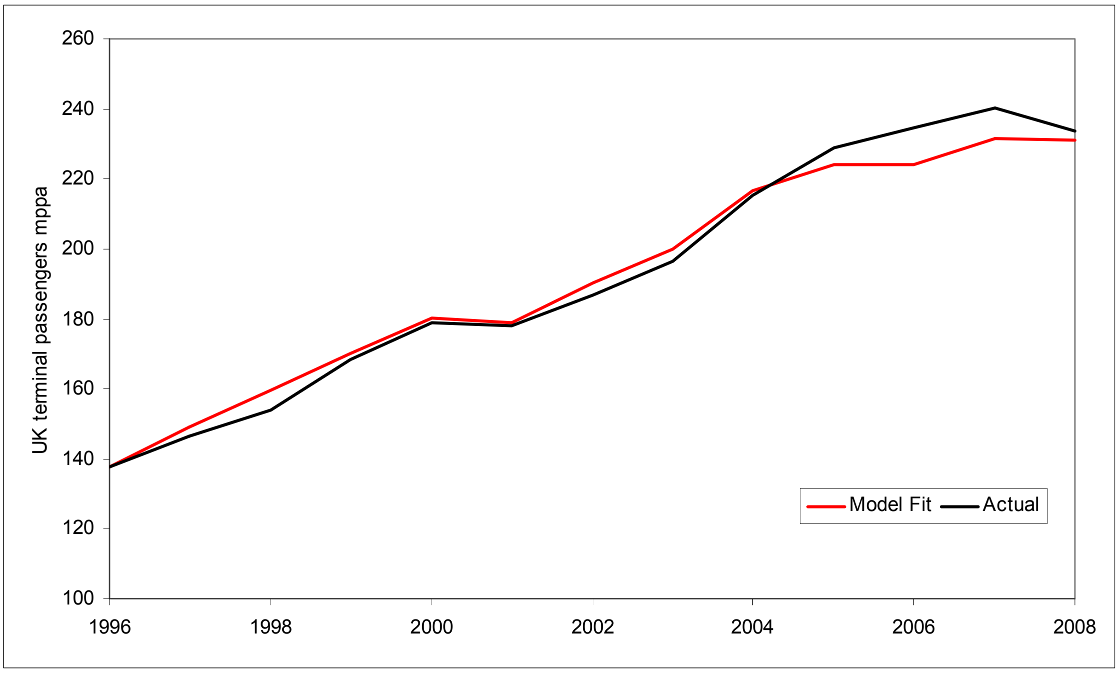
The income elasticity of UK leisure travel is found to be 2.0 by Graham, 1.5-1.8 (outbound) by CAA, 1.1 by Dargay & Hanley, and 1.0 for short haul and 2.9 for long haul by Dargay, Menaz & Cairns. These results match well with the elasticity underpinning the updated forecasts of 1.4. UK business travel's income (trade) elasticity is found to be 1.5 by Dargay & Hanley, and 3.5 for short haul and 0.2 for long haul flights by Dargay, Menaz & Cairns. The domestic income elasticity (1.2) used reporting the updated forecasts therefore lies comfortably within this range. Only Dargay and Hanly (1.8), estimated income elasticities for the foreign leisure sector, rather higher than the elasticity used here of 1.0.

[1] Graham (2000) *Demand for leisure air travel and limits to growth*, Journal of Air Transport Management 6, 2000, 109-118
[2] Dargay & Hanley (2001) *The Determinants of demand for international air travel to and from the UK*
[3] CAA (2005) *Demand for outbound leisure air travel and its key drivers*
[4] Dargay, Menaz and Cairns (2006) *Public attitudes towards aviation and climate change*

Model fit

2.20 The models resulting from this estimation process show a strong ability to fit the historic data up to the model baseline of 2008. Figure 2.4 shows that, when aggregated to the national level, the models accurately predict the trend in passenger demand, while also capturing many shorter term movements. Annex A provides details of the performance of the individual models used for each of the 19 market sectors. Section 2.3 includes discussion on the performance of the models when forecasting forward for the two years 2009 and 2010 (for which actual data not used in calibration is now available) and the steps taken to adjust model results for the exceptional factors influencing demand since 2008.[10]

Figure 2.4: Actual and fitted UK terminal passengers 1996-2008



Note: not every model is fitted to data prior to 1996, so totals consistent with CAA outturn data can be presented from 1996 only.

Market maturity and changes in the relationship between air travel and its key drivers through time

2.21 Air travel demand has shown very strong growth for several decades. While it would seem reasonable to start from the premise that the drivers of demand in the past will continue to drive demand in the future, this can only be the starting point; any exercise to forecast the future must also consider how the relationships observed in the past might change in the future and whether any additional drivers might become important.

---

[10] In particular, see paragraphs 2.107 - 2.110

2.22 For example, as with most markets, one might expect there to be some product cycle in aviation, with rapid early demand growth giving way to steadier growth in later years. Various possible explanations for this phenomenon are suggested in the literature. One explanation, specific to the market for leisure air travel, is that as the number of flights people take increases the less remaining time they have available for additional trips. This increases the value they place on their remaining leisure time and reduces the likelihood that they will respond to increases in their incomes by increasing their demand for leisure travel. The term 'market maturity' is often used to refer to the process by which the demand for a product becomes less responsive to its key drivers through time.

2.23 A detailed review of the available evidence on market maturity and other factors potentially affecting the relationship between air travel demand and its key drivers has been undertaken. The econometric models used here are estimated from data covering the past thirty years, and so reflect the most recent form of the relationship between demand and its drivers. As part of the work to re-estimate these models (described in annex A) an attempt was made to fit models with a variety of functional forms. It was found consistently across the market segments that models which imply constant relationships between demand and its key drivers (so-called constant elasticity models) perform better in explaining past changes in demand than models that imply that the responsiveness of demand to income and price changes is falling through time.

2.24 A review of the academic literature found that, despite several efforts, researchers have yet to be able to identify clear quantified evidence of the impact of market maturity on the market for air travel in the UK in historic data.

2.25 In the absence of quantified evidence of how maturity is likely to affect the way demand responds to its key drivers in future, market maturity is reflected in the updated forecasts via judgement-based adjustments to the elasticities used in the econometric models. For each of the sectors of the air travel market separately modelled, assumptions are made about the date from which market maturity will take effect and the scale of the impact on the way passenger demand responds to changes in its key drivers.

2.26 A range of assumptions have been developed to reflect the significant uncertainty around how maturity and market liberalisation might affect the market for UK air travel in future. While it is impossible to attach probabilities to different points in the range, the higher and lower bounds of the range are regarded as either end of a range of reasonably likely outcomes. The lower bound of the range of maturity assumptions is used to produce the upper bound of the range of forecasts presented in this document. The upper bound of the range is used in producing the lower bound of the forecast range. A central set of maturity assumptions has been defined to underpin the central forecasts. Annex B summarises the results of the review of the available evidence and explains in detail how changes in the relationship between air travel demand and its key drivers are reflected in the updated forecasts.

National Air Passenger Demand Model input assumptions

2.27 The previous section described the econometric analysis underpinning the National Air Passenger Demand Model, and explained how the estimated models have been adjusted to reflect the likelihood that the relationship between UK air travel and its key drivers will change in the future. Having chosen the econometric models to use in forecasting, the next step in producing the updated forecasts was to feed projections of the relevant driving variables into the econometric models for each market segment.

2.28 The central forecasts are based on central projections for each driving variable. The upper and lower bounds of the overall forecast range are derived by combining sensitivity tests in which the projections of each driving variable are varied within reasonable bounds. The following section outlines the assumptions made when projecting each driving variable, starting with the assumptions used to produce the central forecast, followed by the assumptions used in performing sensitivity tests and in deriving the overall forecast range. Annex C provides more detailed information.

Central Forecast

Macroeconomic factors

2.29 Growth projections to 2050 for UK GDP, and UK consumer spending are based on the latest Office for Budget Responsibility (OBR) projections[11]. Growth projections for Western Europe, OECD, NIC and LDC are taken from the IMF World Economic Outlook[12]. The growth rates vary between regions and time periods, but generally show continued growth in incomes around the world, with much stronger growth in newly industrialising and less developed countries.

2.30 Projections of UK international trade are based on trade's historic relationship with UK and overseas GDP. These indicate continued steady growth in trade with Europe and OECD nations, and stronger growth for newly industrialising and less developed countries.

2.31 Exchange rates are particularly challenging to project over many years, being subject to both long term trends and short term movements. However, since the late 1980s, the US$/GBP exchange rate has traded within a fairly well defined band between US$1.40/GBP and US$1.97/GBP. The central forecasts are based on the assumption that

---

[11] *Economic and fiscal outlook – March 2011,* Office for Budgetary Responsibility, 2011 (available at http://budgetresponsibility.independent.gov.uk/economic-and-fiscal-outlook-march-2011/)

[12] *World Economic Outlook, Statistical Appendix*, International Monetary Fund, 2010

the (nominal) exchange rate will remain constant at the median value within this range.

Air fares

2.32 Air fares are assumed to move in line with airline costs. These are split into fuel costs, and non-fuel costs (including tax and environmental cost elements).

2.33 Fuel costs are driven by fuel price and fuel efficiency. Fuel prices are projected by assuming that the strong historical relationship between kerosene and oil prices continues. Oil prices are assumed to move in line with the DECC Scenario 2 – "timely investment, moderate demand" oil price projection, which falls from $102 per barrel in 2008 (in 2008 prices) to $70 per barrel in 2010, before rising back to $90 per barrel in 2030[13]. The scope for biofuels to have a significant impact on air fares and consequently levels of demand has also been considered. Biofuels are assumed to account for 2.5% of fuel use on flights using UK airports by 2050 in the central forecasts. There is significant uncertainty surrounding future biofuel prices. In producing the updated forecasts it has been assumed that airlines' use of biofuels will not significantly affect their combined fuel and carbon allowance costs[14]. The penetration of biofuels into the aircraft fleet, therefore, is assumed to have a neutral effect on air fares and on the demand forecasts.

2.34 Fuel efficiency growth assumptions are derived from the fleet mix model, changes in air traffic management systems and airline operational practices which are explained in chapter 3.

2.35 APD rates are assumed to remain constant in real terms beyond the rates announced in the 2011 Budget[15].

2.36 To reflect the entry of aviation into the EU ETS from 2012, airlines are assumed to pass on the costs of EU Allowances (EUAs) to passengers in the same way as they do APD. In estimating these costs CO_2 emissions per flight have been estimated at the route level and DECC projections of the traded carbon price out to 2050 have been used [16].

2.37 Analysis of airline cost data shows that other non-fuel costs (i.e. aircraft fleet and staffing costs, passenger handling costs, landing charges etc) have trended downwards in the last decade, for both short-haul and long-haul operations. From 1998 to 2008, non-fuel costs for short haul flights declined, on average, by around 3.3 % per annum (pa), while non-fuel costs for long-haul flights declined, on average, by around 4.1%. This was driven by: increasing airline competition; convergence of lower cost and full service airline business models; and, the continuing evolution of non-fare revenue streams by airlines. These negative

---

[13] *Communication on DECC Fossil Fuel Price Assumptions,* DECC, March 2009.

[14] Under the EU ETS airlines do not need to surrender allowances for their biofuels use.

[15] 2011 Budget, HM Treasury, March 2011, HC 836

[16] *Updated short term traded carbon values for UK public policy appraisal*, DECC, June 2010

trends are projected to continue for a time, but at a slowing rate. Short-haul and domestic non-fuel costs are assumed to have fallen (in real terms) by 1.4% pa between 2008 (the model base year) and 2010, and are then projected to fall by 1.1% pa in the period 2011-2015, and 0.7% pa in the period 2016-2030, after which they are held constant. Similarly, long-haul non-fuel costs are assumed to have fallen by about 1.7% pa between 2008 and 2010, and are then projected to fall by 1.4% pa in the period 2011-2015, and by 1.0% pa in the period 2016-2030, after which they are held constant.

Box 2.4: Carbon dioxide price projections

The current DECC guidance gives a 2010 price of carbon emissions of £14.1/tCO_2e (in 2009 prices), rising to £200/tCO_2e (in 2009 prices) by 2050. This guidance is available at:
http://www.decc.gov.uk/en/content/cms/emissions/valuation/valuation.aspx

The guidance also provides a range of carbon prices with a lower bound value of £100/tCO_2e and upper bound value of £300/tCO_2e (both in 2009 prices) by 2050. This range has been adopted in sensitivity tests.

DECC announced alongside this guidance that it intended to review the short term carbon values (out to 2030) annually and long term carbon values once every five years beginning this year.

Sensitivity tests

2.38 As with any forecasting exercise looking so far into the future, there is uncertainty over the future path of the driving variables. Therefore a range of values around the central projection has been produced for each of the key variables. These values are used in sensitivity tests to illustrate the impact on the forecasts of varying the projections of the driving factors within reasonable bounds. The nature of each sensitivity test depends on the uncertainty surrounding the projected variable.

2.39 The range of values used for each driving variable is summarised below, and Annex C provides more detail.

Economic activity: trend growth

2.40 The economic activity ‘trend growth’ test allows growth in each variable reflecting economic activity (GDP, consumer spending and trade) to vary by +/-0.25% per annum.

Oil prices

2.41 The oil price test varies the projection of oil prices within the DECC oil price projection range of $60 per barrel to $150 per barrel (2030 values in 2008 prices).

Carbon price

2.42 Box 2.4 explains that the range of DECC projections of carbon prices has been used i.e. between £100/tCO_2 and £300/tCO_2 in 2050.

Fuel efficiency of new aircraft

2.43 Chapter 3 explains the sensitivity test performed on the fuel efficiency of aircraft entering service.

Videoconferencing

2.44 For the lower bound forecasts, it is assumed that the increasing availability of videoconferencing facilities will result in a 10% reduction in business air travel by 2050, relative to the level of demand implied by National Air Passenger Demand Model forecasts. This assumption is consistent with that made by the Committee on Climate Change's (CCC) in the 'optimistic' scenario presented in *Meeting the UK aviation target – options for reducing emissions to 2050*. For the upper bound forecasts, a 5% increase in business air travel by 2050, relative to the level of demand implied by National Air Passenger Demand Model forecasts, is assumed. This reflects recent research cited by the CCC that suggests that rather than substituting for business travel, greater telecommunications use accompanies increases in total travel[17].

Overall Forecast range

2.45 The overall range of forecasts combines the sensitivity tests described above. The lower bound of the forecast range (the low baseline used in the MAC curve analysis) combines high market maturity, low GDP, low oil prices, low carbon prices, high exchange rates (i.e. a stronger pound), high fuel efficiency and high video conferencing assumptions. The upper bound of the forecast range combines low market maturity, high GDP, high oil prices, high carbon prices, low exchange rates (i.e. a weaker pound), low fuel efficiency and low video conferencing assumptions.

2.46 In addition, the range of forecasts also reflects different assumptions about the extent to which there will be a 'bounce-back' of the exceptional loss of demand following the 2008 financial crisis. Section 2.3 shows that even when outturn data for all the key drivers of demand are input into the model, the forecasts of UK air passenger numbers for 2009 and 2010 exceed observed passenger numbers. This forecasting error

---

[17] *'Meeting the UK aviation target – options for reducing emissions to 2050',* Committee on Climate Change, 2009

indicates that UK passenger numbers have been significantly affected in the past two years by a factor (or factors) that is not included in the forecasting models.

2.47 It is necessary to take a view as to whether the factor that has caused passenger numbers to be below the levels implied by the forecasts has changed temporarily, and passenger traffic will bounce-back, or whether it has changed permanently. The central forecasts and lower bound of the forecast range reflect the cautious view that the effect is permanent, while the upper bound of the forecast range reflects the assumption that there is a complete and swift bounce-back of demand. The reasons why the effects of the financial crisis are treated as an exceptional factor in forecasting air passenger numbers are discussed further in section 2.3.

2.48 The forecast range reported in this document, and used in the MAC curve analysis, does not represent the most extreme combination of the assumptions possible. Extreme ranges ("lowlow" and "highhigh"), in which the sensitivity tests for each key variable are combined to minimise or maximise total UK air passenger numbers, have been produced and are reported alongside sensitivity tests. The more extreme range is regarded as a less useful basis for policy development as it is based on combinations of input assumptions that are unlikely to be realised. For example, combining low GDP growth projections with high oil price and EU ETS allowance price projections produces lower forecasts than the lower bound of the overall forecast range, but the positive relationship between GDP and oil and EU ETS allowance prices means that this scenario is significantly less likely to occur.

Constrained passenger forecasts to 2050

2.49 The unconstrained demand forecasts from the National Air Passenger Demand Model provide an input to the DfT National Air Passenger Allocation Model in producing 'constrained' UK air passenger and ATM forecasts, taking into account the effect of airport capacity constraints.

2.50 The DfT National Air Passenger Allocation Model comprises several sub-models and routines. These are used in combination and iteratively:

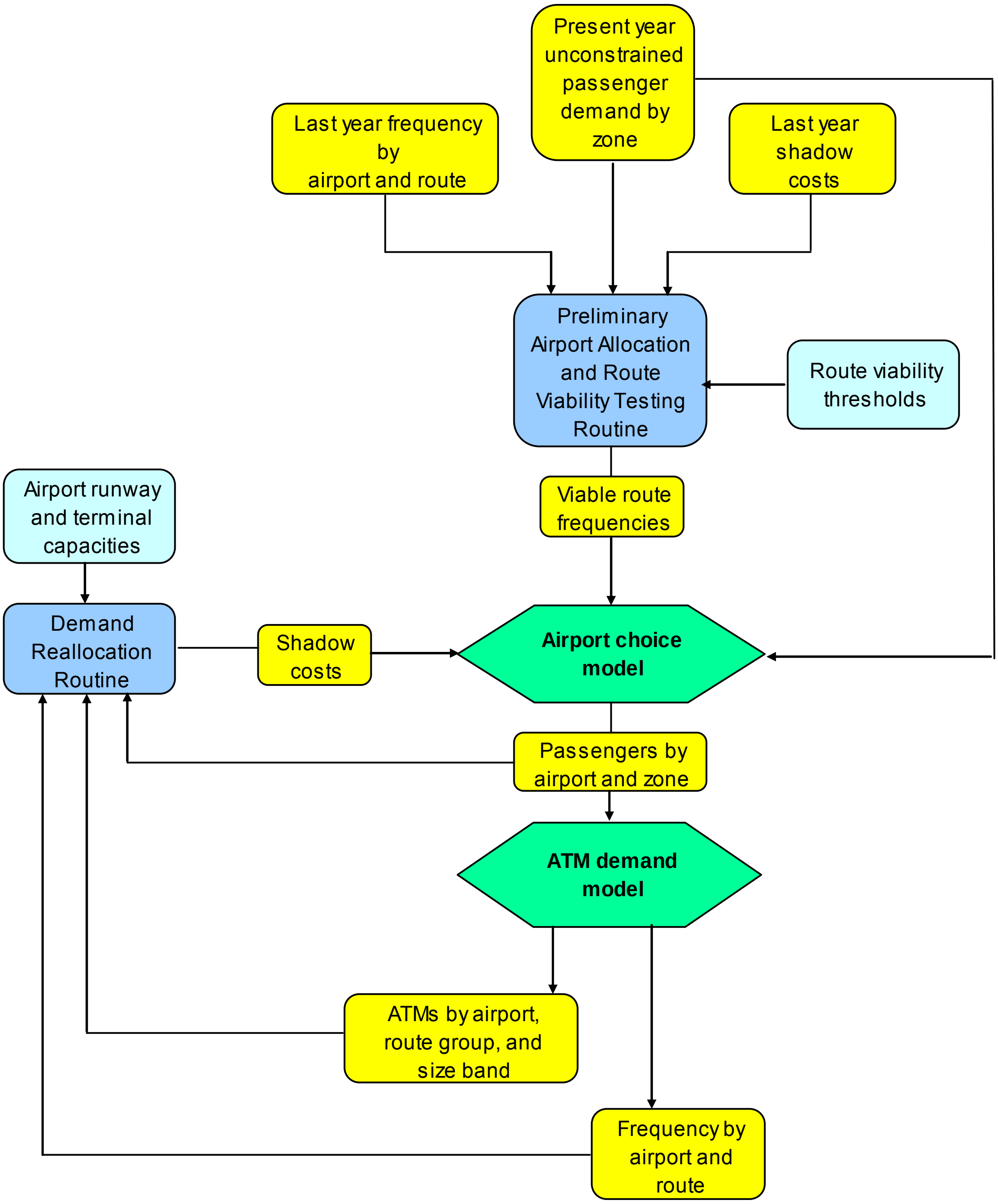
- the Passenger Airport Choice Model forecasts how passenger demand will split between UK airports;
- the ATM Demand Model translates the passenger demand forecasts for each airport into ATM forecasts; and,
- the Demand Allocation Routine accounts for the likely impact of future UK airport capacity constraints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

2.51 Figure 2.5 below illustrates this structure and process. The discussion below outlines:

- what the sub models do;
- how they are estimated;

- their validation, by showing how well they reproduce the base year data; and,
- how they are used to forecast constrained passenger numbers.

Figure 2.5: National Air Passenger Allocation Model



Passenger Airport Choice Model

2.52 The Passenger Airport Choice Model component of the National Air Passenger Allocation Model has been built to explain and reproduce passengers’ current choice of airport, as recorded in CAA passenger interview surveys. The forecasts of demand by airport are obtained by feeding projections of the variables which have been found to drive passengers' airport choice into the model.

2.53 Importantly, this means that the forecasts of airport choice (and thus the impact of capacity constraints on demand) are grounded in passengers' actual, observed behaviour. They are not based simply on, for example, assumptions about how excess demand spills between airports, nor simple extrapolations of recent trends at particular airports. An explanation of how the model is estimated and used to forecast the split of demand between airports is set out below.

Model estimation

2.54 A passenger flight is usually one part of a journey, comprising several stages and modes, between different parts of the world. To understand how passengers choose between UK airports it is therefore necessary to consider not just the airports they are flying between, but the initial origin or ultimate destination of their journey in the UK. For example, a passenger leaving Gatwick might have an initial origin at their home in Kent, and a passenger arriving at Leeds-Bradford might have a destination in York.

2.55 A traveller's choice of airport will therefore be determined by a number of factors, including:

- the initial origin (for outbound) or ultimate destination (for inbound) in the UK of their trip;
- the location of airports in the UK;
- the availability of flights offered at each airport;
- the possibilities of transferring and making onward connections at UK and overseas airports;
- the travel time and other costs for accessing each airport by road and public transport; and,
- the traveller's preference for services offered at each airport and their value of time.

2.56 The Passenger Airport Choice Model component of the DfT National Air Passenger Allocation Model quantifies the relationship between these factors and passengers' current airport choice, estimating the extent to which each of the driving factors influences airport choice.

2.57 To do this, the model splits the UK into 455 zones (see Figure 2.6), and assumes that the share of travellers originating in, or destined for, each zone potentially travelling via each of the 31 modelled airports[18] depends on:

---

[18] The 31 airports are listed in Annex D. They were selected when the National Air Passenger Demand Model was first developed in 2000 and were the busiest 27 mainland UK airports for

- the time and money costs of accessing that airport by road or public transport based on the network of road and rail services, as illustrated in Figure 2.7 and using the standard transport modelling approach of combining journey time, including waiting and interchanging, and money costs into a single 'generalised cost' measure
- flight duration and the frequency of the service at each airport
- travellers' preferences for particular airports; and,
- travellers' value of time (which varies by journey purpose).

For example, the lower the time and money costs of accessing an airport, and the greater the range and depth of services offered, the greater will be the share of demand to/from a given zone the airport will attract.

2.58 Air fares have not been included in the list of driving factors. An extensive exercise to re-estimate the factors driving airport choice failed to find a statistically significant relationship between fares for particular routes and passengers' choice of airport. This may in part be attributable to the difficulty in deriving reliable mean fares with the increasingly wide spread of fares for each route available with web based ticketing and modern yield management systems. The decision to omit fares as an airport choice variable was supported by the Peer Review process.[19] However, as the previous section has described, fares remain a key driver of the underlying unconstrained demand forecasts. They are important in forecasting the overall decision whether or not to travel by air, if not the choice of airport itself.

2.59 The strength of each factor in driving an airport's share of demand is determined by calibrating the model to 2008 CAA airport choice data.[20] Calibration is a statistical technique by which the weight placed on each factor is chosen so as to maximise the model's accuracy in predicting current choices. This means that the model represents passengers' actual, observed, airport choice behaviour. Annex D gives further detail on the model's functional form, and annex E summarises improvements to the model since *UK Air Passenger Demand and CO_2 Forecasts 2009*.

---

passenger activity plus the two Belfast airports. In 2006 Coventry and Blackpool were added and Doncaster-Sheffield replaced Sheffield City to reflect then current activity. At present all 27 of the busiest mainland airports are still included, plus the two Belfast airports. Two of the airports, Coventry and Plymouth have ceased or are ceasing passenger operations, but are currently retained – the two airports now busier, Isle of Man and Derry are both 'offshore'.

[19] *Peer Review of NAPALM*, John Bates Services, October 2010 (available at www.dft.gov.uk)

[20] Passengers are interviewed by the CAA at Heathrow, Gatwick, Stansted, Luton and Manchester every year with all but the smallest regional airports in the model being rotated on an annual basis normally on a 3-5 year cycle. The 2008 choice data includes the nine airports surveyed by the CAA in 2008 with data from other airports taken from the most recent survey and updated to 2008 traffic levels from published CAA activity statistics.

Using the Passenger Airport Choice Model to forecast airport choice

2.60 The model of passengers' airport choice delivered by the estimation process outlined above is used to forecast passenger demand at each modelled UK airport. The first step is to use the unconstrained demand forecasts from the National Air Passenger Demand Model for each type of passenger journey purpose to project growth in demand to/from zones (the districts of ultimate origin or destination) in the UK. Immediately prior to allocation to airports, growth rates by journey purpose are varied at the zonal (district) level to take account of local DfT forecasts of population, households, employment and income. The growth in passengers at the national level is however, controlled to be consistent with the forecast growth from the National Air Passenger Demand Model.[21] The following are then also projected to forecast how this demand splits between airports:

- travel time and costs between each zone and each airport, based on future road and rail network and conditions: these have been assumed to be broadly constant at 2008 levels and assume that road improvements or other management measures offset future traffic growth and maintain broadly similar levels of service; the 2008 rail network is supplemented by High Speed Rail introduced between 2026 and 2033.[22]
- route availability and frequency at each airport;
- travellers' value of time; and,
- for modelling domestic air travel, comparative road, rail and air travel time and other costs between all UK zones.

2.61 As illustrated in Figure 2.5, the availability of routes from each modelled airport is initially checked at the start of each model year. The process of checking whether sufficient demand exists to support new routes, or indeed whether existing routes are still viable, is a key part of the calculation of route frequencies and is described in the next subsection on ATM demand.

---

[21] See Annex E, paragraph 135 E.21-E.23 and footnotes for more information on this process.

[22] The High Speed Rail network is the Y-shaped route to Manchester and Leeds via Birmingham published in February 2011 Consultation Summary (available at http://highspeedrail.dft.gov.uk/sites/highspeedrail.dft.gov.uk/files/hsr-consultation-summary.pdf (p4)). The phasing of the network is taken from the Consultation Summary (p.12) with London to Birmingham via the Heathrow interchange at Old Oak Common assumed to be introduced in 2026, and the Leeds and Manchester extensions in 2033. The networks from which these road and rail district to airport surface access costs have been extracted were created in the DfT's Long Distance Model, (LDM) to reflect the detailed service pattern used in the Consultation Report.

Figure 2.6: Zones used in the National Air Passenger Allocation Model

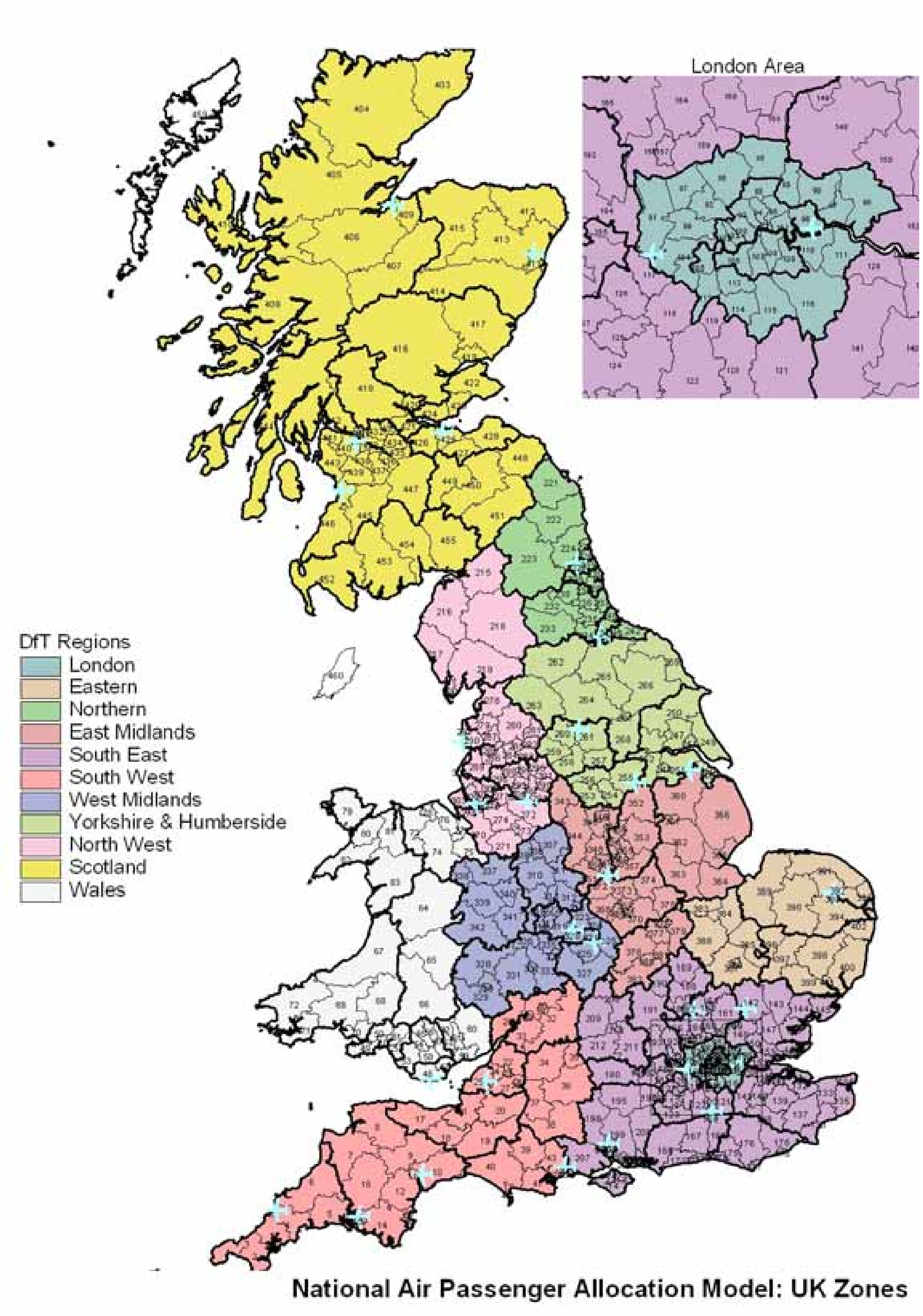
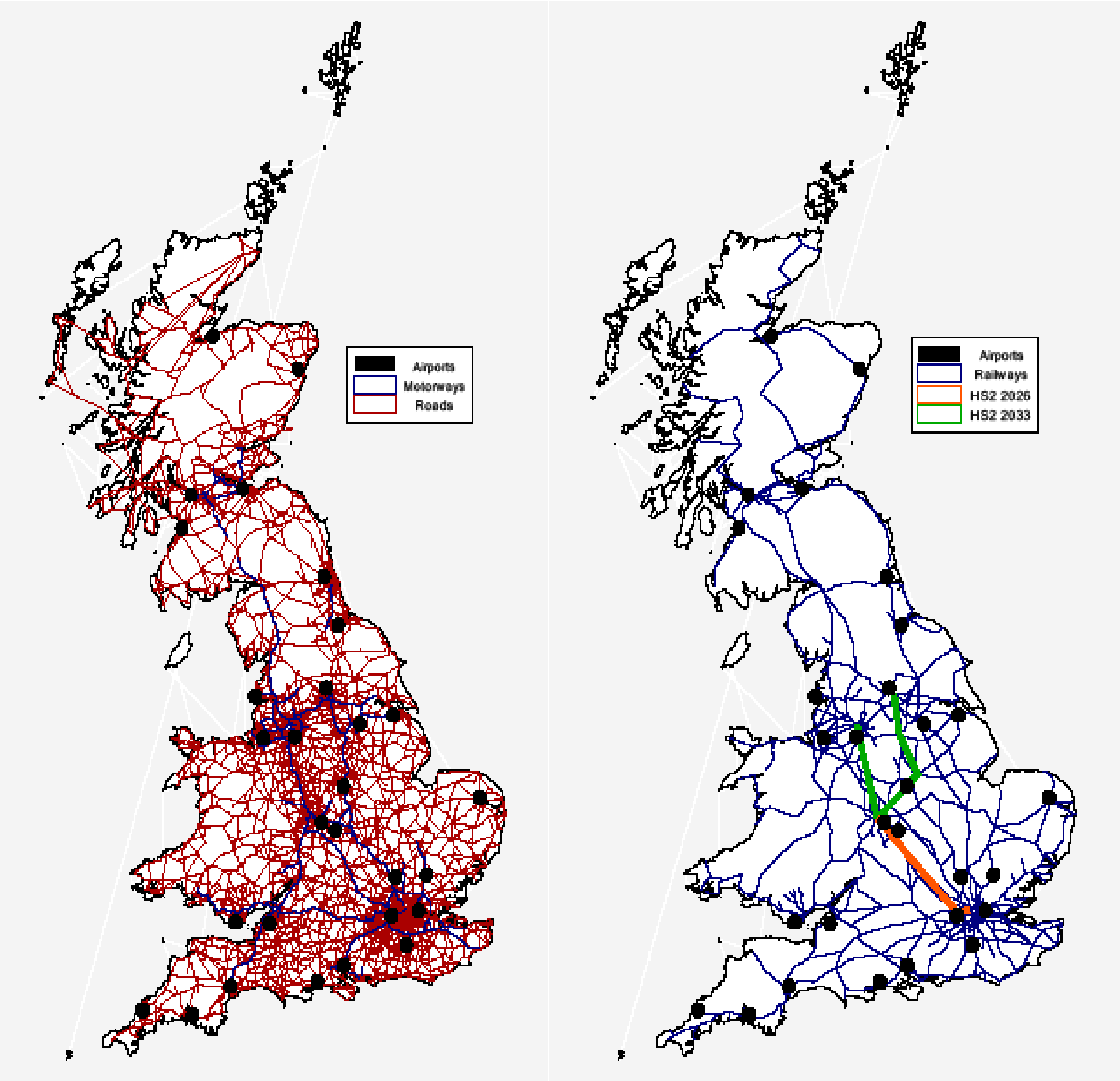


Figure 2.7: Surface access networks used in the National Air Passenger Allocation Model

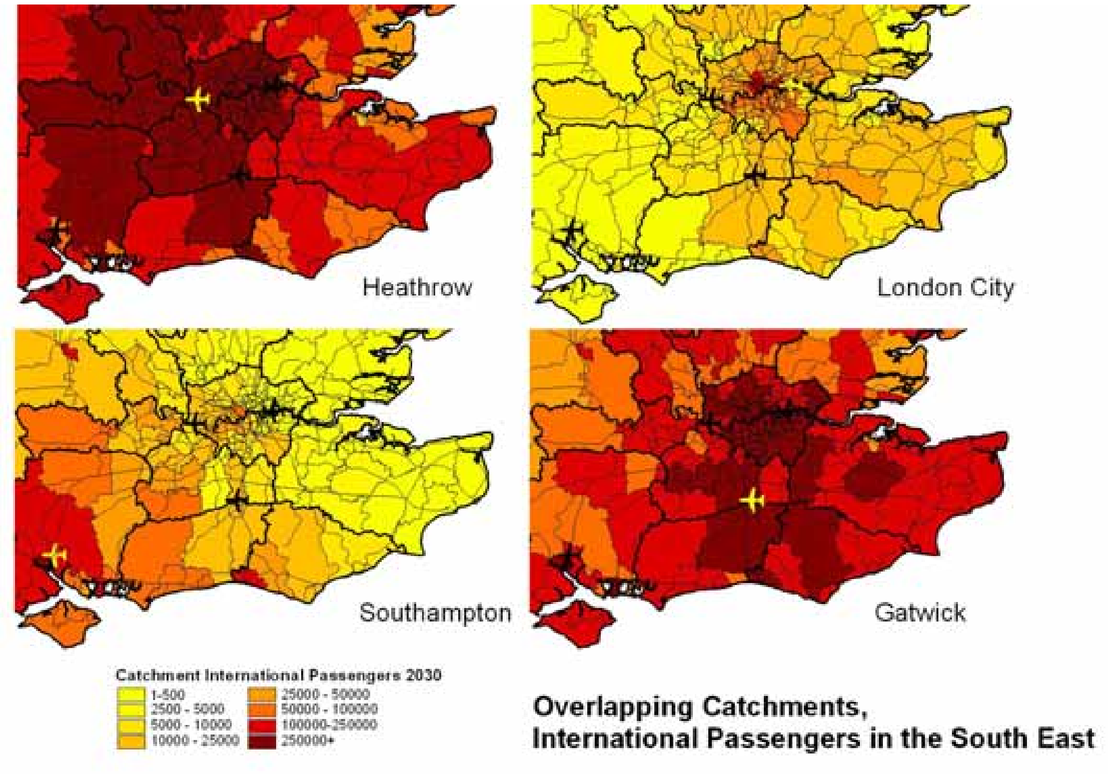


(Source DfT LDM Model)

2.62 The choice data are fed into the Passenger Airport Choice Model, which applies the calibrated relationship between these driving factors of airport choice to forecast how much of the forecast demand to/from each zone will travel via each airport. Summing forecast demand for each airport across all the zones and passenger markets gives the total forecast demand for each airport, unconstrained by airport capacity.

2.63 A key element of the constrained airport forecasts is that they are derived system-wide and allow airports to compete for demand for particular destinations. This demand originates at ground level and results in each airport having distinct catchment areas for its differing services. Figure 2.8 below illustrates how the National Air Passenger Allocation Model has produced overlapping catchments for four South East airports for the 2030 forecast year. It shows how the modelling allows passengers from individual catchments to travel to a range of airports. These catchments and potential airport choices can and do change over time as the system changes.

Figure 2.8: Projected overlapping catchments from four South East airports in 2030



ATM Demand Model

2.64 The Passenger Airport Choice Model provides the forecast demand at each modelled UK airport. As demand is forecast to grow, forecast demand will exceed capacity at some airports. The limiting capacity could be the airport terminal, runway, or planning constraint. Runway capacity is measured not by passenger numbers, but by the number of air transport movements (ATMs). The ATM Demand Model translates passenger demand into ATM demand at each airport, to allow comparison of demand with both passenger and ATM capacity constraints.

2.65 The ATM Demand Model also projects the availability of routes from each modelled airport. It is assumed that, in line with mainstream economic theory, supply will respond to demand, subject to airport capacity, so long as the market is commercially viable. Hence the supply of flights on routes is forecast to grow with demand, provided markets satisfy a minimum viability threshold. 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.

2.66 For each route from each airport, the ATM Demand Model then forecasts the size of aircraft, load factor, and frequency of operation used to meet forecast passenger demand, subject to demand, by applying relationships between passenger demand, aircraft size and load factors, and flight frequency derived statistically from historical data. These relationships indicate the stages of passenger demand growth that are likely to be accommodated by increases in frequency, and the points in the growth of demand at which a switch to operating larger aircraft can be expected. Box 2.5 provides further detail on the modelled relationship between capacity, demand, and aircraft size.

Box 2.5: Relationship between capacity, demand and aircraft size

The relationship between aircraft size and airport capacity is complex. The historical relationship between aircraft size and passenger demand at the route level shows a well established correlation between increasing aircraft size and rising passenger demand. When this relationship is extended into the future, adding new capacity increases route level demand and aircraft sizes can grow.

However, a shortage of runway capacity can also favour the use of larger aircraft, to maximise the passengers using scarce slots. The most prevalent effect in the ATM Demand Model is in line with the underlying historic data of aircraft loads tending to increase as demand rises. But the capacity response effect also occurs, and in practice the response to capacity limits will vary between airlines depending on their differing business models and commercial objectives.

2.67 The ATM model produces forecasts of the number of ATMs by aircraft size band and route, at each airport. Forecasts of CO_2 emissions and environmental assessments require more detailed assumptions to be made about the specific aircraft types that make up the stock of aircraft in each forecast year. These are generated in the Fleet Mix Model, which is explained in chapter 3.

Demand Reallocation Routine

2.68 As illustrated in Figure 2.5, the Passenger Airport Choice Model and the ATM Demand Model jointly forecast passenger and ATM demand at each airport. However, a successful forecast must account for the effect of capacity constraints on demand at every airport in a system-wide manner. The Demand Reallocation Routine component of the National Air Passenger Allocation Model therefore models the impact of capacity constraints on the numbers of air passengers, and on ATMs and their passenger loads at each UK airport.

2.69 If unconstrained passenger demand at an airport exceeds capacity, the Demand Reallocation Routine estimates the extra cost of using the airport that would be necessary to reduce excess demand to zero. This is known as a ‘shadow cost’, or ‘fare premium’ and performs the mechanical function of limiting passengers to capacity. It also represents the value a marginal passenger would place on flying to/from that airport, if extra capacity were available. It is therefore a key input to the appraisal of potential additional capacity.

2.70 The Demand Reallocation Routine adds the shadow cost to the other costs of using each over-capacity airport, then re-runs the Passenger Airport Choice and ATM Demand models to re-forecast passenger and

ATM demand at each airport. This routine is iterated until an equilibrium solution is found in which capacity is not exceeded at any airport[23,24].

2.71 The Demand Reallocation Routine tests for breaches of both runway and terminal capacity. The effects of runway and terminal shadow costs tend to differ. As the shadow cost is ultimately added to the individual passenger's overall cost of travel, a runway constraint will stimulate the use of larger aircraft and higher passenger loads (to help airlines meet demand and because the charge levied on the use of the runway is lower on a per passenger basis for heavier loaded aircraft). Conversely a terminal shadow cost will not penalise the use of smaller aircraft. Runway capacity is generally a more finite or 'binding' limit than terminal capacity and the settings of the Demand Reallocation Routine encourage a runway shadow cost solution, particularly at the congested London airports

2.72 Importantly, this means that in the forecasts the effect of capacity constraints on the numbers of air passengers using UK airports takes into account capacities at all airports, and is based on passengers' observed airport choice behaviour.

Projections to 2050

2.73 The forecasts in *UK Air Passenger Demand and CO_2 Forecasts, 2009* used a version of the modelling that predicted passengers and ATMs out to 2030 in detail. The MAC curve analysis requires robust forecasts of CO_2 out to 2050. HMT guidance also requires appraisal of airport development to include the costs and benefits for 60 years after the scheme opening date that in effect creates a further requirement for more simplified forecasting out to 2080.

2.74 In most cases, forecasts to 2050 can be produced using sophisticated statistical and other modelling techniques in the National Air Passenger Allocation Model. In a minority of cases, however, the model fails to reach 2050. This occurs when the forecast levels of unconstrained air passenger demand are significantly higher than the system-wide airport capacity assumptions input to the model. In cases where forecasts to 2050 cannot be produced using more sophisticated modelling techniques, simpler extrapolation methods are used. This is discussed in annex E which describes recent model improvements.

---

[23] *Rules and Modelling: A Users Guide to SPASM, Edition 2,* DfT/Scott Wilson, April 2004, see Chapter H.

[24] An equilibrium solution which satisfies capacity limits at all airports is computationally intensive and progressively more difficult to solve as demand mounts through the forecasting period. The solution is generally deemed to be found when over-capacity airports are within +/-3% of their input capacities. Runway capacity is regarded as a "harder" capacity than terminal capacity in the search for an equilibrium solution.

Passenger Model Validation - airport level

2.75 An important factor determining the confidence that can be placed in a calibrated model is its ability to replicate the observed data - this is the process known as 'validation'. For airport modelling, this can be assessed both at the airport level, and in considerably more detail at the route level. The former involves comparing actual (base year) and predicted demands at each airport, while the latter compares actual and predicted demands on each route.

2.76 Table 2.2 below reports the accuracy of the model in predicting passenger demand at the London airports and those airports that handled more than 3mppa in 2009 (in total these comprise 92% of modelled demand). It shows that the model is very successful in predicting the number of passengers travelling through each UK airport. Demand is predicted to within +/-1% at the three largest London area airports. The London area total fitted value is highly accurate. Similarly, at most airports outside the London area the model is accurate to within +/-5%. The national total for all 31 airports in the model is also highly accurate.

Table 2.2: Actual and predicted passengers at modelled airports, mppa in 2009 base year

	Actual	Fitted	Difference	Difference (%)
Heathrow	65.9	66.7	0.8	1%
Gatwick	32.4	32.6	0.2	1%
Stansted	19.9	19.4	-0.5	-3%
Luton	9.1	8.6	-0.5	-5%
London City	2.8	2.6	-0.2	-7%
London Subtotal	130.1	130.0	-0.1	0%
Manchester	18.6	20.2	1.6	8%
Birmingham	9.1	8.9	-0.2	-2%
Glasgow	7.2	6.8	-0.4	-5%
Edinburgh	9.0	8.6	-0.5	-5%
Bristol	5.6	5.6	0.0	-1%
Newcastle	4.6	4.4	-0.2	-4%
Belfast International	4.5	4.5	-0.1	-2%
Liverpool	4.9	5.1	0.2	4%
East Midlands	4.7	4.8	0.2	3%
Other Airports in Model	18.3	18.0	-0.3	-2%
Total in Model	216.6	216.8	0.1	0%
Other Non-Modelled Airports	2.2			
National Total	**218.8**			

2.77 More detailed analysis of the model’s calibration and validation at all airports is set out in annex F.

Passenger Model Validation - route level

2.78 Table 2.3 summarises the model's success in predicting passenger demand on individual routes. The table presents the validation against data for the 748 modelled routes[25] which each carried more than 25,000 passengers per annum in 2009[26]. The results are weighted by the number of passengers on each route. The table shows that over 75% of the passengers are on routes where passenger numbers are predicted to within +/-10% of actual figures, rising to almost 90% within +/-20%. Of the 2% of passengers travelling on routes in the 50%+ error band, 69% of those are on routes carrying fewer than 50,000 passengers per annum and 80% are on routes carrying fewer than 75,000 passengers.

2.79 Figure 2.9 illustrates the correlation between the actual and fitted passenger numbers in a scatter plot. The trend line has a slope very close to one, and the data are scattered very closely around the trend line. This indicates that the model is very successful in predicting route level demands in the base year. Annex F provides more detailed validation results.[27]

Table 2.3: Route level passenger prediction, 2009, all flights (domestic and international)

Error band	Proportion of passengers on routes in band	Cumulative proportion
0%-5%	55%	55%
5%-10%	22%	77%
10%-20%	12%	89%
20%-30%	5%	94%
30%-40%	3%	98%
40%-50%	1%	98%
50%+	2%	100%

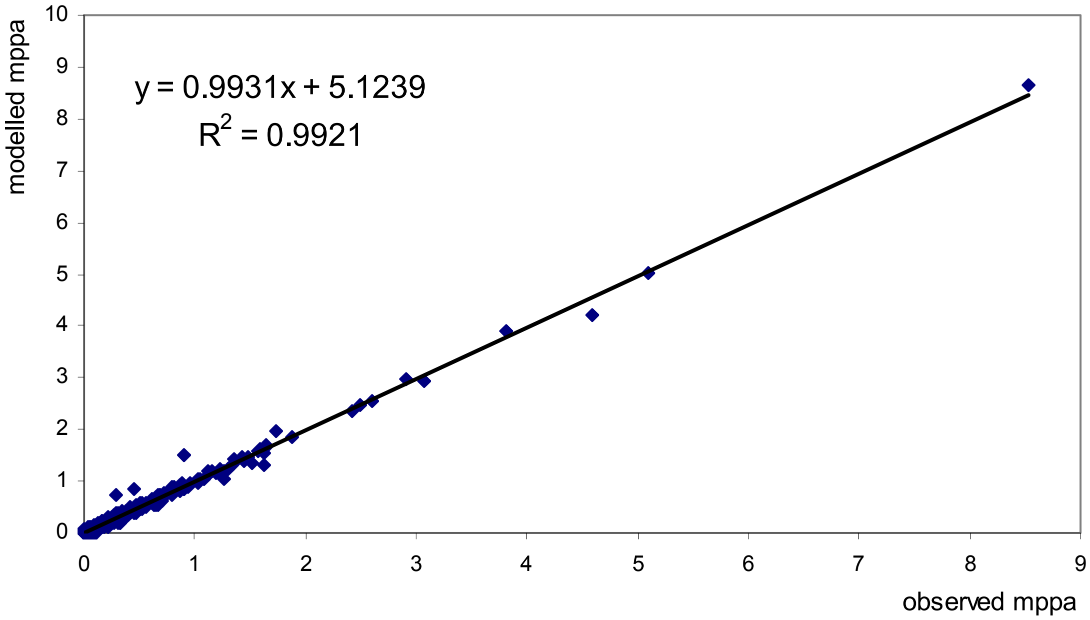
---

[25] The model has 59 specific airport destinations in the UK and Europe and 21 destinations which are geographical groupings of routes to smaller or more remote airports (a "route group"). Strictly the definition of route here is "route or route group".

[26] Validation in practice extended to all routes with more than 5,000 passengers in 2009, extending the total calibration exercise to include close to 1,000 separate routes.

[27] A technical note giving more detail on the validation process and results is available on request.

Figure 2.9: Scatter plot of actual and fitted passenger numbers by route, all flights (domestic and international), 2009



ATM Model Validation - airport level

2.80 As with the model of passengers' airport choice, an important factor determining the confidence which can be placed in this calibrated model is its ability to replicate observed data on passenger ATMs, and their loadings. The model's ability to successfully predict 2009 ATM demand has therefore been examined at both the airport and route level.

2.81 Table 2.4 below reports actual and predicted ATMs at the London airports and those regional airports with over 3mppa demand (these comprise 92% of passenger demand). It shows that the model predicts ATMs accurately at London area airports. At Heathrow and Gatwick, ATMs are predicted to within +/-2%. At Luton and Stansted ATMs are within +/-7%. The tolerance widens at London City, but its relatively small throughput means total London area traffic is accurately forecast to within +/-1%.

2.82 The ATM predictions at the larger airports outside the London area are similarly accurate, all being within +/-12% of actual figures. Annex F sets out the results for all modelled UK airports.

Table 2.4: Actual and predicted passenger ATMs at modelled airports, 000s pa in 2009 base year

	Actual 2009	Fitted	Difference	Difference (%)
Heathrow	461	471	10	2%
Gatwick	247	250	4	1%
Stansted	157	168	10	6%
Luton	78	72	-6	-7%
London City	74	64	-10	-13%
London Subtotal	1017	1026	9	1%
Manchester	162	182	20	12%
Birmingham	94	95	1	1%
Glasgow	78	68	-10	-12%
Edinburgh	111	106	-5	-4%
Bristol	54	54	0	0%
Newcastle	50	45	-5	-9%
Belfast International	45	46	2	3%
Liverpool	43	46	3	6%
East Midlands	60	58	-2	-3%
Other Airports in Model	374	345	-29	-8%
Total in Model	2088	2072	-16	-1%
Other Non-Model	137			
National Total	**2226**			

ATM Model Validation - route level

2.83 Table 2.5 shows the performance of the model in predicting aircraft movements on individual routes. As with the passenger demand predictions, the large number of routes means the results are summarised by accuracy band.

2.84 The validation of aircraft movements by route is a particularly stringent test of the model accuracy, being dependent on both the modelled passenger allocation to the route and the performance of the ATM Demand Model in allocating appropriate aircraft sizes and types to each route. It also requires that the model satisfactorily predicts aircraft loads (passengers per ATM) at the route level.

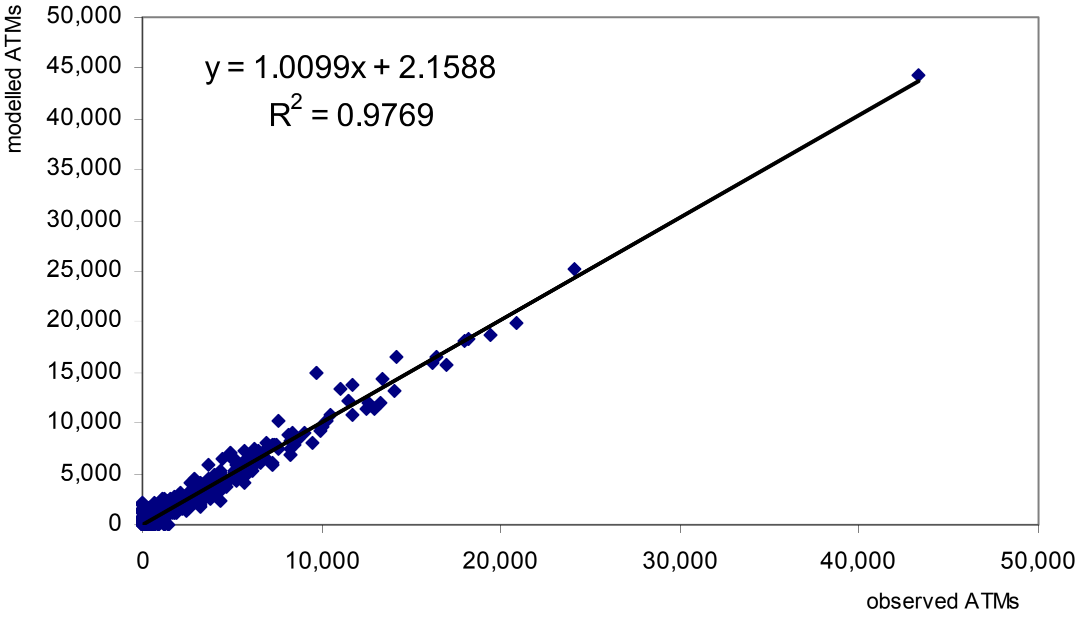
2.85 Table 2.5 shows that about 45% of routes have ATMs predicted to within +/-10% of actual and two thirds of routes have ATMs predicted to within +/-20%. Of the 8% of routes in the 50%+ error band, these were predominantly very minor or ‘thin’ routes: 71% under 750 ATMs per annum (approximately a single rotation per day) and 81% were under 1500 ATMs per annum.

2.86 Figure 2.10 shows the correlation between actual and fitted ATMs by route. The slope of the trend line being close to one, the low intercept, and the fairly tight fit of the data around the trend line indicate that the model is successful in predicting base year ATMs by route.

Table 2.5: Route level ATM prediction, 2009, all flights (domestic and international)

Error band	Routes in band	Cumulative proportion
0%-5%	28%	28%
5%-10%	18%	45%
10%-20%	23%	69%
20%-30%	12%	80%
30%-40%	9%	89%
40%-50%	3%	92%
50%+	8%	100%

Figure 2.10: Scatter plot of actual and fitted ATMs by route, all flights (domestic and international), 2009



Airport capacity assumptions

2.87 Modelling the impact of capacity constraints requires assumptions about both the terminal and runway capacities of each modelled airport. Box 2.6 summarises the approach to determining the capacity of airports.

Box 2.6: Runway capacity estimation

Runway capacity assumptions are a key input to the forecasts. The National Air Passenger Allocation Model works in annual passenger and aircraft units and uses annual estimates of runway capacity.

The annual runway capacity depends on physical, operational and demand characteristics. Physical characteristics include the runway length and the provision of parallel taxiways and rapid access and exit taxiways. Operational characteristics include the hours of operation, aircraft separation requirements, air traffic control restrictions and in some cases planning limits on ATMs. Demand characteristics include the prevailing daily and seasonal profiles, because airports with a high proportion of seasonal holiday traffic will have less effective capacity than airports that can make full use of their runways all year round, and airports which depend heavily on premium business traffic can make relatively less use of their off-peaks.

The annual capacity inputs were originally developed during runway simulations and consultations with regional airport operators during the Regional Air Services Coordination Study (RASCO, 2002) and with BAA and others during the South East Regional Air Services Study (SERAS, 2002). Typical annual capacities input for forecasting are usually around 225,000 annual ATMs for single runways. This is a little higher than many airports might currently estimate, but allows for some piecemeal improvements to taxiways and aprons to achieve maximum use of existing runways. It also allows for an increase in off peak and out of season movements as national demand grows. Some airports which depend heavily on peak period traffic might consider themselves runway constrained at lower levels such as 190,000-200,000 annual ATMs.

2.88 All the forecasts presented in this document are based on a ‘maximum use’ capacity scenario (shortened to ‘max use’ elsewhere), unless it is clearly stated that the forecasts are ‘unconstrained’. Under the ‘max use’ scenario no new runways are built in the UK but, where there is no explicit planning prohibition, most airports develop as necessary in the medium term to utilise their current potential runway capacity. This case does imply new consents for terminal expansions beyond the current planning horizons.[28] It approximates most closely to the 'maximum use' scenario (code 's02') from the previous DfT forecasts.

---

[28] In common with previous forecasts ‘medium term’ is defined as up to 2030 and no capacity expansion is assumed to occur anywhere after this date. Planning controls at airports such as Doncaster Sheffield and Belfast City remain in force throughout the forecasting period.

2.89 Table 2.6 shows the 2050 runway and terminal passenger capacities assumed for each airport in the 'max use' scenario. The terminal passenger capacity is the maximum number of passengers an airport's terminal and associated passenger handling infrastructure is assumed capable of serving per annum. The table shows that most of the additional capacity is provided at regional airports to allow them to fully utilise their practical annual runway capacities with enhancements to terminal capacity to match.

Table 2.6: ATM and passenger capacity assumptions for max use

	ATMs (000s)		Terminal Passengers (mppa)	
Airport	2008	2050	2008	2050
London Airports				
Heathrow	480	480	86	86
Gatwick	260	260	42	42
Stansted	259	259	35	35
Luton	104	135	10	17
London City	120	120	8	8
London, Total	1,223	1,254	181	188
Aberdeen	200	226	5	10
Belfast International	200	260	10	23
Belfast City	48	48	4	4
Birmingham	189	206	18	27
Bournemouth	200	226	2	6
Bristol	200	226	7	12
Cardiff	200	226	12	12
East Midlands	200	226	25	25
Edinburgh	205	226	20	20
Exeter	200	226	2	12
Glasgow	200	226	12	20
Humberside	200	226	1	12
Inverness	200	226	1	8
Leeds/Bradford	150	150	5	12
Liverpool	200	226	12	20
Manchester	321	500	30	56
Newcastle	200	226	6	20
Newquay	200	226	1	3
Norwich	200	226	2	3
Plymouth	89	102	1	4
Southampton	150	150	5	7
Teesside	200	226	3	10
Blackpool	150	150	3	8
Coventry	0	150	0	2
Doncaster Sheffield	57	57	2	2
Prestwick	200	226	3	15
Regional, Total	4,567	5,382	191	352
National, Total	**5,790**	**6,636**	**372**	**540**

2.3 UK Air Passenger and ATM Forecasts

2.90 This section summarises the unconstrained and constrained forecasts of UK air passengers and ATMs derived using the methodology and assumptions described in the previous section. Annexes G and H provide more detailed results.

Passenger Forecasts

National unconstrained demand forecasts

2.91 The unconstrained demand forecasts produced by the National Air Passenger Demand Model are an intermediate step in the forecasting process. Unconstrained demand forecasts from the National Air Passenger Demand Model can be converted to airport level terminal passenger forecasts using the National Air Passenger Allocation Model. This is achieved by switching off the airport capacity constraints used in the National Air Passenger Allocation Model. The results are summarised in Table 2.7 below[29]. Only the final, constrained forecasts take account of expected future airport capacities.

2.92 Table 2.7 shows that in the absence of capacity constraints the underlying trend of growth in UK air passenger demand is forecast to continue, rising from 211 million passengers per annum (mppa) in 2010 to 345mppa in 2030, within the range 305mppa to 400mppa, and to 520mppa by 2050, within the range 400mppa to 700mppa. Figure 2.11 illustrates the range of unconstrained forecasts diagrammatically. Annex G provides more detailed results.

Table 2.7: UK terminal passenger forecasts (unconstrained), mppa

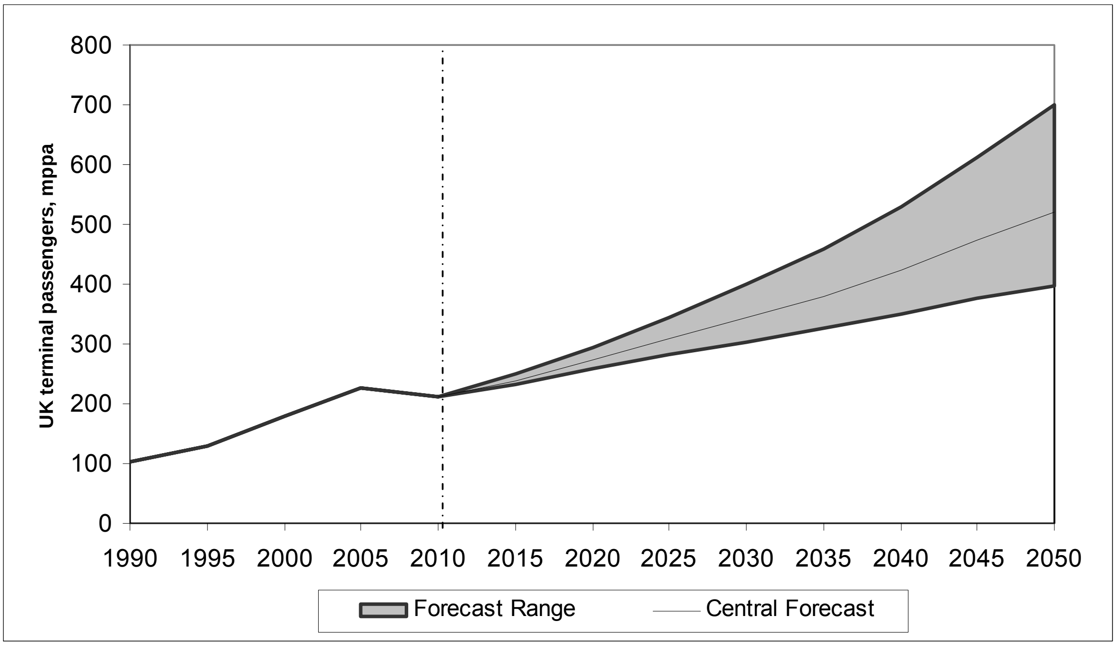
	Low	Central	High
2010	211	211	211
2015	230	240	250
2020	260	275	295
2025	285	310	345
2030	305	345	400
2035	325	380	460
2040	350	425	530
2045	375	475	610
2050	400	520	700

Note : Figures in forecast years rounded to nearest 5 mppa.

---

[29] These are modelled unconstrained passengers after allocation by the National Air Passenger Allocation Model. These will differ from (and usually exceed) the unconstrained terminal passenger forecasts produced by the input National Air Passenger Demand Model (e.g. Annex G1) because the National Air Passenger Allocation Model allocates passengers to indirect routes such as via UK hubs where a single one way journey may be counted as three terminal passengers. See Box 2.1.

Figure 2.11: UK unconstrained demand – historic with central, low and high forecasts



2.93 Section 2.2 explained that the range around the central unconstrained demand forecast is established by combining a set of sensitivity tests, which vary the projections of key driving variables within reasonable bounds. Table 2.8 and Table 2.9 show the results of tests performed to illustrate the sensitivity of the unconstrained air passenger demand forecasts to changes in the key input variables. Table 2.8 shows the impact on 2030 and 2050 forecasts of varying the value of each variable in isolation. Table 2.9 then shows the results of cumulatively combining sensitivity tests to move from the central forecasts to the low and high end of the forecast range.

2.94 These tables show that the key drivers of the range of unconstrained forecasts in 2030, in order of significance, are assumptions about the impact of market maturity on UK air travel, assumptions about whether there will be a bounce-back from the exceptional reduction in passenger numbers following the 2008 financial crisis (in defining the upper bound of the forecast range only), and assumptions about future economic growth and changes in carbon allowance prices. By 2050, the same factors drive the range in forecasts, but the assumptions about the extent to which there is a bounce-back in demand following the 2008 financial crisis becomes relatively less important. The input low and high oil prices from the DECC scenarios are constant after 2015, and so this variable soon has no effect on the real annual fare increases which drives demand. This is in contrast to the traded price of carbon which increases annually throughout the period in the tests and therefore impacts fares throughout.[30]

---

[30] There is an anomalous small drop in 2050 demand low growth with the lower oil prices test. This might best be interpreted as no change from central. It is predominantly an artefact from

Table 2.8: UK terminal passengers forecast (unconstrained), individual variable sensitivity tests, 2030 and 2050

		Tests on individual variables			
		2030		2050	
Sensitivity	MAC Demand Scenario	2030 mppa	Difference from central case (mppa)	2050 mppa	Difference from central case (mppa)
Central		345		520	
Low GDP	Low	325	-20	470	-50
Low Oil Price	Low	345	0	515	-5
Low Carbon Price	Low	355	10	560	40
Improved Fuel Efficiency	Low	345	0	530	10
Videoconferencing Demand Reduction	Low	335	-10	510	-10
Financial 'bounce-back'		n/a	n/a	n/a	n/a
Faster market maturity	Low	310	-35	415	-105
High GDP	High	360	15	575	55
High Oil Price	High	330	-15	520	0
High Carbon Price	High	335	-10	490	-30
Poorer Fuel Efficiency	High	340	-5	505	-15
Videoconferencing Demand Increase	High	345	0	525	5
Financial 'bounce-back'	High	385	40	585	65
Slower market maturity	High	355	10	595	75

Note : Forecasts rounded to nearest 5 mppa.

2.95 The 2030 results in Table 2.9 confirm that in the low forecast the assumptions about earlier market maturity account for most of the overall difference from the central forecast. In the high forecast most of the overall difference is explained by the inclusion of the bounce-back from the recent financial crisis / economic recession, and slower market maturity. GDP is another significant factor at both ends of the range, but is often substantially counter-acted by assumed changes in carbon prices. Changes in oil prices become less important later in the period while the demand effects of changes in fuel efficiency and video-conferencing become progressively more significant. These other variables largely cancel each other out.

---

the intermediate model between the National Air Passenger Demand Model and the unconstrained passenger to airport allocation that makes regional adjustments to national demand prior to allocation (see Annex E, paragraph E.21).

Table 2.9: UK terminal passengers forecast (unconstrained), incremental variable sensitivity tests, 2030 and 2050

			Cumulative change of variables			
			2030		2050	
	Sensitivity	MAC Demand Scenario	2030 mppa	Difference from previous case (mppa)	2050 mppa	Difference from previous case (mppa)
	Central		345		520	
L1	Central + rapid maturity	Low	310	-35	415	-105
L2	L1 + bounceback					
L3	L2 + Low GDP	Low	300	-10	385	-30
L4	L3 + Low Carbon £	Low	305	5	405	20
L5	L4 + Low Oil £	Low	310	5	405	0
L6	L5 + Video-conferencing business travel reduction	Low	305	-5	395	-10
L7	L6 + others (demand effects of weak £ ExR & improved fuel eff)	Low	305	0	400	5
H1	Central + slower maturity	High	355	10	595	75
H2	H1 + bounceback	High	395	40	665	70
H3	H2 + High GDP	High	420	25	745	80
H4	H3 + High Carbon £	High	405	-15	700	-45
H5	H4 + High Oil £	High	400	-5	715	15
H6	H5 + Video-conferencing demand increase	High	405	5	720	20
H7	H6 + others (demand effects of stronger £ ExR & poorer fuel eff)	High	400	-5	700	-20

Note : Forecasts rounded to nearest 5 mppa.

2.96 Table 2.10 shows the results of combining the sensitivity tests above to produce the extreme minimum and maximum ends of the possible range. As explained in section 2.2, the more extreme range is regarded as less useful as the basis for policy development as it is based on combinations of input assumptions that are unlikely to be realised.

Table 2.10: UK terminal passengers forecast (unconstrained), extreme ‘lowlow’ and ‘highhigh’ sensitivity tests.

	2030		2050	
	2030 mppa	Difference from central case (mppa)	2050 mppa	Difference from central case (mppa)
Central	345		520	
"LowLow" (high maturity, low GDP, high carbon, high oil, low fuel efficiency, low ExR)	275	-70	350	-170
"HighHigh" (low maturity, high GDP, low carbon, low oil, high fuel efficiency, high ExR)	445	100	825	305

Note : Forecasts rounded to nearest 5 mppa.

National constrained passenger forecasts

Central forecast

2.97 The final constrained forecasts of UK air passengers are obtained by feeding unconstrained demand forecasts from the National Air Passenger Demand Model into the National Air Passenger Allocation Model along with assumptions about future terminal and runway capacities at each of the modelled airports. Table 2.11 shows that after accounting for airport capacity constraints, under the ‘max use’ capacity scenario, the number of UK air passengers is forecast to recover from the recent downturn, rising to 335mppa in 2030, within the range 300mppa to 380mppa. By 2050, the number of UK air passengers is forecast to reach 470mppa within the range 380mppa to 515mppa. Annex G gives more detailed passenger forecasts, and Box 2.7 sets out how these forecasts can be interpreted in terms of future trip-making by air passengers.

Table 2.11: UK terminal passengers forecast, 'max use' capacity, mppa[31]

	Low	Central	High
2010	211	211	211
2015	230	235	250
2020	255	270	295
2025	275	305	335
2030	300	335	380
2035	320	365	430
2040	340	405	465
2045	365	445	500
2050	380	470	515

Note : Figures in forecast years rounded to nearest 5 mppa.

▨ Model extension.

National Air Passenger Allocation Model failed to reach 2050.

---

[31] Modelled volumes of domestic interliners will not exactly agree with the unconstrained estimate and occasionally where constrained and unconstrained demand is close, could marginally exceed the unconstrained estimate.

Box 2.7: Forecast terminal passengers and journeys

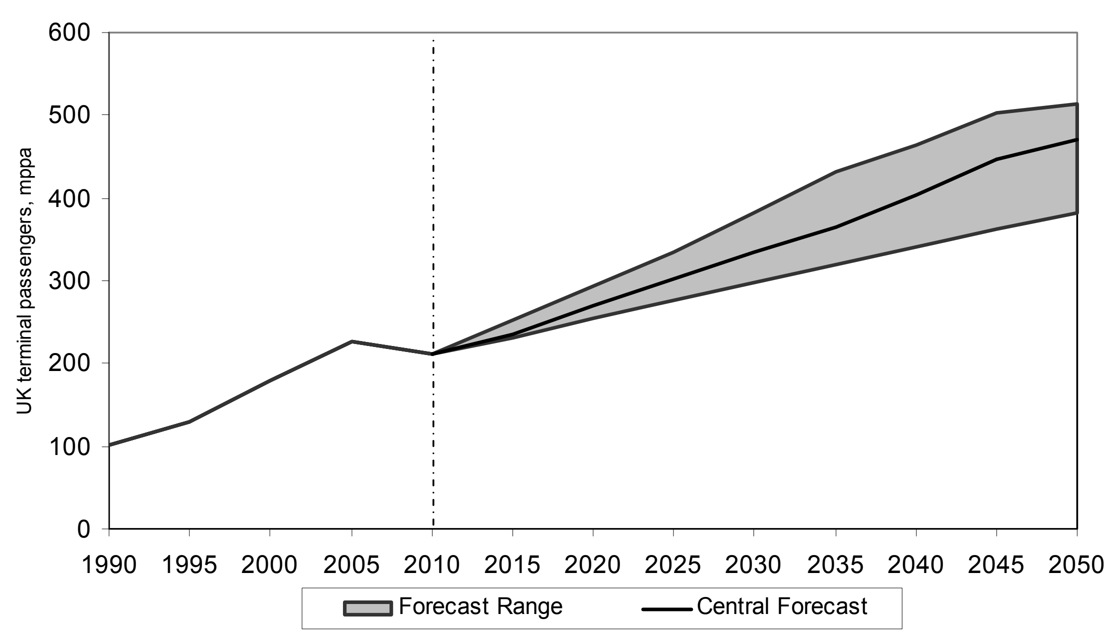
Interpreting the forecasts is aided by knowing what they imply for the average number of journeys by UK residents, and the total number of foreign visitors by air. To convert the central 2030 air passenger forecasts of 335mppa into journeys requires a careful application of the definition of terminal passengers set out in Box 2.1. Applying this definition shows:

- excluding connecting trips by foreign travellers at UK hub airports reduces the constrained 2030 forecast to 305m terminal passengers;
- 45m terminal passengers account for 11.25m internal domestic return journeys, leaving 260m terminal passengers (130m return journeys on international trips);
- of the remaining 260m terminal passengers over two thirds (170m) will be UK residents; and
- hence the forecast implies that there will be about 85m return international journeys made by UK residents and some 45m visits by foreign residents in 2030.

The UK population is projected to grow to around 70m by 2030, so 85m international and 11m domestic return journeys implies an average of a little over one return air journey per UK resident in 2030. This compares to just under one return journey per UK resident, and 20m visits by foreign residents in the model base year, 2008.

2.98 Figure 2.12 further illustrates the range of updated UK air passenger forecasts, all based on the ‘max use’ capacity scenario. A comparison of the constrained forecasts presented in Table 2.11 and Figure 2.12 with the unconstrained forecasts in Table 2.7 and Figure 2.11 shows that the assumed future airport capacities constrain forecast throughput at UK airports, and that the impact increases through time. In the central forecasts, airport capacity constrains throughput by 10mppa in 2030 rising to 50mppa by 2050. At the lower end of the forecast range, capacity is forecast to constrain airport throughput by 5mppa in 2030 and by 20mppa in 2050. At the upper end of the forecast range, airport capacity constrains throughput by 20mppa in 2030 and 185mppa in 2050. The central forecasts suggest that the largest airports would be at capacity from about 2040 (or about 2030 for airports in the South East).

Figure 2.12: UK terminal passengers (constrained – 'max use') - historic with central, low, and high forecasts



Sensitivity tests

2.99 Table 2.12 and Table 2.13 show the results of the sensitivity tests described in section 2.2 on the constrained UK air passenger forecasts. Table 2.12 presents the impact of varying the key driving variables individually and table 2.13 shows the results of cumulatively combining sensitivity tests to move from the central forecasts to the low and high end of the forecast range. Data is shown in grey where the simplified extrapolation methods (see annex E) have been employed to complete the forecast out to 2050.

Table 2.12: UK terminal passengers forecasts (constrained – 'max use'), individual variable sensitivity tests, 2030 & 2050

		Tests on individual variables			
		2030		2050	
Sensitivity	MAC Demand Scenario	2030 mppa	Difference from central case (mppa)	2050 mppa	Difference from central case (mppa)
Central		335		470	
Low GDP	Low	320	-15	440	-30
Low Oil Price	Low	335	0	465	-5
Low Carbon Price	Low	345	10	495	25
Improved Fuel Efficiency	Low	335	0	480	10
Videoconferencing Demand Reduction	Low	325	-10	460	-10
Financial 'bounce-back'		n/a	n/a	n/a	n/a
Faster market maturity	Low	305	-30	395	-75
High GDP	High	350	15	495	25
High Oil Price	High	325	-10	465	-5
High Carbon Price	High	325	-10	450	-20
Poorer Fuel Efficiency	High	330	-5	460	-10
Videoconferencing Demand Increase	High	335	0	460	-10
Financial 'bounce-back'	High	370	35	500	30
Slower market maturity	High	345	10	505	35

Note : Forecasts rounded to nearest 5 mppa.

2.100 The pattern of results of individually changing the input variables largely echoes that of the unconstrained tests shown in Table 2.8. Market maturity and financial bounce-back have the greatest impact in the low and high ranges respectively. During the period 2040 to 2050 most tests reach system capacity and simpler extrapolation methods are employed to produce forecasts to 2050.[32] Where detailed model runs have not reached 2050 they are shaded grey in the table above. These results should be treated with caution. Compared to detailed model runs, the extrapolated forecasts increase the level of demand suppression, as opposed to reallocation of demand to alternative airports, in response to airport capacity constraints. This causes the passenger forecasts derived using the simple extrapolation methods to be lower than they would be had they be produced using a detailed modelled run to 2050. This effect is most evident in the 2050 forecasts for the high demand sensitivity tests, where it is estimated to have caused the forecasts to be up to around 3 or 4% lower than they would have been had all the model runs reached 2050.[33]

2.101 The cumulative combination of sensitivity tests to move from the central to the low and high ranges shown below in Table 2.13 illustrates the importance of higher market maturity assumptions in defining the lower bound of the forecast range and the assumptions about financial bounce-back in defining the upper bound of the range. The airport system is highly constrained by the 2030s in all the tests that trace the

---

[32] See description in Annex E, paragraph E.13

[33] For example, the anomalous 2050 forecast for the "videoconferencing demand increase" sensitivity test, which is lower than the equivalent central forecast for 2050. While the central forecast model run reached 2050, the "videoconferencing demand increase" test only reached 2043. The use of extrapolation between 2043 and 2050 for this test is estimated to have caused the passenger forecast to be between 2 and 3% (i.e. between 10 and 15mppa) lower than it would have been had the model run reached 2050 (i.e. the forecast would have been around 475mppa, around 5mppa higher than the central forecast).

movement from the central forecast to the upper bound of the forecast range (i.e. tests H1-H7). As before, grey shading is used to indicate that none of the model runs for these tests reached 2050 and extrapolation was used to produce forecasts to 2050. They should therefore be treated with caution. The model runs for these tests all collapsed in the period 2031 and 2040, and it is estimated that the use of simpler extrapolation methods has caused the forecasts to be up to around 5% lower than they would have been had the model runs reached 2050. After the lower market maturity assumptions have been implemented the results are all effectively capped at a similar level. This is because the effect of system-wide capacity constraint dominates and tends to nullify the impact of the final variations in input demand.

Table 2.13: UK terminal passengers forecast (constrained – 'max use'), incremental variable sensitivity tests, 2030 and 2050

			Cumulative change of variables			
			2030		2050	
	Sensitivity	MAC Demand Scenario Case	2030 mppa	Difference from previous case (mppa)	2050 mppa	Difference from previous case (mppa)
	Central		335		470	
L1	Central + rapid maturity	Low	305	-30	395	-75
L2	L1 + bounceback					
L3	L2 + Low GDP	Low	295	-10	370	-25
L4	L3 + Low Carbon £	Low	300	5	385	15
L5	L4 + Low Oil £	Low	305	5	385	0
L6	L5 + Video-conferencing business travel reduction	Low	300	-5	375	-10
L7	L6 + others (demand effects of weak £ ExR & improved fuel eff)	Low	300	0	380	5
H1	Central + slower maturity	High	345	10	495	25
H2	H1 + bounceback	High	380	35	510	15
H3	H2 + High GDP	High	400	20	510	0
H4	H3 + High Carbon £	High	390	-10	510	0
H5	H4 + High Oil £	High	385	-5	515	5
H6	H5 + Video-conferencing demand increase	High	385	0	515	5
H7	H6 + others (demand effects of stronger £ ExR & poorer fuel eff)	High	380	-5	515	0

Note : Forecasts rounded to nearest 5 mppa.

2.102 Table 2.14 shows the results of varying all of the input variables used in the sensitivity tests to produce a more extreme range of (constrained) UK air passenger forecasts. Comparing Table 2.14 with Table 2.10 shows that under the "Highhigh" end of the range, capacity constraints reduce UK terminal passenger numbers by 300 million passengers per annum by 2050.

Table 2.14: UK terminal passengers forecast (constrained – ‘max use’), extreme ‘lowlow’ and ‘highhigh’ sensitivity tests

	2030		2050	
	2030 mppa	Difference from central case (mppa)	2050 mppa	Difference from central case (mppa)
Central	335		470	
"LowLow" (high maturity, low GDP, high carbon, high oil, low fuel efficiency, low ExR)	270	-65	340	-130
"HighHigh" (low maturity, high GDP, low carbon, low oil, high fuel efficiency, high ExR)	420	85	525	55

Note : Forecasts rounded to nearest 5 mppa.

Performance of previous passenger forecasts and current model performance since 2008

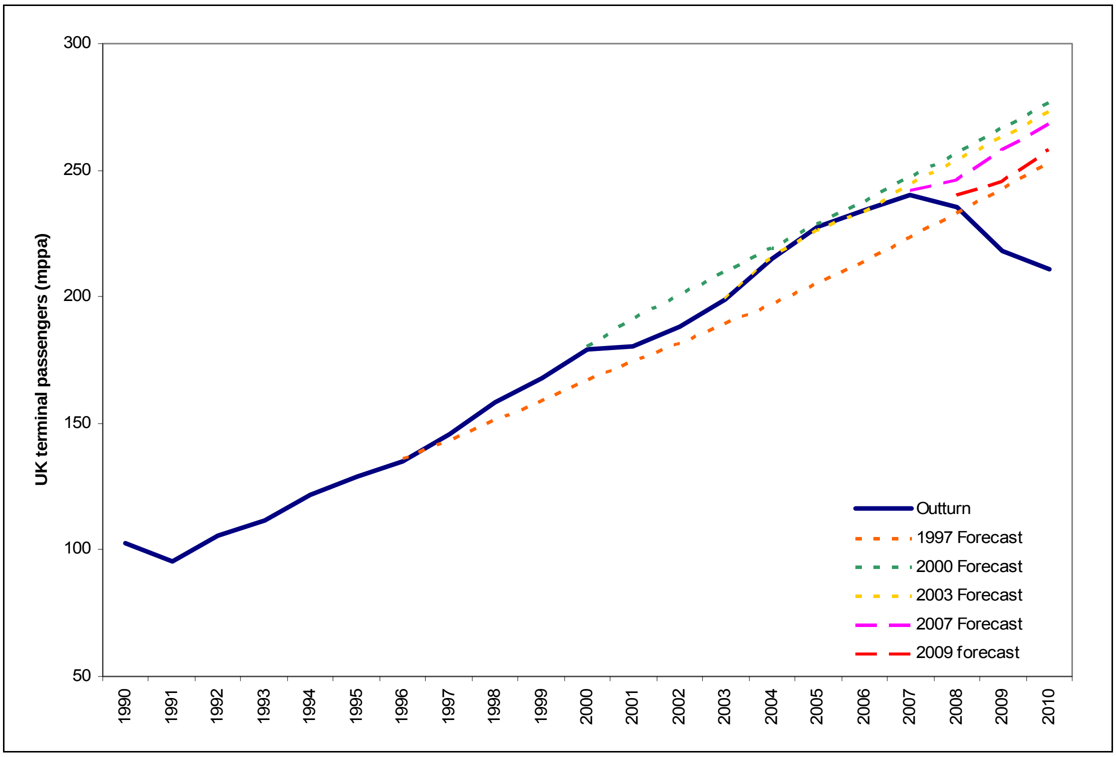
Previous forecasts

2.103 The Department for Transport has issued forecasts of UK air passenger demand for many years. Up to 2000, these were unconstrained demand forecasts only. However, for the 2003 White Paper, unconstrained demand forecasts were combined with the National Airport Passenger Allocation Model to produce constrained passenger forecasts for the first time. These were updated in the 2006 *Progress Report*, and in the 2007 and 2009 versions of *UK Air Passenger Demand and CO_2 Forecasts*.

2.104 The volume of detailed historic data required to produce forecasts (e.g. a comprehensive time series of passenger traffic by market sector from interview surveys, worldwide trade and economic output data etc.) determine that the forecast base year lags some time behind the year forecasts are published. For example, the 2009 published forecasts were produced in 2008 using 2004 base year data; the updated forecasts were produced in 2011 using 2008 base year data.

2.105 Figure 2.13 below compares these earlier forecasts against outturn. It shows that the good fit broke down following the impact of the financial crisis and associated economic slowdown in late 2008 / 2009 that was not foreseen in the input economic assumptions.

Figure 2.13: 1997, 2000, 2003 and 2007/9 demand forecasts versus outturn



2.106 The central forecasts published in 2009 were based on projections that implied that UK GDP would be 10.8% higher in 2010 than in 2006, in line with the latest HMT forecasts at the time. UK GDP actually fell by 1.2% between 2006 and 2010. The projections of foreign GDP and trade growth proved to be similarly inaccurate. The variance between the projections of the variables used to produce the forecasts and their actual values, explains most of the difference between the air passenger forecasts published in 2009 and the actual number of UK air passengers observed in 2009 and 2010.

Model performance since 2008

2.107 As the latest version of the model begins forecasting from 2008, it can be used to produce 'forecasts' for 2009 and 2010 using outturn values for all the driving variables included in the models (i.e. GDP, oil prices, APD etc). This reveals whether the latest version of the model performs well in explaining the recent downturn in UK aviation activity, and indicates whether some other factor not included in the model has had a significant effect on passenger numbers over the period.

2.108 When outturn data on GDP growth, oil prices and other driving variables are input into the model, the forecasts of UK air passengers exceed the outturn statistics for the numbers of passengers using UK airports in 2009 and 2010. Much of the over-forecast is concentrated in the domestic and international business markets. The reasons for this could include:

- structural changes in the domestic aviation air market; and
- sectors of UK business activities with high propensity to fly such as finance and banking taking a harder hit than other areas, making overall UK GDP a relatively blunt input.

Additionally, the volcanic ash episode of May-June 2010 could not be forecast and resulted in an estimated 4.8m lost terminal passengers.

2.109 It is possible to adjust the unconstrained forecasts produced by the National Air Passenger Demand Model before they are used as inputs to the National Air Passenger Allocation Model. In producing the updated forecasts the national unconstrained forecasts for 2009 and 2010, produced by the National Air Passenger Demand Model, have been adjusted to equal the observed number of UK terminal passengers in those years prior to being used as inputs to the National Air Passenger Allocation Model.[34] The forecasts also reflect the assumption that the reduction in passengers caused by the volcanic ash episode in 2010 was temporary and that these passengers return in 2011 in addition to normally forecast growth. The exceptional impact of the recent financial

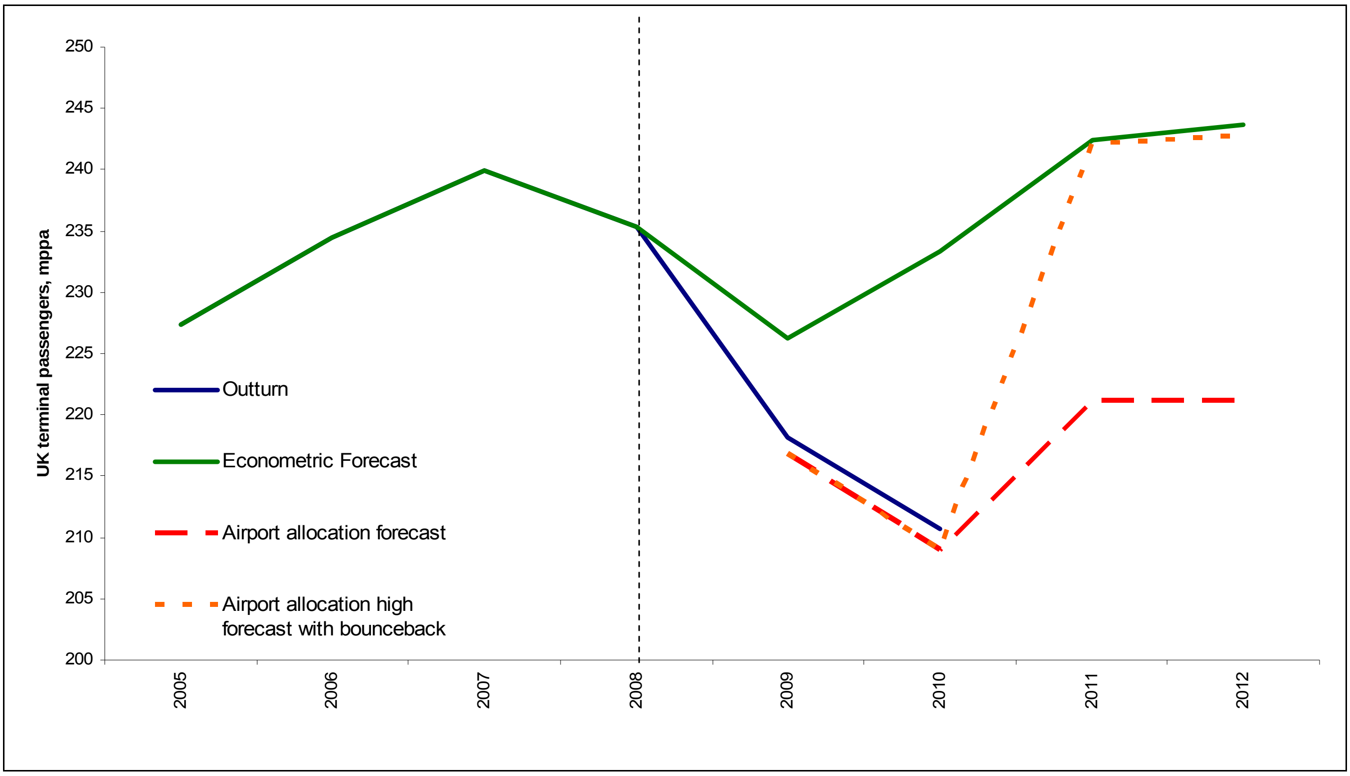
---

[34] This serves to ensure that the UK terminal passenger 'forecasts' produced by the National Air Passenger Allocation Model for 2009 and 2010 are, at a national level, equal to the observed numbers.

crisis and economic downturn in 2009 and 2010 over that implied by the NAPDM forecasts produced using the outturn economic data is assumed to be permanent in the central forecasts, and in defining the lower bound of the range. However, the upper bound of the range reflects the assumption that there is a swift bounce-back in demand, represented as a one-off boost in passenger numbers in 2011.[35]

2.110 Figure 2.14 shows the latest model's econometric forecasts of demand, based on the latest outturn data on GDP, oil prices and APD. It reveals the over-forecast in 2009-2010. The figure then shows how corrections to the national air passenger forecasts produced by the National Air Passenger Demand Model have been applied prior to airport allocation to allow for the exceptional impact of the financial crisis. Note that the high forecast assumes that all the lost traffic in 2009 and 2010, not explained by the outturn economic data, bounces back in 2011. It is acknowledged that this return to trend would, in reality, be likely to take place over a longer period. It should also be noted that the 'outturn' figures include 1-2mppa of terminal passengers at minor airports which are not included in the airport allocation causing the small divergence between outturn and airport allocation forecast up to 2010.

Figure 2.14: Outturn and forecast UK passenger demand, 2005-2012



---

[35] As these are long term forecasts, no attempt is made to predict the timing of this bounceback, the 2011 supplement in high growth is a proxy for the return of demand expected some time in the period 2011-2015.

Airport level passenger forecasts

2.111 The National Air Passenger Allocation Model forecasts how passenger demand will be distributed in a system-wide manner between airports around the UK, after accounting for likely airport capacity constraints. Table 2.15 below shows the central airport forecasts to 2050 for the South East airports, under the central 'max use' capacity scenario. It shows that between 2030 and 2040 all airport passenger growth at the London airports is forecast to cease, as they reach full capacity. After 2040 growth is forecast to only occur at regional airports. Annex G shows the results for each modelled UK airport.

Table 2.15: UK terminal passenger forecasts (constrained – 'max use'), South East airports (central forecast)

Airport	2010	2020	2030	2040	2050
Heathrow	65	80	85	85	85
Gatwick	30	35	40	40	40
Stansted	20	25	35	35	30
Luton	9	12	15	15	15
London City	3	7	7	7	7
London	125	155	180	185	185
annual growth rate		2.2%	1.5%	0.3%	0.0%
Others	80	115	150	210	285
annual growth rate		3.7%	2.7%	3.4%	3.1%
Total	**210**	**270**	**335**	**405**	**470**
annual decennial growth rate		2.5%	2.2%	1.9%	1.5%

Notes:

National forecasts and throughputs at the three largest airports rounded to nearest 5 mppa

Columns may not sum to total due to rounding

Individual airport totals capped strictly to capacity, modelling constraint tolerances removed, model output totals may differ.

2.112 The forecasts in Table 2.15 above imply a slight drop in the number of terminal passengers at Stansted between 2040 and 2050. Within the model, the airport remains fully constrained by both terminal and runway capacity, but the form of the "binding" constraint has switched from the runway to the terminal resulting in a drop in forecast throughput.[36] This is purely a model artefact and indicates that the model is working increasingly hard to cope with the excess demand at London airports. The forecasts should be interpreted as implying that all the London airports are at full capacity from around 2030 onwards.

---

[36] The National Air Passenger Demand Modelling has a number of controls to resist an overloaded airport's "binding constraint" switching. The runway is treated as the harder constraint and a higher tolerance of the terminal constraint is allowed, but in heavily congested situations such as the end of the model period, the switch can still occur.

ATM forecasts

National constrained ATM forecasts

2.113 The CO_2 emissions forecasts reported in chapter 3 are highly dependent on the ATMs forecast at each UK airport. The ATMs are in turn dependent on the forecasts of passengers, routeings and passenger loads on aircraft. Table 2.16 and Figure 2.15 show the forecast range for ATMs to 2050. The ATM forecasts are presented at a more detailed airport level in Annex H.

2.114 It can be seen from Figure 2.15 that in comparison with the constrained passenger forecasts the high ATM forecast lies further above the central forecast. This is because in the high forecast all major airports are unable to accommodate further runway movements in the 2030s and 2040s. The additional activity is taking place at smaller regional airports which still have some capacity, but where the ATMs are predominantly performed by smaller aircraft on short haul routes, resulting in a higher number of ATMs for a given number of air passengers. Therefore the higher level of activity does not lead to a proportionate increase in CO_2 emissions.

Table 2.16: Range of UK air ATM (000s) forecasts to 2050

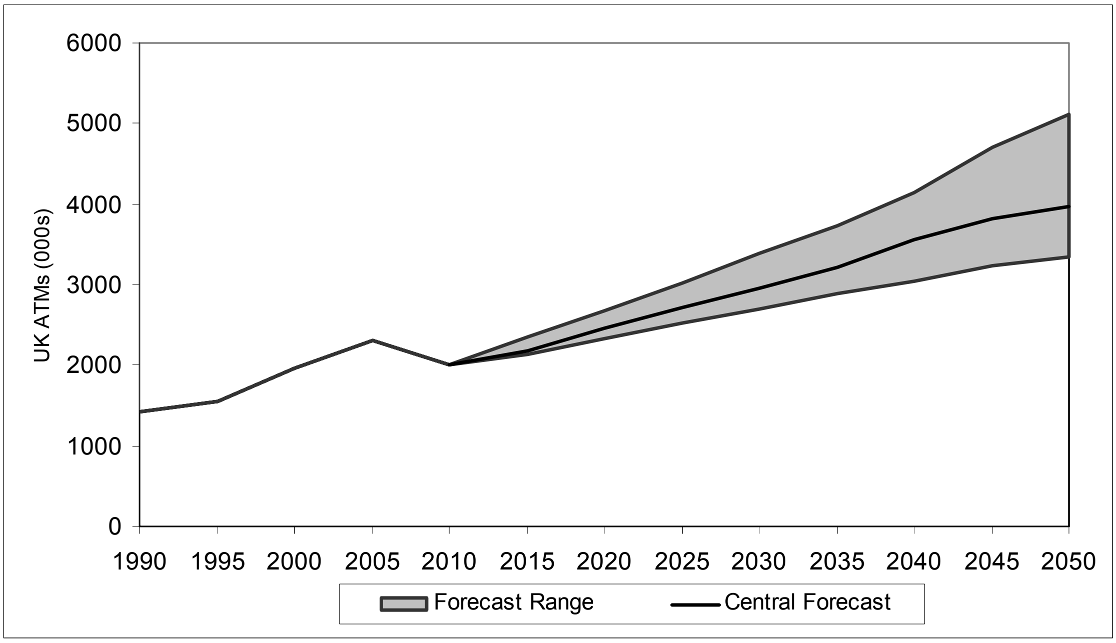
000s ATMs	Low	Central	High
2010	2,000	2,000	2,000
2015	2,100	2,200	2,400
2020	2,300	2,500	2,700
2025	2,500	2,700	3,000
2030	2,700	3,000	3,400
2035	2,900	3,200	3,700
2040	3,000	3,600	4,100
2045	3,200	3,800	4,700
2050	3,400	4,000	5,100

▨ Model extension.

National Air Passenger Allocation Model failed to reach 2050.

Forecasts rounded to near nearest 100,000 ATMs

Figure 2.15: Projected range of constrained ATM demand to 2050



3 Aviation Carbon Dioxide Emissions Forecasts

- The aviation sector is responsible for approximately one to two per cent of global greenhouse gas emissions.
- If international emissions from shipping and aviation are added to the UK total for 2009, UK aviation (domestic and international) accounted for 5.8 per cent of the UK's greenhouse gas emissions.
- Carbon dioxide (CO_2) makes up about 99 per cent of the Kyoto greenhouse gas emissions from UK aviation.
- UK aviation's CO_2 emissions have grown substantially in past decades, doubling from 16.9 $MtCO_2$ in 1990 to 34.7 $MtCO_2$ in 2009. This reflects the demand for aviation growing faster than fuel efficiency improvements.
- UK aviation CO_2 emissions are forecast to grow steadily over the next twenty years, growing from 33.4 $MtCO_2$ in 2010 to 47.6 $MtCO_2$ by 2030, within the range 43.2 - 53.4 $MtCO_2$.
- Post 2030, the growth in aviation CO_2 emissions is forecast to slow as the effects of market maturity and airport capacity constraints cause the growth of activity at UK airports to slow. Improvements in aircraft fuel efficiency are expected to continue beyond 2030 and, in the central and high forecasts, biofuels are expected to penetrate the aircraft fleet as kerosene and carbon allowance prices increase. By 2040, the balance of these two effects causes emissions to stabilise, before starting to fall by 2050.
- By 2050, UK aviation CO_2 emissions is forecast to be 49.0 $MtCO_2$, within the range 39.6 – 58.4$MtCO_2$.
- At a European level, the inclusion of aviation in the EU Emissions Trading System will limit net CO_2 emissions from all arriving and departing flights into Europe at 212.9 $MtCO_2$ in 2012 and 208.5 $MtCO_2$ from 2013. Any growth in the aviation sector above this limit will need to be offset with the purchase of carbon reductions made elsewhere in the ETS or international credits.

3.1 This chapter comprises three sections that set out:

- in section 3.1, the nature, purpose, context and interpretation of the forecasts of carbon dioxide (CO_2) emissions from UK aviation;
- in section 3.2, the methodology and assumptions used to forecast UK aviation CO_2 emissions; and
- in section 3.3, the updated UK aviation CO_2 emissions forecasts.

3.1 Overview

Nature and purpose of the forecasts

3.2 There is currently no internationally agreed way of allocating international emissions to individual countries. DfT forecast CO_2 emissions produced by all flights departing UK airports to 2050, adjusted to match the DECC estimate of outturn (i.e. published) aviation CO_2 emissions (using the UNFCCC reporting method) in the base year[37], as reported in the National Atmospheric Emissions Inventory (NAEI)[38] . The forecasts therefore include CO_2 emitted from all domestic flights within the UK, and all international flights which depart UK airports, irrespective of the nationality of passengers or carriers.

3.3 The scope of aviation CO_2 could cover many possible sources of emissions. For example, some might argue that emissions from journeys to and from an airport are 'generated' by the existence of the airport and its services. However, this potentially will cause double-counting of emissions in different parts of the UK national inventory where surface transport emissions are accounted for separately.[39]

3.4 The sources of emissions covered in the forecasts in this chapter are set out in Table 3.1 below. The approach used is consistent with the DECC outturn estimates and the UNFCCC recommended approach for reporting on CO_2 emissions from international aviation[40].

---

[37] This covers the 31 largest airports in the UK. Emissions from the other minor airports are unlikely to be significant as they offer only short range services. DECC's estimates of outturn CO_2 emissions from aviation are based on the amount of aviation fuel uplifted from bunkers at all UK airports. The 'forecast' for 2008 is about 0.5MtCO_2 (1%) below the latest revised DECC estimate for that year. This residual amount is added back into the forecasts. A similar procedure is required by DECC when converting air fuel sales data to CO_2 bunker emissions data for domestic and international civil aviation. In the modelling the normalisation also reflects any difference in definition, including the absence from the modelling of the minor types of traffic such as business jets which are difficult to model, or flights from very small airports that are not included in the model.

[38] See www.naei.org.uk/.

[39] The CO_2 forecasts in this report relate specifically to aircraft both on the ground and in the air. However, in appraising potential policy measures affecting capacity/level of activity at specific airports the DfT also considers the potential for significant impacts on CO_2 emissions from airport surface access.

[40] There, UK domestic aviation CO_2 emissions are reported in the UK total and international aviation emissions are reported as a memo item.

Table 3.1: Definition of CO_2 emissions in the forecasts

Emissions source	Included in the forecasts?
All domestic passenger flights within the UK	✓
All international passenger flights departing UK airports	✓
All passenger aircraft while on the ground in the UK e.g. taxiing	✓
All domestic freighter aircraft departing UK airports	✓
All international freighter aircraft departing UK airports[41]	✓
All freighter aircraft while on the ground in the UK e.g. taxiing	✓
General aviation (non commercial flights) in UK airspace	✗
Surface access, i.e. passenger and freight journeys to and from a UK airport	✗
Non-aircraft airport sources, e.g. terminal lighting and airfield vehicles	✗
UK registered aircraft flying from airports not in the UK	✗
International flights arriving in the UK	✗
Overflights passing through UK airspace	✗

3.5 It is important to recognise that actions or events that reduce UK inventory aviation CO_2 emissions do not necessarily reduce global aviation CO_2 emissions (and vice versa). For example, constraining activity at UK hub airports could result in some passengers making transfers via neighbouring continental hub airports instead of the UK, thereby offsetting the reduction in the UK emissions inventory with increases in emissions elsewhere. The scope of the CO_2 emissions modelling is aircraft departing UK airports. Although forecasts are produced of numbers of UK transfer passengers opting to use foreign hubs, there are no forecasts of aircraft departing foreign hub airports from which robust assessments of global emissions could be calculated.[42]

3.6 The DfT's UK aviation CO_2 emission forecasts are used to help monitor and inform long term strategic UK aviation and climate change policy. The updated forecasts have been central to the MAC curve analysis

---

[41] Emissions from freight carried in the belly hold of aircraft are captured in the passenger aircraft emissions.

[42] Suitable emissions forecasts from continental hub airports affected by changing patterns of UK passenger movement would require modelling of ATMs at overseas airports. This requires estimates of future service patterns, future fleet mixes and future pressure on capacity at overseas hub airports. This is beyond the scope of DfT modelling.

presented in the Department's response to the CCC report[43], forming the baselines against which a range of policy options for reducing CO_2 emissions from UK aviation have been assessed. They will also inform the development of the Government's sustainable aviation policy framework.

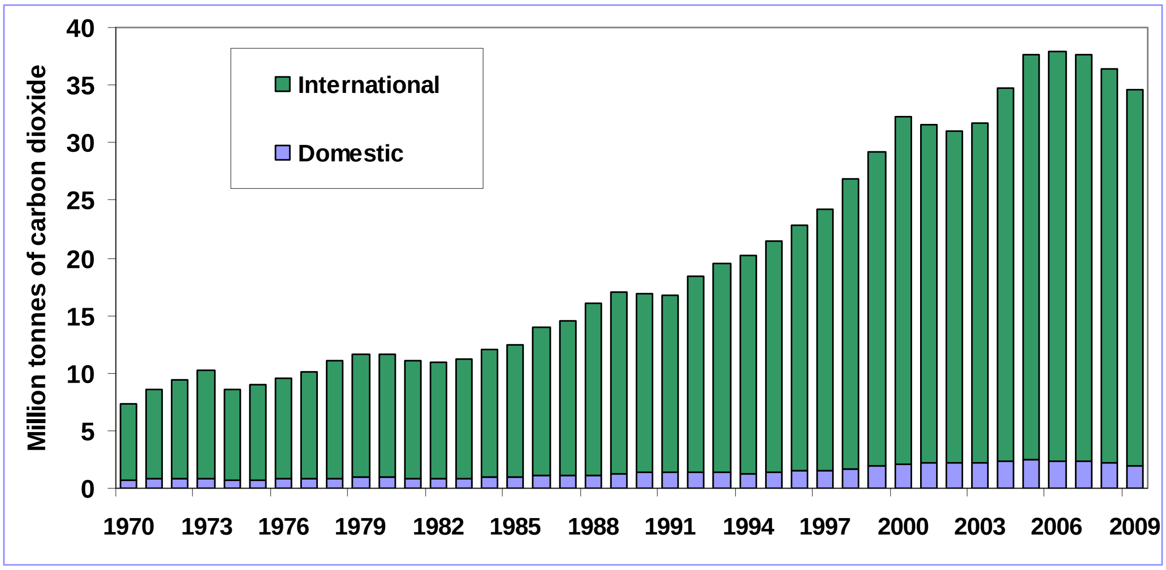
Context of aviation greenhouse gas emissions

3.7 This section sets out how aviation's greenhouse gas emissions have grown, and how they currently compare to total greenhouse gas emissions, at the national and global level.

3.8 CO_2 makes up about 99 per cent of the Kyoto greenhouse gas emissions from UK aviation[44].

3.9 Figure 3.1 shows UK aviation emissions since 1970. It demonstrates that in keeping with the global growth in demand for air travel discussed in Chapter 2, CO_2 emissions have tended to grow strongly. Some deviations from the trend are evident, and these are explained by demand variations, such as those resulting from the oil price shocks in the 1970s, recessions, terrorism threats or fears of global pandemics. The unprecedented reduction in aviation CO_2 emissions following the recent financial crisis and economic recession is clearly visible. Figure 3.1 also shows that international travel from the UK, as opposed to domestic flights, has been the main source of emissions growth, consistently accounting for over 90% of aviation emissions.

Figure 3.1: Aviation CO_2 emissions, $MtCO_2$, 1970-2009



Source: DECC emissions statistics, www.decc.gov.uk

---

[43] *Government Response to the Committee on climate change's report on reducing emissions from UK Aviation to 2050*, Department for Transport, August 2011

[44] *UK Greenhouse Gas Emissions*, Department for Energy & Climate Change, 2009 www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/uk_emissions/2009_final/2009_final.aspx

3.10 While aviation is currently a relatively small contributor to total greenhouse gas emissions (both at the UK and global levels), the projected continuing growth in its emissions alongside projected reductions in other sectors means that aviation's contribution will increase significantly in the coming decades.

3.11 Available evidence indicates that the aviation sector is responsible for approximately one to two per cent of global greenhouse gas emissions[45]. At the UK level, Table 3.2 shows that domestic aviation accounts for 0.3% of UK greenhouse gas emissions. If internal shipping and aviation emissions are added to the total in 2009, UK aviation (domestic and international) accounted for 5.8% of UK GHG emissions and total transport accounted for 27.3%.

Table 3.2: UK greenhouse gas emissions ($MtCO_2e$) in 2009[46]

	Million tonnes of carbon dioxide equivalent	% of total UK greenhouse gas emissions *
Total UK emissions excluding international aviation and shipping	563.6	92.8
Total UK emissions including international aviation and shipping	607.2	100
Total Transport – including international aviation and shipping	165.8	27.3
Of which		
- Road	113.6	18.7
- Rail	2.1	0.4
- Shipping	12.1	2.0
- Aviation	35.0	5.8
- domestic	*2.0*	*0.3*
- international	*33.0*	*5.4*

Note
* including international shipping and aviation in the total, based on bunker fuel sales

Interpreting the forecasts

3.12 The forecasts of UK aviation CO_2 emissions should be interpreted within the context of broader UK and EU climate change policy. In particular, aviation's entry into the EU ETS in 2012 will mean that although aviation CO_2 emissions are expected to grow in the UK and in other countries, any growth above the level of the aviation cap will be exactly offset by emission reductions from other sectors within the EU ETS, paid for by the aviation sector. Box 3.1 provides further details.

---

[45] *Reducing Transport Greenhouse Gas Emissions: Trends and Data*, International Transport Forum, 2010 http://www.internationaltransportforum.org/Pub/pdf/10GHGTrends.pdf/
Aviation and Marine Transportation: GHG Mitigation Potential and Challenges, Pew Center on Global Climate Change, 2009 http://www.pewclimate.org/docUploads/aviation-and-marine-report-2009.pdf.

[46] *UK Greenhouse Gas Emissions*, Department for Energy & Climate Change, 2009

3.13 The forecasts are intended to capture the long term trend in UK aviation CO_2 emissions. While they can capture some short term effects to the extent that the factors driving changes in aviation (e.g. economic growth) can be accurately forecast, they are not primarily intended to predict short term deviations from the trend, as could be caused by an unforeseen recession or other external shock.

3.14 There are significant uncertainties about the future path of the factors driving changes in aviation CO_2 emissions. As with the air passenger forecasts, this uncertainty is reflected by presenting the CO_2 forecasts as a range and by performing sensitivity tests to illustrate the sensitivity of the forecasts to changes in key drivers. The assumptions underpinning the overall forecast range and sensitivity tests are set out in section 3.2.

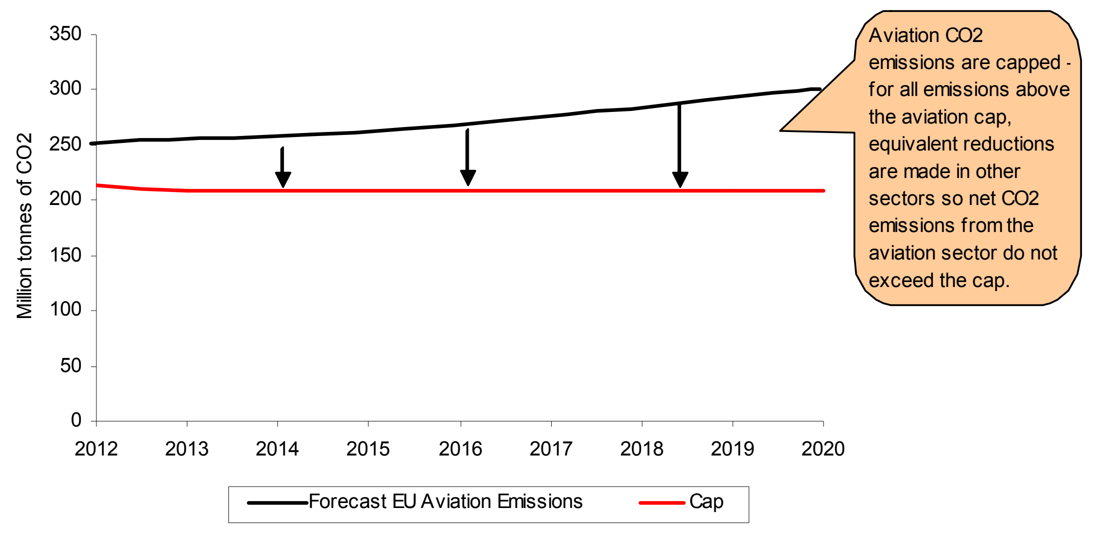
3.15 A further issue to note is that the total climate change impacts of aviation are greater than its CO_2 emissions alone. This is discussed further in Box 3.2.

Box 3.1: EU Emissions Trading System

Aviation will begin trading in the European Union Emissions Trading System (ETS) from 1 January 2012. The ETS will require aircraft operators who operate flights into, within and out of the EU to surrender carbon allowances to cover their annual CO2 emissions. In 2012, the emissions limit (or cap) for the aviation sector will be set at 97% of the average level of emissions over the period 2004-2006 (equivalent to 212.9 million tonnes of CO2) and will tighten to 95% of average 2004-2006 emissions from 2013 onwards (208.5 million tonnes of CO2). If aircraft operators want to exceed the aviation cap, they will be required to buy allowances from other sectors of the market where emissions reductions have taken place.

Therefore, although CO_2 emissions from aviation are expected to grow in the UK and in other EU countries, this growth will not result in any overall growth in CO_2 emissions in the trading system, because the aviation sector will have to pay for reductions to be made elsewhere. The overall result will be that the net contribution of aviation to CO_2 emissions will not exceed the level of the cap.

For illustration, the chart below shows the ETS in operation.



Box 3.2: Non-CO_2 climate effects

Although aviation does not emit significant quantities of any other Kyoto greenhouse gases, it results in other emissions that have both cooling and warming effects on the climate. These effects come about as a direct result of the atmospheric conditions in which they are emitted. Non-CO_2 emissions with climate impacts include water vapour and nitrogen oxides (NOx). Emissions of NOx result in the production of ozone, an air pollutant with harmful health and ecosystem effects and a greenhouse gas, and the reduction of ambient methane which has a cooling effect. The current understanding is that the overall balance of NO_x is warming.

The last major international assessment of these impacts was made by the Intergovernmental Panel on Climate Change (IPCC) in 1999. A comprehensive updated assessment of aviation emissions was undertaken by Lee et al in 2009[1]. CCC (2009) summarises the findings of Lee et al (2009), including its estimates of the different climate effects of aviation[2]. For example, the estimated 100-year Global Warming Potentials from Lee et al (2009) indicate that, once the non-CO_2 climate effects of aviation are taken into account, aviation's overall climate effects could be up to double the climate effect of its CO_2 emissions. However, whilst scientific advances since the 1999 assessment have reduced key uncertainties, considerable scientific uncertainty still remains.

[1]. Lee et al. (2009) *Aviation and global climate in the 21st century*, Atmospheric Environment.

[2]. Committee on Climate Change (2009) *Meeting the UK aviation target – options for reducing emissions to 2050*

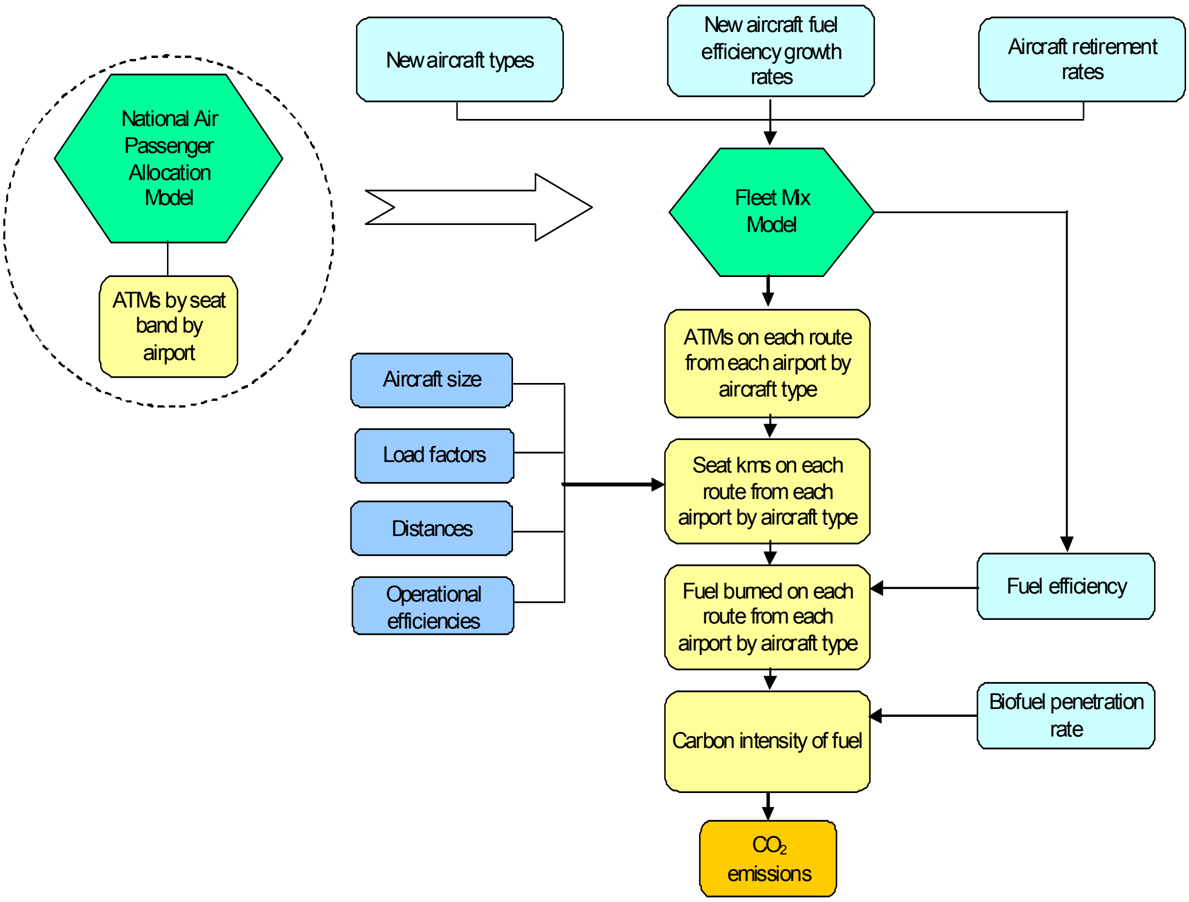
3.2 Methodology and Assumptions

3.16 Aviation CO_2 emissions are directly related to the amount and type of aviation fuel consumed. There are therefore three key drivers of aviation CO_2 emissions:

1. **Total distance flown:** this comprises the volume and average distance of flights from the UK, in turn driven by passenger and freight demand after accounting for airport capacity constraints;
2. **Fuel efficiency of aircraft**: the fuel required to fly a given total distance will fall as aircraft efficiency driven by technological and operational improvements improves; and,
3. **Type of fuel used by aircraft**: the CO_2 emissions associated with a given amount of fuel burn will fall as the penetration of alternative fuels increases.

3.17 Chapter 2 explained how the passenger demand forecasts are obtained, and how they are converted into a forecast of air transport movements (ATMs) from each airport in the UK to destinations around the world. This section sets out how the ATM forecasts are converted into CO_2 forecasts. Figure 3.2 provides an overview of the modelling components and key assumptions that together produce the forecast of CO_2 emissions to 2050. Below each step is explained in more detail. Annex E summarises the key developments to the methodology used to forecast UK CO_2 emissions since the DfT last published forecasts in 2009.

Figure 3.2: Forecasting aviation CO_2 emissions



Passenger ATMs by aircraft type

3.18 The National Air Passenger Allocation Model forecasts ATMs for each airport and route by 'seat-band' of aircraft (i.e. the seating capacity of the aircraft, split into six bands). This feeds into the Fleet Mix Model (FMM) which forecasts the particular composition of the aircraft fleet for each airport and route by specific aircraft type and age. It achieves this by taking the base year distribution of ATMs by aircraft type and age operating at all UK airports, and projects it forward using the forecast of ATM demand by seat band at each airport from the National Air Passenger Allocation Model, with assumptions about:

- the retirement age of each aircraft type; and,

- the split of new aircraft entering the fleet each year between specific aircraft types (by seat band and class of airline).

3.19 The CO_2 forecasts rely on the demand and fuel efficiency forecasts. These are generally available to 2050.[47]

3.20 The FMM retires aircraft from the UK fleet as they reach the end of their serviceable life, typically 20-25 years, and replaces them with new aircraft. When an aircraft retires, it is assumed to be replaced by one of three types:

1. a new aircraft of the same type;

2. a new aircraft of an existing but different type; or,

3. a new aircraft of a new type

3.21 Reflecting the variation in business models in the aviation industry, different fleet replacement assumptions are used in different sectors of the market, i.e. scheduled, charter and low cost airlines.

Seat-kilometres

3.22 The forecast number of ATMs by specific aircraft types at each airport are then converted into forecasts of seat-kilometres at the same level of detail, by applying projections of aircraft size (i.e. the number of seats per ATM), and the distance flown on each airport route. The latter is based on 'great circle' distances, which is a common metric for aviation purposes, and represents the shortest air travel distance between two airports taking account of the curvature of the earth. The actual distance flown is likely to be longer than the great circle distance in reality due to sub-optimal routeing and stacking at airports during periods of heavy congestion. An adjustment factor is therefore applied to uplift the distance flown by 8%[48].

Freight ATM kilometres

3.23 The ATMs of passenger aircraft will account for the emissions from moving some freight as it is carried in the bellyhold of those aircraft.

---

[47] A minority of model runs such as the high demand cases do fail to reach the target year because of capacity constraint issues so CO_2 emissions to 2050 are projected using simpler extrapolation methods. See annex E for further explanation.

[48] *Aviation and the Global Environment,* IPCC, 1990, paragraph 8.2.2.3 states that ATM routeing problems add an average of 9-10% to the distance of all European flights. More recently, the Civil Air Navigation Services Organisation (CANSO) stated in 2008 that baseline global ATM efficiency was between 92%-94% in 2005, i.e. there was 6-8% air traffic management inefficiency. In European airspace the inefficiency was estimated at 7-11%. The central forecasts are based on the upper CANSO estimate of the global inefficiency. See *ATM Global Environment Efficiency Goals for 2050*, CANSO, 2008 (http://www.canso.org/xu/document/cms/streambin.asp?requestid=BF60D441-40D0-4293-9675-A3517F0AC9A9).

However, dedicated freight aircraft must be accounted for separately. It is therefore necessary to forecast ATMs and emissions from freighter aircraft.

3.24 Forecasts of UK freight demand, split between bellyhold and freighters, were produced prior to the previous Government's 2003 White Paper using MDS-Transmodal and Halcrow forecasts.[49] Using the relationship between freight demand and GDP, the strong demand seen over the 1990s was projected to continue.

3.25 Since 2000, air freight demand growth has been subdued. Several reasons for this have been suggested, including: increased capacity and frequency of shipping services; aviation fuel prices rising faster than shipping fuel prices; disruption to air services (particularly on the North Atlantic routes) following the 2001 terrorist attack in New York; and the increasing importance of the Far East market. While these appear to have held back air freight demand growth, it is unlikely that the underlying long run relationship between GDP and air freight demand has been completely eroded.

3.26 It is assumed that total air freight tonnage (driven by GDP) will grow again from its 2010 level in line with the forecasts produced for the 2003 White Paper. The freighter share of this tonnage is assumed to rise in line with the MDS-Transmodal projection, and the average tonnage per freighter ATM is grown in line with the Halcrow projection. These are combined to obtain the national freighter demand forecast.

3.27 Unconstrained airport level freighter demand is forecast by growing base year freighter tonnage at each airport in line with the national tonnage demand forecast, and applying airport-specific payload projections. Future capacity constraints are accounted for by comparing unconstrained demand against freighter capacity at each airport, and iteratively redistributing unsatisfied demand to other airports which have spare freighter capacity pro rata to the base year distribution of demand.

Fuel burn

3.28 The forecast of seat-kilometres by airport, route, and aircraft type is then combined with the projected fuel efficiency of each aircraft type for that forecast year (measured in seat-kilometres per tonne of fuel) to generate the forecast of fuel burned by flights departing each airport, on each route.

3.29 For freighters, a similar approach is taken by forecasting at the national level using the constrained forecast of freighter ATMs. Emissions are projected to grow by combining the freighter ATMs, average trip length, and fuel efficiency projections. Trip length is projected to grow at a

---

[49] *UK Air Freight Study Stage 1*, MDS Transmodal, August 2000; *UK Air Freight Study Stage 2*, MDS Transmodal, August 2001; and, *SERAS Stage 2, Appraisal Findings Report – Supporting Documentation: Freight Forecasting*, Halcrow, May 2002.

decreasing rate, and fuel efficiency is assumed to follow a similar path to that of other passenger aircraft.

Fuel efficiency assumptions

3.30 Current fuel burn rates by aircraft type measured in kilograms of fuel per aircraft for different distance bands flown, and for different stages of the flight are initially taken from the European Environment Agency's 'CORINAIR' Emission Inventory Guidebook[50]. This is an established and authoritative source of data on aircraft fuel burn rates, giving separate values for the different stages of the flight such as landing and take off including taxiing and cruise emissions for different aircraft types[51]. It is used for general reference and for use by parties to the Convention on Long Range Transboundary Air Pollution (LRTAP) for reporting to the UNECE Secretariat in Geneva.

3.31 Seat-kms per mass of fuel (i.e. seat-kms per tonne or kg of fuel) is the preferred metric for measuring aviation fuel efficiency. It was widely used by the IPCC and the research on which the IPCC study drew.[52] There are in practice number of fuel efficiency measures. The value of this metric is that it is essentially unaffected by the assumed or modelled load factors. Box 3.3 includes data that illustrate how significantly efficiency rates can change when passenger loads are included, e.g. fuel used per passenger-km.

3.32 In 2009, the DfT commissioned QinetiQ to re-assess the suitability of the current CORINAIR guidebook rates of fuel burnt by distance band for each CORINAIR aircraft type and for each aircraft type used in DfT modelling.[53] QinetiQ's study:

- reviewed the mapping of all aircraft types to the subset of mainly older types in the CORINAIR guidebook data;
- assessed the accuracy of the curve fits of projected fuel burnt by distance band flown in the CORINAIR data and the volume of fuel burnt at each distance by relating it to detailed operational data from the AERO2k project[54]; and
- reviewed the assumptions about the composition of the supply pool expected to replace retiring aircraft.

---

[50] EMEP/CORINAIR Emission Inventory Guidebook - 2006, European Environment Agency http://reports.eea.europa.eu/EMEPCORINAIR4/en/page002.html

[51] It is assumed that fuel burn on a 100% loaded jet aircraft will be 5% higher than on a 70% loaded aircraft, due to the increased weight. See *An evaluation of aircraft emissions inventory methodology by comparisons with reported airline data*. Daggett, D. L., D. J. Sutkus Jr., D. P. DuPois, and S. L. Baughcum, 1999: NASA/CR-1999-209480.

[52] *Aviation and the Global Atmosphere*, Inter-governmental Panal on Climate Change, 1999

[53] *Future Aircraft Fuel Efficiencies – Review of Forecast Method*, QinetiQ, March 2010.

[54] The QinetiQ AERO2k greenhouse gas model, is one of the models approved for CAEP (the Committee for Aviation Environmental Protection). It uses a huge range of operational data from missions flown. It was possible to create CORINAIR style burn rates using the PIANO aircraft design software and actual operational data rather than the standardised operational settings used in the CORINAIR guidebook.

3.33 The QinetiQ study made recommendations on mapping of specific aircraft types to CORINAIR types, adjusting burn rates for existing aircraft, improving the form of the fuel burn over distance curves and extrapolating CORINAIR burn rates over longer flight distances. QinetiQ also provided advice on more precise rates for recent aircraft not well represented in the CORINAIR guidebook such as extended range versions of the B777 and the A380. Finally, the study also made recommendations on the burn rates to assume for aircraft due to enter service in the next few years such as Boeing 787s, Airbus A350s and the Bombardier C Series[55] and then the subsequent generations of new aircraft from 2020s onwards.

3.34 Gains in the fuel efficiency of air travel on the metric of seat-kms delivered per tonne of fuel can be split into two sources[56]:

- **Air traffic management and operational efficiencies**: through better co-ordinating and controlling air transport movements, or eliminating non-essential weight, optimising aircraft speed, limiting the use of auxiliary power etc, less fuel will be needed for a given number of seat-kms flown.
- **Aircraft efficiency**: as new, more efficient aircraft replace older aircraft, the average efficiency of the fleet will rise. Improvements in new aircraft efficiency can be driven by better engine or airframe technology. These gains could take the form of new types of aircraft entering production (e.g. Boeing 787, Airbus A380 and A350) or incremental improvements to existing types of aircraft. It is also possible for certain existing aircraft to become more efficient through retrofitting of the latest engine technology or the fitting of aerodynamic devices such as winglets and riblets.

3.35 In the 2009 forecasts, it was assumed that air traffic management and operational efficiency gains would meet the midpoint of the IPCC projection of a 6%-12% gain in fuel efficiency over the period 2006-2019[57]. However, on the basis of the advice of independent experts working on the MAC curve analysis that it is unlikely that these gains will be realised, the updated forecasts are now based on less optimistic assumptions. The central forecasts are based on the assumption that future net gains in ATM fuel efficiency from SESAR and other programmes are offset by an increase in traffic. In producing the forecast range a net +1% improvement by 2050 (i.e. a 1% reduction in actual distances flown) is assumed to define the lower bound and a net 4% deterioration (i.e. an increase in flight distance) defines the upper bound.

---

[55] See *Future Aircraft Fuel Efficiencies – Review of Forecast Method*, QinetiQ on behalf of the DfT, March 2010, Chapter 6.

[56] Fuel efficiency is defined in DfT modelling as seat-km per tonne of fuel. It is therefore independent of load factors, which are accounted for elsewhere in the forecasting. A key issue is that a specific load factor can then be assumed, so a seat-km implies a certain tonne-km. This is helpful for making assumptions transparent when defining industry standards.

[57] *Aviation and the Global Atmosphere*, IPCC, 1999 suggested a range of 6-12% (page 278-9) so the mid-point has been taken.

3.36 In producing the forecast range some allowance has been made for changes in airline operational practices (e.g. optimised payloads, flying speeds and altitudes) to deliver fuel efficiency gains. No additional improvement has been assumed in producing the central forecast, but +/- 0.25% efficiency improvement relative to the central forecast has been assumed in producing the lower/upper bound of the range

3.37 The primary source of fuel efficiency gains is likely to come from the retirement of less efficient current aircraft types and their replacement by newer more fuel efficient types. As explained above, the Fleet Mix Model (FMM) forecasts the distribution of the future fleet by aircraft type, based on the retirement of old aircraft and the entry into the fleet of new aircraft. To project gains in the fleet's efficiency due to the replacement of older aircraft with newer, more efficient models, it is therefore necessary to project the efficiency of the aircraft that will enter service in the years to 2050, and feed that into the FMM. The fuel efficiency assumptions made impact on the whole fleet. Box 3.3 presents some of the available evidence on fuel efficiency improvements seen over recent years and what might be expected in the future. The following section sets out the method used to project fuel efficiency improvements into the future.

Box 3.3: Trends in aircraft fuel efficiency

A range of estimates exist for the improvements in fuel efficiency in the aviation sector over recent years. Some studies have also set out their estimates of expected future improvements in efficiency.

To represent the range of evidence, the following sets out some illustrative examples to demonstrate the order of magnitudes. Despite the different metrics for assessing fuel efficiency, the results are indicative of the scale of change seen in the past and expected in the future.

The IPCC (1999)

Historically, improvements in fuel efficiency have averaged at 1-2% per annum (measured as fuel burn per seat km) for new production aircraft. This has been achieved through new engine and airframe technology. A similar trend is assumed when projecting forward to 2050.

IPCC draw on the research by Greene (1992) which looked at fuel efficiency (seat km per kg of fuel) to 2000 and extrapolated this forward to forecast annual fuel efficiency improvements over time:

	Annual fuel efficiency improvement
1990-2010	1.3%
2011-2020	1.0%
2021-2050	0.5%

IPCC, Aviation and the Global Atmosphere, 1999

Peeters et al (2005) took this work further to explore the impact of applying a fitted curve (instead of a linear trend) to the IPCC data and to that of Lee (2001) with the following fuel efficiency (all expressed in fuel used per available seat km) improvements per annum.

Fuel efficiency improvements per annum

	IPCC	Peeters et al (2005)
1960-1980	2.6%	2.2%
1980-2000	1.2%	0.9%
2000-2040	0.6%	0.5%

Peeters, P, Middel J and Hoolhorst A "Fuel efficiency of commercial aircraft. An overview of historical and future trends", 2005.

Box 3.3 (continued): Trends in aircraft fuel efficiency

Lee et al (2001)

This study looks at the efficiency changes in the US only and suggests that annual improvements in energy intensity (fuel use per seat-km and per passenger km) were relatively strong in the past but are set to slow.

	Gain in efficiency per annum including load factor effects (fuel per passenger km)	Gain in efficiency per annum excluding load factor effects (fuel per seat km)
1971-1985	4.6	2.7
1985-1998	2.2	1.2
Present to 2025	1.3-2.5	0.7-1.3

Source: Formulated using Lee, J, Lukatchko S, Waitz I and Scafer A (2001) 'Historical and future trends in aircraft performance, cost and emissions. Annual Review of Energy and the Environment 17 p537-573

IATA (2007)

IATA suggest that fuel efficiency at the global level measured in terms of annual changes in fuel use per 100 revenue tonne kilometres (which includes load factor effects) and per available tonne kilometres (which excludes load factor effects) increased in recent years at a faster rate than is expected in the future:

	Gain in efficiency per annum including load factor effects (fuel per passenger km)	Gain in efficiency per annum excluding load factor effects (fuel per seat km)
1997-2006	2.3%	2.4%
2006-2020	1.9%	n/a

Source: IATA World Statistics 2007

On the basis of the evidence in these studies, there appears to be a consensus that fuel efficiency has improved over recent years due to both improvements in technology, and owing to higher load factors.

Projecting fuel efficiency of new aircraft

3.38 In general the forecasts are based on the assumption that there will be gradual improvements relative to conventional technologies. These improvements are expected to reduce the weight of the engines and airframe through the increased use of new materials, improve various airframe efficiency metrics such as the reduction of aero-dynamic drag and increase both the thermo-dynamic and propulsive efficiency of engines. The forecasts do not reflect more radical departures such as the blended wing body aircraft or open rotor engines. The limited introduction of biofuels into the central and high baselines also has an impact on the emissions forecasts, although this assumption is independent of aircraft type.

3.39 It was noted above that aircraft entering service in a future year could be of an existing type, a known new type (i.e. aircraft not yet in service but which are on order such as the Boeing 787, Airbus A350 and the Bombardier C Series) or a completely new type. The efficiency of new types of aircraft expected in the near future can be projected using manufacturers' specifications for their aircraft and PIANO aircraft design and performance software[58]. Box 3.4 sets out the specific assumptions.

Box 3.4: Efficiency of new aircraft types in the near future

Manufacturers' data and the PIANO aircraft design and performance model are used to project the fuel burn rates of new aircraft types expected to enter service in the near future. For example, the next generation of Boeing 737s and Airbus A320s are assumed to burn 15% less fuel than the current types. Boeing 787s are assumed to burn 5% less fuel than the B767s they will often replace. Airbus A350s are assumed to burn 7% more fuel than a B767, but their potential larger seating capacities mean that significant efficiencies can be delivered to the efficiency metric of seat-kms per tonne of fuel. The Airbus A380 is assumed to burn 15% more fuel than a Boeing 747-400, but could deliver efficiencies of up to 12% in terms of seat-kms per tonne of fuel depending on the seating configurations of each type. These updated rates are applied to the CORINAIR data of the respective existing aircraft types to project burn rates for the new types. An adjustment is also made to reflect the potential variation in seating configurations of the new aircraft.

With the smaller jets, the main new type is the Bombardier C Series regional jet which is assumed to have a 20% fuel saving on the Airbus A319.

3.40 No great technological change is assumed before 2020 beyond aircraft already in development. Mid-generation upgraded and re-engined Airbus A320 and B737 aircraft are assumed to enter service from around 2016. The introduction of Boeing 787s, Airbus A350s and Bombardier C Series aircraft are also assumed to improve on the types they replace. The forecasts do not assume any fuel efficiency gains are delivered through retrofitting because these gains are likely to be relatively small and limited to a relatively narrow range of aircraft currently in service.

3.41 The development of new aircraft types tends to follow a product cycle over many years, and it is probable that future generations of aircraft types will enter production and the fleet during the 2020s with further waves in the 2030s and 2040s. However, their introduction will vary by

---

[58] PIANO-X Aircraft performance and emissions software. LIssys Ltd. http://www.piano.aero/.

size classes and the position of aircraft of that class in the approximate 20 year production and development cycles. For example it is assumed that there will be relatively few new types to replace 120-200 seat narrow-bodied types in the 2020s because of the potential introduction of re-engined new generation B737s and A320s after 2016. New 2020 generation 500+ seat aircraft are not assumed to enter the replacement pools until late in the decade because of the current development of the A380 and B747-800.

3.42 The DfT's previous emissions forecasts assumed that future generations of aircraft introduced in 2020 and beyond would be influenced to some degree by the Advisory Council for Aeronautics Research in Europe (ACARE) target for fuel efficiency[59]. The ACARE 2020 vision is that aircraft manufacturer R&D, operational efficiency and air traffic management combine to deliver a 50% improvement in fuel burnt per seat-km by new aircraft entering service compared with their equivalents of 2000.[60] NASA has similar expectations for the future American aircraft fleet. It is not now assumed that future generations of aircraft coming into service beyond 2020 are uniformly "ACARE compliant".

3.43 This judgment is because the updated forecasts have gone a step further in reflecting expert industry advice on:

- the effectiveness of economic motives driving fuel cost reduction;
- the ICAO/CAEP expert review of fuel burn reduction technology in 2010 with more detailed analysis becoming available;[61]
- the willingness of manufacturers to anticipate agreements on ICAO/CAEP CO_2 standards; and
- the willingness of airlines to rollover their fleets more responsively to fuel costs and to anticipate potential new regulatory standards.

3.44 Fresh advice was also received on how international collaboration and R&D development might advance aircraft design through the nine NASA defined Technological Readiness Levels (TRLs) with baseline levels of government and industry funding[62]. So although attainment of fuel burn goals remains an important part of the view of future aircraft efficiency, the availability of more detailed analysis of the specific factors driving

---

[59] See *The Challenge of the Environment, Strategic Research Agenda*, Advisory Council for Aeronautics Research (ACARE), Volume 2, October 2002, (http://www.acare4europe.org/docs/es-volume1-2/volume2-03-environment.pdf)

[60] *A Strategy Towards the Development of Sustainable Aviation*, Sustainable Aviation, 2005

[61] ICAO/CAEP: *Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction From Technology, 2010* (Doc 9963)

[62] *Technology Readiness Levels, A White Paper,* John C Mankins (NASA), 1995 (http://www.hq.nasa.gov/office/codeq/trl/trl.pdf) and also http://www.nasa.gov/topics/aeronautics/features/trl_demystified.html
It has been suggested that the ACARE targets refer to TRL6. This implies that when the ACARE goal is met the aircraft in development would still be several (possibly up to 10) years away from entering commercial service.

aircraft technological development emerging from the MAC curve analysis project removes the need to make assumptions about new aircraft fuel efficiencies in line with ACARE aspirations. Allowance is also now made for the different development cycles for different size classes of aircraft.

3.45 Table 3.3 below shows what is assumed to be the fuel efficiency gains for the future generations of aircraft introduced in the 2020s, 2030s and 2040s. The model uses these values as “available technology”. The individual seat classes then get either this value (as a future generation type) or a reduced value (representative of a incremental improvement on an existing type) depending on where they are assumed to be on the 20-year development cycle, as described in section 3.41.

Table 3.3: Fuel efficiency gains of future generation (FG) aircraft

			Fuel Efficiency Gain: Central Case		
		Base "2000" aircraft TYPE	2020s FG	2030s FG	2040s FG
Class1	0-70 seats	ATR42-320	21.5%	24.5%	31.5%
Class2	71-150 seats	B737-400	21.5%	24.5%	31.5%
Class3	151-250 seats	B757-200	21.5%	24.5%	31.5%
Class4	251-350 seats	B777-200	17.5%	27.5%	29.5%
Class5	351-500 seats	B777/A340-200	17.5%	27.5%	29.5%
Class6	500+ seats	A380	17.5%	27.5%	29.5%
Low case efficiency improvement on central			2.0%	4.0%	5.5%
High case efficiency improvement on central			-2.0%	-4.0%	-5.5%

3.46 Table 3.4 below shows the range of annual average fuel efficiency improvements underpinning the updated forecasts. It shows that under the central forecasts average fleet fuel efficiency improves by 10% between 2010 and 2030, equivalent to 0.4% per annum, with efficiency gains accelerating in the 2020s as the current fleet is largely replaced.

Table 3.4: Annual average fuel efficiency improvements to 2050

Year	Annual average			
	DfT passenger demand range forecasts 2008			IPCC 1999
	Low	Central	High	
2010-2020	0.1%	-0.1%	-0.2%	1.00%
2020-2030	0.9%	1.0%	0.7%	0.50%
2010-2030	0.4%	0.4%	0.2%	0.90%
Aggregate 2010-2030	10.8%	9.9%	4.4%	
2030-2040 pa	1.3%	1.0%	1.2%	
2040-2050 pa	2.2%	2.0%	2.7%	
Aggregate 2010-2050 pa	1.0%	0.9%	1.0%	

3.47 The DfT forecast fuel efficiency is significantly below that predicted by the IPCC in 1999 for the period to 2030 . The IPCC forecast efficiencies primarily to 2010 based mainly on research published in the early 1990s and based on technical data on energy use by aircraft operating between 1970 and 1989.[63] This research forecast baseline efficiency improvements of 1.3% per annum to 2010 using only existing types expected to be in service by 1995. Forecasts for the IPCC beyond 2010 were extrapolations of this research made by the then DTI and implicitly included “post 2000” types that the original research by Greene excluded from the baseline case.[64]

3.48 The assumption of both Greene and the IPCC was that soon after 2000 new aircraft models beyond the mid-1990s types (such as the current Airbus A320 family and the ‘Next Generation’ Boeing 737-700/800/900) would be entering the fleet. With the exception of a limited number of A380s there has been no introduction of significant new types in the past decade. These earlier forecasts would, for example, have been based on the assumption that Boeing 787s (and possibly A350s) would have,

---

[63] Greene, D.L. 1992: *Energy-efficiency improvement potential of commercial aircraft* in *Annual Review of Energy and the Environment*, USA, pp.537-574.

[64] *Aviation and the Global Atmosphere*, IPCC, 1999, Table 9-2, p.302. Note also that IPCC (but not Greene) imply that improvements in passenger management and operational efficiencies may have contributed to the fuel efficiency rates (p.302). No such improvements are included in the central forecasts, but alternative assumptions about the scope for improvements in air traffic management and airline operating efficiency are reflected in the overall forecast range .

by now, replaced many less efficient medium and long haul types. Entry into service may have lagged almost 10 years behind the expectations in the early 1990s. More recent work by ICAO/CAEP Modelling and Data Task Force (MODTF) suggests that without significant new aircraft in the fleet before 2016 fuel burn efficiency improvements are likely to be around 0.6% per annum rising to 1.0% per annum with new 'known' aircraft such as Boeing 787s.[65] This recent work corresponds more closely with the DfT modelling, although local UK efficiency gain rates will differ as there tend to be fewer older inefficient types left to retire in the UK fleet.

3.49 The structure of the Fleet Mix Model (FMM) can contribute to an understatement of fuel efficiency gains in the first decade of the modelling period. As described earlier in this section, the National Air Passenger Allocation model forecasts ATMs in six seat bands[66] and the FMM allocates particular aircraft to movements within these bands. There is often a wide mix of different aircraft sizes within each band. For example in the 71-150 seat band, there will be a tendency for older 70-100 seat aircraft (often turboprops) to be replaced by bigger aircraft with higher fuel burn rates such as Airbus A319s and A320s. Ultimately, in terms of the seat-kms per tonne of fuel metric, larger aircraft are more fuel efficient and the increase within the overall fleet efficiency forecast mirrors the transition to large aircraft. However, when the transition occurs within the same modelled seat band class, the model is in effect using heavier more fuel intensive aircraft to transport the same number of passengers.[67] This is a model construct which means that the forecast fuel efficiency improvements presented in Table 3.4, are likely to be slightly understated, particularly in the early forecasting period. So while Table 3.4 implies a gradual worsening of fuel efficiency between 2010 and 2020 under the central and high forecasts, this could, more realistically, be interpreted as a very slight improvement in efficiency over the period.

Alternative fuels

3.50 DfT's previous forecasts assumed no penetration of alternative fuels into the aircraft fleet during the period of the forecasts. In practice, the industry has been investigating keenly the potential for alternative fuels for some time. Test flights have shown that some forms of biofuel can successfully be mixed with kerosene. Most recently, Thomson Airways announced that, later in 2011, it will become the first UK airline to fly passengers commercially on biofuel when it begins operating one flight per week from Birmingham to Palma using a 50% biofuel blend in both engines.

---

[65] CAEP/8-IP/8 Environmental Goals Assessment Report by MODTF to the Eighth Meeting of CAEP February 2010. See Appendix P.

[66] 1-70, 71-150, 151-250, 251-350, 351-500 and 500+ seats.

[67] Another example is the Airbus A380 which was originally anticipated to be a 500+ seat aircraft (seat band 6) but which has now been used in the 351-500 seat band to reflect current airline operational practice. Reflecting such current commercial practice also reduces overall modelled fleet efficiency.

3.51 The updated central forecasts assume that biofuels are gradually introduced in the 2020s and only make up 2.5% of all aviation fuel burnt by aircraft departing UK airports in 2050. In defining the lower bound of the forecast range, no biofuels penetration is assumed to 2050, while in defining the upper bound of the range, biofuel penetration is assumed to rise gradually to 5% by 2050. These assumptions reflect the advice of the independent experts working on the MAC curve analysis following their review of the latest evidence on future biofuels prices.

Carbon intensity of fuel

3.52 Once the above method has forecast the amount of fuel that is burned on flights departing each airport on each route by aircraft type, this is converted into CO_2 emissions on the basis that 1.00 kg of kerosene emits 3.15 kg of CO_2[68]. Where biofuel uptake is assumed, this average carbon intensity factor is reduced on the assumption that biofuels are accounted for in the transport sector as having zero emissions[69]. For example, in the central forecast in 2050 with 2.5% biofuel take up, it is assumed that across the entire fleet 1.00kg of fuel emits 3.07kg of CO_2.

Summary of CO_2 forecasting range assumptions

3.53 The CO_2 emissions forecast range is based on the same combinations of sensitivity tests used to produce the range of air passenger forecasts described in chapter 2 and annexes 2 and 3. These assumptions determine the volumes of passengers, aircraft loads and ATMs by seating band that are output by the National Air Passenger Allocation Model.

3.54 After the forecasting of ATMs, further assumptions relating to the composition of the fleet and operational practice are applied. Although these assumptions potentially have some further effect on airline fuel costs and therefore fares, they are not fed back into the National Air Passenger Demand Model at this stage. [70] The assumptions made are:

---

[68] Each 1 kg of kerosene contains 858 g of carbon. Each 1kg of carbon is equivalent to 44/12 or 3.67 kg of CO_2.

[69] In practise, different biofuel feedstocks have different levels of life-cycle emissions and biofuels use in aviation is expected to result in lower emissions, but not reduce emissions to zero. The approach taken here is consistent with the accounting of biofuel use in the UK's carbon budget and in the EU ETS, and with the latest guidance from the International Panel for Climate Change (IPCC).

[70] Fleet fuel efficiency is an input to the fares faced by passengers in the National Air Passenger Demand Model because fuel efficiency is an input to the forecasts of fares faced by passengers. Representative fuel efficiencies for the low, central and high demand scenarios from recent (but not final) model runs are used in these fare forecasts. The principle is to use the best available model outputs on fleet fuel efficiency rates while avoiding unnecessary iterations between the demand and CO_2 model components of the forecasting framework where changes in output passenger demand would be very small.

Central

- no regulatory CO_2 standard;
- standard DfT retirement ages of 22 years[71];
- no retro-fitting;
- 2020 future generation having a 17.5-21.5% fuel burn improvement on 2000 standard types, the 2030 future generation having a 24.5-27.5% improvement and the 2040 future generation having a 29.5-31.5% improvement;
- no net air traffic management system gains as improvements from SESAR and other programmes are assumed to accommodate the growth in ATMs without further deterioration in levels of service;
- no improvement from airline operational efficiency practices; and
- 0.5% biofuel use in 2030 rising to 2.5% by 2050.

Low (where different from central)

- 2020 future generation having a 19.5-23.5% fuel burn improvement on 2000 standard types, the 2030 future generation having a 28.5-31.5% improvement and the 2040 future generation having a 35.0-37.0% improvement;
- After ATM growth, SESAR and other programmes achieve a 1% net air traffic management system gain by 2050;
- 0.25% extra efficiency each year through airline operational efficiency practices; and
- no biofuel use.

High (where different from central)

- 2020 future generation having a 15.5-19.5% fuel burn improvement on 2000 standard types, the 2030 future generation having a 20.5-23.5% improvement and the 2040 future generation having a 24.0-26.0% improvement.
- A 4% deterioration in the net air traffic management system despite the implementation of SESAR and associated programmes;

---

[71] Based on analysis of DfT analysis of UK fleet turnover using airframe data from CAA. There are some exceptions to 22 years for the earlier retirement of very old types and slightly later retirement for the charter fleet.

- 0.25% less efficiency each year through airline operational practices; and
- 1% biofuel use in 2030 rising to 5% by 2050.

3.3 UK Aviation CO_2 Emissions Forecasts

UK Aviation CO_2 Forecasts

3.55 Chapter 2 explained how the ATM forecasts have been developed from the passenger demand forecasts. The previous section set out the methodology and assumptions used to convert the detailed forecasts of ATM by seat band class and specific route into forecast CO_2 emissions to 2050. This section sets out the range of forecasts obtained by applying these methods.

3.56 Table 3.5 reports the central forecast and overall forecast range for CO_2 emissions from UK aviation to 2050. The forecast range combines the range of ATM forecasts (explained in chapter 2), with alternative assumptions relating to the composition of the fleet and operational practises (as explained above). Table 3.5 shows that under the central forecast aviation emissions rise from 33.4MtCO_2 in 2010 to 47.6MtCO_2 in 2030, within the range 43.2MtCO_2 to 53.4MtCO_2. After 2030, the growth in aviation CO_2 emissions is forecast to slow as the effects of market maturity and airport capacity constraints cause the growth of activity at UK airports to slow while fuel efficiency gains continue with aircraft design improvement and the carbon intensity of emissions reducing with the introduction of biofuel. By 2040, the balance of these effects causes emissions to stabilise, before starting to fall by 2050. The forecasts suggest that, in 2050, UK aviation CO_2 emissions will reach 49.0MtCO_2, within the range 39.6 MtCO_2 to 58.4MtCO_2.

Table 3.5: UK Aviation CO_2 forecasts to 2050, MtCO_2

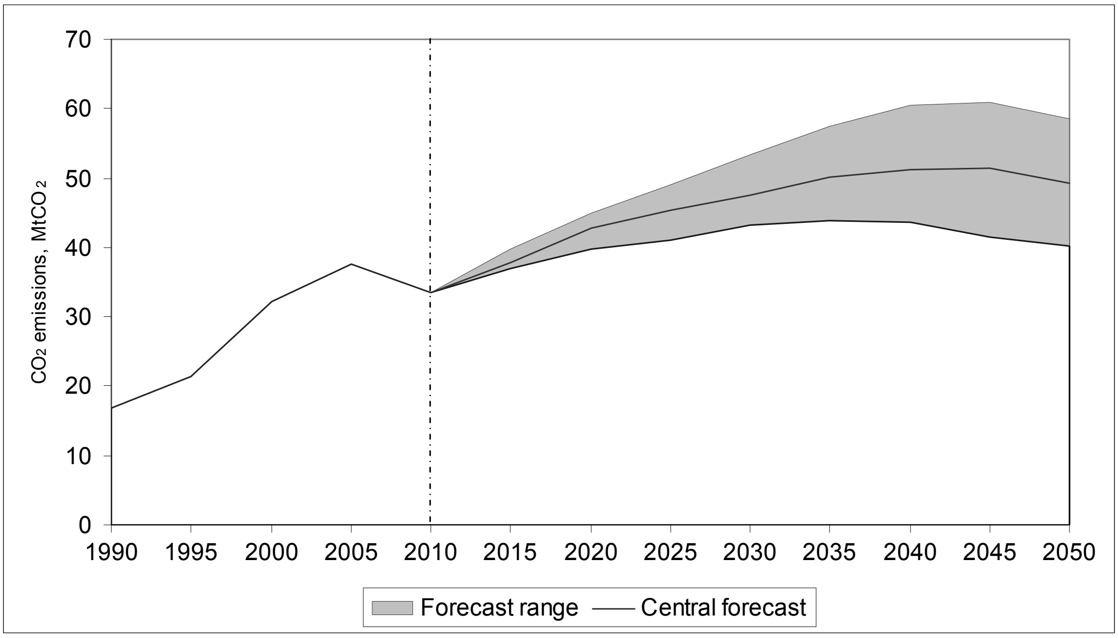
	Low	Central	High
2010	33.4	33.4	33.6
2020	39.8	42.9	45.1
2030	43.2	47.6	53.4
2040	43.3	51.1	60.4
2050	39.6	49.0	58.4

3.57 Figure 3.3 presents the range of aviation CO_2 forecasts alongside historic aviation CO_2 emissions as a diagram.[72]

---

[72] After 2030 these baseline range forecasts differ very slightly from those reported in *Marginal Abatement Cost Curve Model for the UK Aviation Sector, Technical Report,* EMRC/AEA, August 2011. These forecasts are updated and include improvement in the forecasting of freighter emissions after 2030 that slightly lower the forecast. The differences are small: generally <0.5MtCO_2 in 2050 and would not materially affect any of the results of the MAC analysis.

Figure 3.3: Range of UK aviation CO_2 forecasts



3.58 Table 3.6 shows the penetration of the new aircraft across UK based aviation activity after their introduction in the 2020s and subsequent decades and their contribution to aviation emissions. The 'new aircraft' are termed 'FG' elsewhere in the modelling and refer to aircraft types which enter the fleet for the first time from separate production cycles in the 2020s, 2030s and 2040s. They are distinct from the 'known' new types expected to enter service in the next ten years such as the wide-bodied Boeing 787 and Airbus 350 families, and narrow-bodied new generations of Boeing 737s and Airbus A320s and the new Bombardier C Series.[73]

Table 3.6: Proportion of aircraft-kms output by future generation ('FG') aircraft

	Aircraft-kms			
	2020	2030	2040	2050
Low	0%	17%	44%	88%
Central	0%	20%	44%	82%
High	0%	18%	45%	78%

3.59 As explained earlier in Box 3.1, the inclusion of aviation in the EU ETS from 2012 means that aviation's emissions will be capped. This means that, although CO_2 emissions from aviation are expected to grow in the UK and in other EU countries, this growth will not result in any growth in the overall CO_2 emissions from sections included in the ETS, because the aviation sector will have to pay for reductions to be made in other

---

[73] These types are discussed more fully in *Future Aircraft Efficiencies – Final Report,* QinetiQ, March 2010, but note that the precise efficiency improvements described there have been superseded by the MAC curve analysis reported in *Marginal Abatement Cost Curve Model for the UK Aviation Sector, Technical Report,* EMRC/AEA, August 2011.

sectors.

Sensitivity tests

3.60 A series of sensitivity tests have been described in chapter 2. These tests fall into 3 categories:

- varying the central settings of the individual demand driving variables (GDP, oil price, carbon price, fuel efficiency and videoconferencing uptake) and market maturity assumptions;
- incrementally varying each variable described above and those variables such as future fleet mix and air traffic management and operational efficiencies that impact CO_2 and not passenger demand to show the transition from the central forecast to the lower and upper bounds of the overall forecast range; and
- examining the extreme ranges of ‘lowlow’ and ‘highhigh’ where each variable is set to the range input setting that minimises or maximises total demand (e.g. lowlow will combine low GDP and high oil price settings etc.).

3.61 Table 3.7 shows changes from the central baseline with the low and high range variables settings applied individually to each of the main demand variables in turn. The signals from the sensitivity tests become increasingly less clear as the model runs approach 2050 and capacity constraints are at their most severe. In many cases extrapolation has been required as full passenger and ATM allocation model runs cannot complete. This is discussed in Annex E (see paragraph E.14). It is noted in Annex E that extrapolations of ATMs imply higher levels of suppression than if the full passenger reallocation model had continued running. It is apparent that the year the full model run terminated is a key factor in determining the relative levels of CO_2 reported in the sensitivity tests. Consequently Table 3.7 only reports emissions to 2030 which was fully modelled so all tests can be compared on a consistent basis without interference from the additional variable of the year the full model run terminated.

Table 3.7: UK CO_2 emissions forecast - individual variable sensitivity tests, 2030.

			Tests on individual variables	
			2030	
index	Sensitivity	MAC Demand Scenario Case	2030 MtCO2	Difference from central case (MtCO2)
	Central		47.6	
1	Low GDP	Low	44.8	-2.7
2	Low Oil Price	Low	47.4	-0.2
3	Low Carbon Price	Low	48.9	1.3
4	Improved Fuel Efficicency	Low	47.6	0.0
5	Videoconferencing Demand Reduction	Low	46.3	-1.2
	Financial 'bounce-back'			
	Faster market maturity	Low	44.6	-3.0
1	High GDP	High	49.6	2.0
2	High Oil Price	High	45.6	-2.0
3	High Carbon Price	High	45.8	-1.8
4	Poorer Fuel Efficiency	High	47.2	-0.4
5	Videoconferencing Demand Increase	High	47.9	0.3
6	Financial 'bounce-back'	High	51.6	4.0
6	Slower market maturity	High	48.5	1.0

3.62 Table 3.8 shows the incremental progression from the central forecast to the lower and upper bounds of the forecast range with each of the relevant variables applied in turn. The low forecasts have been reported to 2050 because full passenger and ATM modelling has been possible and provides coherent incremental results for all the tests. But, as paragraph 3.61 above discusses, where model extrapolation is required the signal from the test can be distorted where each full run has terminated prematurely. This is the case for all the high range forecasts, so in order to keep the comparison consistent, only 2030 CO_2 emissions are shown.

Table 3.8: UK CO_2 emissions forecast - incremental variable sensitivity tests, 2030 and 2050.

			Cumulative change of variables			
			2030		2050	
	Sensitivity	MAC Demand Scenario	2030 MtCO2	Difference from previous case (MtCO2)	2050 MtCO2	Difference from previous case (MtCO2)
	Central		47.6		49.0	
L0	Central + Low growth fleet and operational improvement	Low	47.4	-0.1	47.2	-1.8
L1	L0 + rapid maturity	Low	44.5	-3.0	39.7	-7.5
L2	L1 + bounceback		n/a	n/a	n/a	n/a
L3	L2 + Low GDP	Low	42.3	-2.2	37.5	-2.2
L4	L3 + Low Carbon £	Low	43.2	0.9	39.2	1.6
L5	L4 + Low Oil £	Low	43.7	0.5	39.3	0.1
L6	L5 + Video-conferencing business travel reduction	Low	43.2	-0.6	38.9	-0.5
L7	L6 + others (demand effects of weak £ ExR & improved fuel eff)	Low	43.2	0.0	39.6	0.7
H0	Central + High growth fleet and operational deterioration	High	48.8	1.2		
H1	H0 + slower maturity	High	49.8	1.0		
H2	H1 + bounceback	High	53.6	3.9		
H3	H2 + High GDP	High	56.1	2.4		
H4	H3 + High Carbon £	High	54.7	-1.4		
H5	H4 + High Oil £	High	53.6	-1.1		
H6	H5 + Video-conferencing demand increase	High	54.1	0.5		
H7	H6 + others (demand effects of stronger £ ExR & poorer fuel eff)	High	53.4	-0.7		

3.63 Table 3.9 shows the more extreme range, derived by combining each of the sensitivity tests to minimise (‘lowlow’) and maximise (‘highhigh’) the passenger forecasts. The ‘highhigh’ forecasts requires the simplified extrapolation methods (see annex E) to complete the forecast out to 2050.

Table 3.9: UK CO_2 emissions forecast - extreme ranges 2030 and 2050

	2030		2050	
	2030 MtCO2	Difference from central case (MtCO2)	2050 MtCO2	Difference from central case (MtCO2)
Central	47.6		49.0	
"LowLow" (high maturity, low GDP, high carbon, high oil, low fuel efficiency, low ExR)	39.0	-8.6	35.0	-13.9
"HighHigh" (low maturity, high GDP, low carbon, low oil, high fuel efficiency, high ExR)	59.4	11.8	55.7	6.8

Airport Forecasts to 2050

3.64 As explained above, the national forecast of UK aviation CO_2 emissions is based on detailed forecasts of passenger and ATM demand at the airport level.

3.65 Table 3.10 presents the central CO_2 emissions forecasts to 2050, for the largest of the UK's airports.

Table 3.10: CO_2 emissions from airports (central forecast)[74]

	Emissions million tonnes CO_2			Share of Total UK Departure CO_2		
	2010	2030	2050	2010	2030	2050
		Central			Central	
Heathrow	18.9	23.1	14.9	56%	48%	30%
Gatwick	3.8	3.8	3.7	11%	8%	8%
Stansted	1.3	2.0	1.8	4%	4%	4%
Luton	0.5	1.0	0.6	2%	2%	1%
London City	0.2	0.6	0.6	1%	1%	1%
London Total	24.7	30.4	21.7	74%	64%	44%
Other UK Airports	6.9	14.1	24.9	21%	30%	51%
Ground APU	0.4	0.6	0.8	1%	1%	2%
Freight	1.1	1.9	1.1	3%	4%	2%
Residual	0.4	0.6	0.6	1%	1%	1%
Total	33.45	47.57	48.96	100%	100%	100%

3.66 Table 3.10 shows that in 2010 London airports accounted for almost 75% of total UK aviation CO_2 emissions. This is forecast to decline to 64% by 2030 and then to 44% by 2050. This is because in the ‘max use’ capacity scenario, growth in aircraft movements is largely only possible at regional airports after 2030. Airports such as Heathrow and Gatwick cannot increase their ATMs because they are at capacity, but they

---

[74] It should be noted that the emissions at the airport level represent emissions from passenger flights only and do not include additional emissions from congestion during taxiing, or the individual airport contribution to the freight total.

benefit from the fuel efficiency gains as new generations of aircraft enter the fleet. At present Heathrow accounts for around half of the UK's aviation CO_2 emissions. This reflects its large share of traffic (around a fifth) and its larger proportion of long haul flights. In the longer term these shares are forecast to decline.

Annex A: Econometric Models in the National Air Passenger Demand Model

Introduction

A.1 Chapter 2 explained that the National Air Passenger Demand Model includes econometric models for each of 19 market segments. This annex provides further details of the data and econometric methods on which these models are based, plus the resulting parameter estimates, diagnostic tests and key long run elasticities.

A.2 The econometric models used for all market segments have been re-estimated since the publication of *UK Air Passenger Demand and CO_2 forecasts, 2009.* The main reasons for re-estimating the models were:

(a) to make use of more recent data – the new models are based on data to 2008 rather than 2004;

(b) to test different specifications of the models; and

(c) to review whether fare variables could be included in more models, given the expectation that aviation's entry into the EU ETS will lead to increases in fares

A.3 Ultimately the aim of the econometric analysis was to estimate models which successfully explained past demand movements, had parameter estimates in line with economic theory, and passed the standard diagnostic tests. Particular emphasis was placed on establishing the relationship between demand and income variables, and searching for fare effects where data permitted.

A.4 The segmentation of passengers into separate market segments is the same as in *UK Air Passenger Demand and CO_2 forecasts, 2009* except that the distinction between charter and other leisure markets has been abandoned. The UK Leisure to Western Europe market now includes what used to be defined as 'Short Haul Charter' passengers, while the UK Leisure to OECD, NICs and LDCs include 'Long Haul Charter' passengers, weighted by traffic[75]. The 19 market segments are, therefore, split according to:

(a) the global region a passenger is travelling to or from;
(b) whether the passenger is a UK or overseas resident;
(c) the passengers journey purpose (business or leisure);
(d) the type of flight the passenger is on (international or domestic); and

---

[75] Leisure traffic is split into scheduled, No Frills Carriers (NFCs) and Charter passengers in a sub-model prior to input into NAPALM.

(e) whether the passenger is making an international to international connection using a UK airport.

A.5 Two technical notes describing the work to re-estimate the models undertaken since the publication of forecasts in *UK Air Passenger Demand and CO_2 forecasts, 2009,* in more detail are being published alongside this report[76]. The first describes re-estimation work in more detail and the second describes the data sources used in more detail.

Data sources

A.6 The primary source of data for air passenger demand and fares paid is the ONS International Passenger Survey (IPS). This survey dataset gives a continuous time series for traffic from 1984-2008, and for fares from 1987-2008. However, it collects fare data from only UK passengers, and does not include domestic air passengers.

A.7 The passenger interview surveys conducted by the CAA provide an important supplementary source which has been used to supply time series for international-to-international interlining passengers, to provide information on journey purpose (business/leisure) and the share of domestic interliner passengers on domestic routes. The survey results also provide some data on domestic air fares and fares paid by foreign passengers as well as providing an independent validation of the IPS dataFares data for 1982 to 1987 was compiled in the form of an index from an earlier DfT forecasting exercise[77].

A.8 Elsewhere ONS data is used for UK GDP and consumer expenditure, UN statistics on foreign GDP, HM Revenue & Customs for trade data, Bank of England quarterly returns for dollar exchange rates, and UN local currency GDP statistics for other currency to dollar exchange rates.

Econometric Methods

A.9 Most of the markets display strongly trended variables. There are upward trends in traffic, but also in independent variables such as GDP, exports and imports. Similarly there is typically a downwards trend in air fares. These trends are non-stationary.[78]

A.10 Using standard regression techniques with non-stationary time series data can result in spurious regressions, because the standard errors on the estimated parameters are biased, leading to measures of parameter significance and model goodness of fit that are misleadingly high.

---

[76] *'Re-estimating the National Air Passenger Demand Model Econometric Equations,* DfT 2011*'*
'Reflecting changes in the relationship between UK air travel and its key drivers in the National Air Passenger Demand Model', DfT, 2011

[77] *Air Passenger Forecasts for the United Kingdom'*, Department for Environment Transport and the Regions, 2000

[78] i.e. they are not following fixed, constant time trends.

A.11 If the data series are non stationary but a linear combination of them is stationary (their time paths are linked), then the series are said to be cointegrated. To be cointegrated the variables must be integrated of the same order.[79] In the presence of cointegration there are a number of alternative time series techniques available.

A.12 Having had problems applying a multiple equation cointegration approach, due to data limitations, a single cointegration approach was adopted for this work. Two single cointegration methodologies were considered - an Engle-Granger two-step model and an Unrestricted Error Correction Model (UECM). The advantage of both of these techniques is that they combine short run dynamic specification with desirable long run properties.

A.13 Both methods require cointegration and, as noted above, for this to exist all the variables must be integrated of the same order. This involves testing variables for unit roots by inspecting correlograms and conducting Dickey-Fuller tests on each variable to determine the order of integration. If the variables do all have unit roots (which is equivalent to being integrated to order one) the long run relationship can then be estimated in a simple Ordinary Least Squares (OLS) regression of the form:

$$\boxed{Y_t = \alpha_0 + \alpha_1 X_t + u_t}$$

A.14 The residuals of this linear regression can then be tested for cointegration using a Dickey-Fuller test. If the null hypothesis of no cointegration can be rejected then the residuals are stationary and it can be concluded that there is a cointegrating relationship.

A.15 Estimating the long run relationship is the 1st step of the Engle-Granger method. The 2nd step of the Engle-Granger method is an error correction model (ECM). This is estimated as the first difference of traffic regressed against the differences of lagged traffic and lagged independent variables and also the lagged level residuals (ECM) from the long run model (i.e. u_{t-1} in the equation above), as shown in the equation below. The lags of traffic and the independent variables determine the short run, dynamic relationship between these variables and traffic.

$$\boxed{\Delta Y_t = \beta_0 + \sum_{i=1}^{\infty} \beta_i \Delta X_{t-1} + \sum_{i=1}^{\infty} \eta_i \Delta Y_{t-1} + \gamma ECM_{t-1} + u_t}$$

A.16 The lagged residuals are the error correction term, which reflects the deviation of traffic in the previous period from its long run equilibrium. The coefficient on the error correction term, γ, reflects the speed of

---

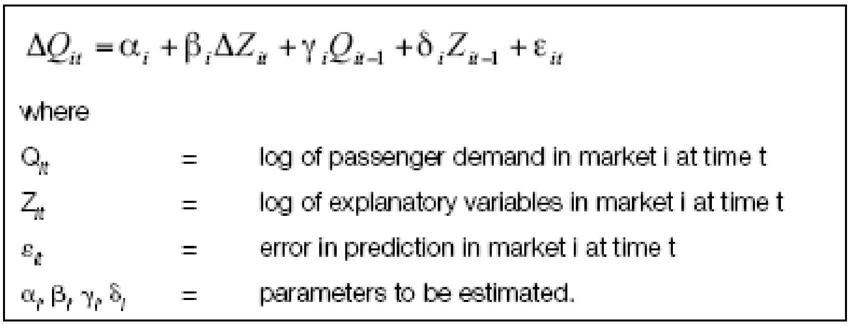
[79] This is the minimum number of differences required to obtain a stationary series.

adjustment: the larger it is, the greater the response to the previous period's deviation from the long run trend.

A.17 A UECM is similar to an Engle-Granger ECM, but involves dropping the error correction term and regressing the lagged dependent and independent variables on traffic in differences and in levels. The levels term provides the error correction in this method. The UECM is more efficient, although it can be seen from these equations that the regressions are identical except for the expression of the error correction term (i.e. γECM_{t-1}= ($\gamma_1 Y_{t-1} + \gamma_2 X_{t-1}$)) and as a result the change in the dependent variable should be equivalent under both methods. A full explanation of these methods can be found in Enders (2004).[80]

$$\Delta Y_t = \beta_0 + \sum_{i=1}^{\infty} \beta_i \Delta X_{t-1} + \sum_{i=1}^{\infty} \eta_i \Delta Y_{t-1} + \gamma_1 Y_{t-1} + \gamma_2 X_{t-1} + u_t$$

A.18 UECM outputs have been used in the forecasting as this method is more efficient. In the initial stages of the work a number of different functional forms were tested but the log-log form, where all variables are expressed in natural logarithms, was chosen for all models as it yielded models best able to explain past movements in air passenger traffic. Therefore all the models take the following form:



$$\Delta Q_{it} = \alpha_i + \beta_i \Delta Z_{it} + \gamma_i Q_{it-1} + \delta_i Z_{it-1} + \varepsilon_{it}$$

where

Q_{it} = log of passenger demand in market i at time t

Z_{it} = log of explanatory variables in market i at time t

ε_{it} = error in prediction in market i at time t

α_i, β_i, γ_i, δ_i = parameters to be estimated.

Technical Peer Review

A.19 Expert academic advice was sought to ensure the methods used to re-estimate the models were suitable. A team at the University of Westminster (UoW), led by Professor Austin Smyth, evaluated the techniques and subsequently ad hoc advice was also provided by Professor Joyce Dargay, Emeritus Professor of Transport Econometrics at the Institute of Transport Studies. Professor Dargay has very extensive experience in dealing with the problems that arise when working within the limitations of real world datasets. She examined all of the final models and endorsed the methods used, as well as making some useful suggestions as to how to interpret the findings.

---

[80] *Applied Time Series Econometrics*, W.Enders, 2004, Wiley, 2nd ed. pp 335-339

Econometric Models used in the NAPDM

Parameter estimates and diagnostics

A.20 The results of the econometric analysis of each of the 19 passenger markets used in the NAPDM are summarised in the following tables. Table A1 reports the parameter estimates and Table A2 reports the t-statistics.

A.21 Each of the 19 passenger markets is described by a typically three letter code used to identify nationality, purpose and the region of the journey:

- **Journeys between the UK and foreign countries:**
  - First letter denotes UK resident (U), or Foreign resident (F).
  - Second letter denotes Business (B), or Leisure (L).
  - Third letter denotes foreign origin or destination: W: Western Europe; O: OECD excluding Western Europe; N: Newly Industrialised Countries (NICs); L: Less Developed Countries (LDCs).
- **Domestic journeys within the UK:** DMB: Domestic business; DML: Domestic leisure.
- **International to international (interliner) passengers:** I-I.

A.22 Thus the codes used for the nineteen market sectors in the following tables are:

UBW	UK resident, business, Western Europe
UBO	UK resident, business, OECD
UBN	UK resident, business, NIC
UBL	UK resident, business, LDC
ULW	UK resident, leisure, Western Europe
ULO	UK resident, leisure, OECD
ULN	UK resident, leisure, NIC
ULL	UK resident, leisure, LDC
FBW	Foreign resident, business, Western Europe
FBO	Foreign resident, business, OECD
FBN	Foreign resident, business, NIC
FBL	Foreign resident, business, LDC
FLW	Foreign resident, leisure, Western Europe
FLO	Foreign resident, leisure, OECD
FLN	Foreign resident, leisure, NIC
FLL	Foreign resident, leisure, LDC
DMB	Domestic, business
DML	Domestic, leisure
I to I	International-international interliner (non-UK transfer)

A.23 The notation used for the column headings in Table A1 and Table A2 is:

lntra	Natural logarithm of Traffic levels
lngdp	Natural logarithm of UK GDP
lncon	Natural logarithm of UK Consumption
lnfgp	Natural logarithm of Foreign GDP
lnips	Natural logarithm of UK Passenger Fares
lnpfr	Natural logarithm of Foreign Passenger Fares
lnexr	Natural logarithm of UK Nominal Exchange Rate
lnimp	Natural logarithm of UK Imports
lnexp	Natural logarithm of UK Exports
d.[variable]	Differenced variable
l.[variable] or L1	Lagged variable (one year)
d.l.[variable] or DL	Differenced lagged (one year) variable
D[year]	Dummy

A.24 Various diagnostic tests have been completed to check that the estimated equations are robust. Plots of fitted versus actual were studied as a first check of accuracy, followed by a test for omitted variables (Ramsay RESET), a test for heteroskedasticity (Breusch-Pagan), and a test for autocorrelation (Breusch-Godfrey). The results of these tests for each passenger market can be found in Table A3. Table A3 also shows the 2008 share of total modelled passenger traffic to and from the UK.

A.25 Tables A1 to A3 show that:

- in all markets an R^2 value[81] exceeding 0.6 is obtained;
- the income variables are significant at the 5% level or higher in all but the FBN and I-I models, where the foreign GDP variable is significant at the 10% level in I-I and insignificant in the FBN model. The fare level variables are significant at the 5% level, with two exceptions (FLN and FBO), where the variable is retained because the variables are jointly significant, the parameter is of the correct sign and plausible magnitude, and therefore likely to be useful in forecasting[82]; and
- there is no evidence of autocorrelation or heteroscedasticity at the 5% level except in the UK Business to Western Europe market – which suffers from autocorrelation.

---

[81] R^2 is a measure of the goodness of fit of a model. It measures the proportion of variability of the dependent variable (the number of air passengers) in the past that is explained by the model.

[82] The critical values for the t-stats, given the 24 observations in the UK and foreign market models (excluding domestic and I-I markets), are 1.71 at the 10% level, 2.06 at the 5% level and 2.80 at the 1% level. Given that there are 19 observations in the domestic models the critical values for the t-stats are 1.73 at the 10% level, 2.09 at the 5% level and 2.86 at the 1% level. The critical values for the t-stat in the I-I model, given 12 observations, are 1.78 at the 10% level, 2.18 at the 5% level and 3.05 at the 1% level.

A.26 In estimating the econometric models a constant was initially included in every model. The constant was only excluded if it was found to be statistically insignificant.

Table A1: Parameter Estimates

Sector			Variable																										
	Dep Variable	Const	d.lngdp	d.lncon	d.lnfgp	d.lnips	d.lnpfr	d.lnexr	d.lnexp	d.lnimp	l.lntra	l.lngdp	l.lncon	l.lnfgp	l.lnips	l.lnpfr	l.lnexp	l.lnimp	l.lnexr	d91	d93	d96	d00	d01	d02	d03	d04	d05	d08
UBW	D-Lnt-Tra	0		1.27		-0.35			0.47		-0.78		0.57		-0.21		0.42												
UBO	D-Lnt-Tra	0			2.40					0.02	-0.41			0.18				0.21											
UBN	D-Lnt-Tra	0	4.98		0.54						-0.86	0.41		0.46										0.26					
UBL	D-Lnt-Tra	0	4.98		0.54						-0.86	0.41		0.46										0.26					
ULW	D-Lnt-Tra	0		2.82							-0.47		0.62		-0.16							0.13							
ULO	D-Lnt-Tra	0				-0.85			0.81		-0.73		0.56		-0.25		0.43												
ULN	D-Lnt-Tra	0		1.88		-0.16					-0.84		1.34		-0.46														
ULL	D-Lnt-Tra	0	2.60			-0.49					-0.51	0.95			-0.44													0.18	
FBW	D-Lnt-Tra	0.79		1.87					0.52		-1.21		0.75			-0.30	0.60									-0.15			
FBO	D-Lnt-Tra	2.95					-0.45		0.67		-1.02					-0.17	0.57												
FBN	D-Lnt-Tra	0.49			0.53						-0.30			0.23											0.64				-0.60
FBL	D-Lnt-Tra	0.54								0.18	-0.39							0.27			0.52								
FLW	D-Lnt-Tra	0.94					-0.67				-0.36		0.44			-0.27				-0.08				-0.21					
FLO	D-Lnt-Tra	8.90			0.94			-0.20			-0.75			0.41					-1.58						-0.20				
FLN	D-Lnt-Tra	3.74			0.20		-0.18				-1.02			0.53		-0.22								-0.28					-0.45
FLL	D-Lnt-Tra	2.10			0.08		0.003				-0.53			0.25		-0.18					0.44				-0.24				
DMB	D-Lnt-Tra	0	2.96								-0.41	0.41															0.12		
DML	D-Lnt-Tra	-2.42		2.41							-0.42		0.95										-0.08						
I to I	D-Lnt-Tra	5.82			0.06		-0.24				-1.06			0.50		-0.70								-0.15					

Table A2: Parameter t-statistics

Sector		Variable																											
	Dep Variable	Const	d.lngdp	d.lncon	d.lnfgp	d.lnips	d.lnpfr	d.lnexr	d.lnexp	d.lnimp	l.lntra	l.lngdp	l.lncon	l.lnfgp	l.lnips	l.lnpfr	l.lnexp	l.lnimp	l.lnexr	d91	d93	d96	d00	d01	d02	d03	d04	d05	d08
UBW	D-Lnt-Tra	0		2.05		-1.93			4.14		-3.65		3.23		-3.17		3.39												
UBO	D-Lnt-Tra	0			6.26					0.19	-6.89			3.52				3.92											
UBN	D-Lnt-Tra	0	3.31		2.32						-5.09	4.63		4.42										3.76					
UBL	D-Lnt-Tra		3.31		2.32						-5.09	4.63		4.42										3.76					
ULW	D-Lnt-Tra	0		4.29							-2.90		2.91		-2.79							-2.56							
ULO	D-Lnt-Tra	0				-2.26			3.88		-3.35		2.78		-2.84		2.51												
ULN	D-Lnt-Tra	0		2.02		-0.79					-3.46		3.29		-2.98														
ULL	D-Lnt-Tra	0	2.62			-2.33					-2.44	2.37			-2.28													2.86	
FBW	D-Lnt-Tra	1.10		3.70					3.70		-8.60		5.00			-3.50	6.90									-3.35			
FBO	D-Lnt-Tra	2.30					-1.50		3.60		-4.10					-0.90	3.60												
FBN	D-Lnt-Tra	2.00			2.20						-1.90			1.60											5.21				-4.98
FBL	D-Lnt-Tra	2.40								1.60	-3.80							4.30			7.71								
FLW	D-Lnt-Tra	1.10					-3.70				-5.50		2.70			-2.80				-1.61				-4.45					
FLO	D-Lnt-Tra	2.80			2.40			-0.20			-4.40			2.50					-2.50						-3.02				
FLN	D-Lnt-Tra	2.70			0.50		-0.40				-4.50			3.60		-1.10								-2.18					-3.07
FLL	D-Lnt-Tra	2.30			0.80						-4.30			3.20		-2.20					6.00				-3.53				
DMB	D-Lnt-Tra	0	4.50								-3.48	3.42															3.39		
DML	D-Lnt-Tra	-2.42		4.86							-2.34		2.27										-2.2						
I to I	D-Lnt-Tra	3.40			0.10		-1.00				-5.80			2.00		-3.40								-4.73					

Table A3: Results of diagnostic tests

Sector	2008 share of modelled traffic	R2	F	F sig	Breusch-Godfrey autocorrelation	Breusch-Godfrey significance	Ramsey RESET	RESET significance	Breusch-Pagan heteroskedasticity	Breusch-Pagan significance
UBW	6%	0.78	8.6	0	5.94	0.01	5	0.02	0.05	0.82
UBO	1%	0.89	30.22	0	0.76	0.38	1.04	0.4	0.23	0.63
UBN	0%	0.79	11.01	0	0.36	0.55	0.4	0.75	0.14	0.71
UBL	1%	0.79	11.01	0	0.36	0.55	0.4	0.75	0.14	0.71
ULW	33%	0.73	10.06	0	0.11	0.74	1.7	0.21	0.23	0.64
ULO	5%	0.7	6.89	0.001	0.5	0.48	0.88	0.47	0.04	0.85
ULN	1%	0.7	8.66	0	0.89	0.35	3.15	0.06	1.35	0.25
ULL	6%	0.79	10.95	0	0.14	0.7	0.33	0.81	0.22	0.64
FBW	5%	0.87	14.85	0	1.14	0.29	3.53	0.05	0.75	0.39
FBO	1%	0.6	5.4	0.003	0.14	0.71	0.66	0.59	1.28	0.26
FBN	0%	0.84	18.44	0	2.41	0.12	0.35	0.71	0.29	0.59
FBL	1%	0.83	23.1	0	3.11	0.08	0.52	0.68	0.33	0.56
FLW	10%	0.82	12.84	0	2.5	0.11	0.88	0.48	1.58	0.21
FLO	3%	0.63	4.91	0.004	4.02	0.05	0.5	0.69	0.66	0.41
FLN	0%	0.7	5.28	0.003	3.04	0.08	1.25	0.33	1.46	0.23
FLL	1%	0.85	13.44	0	0.02	0.89	2.14	0.14	0.96	0.33
DMB	7%	0.75	11.19	0	1.19	0.28	0.74	0.55	0.18	0.67
DML	8%	0.66	6.88	0.003	2.09	0.15	1.58	0.25	0.29	0.59
I to I	10%	0.96	22.8	0.002	0.11	0.74	0.61	0.67	0.02	0.9

Long run air fare and income elasticities

A.27 Price and income elasticities have been calculated (where possible) using the method in Figure A1.

Figure A1: Calculating point elasticities from Error Correction Models (ECMs) when all variables are expressed in logs

Given an ECM equation with *traffic* and *fares* variables expressed in natural logarithms (simplified):

$$d\ln tra = \alpha \ln tra_{t-1} + \beta \ln fare_{t-1} + \gamma(d \ln fare)$$

Fare elasticity of demand with respect to traffic can be derived. Assuming that in the long run equilibrium, *d lntra* and *d lnfare* are zero:

$$\begin{aligned} 0 &= \alpha \ln tra_{t-1} + \beta \ln fare_{t-1} \\ \alpha \ln tra_{t-1} &= -\beta \ln fare_{t-1} \\ \ln tra_{t-1} &= \frac{-\beta}{\alpha} \ln fare_{t-1} \end{aligned}$$

Now each side can be differentiated and rearranged to find that the fare elasticity of demand is given by (-β/α):

$$\begin{aligned} \frac{1}{tra_{t-1}} dtra_{t-1} &= \frac{-\beta/\alpha}{fare_{t-1}} dfare_{t-1} \\ \frac{dtra_{t-1}}{dfare_{t-1}} \frac{fare_{t-1}}{tra_{t-1}} &= \frac{-\beta}{\alpha} \end{aligned}$$

A.28 The measurement of income elasticities was complicated in some markets by the presence of more than one income variable. This was primarily an issue in business markets where it was found, not unexpectedly, that demand was driven by economic activity in the UK and in the overseas market. This was dealt with by taking the sum of the coefficients on these components and dividing through by the (negative of the) coefficient on lagged traffic (α in Figure A1) to find the income elasticity.

A.29 Another complication in calculating income elasticities concerned the foreign leisure market to Western Europe which contained UK consumer spending as its only income variable. In this market the coefficient on UK consumer spending was used to calculate the income elasticity on the basis that UK consumer spending is treated as operating as a proxy for consumer spending in the rest of Europe.

A.30 There are a few markets where it was suspected that model or data limitations led to unexpected values for the income elasticities (YEDs) and price elasticities (PEDs). In these circumstances, it is reasonable, for the purposes of forecasting, to impose YEDs or PEDs if there is a strong rationale for believing a certain relationship exists which, because of data limitations, has not been picked up in the estimated equations.

A.31 This led to imposing PEDs in three markets – ULW, DML, DMB and FLO – and a YED in the DML market.:

- **PED of -0.7 imposed in ULW:** The long run PED of -0.33 estimated for the ULW market is likely to be biased downwards because the fare series used reflects scheduled fares only. When we estimated a model for the scheduled market only we find a long run PED of -0.7. This PED is more in line with prior expectations that this would be one of the more price elastic markets. This is because 1) traffic in this segment was dominated by holiday traffic and 2) passengers in this segment are more likely to have alternative modes of transport available to them. The PED of -0.7 is also more consistent with the literature on price elasticities.
- **PED of -0.33 imposed in FLO:** It was not possible to estimate a PED for this model. Based on the expectation that the PED for this market should be of the same order of magnitude as that for ULO (because traveller incomes are broadly similar, there are no realistic alternative travel modes, and FLO passengers tend to have at least as many alternative travel destinations available to them), for forecasting purposes it was decided to impose the PED estimated for the ULO market (-0.33).
- **PED of -0.3 imposed in DMB:** Despite the availability of alternative modes, it was not possible to estimate a PED for this model. Therefore, based on the expectation that the PED market should be of the same order of magnitude as that estimated for the UBW market, for forecasting purposes it was decided to impose the PED estimated for the UBW market (-0.3)
- **PED of -0.7 imposed in DML:** Surpisingly, given the expectation that it would be one of the more price elastic it was not possible to estimate a PED for this sector. Based on the expectation that the PED for this sector should be of broadly the same order of magnitude as that estimated for the ULW market (because of passengers having similar income levels and availability of alternative modes of travel) for forecasting purposes it was decided to impose the PED estimated for the ULW market (-0.7).
- **YED of 1.5 imposed in DML in 2010:** It is considered that the long run YED of 2.3 for the DML market is likely to be an overestimate, and potentially biased because of the omission of a fares variable from the estimated model. It was therefore decided to impose a lower YED of 1.5 in 2010 to compensate for the imposition of a significant fare variable, and to bring the YED closer to that estimated for the ULW sector.

A.32 In addition it proved impossible to derive a satisfactory model for the UBL market. Therefore, for forecasting, the elasticities estimated for the UBN market have been used, on the basis that this is expected to be the most similar of the other sectors for which models were estimated to the UBL sector. Given that the UBL sector is one of the smallest (accounting for 1% of total UK terminal passengers in 2008), the imposition of the model for UBN will not significantly affect the overall forecasts.

A.33 Table A4 below summarises the resulting long run income and air fare elasticities.

Table A4: Long run price and income elasticities of UK air passenger demand

Sector	2008 share of passenger traffic	Sector PED	Market PED	Sector YED	Market YED
UBW	6%	-0.3	-0.2	1.3	1.2
UBO	1%	0.0		1.0	
UBN	0%	0.0		1.0	
UBL	1%	0.0		1.0	
ULW	33%	-0.7	-0.7	1.3	1.4
ULO	5%	-0.3		1.3	
ULN	1%	-0.6		1.6	
ULL	6%	-0.9		1.9	
FBW	5%	-0.2	-0.2	1.1	1.0
FBO	1%	-0.2		0.6	
FBN	0%	0.0		0.8	
FBL	1%	0.0		0.7	
FLW	10%	-0.8	-0.6	1.2	1.0
FLO	3%	-0.3		0.5	
FLN	0%	-0.2		0.5	
FLL	1%	-0.3		0.5	
DMB	7%	-0.3	-0.5	1.0	1.7
DML	8%	-0.7		1.5	
I to I	10%	-0.7	-0.7	0.5	0.5
Overall	100%		-0.6		1.3

Notes
Income variable depends on sector
Price and income elasticities are point estimates
Results are elasticity of terminal passengers to income or fares;

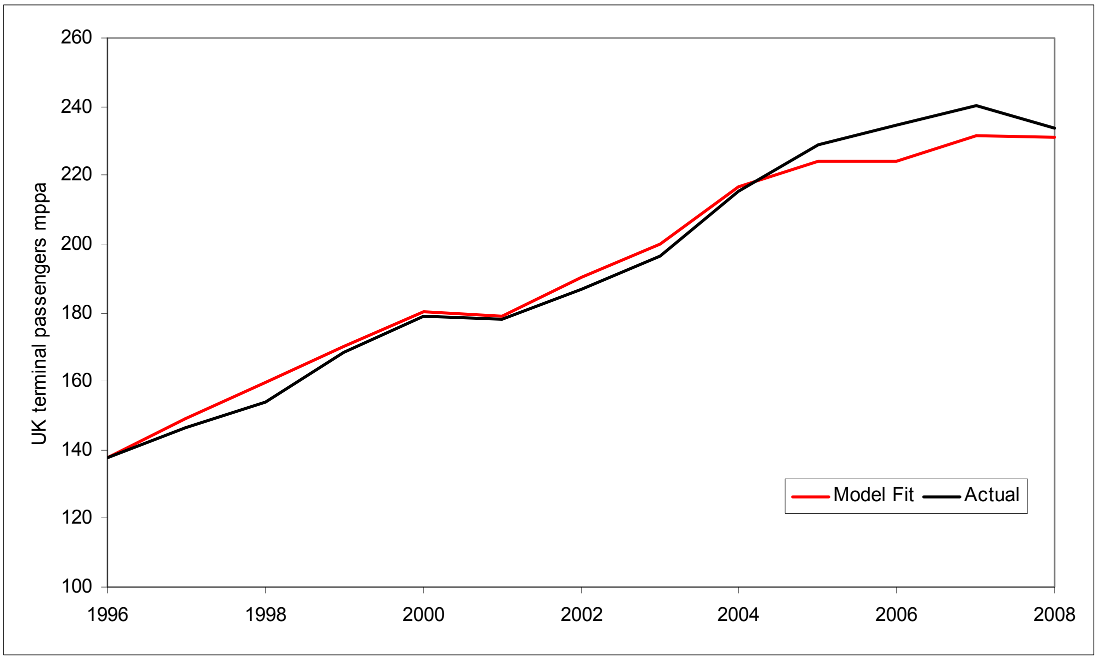
A.34 The average PED across all markets is -0.6 and the overall YED is 1.3. It is intuitive that the overall price elasticity is some way below unity, given that passengers may have options for responding to (e.g.) an increase in price which reduces the cost of their trip without preventing it, such as travelling to a less expensive destination, or by a less expensive class of travel or airline. It is also in keeping with findings for other modes that UK transport demand is relatively price inelastic. Chapter 2 demonstrates that these results are broadly in line with other relevant published studies.

A.35 Further adjustments were made to the models for use in forecasting to reflect the likelihood that the relationship between passenger numbers in each market and its key drivers will change in future. Annex B explains in detail how changes in the relationship between air travel demand and its key drivers have been reflected in the updated forecasts.

Model fit

A.36 The models resulting from this estimation process show a strong ability to fit the data from 1996 to 2008. Figure A2 shows that, when aggregated to the national level, the models accurately predict the trend in passenger demand, while also capturing shorter term movements. Unfortunately, as explained in Chapter 2, the models have performed less well in capturing the full extent of the reduction in UK terminal passengers following the recent financial crisis and global economic slowdown since 2008.

Figure A2: Actual and fitted UK terminal passengers, 1996-2008



Note: not every model is fitted to data prior to 1996, so totals consistent with CAA outturn data can be presented from 1996 only.

Annex B: Reflecting changes in the relationship between UK air travel and its key drivers in the National Air Passenger Demand Model

Introduction

B.1 Chapter 2 explains how econometric analysis of the relationship between air travel and its key drivers in the past underpins the unconstrained forecasts of UK air passengers produced by the National Air Passenger Demand Model (NAPDM). It explains further, that before using the econometric models for forecasting, they are adjusted to reflect the likelihood that the relationship between UK air travel and its key drivers observed in the past will change in the future.

B.2 This annex summarises how changes in the relationship between UK air travel and its key drivers are reflected in the National Air Passenger Demand Model. It is divided into four sections:

Section 1 – Why is the relationship between UK air travel and its key drivers expected to change?

Section 2 - How have the impacts of maturity and market liberalisation been reflected in the previous forecasts?

Section 3 - Evidence of impact of maturity and market liberalisation in the market for UK Air Travel.

Section 4 - Approach to reflecting change in the National Air Passenger Demand Model (NAPDM) used in updated forecasts.

Section 1 - Why is the relationship between UK air travel and its key drivers expected to change?

B.3 Many factors will affect the number of passengers using UK airports in future decades that cannot be forecast from past data. For example, an exogenous increase in the rate of migration might lead to UK air travel growing faster than would be projected from past trends; or changes in communications and aviation technology can be imagined that might in future drive air travel up or down. The historical effects of some such changes, e.g. the massive development of electronic communications since the mid 1990s, are subsumed in the estimated elasticities. However, there are some ways in which it can be foreseen that the future will differ from the past and about which quantitative judgements can be made. This applies in particular to market maturity and to the effects of market liberalisation. These are addressed in turn below.

Market Maturity

B.4 As with most markets, it might be expected that there would be some product cycle in aviation demand, with rapid early demand growth giving way to steadier growth in later years. Various possible explanations for this phenomenon are suggested in the literature. One explanation is that, when a good is introduced to the market, it experiences a rapid growth phase as consumers gradually become more aware of it. The growth of demand then gradually slows and becomes less responsive to changes in its key drivers as the product becomes more familiar and widely available. An alternative explanation, more specific to the market for leisure air travel, is that as the number of flights people take increases they have less remaining time available for additional trips. This increases the value they place on their remaining leisure time and reduces the likelihood that they will respond to increases in their incomes by increasing their demand for leisure travel. The term 'market maturity' is often used to refer to the process by which the demand for a product becomes less responsive to its key drivers over time. In the literature, income elasticity of demand (YED) is often used as an indicator of the maturity of a market. The YED is a measure of the responsiveness of the demand for a good or service to changes in income, expressed as the percentage change in demand associated with a 1% change in incomes, and will tend to decrease as markets become more mature.

B.5 Dr Anne Graham, at the University of Westminster, has produced a significant amount of work in this area. She argues that product markets are often characterised as having a life cycle which can be broadly decomposed into five stages. Table B1 below shows Graham's model of income elasticities for different markets, comparing the results against a five-stage model of the market maturation process.

Table B1: Product life cycle

Income elasticity value	Maturity/saturation stage
Constant and substantially greater than 1	Stage 1 (Full Immaturity)
Decreasing but still greater than 1	Stage 2
Approaching 1	Stage 3
1	Stage 4 (Full Maturity)
0	Stage 5 (Full Saturation)

B.6 As markets mature, and as demand becomes less responsive to changes in income levels, they move gradually from stage 1 through stages 2, 3 and 4 to stage 5. Early stages of market maturity are considered to exist when elasticity values are falling but are still larger than one. Graham defines 'full' maturity as occurring when the income elasticity is unity, although this is not a universally accepted definition of maturity. Correspondingly, 'full' saturation is defined as occurring when the elasticity value is zero and an increase in income has no effect on demand.

B.7 This five stage model is highly stylised. It is not clear what Graham intended to happen between stage 4, maturity, and stage 5, saturation. It is probably more helpful to think of maturity as being a process that continues to full market saturation.

B.8 In principle, market maturity affects the way demand responds to all of its key drivers (e.g. fares) and not just income. In fact, it is standard practice in transport models to assume that travellers' response to fare changes also decreases through time as their incomes increase and they place higher value on the time costs associated with travel.

Market liberalisation

B.9 One factor that has attracted particular attention in the literature as a potential source of bias in aviation forecasting is market liberalisation. Some commentators[83] have argued that estimates of the income elasticity of air travel derived from econometric analysis of quantitative historic data are often biased because they do not take account of the degree of market liberalisation over the estimation period. The argument is that YEDs estimated for markets that have experienced significant liberalisation, (e.g. the US domestic market) overstate the relationship between GDP and air travel growth, because the positive effect of liberalisation in the past on air travel demand has wrongly been attributed to income growth. On the other hand, these commentators argue, the elasticities estimated for the markets that are still heavily regulated (e.g. markets to/from the Asia-Pacific region) may be biased downwards, because demand growth has been suppressed by artificial restrictions on the availability of air travel options.

B.10 The potential for bias from this source in a given piece of econometric analysis is dependent on the extent to which the econometric models are specified to control for the effects of market liberalisation. Liberalisation manifests itself in a number of ways including, for example, lower fares, changes in service quality and an increase in the number of routes served. Fares are included as an explanatory variable in the econometric models that have been estimated for most of the 19 market segments considered in the NAPDM. Dummy variables are also used in some markets to account for the short term boost in demand that occurs when markets are further liberalised. The inclusion of fares and dummy variables in the models should help to avoid any bias in the elasticities estimated.

B.11 Liberalisation is a process that tends to happen gradually through time. In so far as market liberalisation has led to the estimation of income elasticities that are biased upwards, the extent to which those elasticities could have led to forecasts of air travel growth that are too high will depend on how closely income growth and liberalisation continue to be linked in future. Where the rate of liberalisation is expected to slow relative to income growth in future, it might be appropriate to represent this as a gradual reduction in YEDs in future (i.e. in the same way as market maturity).

---

[83] *Forecasting Air Travel with Open Skies*, Swan, W., 2008, presented at the joint EWCKOTI Conference, August 13-15, 2008 in East West Center, Honolulu.

Section 2 - How have the impacts of maturity and market liberalisation been reflected in the previous forecasts?

B.12 In the absence of quantified evidence on how maturity is likely to affect the way demand responds to its key drivers in future, market maturity has been reflected in the NAPDM via judgement-based adjustments to the passenger forecasts produced by the econometric models. For each of the sectors of the air travel market separately modelled, assumptions were made about the date from which market maturity would take effect and the scale of its impact on demand.

B.13 The formula for adjusting the forecast number of passengers in each segment to reflect maturity was given by the following formula:

$$\boxed{Pax_t^* = \left(\frac{Pax_t}{Pax_{y0}}\right)^x \times Pax_t}$$

Where:
Pax_t* is the number of passengers in the segment after taking account of maturity,
Pax_t is the unconstrained passenger forecast in year *t* obtained by applying the econometric model for the segment (i.e. before adjusting for maturity)
y0 is the year from which maturity is applied.

B.14 The values of 'x' and of 'y0' vary across the market segments and are shown in Table B2.

Table B2: Previous maturity factors

Sector	X	Year applied from (y0)
Short Haul Business	-0.1	2020
Domestic Business	-0.2	2010
Long Haul Business	-0.1	2020
Short Haul Leisure	-0.3	2015
Domestic Leisure	-0.5	2010
Short Haul Charter	-0.7	2010
Long Haul Leisure	-0.2	2020
Long Haul Charter	-0.2	2020

B.15 These maturity adjustments reduced the central unconstrained forecasts presented in *UK Air Passenger Demand and CO2 Forecasts, 2009* by 4% in 2015 and 17% in 2030 at a national level.

B.16 In previous forecasts no attempt was made to explicitly differentiate between the impacts of market maturity and market liberalisation.

Section 3 - Evidence of the impact of maturity and market liberalisation in the market for UK Air Travel

DfT attempts to find evidence in historical data

B.17 As explained in Chapter 2, the econometric models used in NAPDM are estimated from data covering the past thirty years, and so reflect the most recent form of the relationship between demand and its key drivers. As part of the work to re-estimate these econometric models, an attempt was made to fit models with a variety of functional forms including some implying falling income elasticities of demand. It was found consistently across the market segments that models which imply constant relationships between demand and its key drivers (i.e. constant elasticity models) performed better in explaining past changes in demand than models that implied that the responsiveness of demand to income and price changes was falling through time.

Advice from University of Westminster

B.18 Having been unsuccessful in the attempts to identify evidence of market maturity in historic data, a team from the University of Westminster (UoW) were commissioned to review the evidence on the maturity of air travel, both in the UK and elsewhere. The team were also asked to:

a. investigate how, if at all, other organisations producing aviation forecasts seek to reflect market maturity in their forecasts; and
b. provide recommendations on how the Department could modify the assumptions and/or forecasting tools to better reflect market maturity

B.19 The UoW team were not specifically asked to consider market liberalisation as a factor that might justify adjusting the elasticities estimated from historic data in producing forecasts.

Evidence of maturity

B.20 The project team reached the following key conclusions as to the empirical evidence on the impact of maturity on the market for air travel:

- Over the last few decades the air transport industry has experienced almost ceaseless growth, yet growth is forecast to remain strong for the foreseeable future, driven in large part by emerging market economies. Air passenger travel is increasing at a slowing rate in some markets but there is little in the empirical evidence at a global level suggesting the market for air travel is mature.

- Different segments of the UK market for air travel are exhibiting very different dynamics. So that while the UK short haul market (including domestic) appears to be exhibiting early signs of maturing, the long haul market shows no such signs.

- More generally, any conclusions that can be drawn from recent changes in the air travel market as to the existence of market maturity are subject to very high levels of uncertainty, and thus professional judgement is required to reflect such evidence in aviation demand forecasting.

Recommendations

B.21 On the basis of their review of the empirical evidence UoW made a number of key recommendations.

- The 'x-factor' approach to incorporating maturity effects used in the previous forecasts should be abandoned. The complexity of the approach implies a spurious level of accuracy and the implicit effects on the way the forecasts respond to changes in key variables is also difficult to interpret.
- The existing approach should be replaced by an approach that involves direct adjustments to the income elasticities estimated for each market segment.
- Given the uncertainties, sensitivity tests should be used to illustrate the sensitivity of the forecasts to alternative assumptions about market maturity.

B.22 The project team went further by suggesting, for each of the market segments used *in UK Air Passenger Demand and* CO_2 *Forecasts 2009*, assumptions about the year in which market maturity might take effect, and alternative income elasticities of demand to replace those estimated from historical data. These are summarised in Table B3 below.

Table B3: Recommended Income Elasticities for use in Sensitivity Tests[84]

Sector	YED Recommended	Year applied from
Short Haul Business	1.0 - ML 0.5 - LL	2015
Domestic Business	1.0 - ML 0.5 - LL	2010
Long Haul Business	1.0	2025
Short Haul Leisure	1.0 - ML 0.5 – LL	2015
Domestic Leisure	1.0 - ML 0.5 - LL	2010
Long Haul Leisure	1.0	2025

Note: ML - More Likely Scenario LL - Less Likely Scenario

B.23 The report left open the question of whether the recommended YEDs should be imposed immediately in the year maturity is assumed to take effect or achieved by gradual reduction through time from the values estimated in the econometric analysis.

---

[84] The project team also included recommendations for the charter markets but these have not been included here because the charter markets have been merged with the appropriate scheduled markets in the latest forecasts.

Section 4 - Approach to reflecting impact of maturity and market liberalisation in the NAPDM used in updated forecasts

B.24 The advice from UoW confirmed that there is a lack of evidence on how market maturity and changes in the rate of market liberalisation are affecting air travel in the UK. Because of this lack of evidence UoW advice has been followed and a range of assumptions developed about how these factors will affect the UK air travel market in future to reflect the significant uncertainty and to form the basis for sensitivity tests.

B.25 UoW's advice to use income elasticities as an indicator of the changing relationship between UK air travel and its key drivers in different market segments has also been followed. However, given the expectation that market maturity will cause demand to become less responsive to all of its key drivers through time, not just to income, the elasticities of demand to its other drivers (e.g. fare) are reduced at the same proportionate rate as the reduction in income elasticity. Given the ambiguity surrounding how UoW believe income elasticities should be assumed to vary through time, it has also been necessary to go beyond the UoW's advice in developing the new approach.

B.26 Finally, the UoW view that the old approach to reflecting maturity in the forecasts was complex to understand and very difficult to interpret from a behavioural perspective was accepted. Therefore, an alternative approach to reflecting market maturity in the models which is significantly more transparent and easier to interpret behaviourally as been developed.

Assumptions

B.27 A range of assumptions to illustrate the uncertainty around the impact of maturity and market liberalisation on the market for UK air travel has been developed. Both the higher and lower bounds of the range can be treated as either end of a range of reasonably likely outcomes, and the central forecast has been defined to fall broadly in the middle of that range.

B.28 There are a number of factors which could be varied in reflecting market maturity in the forecasts. These include:

(a) the year maturity is assumed to affect each market;

(b) how the income elasticities in each market change once maturity is assumed to take effect; and

(c) how the responsiveness of passenger demand to other key drivers (e.g. fare) varies through time.

B.29 In defining the range of assumptions, the 19 market segments for which econometric models have been estimated in the National Air Passenger Demand Model are split into 3 groups. Broadly, the groups bring together markets according to how soon they are expected to show signs of market maturity.

Table B4: Maturity of different markets

Maturity of markets	Markets included
1. Most mature	DMB, DML
2. Fairly mature	UBW, UBO, ULW, ULO, FBW, FBO, FLW, FLO, ULN, ULL
3. Least mature	UBN, UBL, FBN, FBL, FLN, FLL

Note: **Domestic journeys within the UK:** DMB: Domestic business; DML: Domestic leisure.
Journeys between the UK and other countries: First letter denotes UK resident (U), or Foreign resident (F).
Second letter denotes Business (B), or Leisure (L).
Third letter denotes foreign origin or destination:W: Western Europe; O: OECD excluding Western Europe;
N: Newly Industrialised Countries (NICs); L: Less Developed Countries (LDCs).

B.30 Group 1 is the domestic markets. While it has not been possible to find definitive evidence of maturity in these segments, these markets have already experienced rapid growth, and have seen their growth slow recently, even before the recent recession. It is expected that the effects of maturity will show more clearly on these markets in the near future.

B.31 Group 2 contains the fairly mature business and leisure markets to/from Western Europe and the OECD. These markets are relatively large markets that have already experienced rapid growth in the period used for the estimation of the econometric models and are considered to have less potential for rapid growth in the future than in the past.

B.32 This group also includes the UK leisure markets to NICs and LDCs. These markets experienced very rapid growth between 1984 and 2008, the period over which the econometric models used in the forecasting model were estimated. The YEDs estimated for these markets are amongst the highest of any of the models. It is considered that the high YEDs are a reflection of these markets having experienced the rapid growth phase of their life cycle. Therefore whilst they appear to be the least mature (according to the estimated YEDs) it is anticipated that they are likely to be affected by maturity in the nearer future than group 3. Therefore these markets are included in the ‘fairly mature’ group such that they will have maturity applied from early in the forecasting period.

B.33 Group 3 includes the less mature business markets in NICs and LDCs as well as foreign leisure to NICs and LDCs. The countries in these markets generally are low income, and are forecast to have the highest GDP growth rates over the forecasting period, such that it is expected that these markets will have significant scope for further growth. It is therefore expected that these markets to mature later than those in groups 1 and 2. This is in line with UoW’s advice that long haul markets are some of the least mature. These markets also have the scope to benefit more than the other segments from further market liberalisation.

B.34 It has been assumed that the econometric models estimated for each segment are applicable until the year at which maturity adjustment takes effect (except in the high growth scenario, where higher YEDs have been imposed in some markets to reflect the possibility that growth in air travel will increase as more markets benefit from liberalisation). For simplicity, it is also assumed that the year in which the maturity adjustment starts to affect the responsiveness of demand in each group of markets is constant across the three projections. Table B5 presents the year in which it is proposed to assume that the maturity adjustments start to affect each group.

Table B5: Year maturity assumption takes effect

Maturity of markets	Maturity starts
1. Most mature	2010
2. Fairly mature	2015
3. Least mature	2025

B.35 In the absence of any empirical evidence to guide the choice of assumptions, a range of alternative assumptions were tested:

a. the value of YED to which each market segment will converge through time;

b. the year in which the final YED is reached in each market segment; and

c. the speed at which maturity affects the YED in each market.

B.36 The range chosen is defined in terms of the YED reached in the most mature markets at the end of the forecasting period (i.e. 2080). All markets are assumed to converge on the same YED value within 70 years of the year from which the maturity adjustment is assumed to take effect. Finally, for simplicity, and to reflect advice from technical experts that market maturity would be most likely to have a gradual effect on YEDs, a constant annual absolute decline in elasticities through time is assumed.

B.37 Ultimately the range of assumptions has been chosen to broadly represent the upper and lower bounds of the range of reasonably likely outcomes.

High Growth Assumptions

B.38 In the high growth (low maturity) sensitivity test it is assumed that that the most mature market segments reach a YED of 1 (full maturity in Dr Graham’s terminology) by the end of the forecasting period. All other markets are assumed to converge to a YED of 1 within 70 years of market maturity adjustment starting to take effect. The YEDs in markets for which a YED of less than 1 was estimated in the econometric analysis are assumed to remain constant over the forecasting period.

B.39 The possibility that the YEDs estimated for the markets to/from Newly Industrialised Countries (NICs), and Less Developed Countries (LDCs), are biased downwards is reflected in the assumption that the YEDs for these markets increase from their estimated value to 1.3 before 2025. This is again in line with the YEDs suggested for these markets in the influential paper delivered to the International Transport Forum in 2009.[85]

B.40 Table B6 shows what this means for the YED in each segment in 2030 and 2080.

Table B6: High growth YEDs

Sector	YED in 2008	YED in 2030	YED in 2080	Year maturity factor is applied from	Year saturation reached
UBW	1.28	1.22	1.02	2015	2085
UBO	0.97	0.97	0.97	2015	2085
UBN	1.01	1.28	1.06	2025	2095
UBL	1.01	1.28	1.06	2025	2095
ULW	1.33	1.26	1.02	2015	2085
ULO	1.35	1.27	1.02	2015	2085
ULN	1.59	1.46	1.04	2015	2085
ULL	1.85	1.67	1.06	2015	2085
FBW	1.11	1.09	1.01	2015	2085
FBO	0.55	0.55	0.55	2015	2085
FBN	0.76	1.28	1.06	2025	2095
FBL	0.69	1.28	1.06	2025	2095
FLW	1.21	1.16	1.01	2015	2085
FLO	0.55	0.55	0.55	2015	2085
FLN	0.51	1.28	1.06	2025	2095
FLL	0.46	1.28	1.06	2025	2095
DMB	0.99	0.99	0.99	2010	2080
DML	2.26	1.71	1.00	2010	2080

🟦	1) Most mature
🟧	2) Fairly mature
🟩	3) Least mature

Low Growth Assumptions

B.41 For the low growth (high maturity) test it is assumed that each market segment reaches saturation 70 years after maturity is assumed to start. Saturation is defined as being reached when demand is growing in line with population growth only. If the income variables were expressed per

---

[85] See *Air Transport Liberalisation and its Impacts on Airline Competition and air passenger traffic,* T.H.Oum et al. OECD, 2009.

capita this would be achieved when the YED was equal to 0. However, as the income variables used in the model are expressed as national aggregates, saturation is reached when the YED is equal to the proportion of income growth that is expected to be related to population growth. On the basis of the latest projections of population and income growth in the UK, it is estimated that saturation occurs at a YED of about 0.2 (i.e. 20% of the projected growth in income is expected to be due to population growth).

B.42 The possibility that the YEDs estimated for the domestic markets, and the markets to/from Europe and OECD are biased upwards is reflected in the imposition of YEDs of 1.0 on these markets at the start of the forecasting period. This is broadly in line with the YEDs suggested for these markets in an influential paper delivered to the International Transport Forum in 2009.[86]

Table B7: Low growth YEDs

Sector	YED in 2008	YED in 2030	YED in 2080	Year maturity factor is applied from	Year saturation reached
UBW	1.28	0.83	0.26	2015	2085
UBO	0.97	0.81	0.26	2015	2085
UBN	1.01	0.95	0.37	2025	2095
UBL	1.01	0.95	0.37	2025	2095
ULW	1.33	0.83	0.26	2015	2085
ULO	1.35	0.83	0.26	2015	2085
ULN	1.59	1.06	0.28	2015	2085
ULL	1.85	1.06	0.28	2015	2085
FBW	1.11	0.83	0.26	2015	2085
FBO	0.55	0.48	0.23	2015	2085
FBN	0.76	0.72	0.32	2025	2095
FBL	0.69	0.65	0.3	2025	2095
FLW	1.21	0.83	0.26	2015	2085
FLO	0.55	0.47	0.22	2015	2085
FLN	0.51	0.49	0.27	2025	2095
FLL	0.46	0.45	0.26	2025	2095
DMB	0.99	0.78	0.25	2010	2085
DML	2.26	0.77	0.2	2010	2080

🟪	1) Most mature
🟧	2) Fairly mature
🟩	3) Least mature

Central Growth

B.43 For the central growth test, which underpins the updated central air passenger and aviation CO_2 forecasts, it is assumed that each market

---

[86] *Air Transport Liberalisation and its Impacts on Airline Competition and air passenger traffic,* T.H.Oum et al., OECD, 2009

segment reaches a YED of 0.6 (i.e. half way between the high growth and low growth scenarios) 70 years after maturity is assumed to start. No further adjustments are made to reflect the possibility that the YEDs estimated in the econometric analysis are biased. This reflects the view that most of the effects of market liberalisation will be captured separately in the models by the inclusion of fares and dummy variables.

B.44 It should be noted that under this scenario the YEDs in 2030 for the Business markets are broadly in line with those recommended by the UoW team – short haul business markets have a YED of slightly over 1, while domestic business and long haul business markets have YEDs of just under 0.9 and 0.8 respectively. The YEDs in 2030 in the leisure markets are slightly higher than recommended by UoW – short haul leisure has a YED of just over 1.1, domestic leisure a YED of just over 1.2 and long haul leisure markets an average YED of just over 1.4. However, in contrast to the UoW recommendations, it is assumed that the YEDs in all markets continue to decrease after 2030, significantly reducing the level of demand in the latter part of the forecasting period. The technical experts overseeing this work agreed that this scenario better reflects the way they expect market maturity to affect the UK air travel market in future.

Table B8: Central growth YEDs

Market	YED in 2008	YED in 2030	YED in 2080	Year maturity factor is applied from	Year saturation reached
UBW	1.28	1.13	0.65	2015	2085
UBO	0.97	0.89	0.63	2015	2085
UBN	1.01	0.98	0.69	2025	2095
UBL	1.01	0.98	0.69	2025	2095
ULW	1.33	1.18	0.65	2015	2085
ULO	1.35	1.19	0.65	2015	2085
ULN	1.59	1.38	0.67	2015	2085
ULL	1.85	1.58	0.69	2015	2085
FBW	1.11	1	0.64	2015	2085
FBO	0.55	0.55	0.55	2015	2085
FBN	0.76	0.75	0.63	2025	2095
FBL	0.69	0.68	0.62	2025	2095
FLW	1.21	1.08	0.64	2015	2085
FLO	0.55	0.55	0.55	2015	2085
FLN	0.51	0.51	0.51	2025	2095
FLL	0.46	0.46	0.46	2025	2095
DMB	0.99	0.88	0.6	2010	2080
DML	2.26	1.24	0.6	2010	2080

🟦	1) Most mature
🟧	2) Fairly mature
🟩	3) Least mature

Implementing maturity adjustments in NAPDM

B.45 Implementing the maturity assumptions described above in the NAPDM proved challenging. In the NAPDM, forecasts for all market segments are derived by applying econometric models estimated to best explain historic changes in passenger numbers in each market. For all market segments, the econometric models take the Unrestricted Error Correction Model (UECM) form such that:

$$\boxed{\Delta Y_t = \alpha_0 + \sum_{i=0}^{\infty} \beta_i \Delta X_{i,t-1} + \sum_{i=1}^{\infty} \eta_i \Delta Y_{i,t-1} + \gamma_1 Y_{t-1} + \sum_{i=2}^{\infty} \gamma_i X_{i,t-1} + u_t}$$

Where:
Y_t is passenger demand in the market segment at time t
$X_{i,t}$ is the value of explanatory variable i at time t
α , β_i, η_i and γ_i are parameters to be estimated

B.46 It has been shown in Annex A that, when all the variables are expressed in log form, the long run elasticity of demand with respect to explanatory variable X_i is equal to $\boxed{-\frac{\gamma_i}{\gamma_1}}$

B.47 It has not been possible to find a way to vary the elasticities through time, whilst retaining the UECM form. Instead the focus is concentrated on the long run relationship between passenger demand and its key drivers implied by the UECM estimated for each market segment. For example, the UECM estimated for the ULN market (UK residents travelling for leisure to/from the NICs) is:

$$\boxed{\Delta \ln Tra_t = 1.88 \Delta \ln Con_t - 0.16 \Delta \ln IPS_t - 0.84 \ln Tra_{t-1} + 1.33 \ln Con_{t-1} - 0.46 \ln IPS_{t-1} + u_t}$$

Where:
$LnTra_t$ is the natural logarithm of the number of passengers in ULN at time t
$LnCon_t$ is the natural logarithm of UK Consumer Spending at time t
$LnIPS_t$ is the natural logarithm of fares at time t

B.48 This implies a long run relationship of the form:

$$\boxed{\ln Tra_t = -\frac{1.33}{-0.84} \ln Con_{t-1} - \frac{-0.46}{-0.84} \ln IPS_{t-1} + u_t}$$

or,

$$\boxed{\ln Tra_t = 1.58 \ln Con_t - 0.55 \ln IPS_t + u_t}$$

B.49 The coefficients on $lnCon_t$ and $lnIPS_t$ can be interpreted as the (constant) income (in this case consumer spending) and fare elasticities of demand respectively. As explained previously, this follows because the model is in log-log form.

B.50 By subtracting $\ln Tra_{t-1}$ from $\ln Tra_t$ the long run relationship in differences can be expressed such that:

$$\boxed{\Delta \ln Tra_t = 1.58 \Delta \ln Con_t - 0.55 \Delta \ln IPS_t + u_t}$$

B.51 This model form is attractive as it allows variation of the income and price elasticities of demand (1.58 and -0.55 above) through time, without affecting the relationship between demand and income and fare in previous periods.

B.52 The above approach has been successfully implemented across all markets. The key advantage of this approach over the previous approach is its transparency. By changing the elasticities of demand directly any changes in passenger numbers in future can be explained with reference to the values of the key explanatory variables. This was not the case with the previous x-factor approach, where it was found that in some circumstances the approach led to reductions in passenger numbers that could not be explained by reference to changes in the key explanatory variables.

B.53 While this approach represents a significant improvement on the previous approach it is not without its limitations. Key amongst them is that it involves abandoning the UECM form. This is unfortunate, as this form has been found to provide the best fit to historic data, especially given how early in the forecasting period maturity is assumed to take effect in most markets.

B.54 The final step in the process of implementing the new approach to reflecting market maturity in the forecasts was a sense check. A calculation was made about what the forecasts imply about the number of annual international trips made per UK resident in the future and compared with the number of annual international trips per UK resident observed in recent years. The sense check showed that the central forecast implies absolute annual growth in the number of international trips per UK resident similar to that which has been observed in the past 25 years, with the growth slowly declining through time. The high end of the range shows a slower decline in the growth in the number of international trips per UK resident while the lower end of the range shows a much more rapid decline. This sense check is more comprehensively covered in a technical note that is being published alongside this report[87].

---

[87] *Reflecting changes in the relationship between UK air travel and its key drivers in the National Air passenger demand model*, DfT, August 2011

Annex C: National Air Passenger Demand Model Forecasting Assumptions

Introduction

C.1 Chapter 2 explained the method for forecasting UK air passengers, unconstrained by airport capacity constraints, using the National Air Passenger Demand Model (NAPDM). This annex explains in more detail the projections of the key driving variables that have been fed into the NAPDM in producing the updated forecasts.

C.2 The central forecasts are based on central projections for each driving variable. The lower bound of the forecasts (the low growth baseline used in the MAC curve analysis) is derived by combining low GDP, low oil prices, low carbon prices, high exchange rates and high fuel efficiency. The upper bound of the forecasts combines high GDP, high oil prices, high carbon prices, low exchange rates and low fuel efficiency. The sensitivity tests which are used to demonstrate the impact of varying key variables also require a 'low' and 'high' projection of each variable.

C.3 In using the NAPDM to produce, unconstrained demand forecasts to 2050, projections of the key driving variables over the period 2008-2050 have been made. Additionally, unconstrained demand forecasts to 2080 have been produced to feed into the appraisal of some of the policy measures considered as part of the MAC Curve analysis. This annex presents the projections of the key driving variables over the full period 2008-2080.

Economic Growth

C.4 These variables comprise UK GDP, UK consumer expenditure, and the GDPs of the four destination world areas: Western Europe, Other OECD, Newly Industrialising Countries (NICs) and Less Developed Countries (LDCs).

C.5 The assumptions for UK growth have been updated using the new Office for Budget Responsibility (OBR) forecasts (2008-2050) [88]. For the period 2051-2080, the HM Treasury 2009 Long-Term public finance report 'principal scenario' rates are used[89]. Consumer expenditure growth is taken from OBR forecasts[90] out to 2015, and beyond this is assumed to

---

[88] *Economic and fiscal outlook – March 2011,* Office for Budgetary Responsibility, 2011 available at http://budgetresponsibility.independent.gov.uk/economic-and-fiscal-outlook-march-2011/

[89] http://www.hm-treasury.gov.uk/d/pbr09_publicfinances.pdf

[90] *Economic and fiscal outlook – March 2011,* Office for Budgetary Responsibility, 2011 available at http://budgetresponsibility.independent.gov.uk/economic-and-fiscal-outlook-march-2011/

remain constant as a share of GDP (62.2%[91]) over the remainder of the forecast period.

C.6 The GDP growth projections for 2008 to 2015 for Western Europe, OECD, NIC and LDC are taken from the IMF World Economic Outlook (WEO) 2010 (2008-2015)[92]. The projections for 2016-2030 are produced by Enerdata and are calibrated to IMF's WEO 2009. Beyond 2030, the GDP growth projections for Western Europe, OECD, NIC and LDC are based on the assumptions used in the EU Adaptation and Mitigation (ADAM) project. For forecasting, it is necessary to produce a single set of GDP growth projections for each geographic zone considered in the NAPDM. This is achieved by weighting each individual country's GDP growth rate by the proportion of traffic that the country contributes to the region, using the latest calendar year CAA passenger statistics.

C.7 Table C1 summarises the resulting central GDP and UK consumer spending projections for each geographical market.

Table C1: Real GDP and UK consumer spending growth assumptions, %pa

	UK	W. Europe	OECD	NIC	LDC	UK Consumer Expenditure
2008 -2015	-4.87-2.90	1.11-2.29	1.08-3.72	7.05-7.86	5.34-6.19	-5.12-2.20
2016-2030	2.25-2.52	1.61-2.33	1.91-2.28	4.21-6.26	4.29-4.76	2.25-2.52
2031-2050	2.22-2.55	1.26-1.64	1.35-1.62	3.68-4.28	4.09-4.32	2.22-2.55
2051-2080	2.16-2.33	1.26	1.35	3.68	4.32	2.16-2.33

C.8 For the lower bound of the updated forecasts (and low GDP sensitivity test) the central annual GDP and consumer spending growth rates are reduced by 0.25%. For the upper bound of the updated forecasts (and high GDP sensitivity test) the central annual GDP and consumer spending growth rates are increased by 0.25%. This is in line with the approach taken in the Department's previous published forecasts – *UK Air Passenger Demand and CO_2 Forecasting, 2009*. This approach was also used for foreign GDP and consumer spending forecasts in Western Europe and OECD countries. A different approach was adopted for NICs and LDCs as GDP growth rates in these regions tend to be higher and more volatile. As a change in the UK GDP and consumer spending growth forecasts of 0.25% is around a 10% change in the growth rate, a 10% reduction in GDP and consumer spending growth rates for NICs and LDCs is used for the lower bound of updated forecasts and the low GDP sensitivity test, while a 10% increase is used for the upper bound of the updated forecasts and the high GDP sensitivity test.

---

[91] According to the OBR, consumer expenditure is projected to fall from 65.3% of GDP in 2009 to 62.2% by 2015, the end of the OBR's forecast period. It is subsequently assumed that consumer expenditure would remain constant, equal to this proportion of GDP out to 2080.

[92] Report available at www.imf.org/external/pubs/ft/weo/2010/01/pdf/text.pdf

Trade

C.9 The growth rates for visible trade volumes have historically followed those of GDP. Therefore trade assumptions are directly based on trade's relationship with UK and foreign GDP growth. Based on historical data, trade with Western Europe and OECDs was found to be more strongly correlated with GDP from those regions. Therefore the growth rate of trade with Western Europe and OECDs grows at the same rate as GDP from those regions. However trade with NICs and LDCs was found to be more strongly correlated with UK GDP. Therefore the growth rate of trade with NICs and LDCs grows at the same rate as UK GDP. The same growth rates are assumed to apply to imports and exports.

C.10 Table C2 summarises the visible trade growth projections for each foreign geographical market.

Table C2: Visible trade growth assumptions, % change p/PATM

	W Europe	OECD	NIC	LDC
2008 -2015	1.11-2.29	1.08-3.72	-4.87-2.90	-4.87-2.90
2016-2030	1.61-2.33	1.91-2.28	2.25-2.52	2.25-2.52
2031-2050	1.26-1.64	1.35-1.62	2.22-2.55	2.22-2.55
2051-2080	1.26	1.35	2.16-2.33	2.16-2.33

Exchange Rates

C.11 It is difficult to project exchange rates as they are subject to both long term trends and short term movements. However, since the late 1980s, the GBP/US$ exchange rate has traded within a fairly well defined band, bound by the February 1991 high of GBP1.97/US$ and the June 2001 low of GBP1.40/US$. Indeed, although the exchange rate briefly breached the upper limit of this band in 2007, the move was swiftly followed by a weakening of the rate back to within the previously defined limits.

C.12 It is anticipated that the exchange rate will remain within this band over the long term. The central updated forecasts assume that the exchange remains at the median value of this range which is 1.68/US$. The data series used to calculate this is the Bank of England monthly historic average spot US$/GB£ exchange rate, XUMAUSS[93].

C.13 For the lower bound of the updated forecasts and the high exchange rate sensitivity test, the 75th percentile of the range of exchange rates between GBP 1.97/US$ and GBP1.40/US$ is used -1.82/US$. For the upper bound of the updated forecasts and the low exchange rate sensitivity test, the 25th percentile of the range of exchange rates is used - 1.54/US$.

---

[93] www.bankofengland.co.uk/mfsd/iadb/FromShowColumns.asp?Travel=NIx&SearchText=XUMAUSS

Air Fares

C.14 The forecasted annual growth rate in air fares is compiled from assumptions about changes in fuel costs, non-fuel costs, taxation and other environmental charges.

Fuel costs

C.15 Forecast fuel costs are driven by projections of fuel prices, which in turn are driven by assumptions about oil prices, biofuel penetration rates, biofuel prices, and fuel efficiency.

Oil Prices

C.16 Oil price projections are based on the latest *Communication on DECC Fossil Fuel Price Assumptions*, published in March 2009[94]. Scenario 2 – "timely investment, moderate demand" is used in the central forecasts, Scenario 1 – "low global energy demand" is used in producing the lower bound of the new forecasts and for the low oil price sensitivity test and Scenario 4 – "high demand and significant supply constraints" is used in producing the upper bound of the new forecasts and for the high oil price sensitivity test. Table C3 shows the range of real oil price assumptions for selected years.

Table C3: Range of real oil price assumptions, $/barrel (2008 prices)

	Low	Central	High	High-High
2008	98	98	98	98
2010	77	77	77	77
2015	60	77	105	146
2020	62	82	123	154
2025	62	87	123	154
2030	62	93	123	154
2050	62	93	123	154
2080	62	93	123	154

C.17 Kerosene prices are then calculated using a simple linear model which specifies the relationship between oil prices per barrel and kerosene prices per litre. This model is used to forecast future kerosene prices up to 2030, after which time they are assumed to remain constant in real terms - an approach agreed with DECC.

---

[94] Table E: Price Assumptions, available at: http://www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx

Biofuels

C.18 The scope for the penetration of biofuels into the aircraft fleet to have a significant impact on air fares and consequently levels of demand has been considered. Combining the latest available projections of biofuel prices with the central projections of oil and carbon prices suggests that biofuels could become cost effective in the 2040s[95], without any further Government action. It is assumed that biofuels will account for 2.5% of fuel use on flights using UK airports by 2050 in the central forecasts. But there is significant uncertainty surrounding future biofuel prices. In producing the updated forecasts it is assumed that the airlines use of biofuels will not significantly affect their combined fuel and EU ETS carbon allowance costs. The penetration of biofuels therefore has no effect on air fares, or on the demand forecasts. However, it does have an effect on CO_2 forecasts. For consistency with the accounting of biofuel use by the transport sector in the UK's carbon budgets and for aviation in the EU ETS, biofuel use is allocated zero CO_2 emissions.

C.19 In defining the lower bound of the forecasts, biofuels are expected to be more expensive than kerosene plus the cost of carbon allowances throughout the forecast period. It is therefore assumed that biofuels make up 0% of aviation fuel use out to 2050. In contrast, for the upper bound of the range, biofuels are expected to become cost effective during the 2030s. It is assumed that biofuels represent 1% of aviation fuel use by 2030 and 5% of aviation fuel use by 2050.

Fuel Efficiency

C.20 Assumptions about fuel efficiency are required to feed into the projection of the fuel used per available seat kilometre (ASK). Improvements in fuel efficiency will lead to a lower fuel cost per ASK, which in turn will tend to lead to lower ticket prices if load factor and trip length are held constant.

C.21 Future changes in the fuel efficiency of the aircraft fleet are derived from the fleet mix model. Chapter 3 explains how the model works, what assumptions it is based on, and the resulting fuel efficiency growth rates for the fleet.

Non – Fuel Costs

Air Passenger Duty (APD)

C.22 The rates reflect the changes to APD announced in the 2011 Budget. There will be no RPI rise in APD in the 2011/12 financial year. The RPI increase will instead be defered and implemented alongside the April 2012 RPI increase. APD is then assumed to remain constant in real

---

[95] Under the EU ETS airlines do not need to surrender allowances for their biofuels use.

terms for rest of the modelling period. Table C4 sets out the current APD rates, as of November 2010 (expressed in nominal prices).

Table C4: APD rates post November 2010

Band, and approximate distance in miles from	In the lowest class of travel	Other than the lowest class of travel	Proportion in the lowest class of travel
Band A (0-2000)	£12	£24	97.5%
Band B (2001-4000)	£60	£120	91.2%
Band C (4001-6000)	£75	£150	93.8%
Band D (over 6000)	£85	£170	89.2%

EU Emissions Trading System (ETS) allowance costs

C.23 Aviation's entry into the EU ETS in 2012 has an effect on fares faced by passengers. It is assumed that the allowance costs faced by airlines are passed through to passengers in the form of higher fares.[96] This means that from 2012 onwards, fares include the cost of purchased allowances in addition to APD.

C.24 DECC published new guidance on the Shadow Price of Carbon in June 2010. The values for the traded price of carbon are used to reflect aviation's entry into the EU ETS. The new values are available on the DECC website[97].

C.25 DECC publishes low, central and high traded price projections. The low price projections have been used for the lower bound of the updated forecasts and the low carbon price sensitivity test and the higher price projections for the upper bound of the updated forecasts and the high carbon price sensitivity test. Table C5 shows the traded price of carbon for all 3 scenarios defined by DECC.

Table C5: DECC traded price of carbon (2008 prices)

	Low	Central	High
2008	£27	£52	£66
2010	£27	£52	£66
2015	£29	£56	£71
2030	£129	£258	£387
2050	£369	£738	£1,107
2080	£395	£1,128	£1,861

Other Non-Fuel Costs

C.26 Figure C1 below shows the trend from 1997 to 2008 in the real costs per seat kilometre for the four largest UK registered airlines (British Airways,

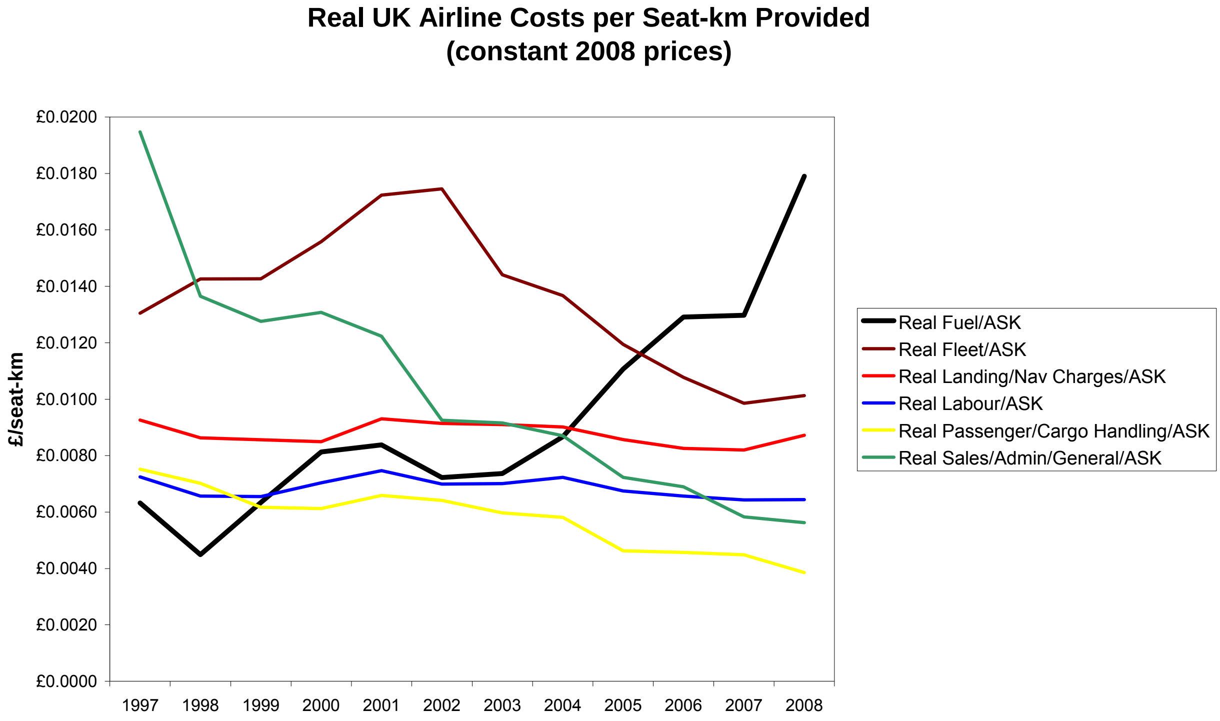
---

[96] These EU ETS fare supplements are applied to passengers and affect demand at the national level. They vary by the destination region and are applied to demand before the passenger to airport allocation process. They are quite distinct from the fare supplements (shadow costs) applied to passengers using an airport operating at full capacity.

[97] http://www.decc.gov.uk/assets/decc/what%20we%20do/a%20low%20carbon%20uk/carbon%20valuation/1_20100610131858_e_@@_carbonvalues.pdf.

Virgin Atlantic, Easyjet and BMI), derived from CAA data[98]. These costs exclude APD and are in 2008 prices. It shows that all of the non- fuel cost elements have trended downwards.

Figure C1: UK airline costs per available seat kilometre (excluding APD), 2008 prices, selected airlines

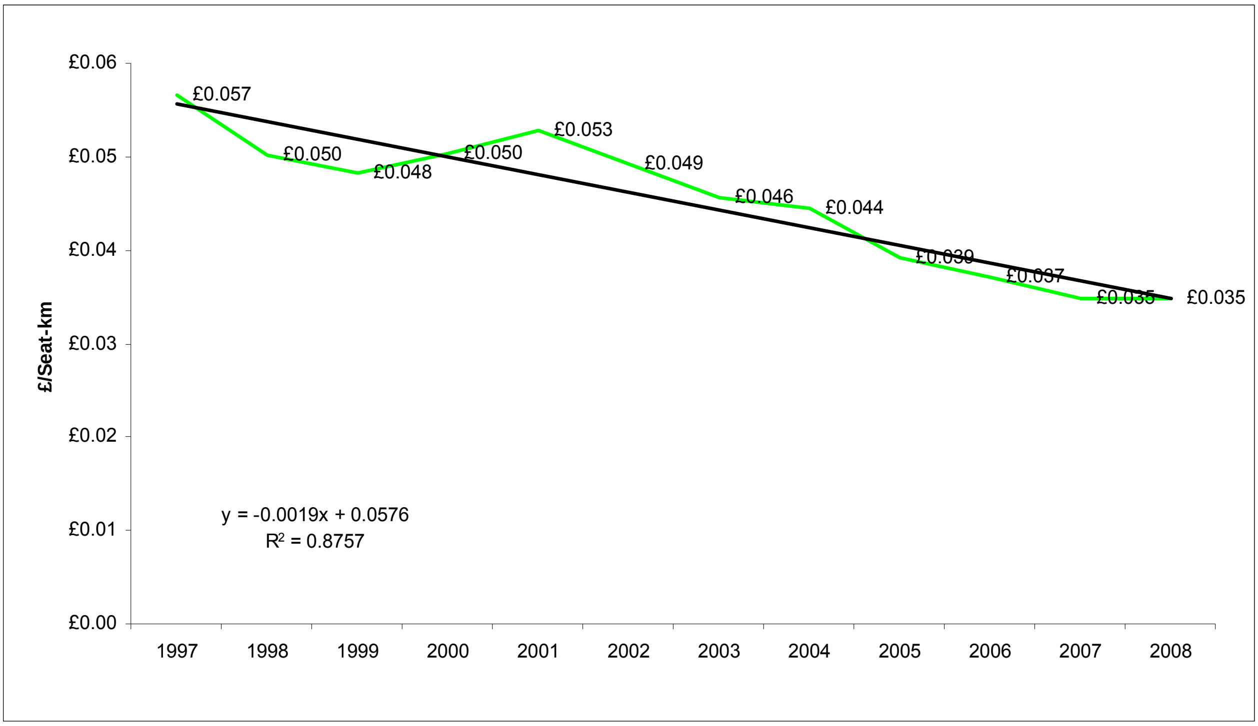


C.27 Figure C2 shows that summing the non-fuel cost elements reveals an overall downward trend to 2008.

---

[98] CAA: UK Airline Financial Tables 1998-2008, Table 2.6 Individual Airline Profit and Loss, Table 2.10 Operating and Traffic Statistics.

Figure C2: UK airline non-fuel costs (excluding APD), 2008 prices



C.28 This downward pressure on non-fuel costs is driven by increasing competition, convergence of lower cost and full service business models and by the development of non fare revenue streams. This trend is projected to continue, but at a slowing rate. The projected annual rates of reduction in airline non-fuel costs in the central forecast are shown in Table C6.

Table C6: Airline non-fuel cost projections, % change p.a.

	Domestic and Short Haul	Long Haul
2009-2010	-1.4	-1.7
2011-2015	-1.1	-1.4
2016-2030	-0.7	-1.0
2031-2080	0.0	0.0

Other NAPDM Assumptions

Load factors

C.29 Load factors are another input into the overall fare faced by passengers in general, because airline costs do not increase proportionally with the number of passengers. The load factor determines how both airline fuel and non-fuel costs and EU ETS emissions charges are shared per passenger in the calculation of the average fare level for each forecasting region.

C.30 Load factors are extracted from the appropriate detailed model outputs at 5 yearly intervals with intermediate years interpolated to remove model noise. Post 2040 the trend of the final 5 modelled years is projected forward until a load factor ceiling for each market is reached. These ceilings are a user judgment input and are currently set at 80% for domestics, 80% for short haul, and 90% for long haul markets. When the last 5 years trend was applied forward, none of these ceilings were reached. Load factors are not allowed to trend downwards post 2040.

Trip length

C.31 Trip length is a key parameter for the fuel cost and carbon cost per passenger, as fuel estimates are based on a seat kilometre basis. It is assumed these do not vary over time, as historical evidence suggests that within regions there is little scope for change.

Videoconferencing

C.32 Technological change where videoconferencing is becoming available on basic computers, coupled with increasing broadband uptake should mean that sophisticated videoconferencing facilities will be widely available. However there is significant uncertainty as to whether this will cause business travel to be lower than is implied if it is assumed that the relationship between business air travel and its key drivers is the same as in the past. For the central forecasts it is therefore assumed that the increasing availability of videoconferencing facilities will have no impact on traffic.

C.33 For the lower bound forecasts, it is assumed that the increasing availability of videoconferencing facilities will result in a 10% reduction in business air travel by 2050, relative to the level of demand implied by NAPDM forecasts. This assumption is consistent with that made by the Committee on Climate Change's (CCC) in the 'optimistic' scenario presented in *Meeting the UK aviation target – options for reducing emissions to 2050*. For the upper bound forecasts, a 5% increase in business air travel by 2050, relative to the level of demand implied by NAPDM forecasts is assumed. This reflects recent research cited by the CCC that suggests that rather than substituting for business travel, greater telecommunications use accompanies increases in total travel[99].

---

[99] Committee on Climate Change *'Meeting the UK aviation target – options for reducing emissions to 2050'* (2009)

Annex D: Passenger Airport Choice Model - Detailed Methodology

Introduction

D.1 Chapter 2 explained that DfT's National Air Passenger Allocation Model is the mechanism for translating the National Air Passenger Demand Model forecasts into passenger and aircraft demands at 31 individual airports operating as a national system. It projects how passengers might choose between airports given the differing amounts of capacity available in the future. It also projects air traffic movement (ATM) demand at each airport and the fare premia (shadow costs) for using passengers wishing to use airports operating at capacity.

D.2 A key component of the model is the Passenger Airport Choice Model, which projects how a given level and pattern of demand is likely to split between airports. This annex gives further detail on how this model works.

Allocation Models

D.3 Modelling and forecasting how people choose between a set of discrete options is an established practice in statistics and transport modelling. The Passenger Airport Choice Model is an application of the standard multinomial logit formulation commonly used in this context. The model assumes the proportion *P* of passengers with journey purpose *p* travelling to/from UK zone *i* to foreign destination *j,* that use airport P_{ijAp}, can be represented by the following very flexible functional form[100]:

$$P_{(i,j,A,p)} = \frac{e^{-\beta_1 \times Cost_{(i,j,A)}}}{\sum\limits_{R \in all\ available\ Routes} e^{-\beta_1 \times Cost_{(i,j,R)}}}$$

where

i = zone of origin
j = zone of destination
p = journey purpose
A = airport
R = route
$Cost_{ijA}$ = generalised cost of travelling from zone i to zone j using airport A
β = unknown parameter to be estimated during calibration

---

[100] The form shown is the simplest of those used.

D.4 Model calibration involves analytically selecting the set of values for the unknown parameters which lead to the model's predictions best fitting the base year data.

D.5 The strength of different drivers of passengers' airport choice is likely to vary between passenger groups. For example, business passengers may be more affected by frequency of flights offered. Therefore separate allocation models for different types of passengers are estimated. Some of which have more complicated functional forms than the generic form shown above[101]:

- international scheduled[102] and charter (package holiday) passengers;
- domestic passengers beginning and ending their journeys in the UK;
- transfer passengers "interlining" by changing planes at a hub airport[103];
- UK and foreign passengers;
- business and leisure passengers, and
- short haul and long haul passengers.

D.6 The multi-nomial logit models which identify the mix and strength of the variables driving the choice of airport of the different passenger groups have recently been re-estimated. New parameters are in use although the functional forms remain largely unchanged.[104]

D.7 Table D1 shows the 31 UK airports (by region) to which passengers can be allocated.

---

[101] A considerably more detailed description of the 2003 White Paper generation of the model is available in DfT/Scott Wilson *Rules and Modelling: A Users Guide to SPASM, Edition 2,* April 2004

[102] A further distinction is currently drawn between conventional scheduled and "No Frills" (NFC) airlines in the allocation as the calibration results showed a difference in parameter estimates. However, these markets have become less clearly differentiated over time, and this distinction is not made at all parts of the forecasting (e.g. the econometric models of unconstrained demand). The distinction has also been withdrawn in the model of internal domestic flights.

[103] These include passengers with UK origins or destinations changing at a UK hub airport ("domestic interliners"); passengers with UK origins or destinations changing at an overseas hub airport such as Amsterdam, Schiphol; or, passengers with no ground origin or destination within the UK but who use a UK hub airport to interchange ("international to international interliners").

[104] A technical note that describes the re-estimation process is available on request. The Peer Review report (*Peer Review of NAPALM*, John Bates Services, October 2010 (available at www.dft.gov.uk) also provides a useful introduction to the re-estimation.

Table D1: UK airports in National Air Passenger Allocation Model

London
Heathrow
Gatwick
Stansted
Luton
London City

Other East & SE
Southampton
Norwich

SW and Wales
Bristol
Cardiff Wales
Bournemouth
Exeter
Newquay
Plymouth

Midlands
Birmingham
Nottingham East Midlands
Coventry

North
Manchester
Newcastle
Liverpool
Leeds Bradford
Durham Tees Valley
Doncaster-Sheffield
Humberside
Blackpool

Scotland
Glasgow
Edinburgh
Aberdeen
Prestwick
Inverness

Northern Ireland
Belfast International
Belfast City

Annex E: Improvements to UK Air Passenger and CO_2 Forecasting Methods

Introduction

E.1 The models used to forecast UK air passengers and aviation CO_2 emissions, and to estimate the monetised net benefits of changes in airport capacity, have evolved over a number of years. It is the Department's policy to continuously improve the models, taking on board latest data and methodological advances, and evolving to meet new policy analysis requirements. The Peer Review is an important part of this process and provides an indication of possible future model developments.

E.2 *UK Air Passenger Demand and CO_2 Forecasts* 2007 (annexes D and I) set out the improvements made to the passenger demand and CO_2 forecasting methods since the Air Transport White Paper and *UK Air Passenger Demand and CO_2 Forecasts* 2009 (annex D) sets out the improvements since 2007. The constraints of a formal aviation consultation limited the improvements to the modelling that could be included between the 2007 and 2009 generations of the modelling. Therefore a significantly extended programme of forecasting enhancements, many driven by the Peer Review Process[105], has been implemented in this version of the modelling framework. This annex notes the incremental improvements made since *UK Air Passenger Demand and CO_2 Forecasts* 2009.

National Air Passenger Demand Model (NAPDM)

E.3 The econometric models and input assumptions used to forecast air passenger demand in the NAPDM are set out in detail in annexes A, B and C.

E.4 In summary, the main changes have been:

- an updating of the forecast base from 2004 to 2008 and inclusion of four more years of explanatory variable data in the model estimation process;
- extension of the unconstrained demand forecasting period from 2030 to 2080;
- estimation of new models which relate growth in passenger demand to input driving variables (GDPs, trade, consumer expenditure, exchange rates, fares), discovery of fare elasticities in some business markets and the imposition of fare elasticities in others (see annex A);

---

[105] See *Peer Review of NAPALM*, John Bates Services, October 2010 and *Peer Review of "Peer review of NAPALM" of 28 October 2010 and the Department for Transport Response*, NERA, July 2011 (both available at www.dft.gov.uk)

- improvements to the way changes in the relationship between UK air travel and its key drivers is reflected in the NAPDM (see annex B);
- review of the sub-models which translate the main econometric model outputs into charter and no-frills airline market shares; and
- updating of input explanatory variables (see annex C):
    - UK GDP and consumer expenditure in line with OBR forecasts;
    - overseas GDP in line with latest IMF World Economic Outlook forecasts;
    - oil prices using current DECC forecast ranges;
    - traded carbon prices using latest DECC projections;
    - revised fuel efficiency impacts on air fares using updated DfT forecasts of national fleet efficiency;
    - review of air traffic management (ATM) system improvements on airline operational costs and fares
    - updated non-fuel related airline costs using latest CAA airline financial reporting data;
    - new distance banded APD charging regimes introduced in 2011; and,
    - the inclusion of aviation in the EU ETS from 2012.

E.5 The January 2009 forecasts were published at a time of significant flux in the levels of input variables used in air passenger demand forecasting. In 2009 the latest GDP outturn[106], the EU ETS and the new APD charging structure could only be included as separate sensitivity tests. In the new forecasts this comprehensive updating of the input variables results in a significant drop in the central NAPDM 2030 forecast from 465mppa to 385mppa. The bulk of this decline is attributable to GDP growth in 2008 and 2009 being much lower than implied by the projections used as an input to the forecasts.

E.6 One other important change to the unconstrained demand forecasts has been in the definition of ranges. The approach employed in the 2007 and 2009 versions of *UK Air Passenger Demand and CO_2 Forecasts* had been to use low and high ranges that were derived by taking the lowest and highest annual forecast from each of the individual variable sensitivity tests for each year in the forecast period. The revised method is to combine the individual sensitivity tests into a coherent and plausible set of inputs to produce lower and upper bound forecasts. For example, the lower bound of the forecast range combines faster market maturity with low projections of GDP and fuel and carbon trading prices; the high upper bound of the forecast range is characterised by low levels of market maturity and high GDP tempered by high oil and carbon prices. In line with other government reporting requirements these forecasts are now supplemented by more extreme “lowlow” and “highhigh” projections,

---

[106] Pre-Budget report Nov. 2008.

produced by combining the individual sensitivity tests to minimise and maximise the passenger forecasts. However, this more extreme range is regarded as less useful for policy development because it is based on combinations of assumptions that are unlikely to be realised.

National Air Passenger Allocation Model (NAPALM)

E.7 The National Air Passenger Allocation Model used to convert unconstrained air passenger demand into constrained passenger and ATM forecasts at the 31 most significant UK airports is set out in more detail in chapter 2 The main changes since *UK Air Passenger Demand and* CO_2 *Forecasts* 2009 are summarised in the sub-sections below.

Base year

E.8 The base year of the model has been moved forward from 2004/5 to 2008/9.[107] This process involves:

- new input passenger demand data taken from the most recent CAA passenger interview surveys which generally date from the period 2005-2008 for medium airports and from 2008 for the busiest airports;
- updated supply side inputs of ATMs by route in 2008 from detailed CAA statistical reporting;
- a comprehensive model validation exercise for the 2009 base reported in chapter 2 and annex F[108]. This process includes:
    - route level comparison of forecast international passengers against CAA reported outturns for each airline market segment (‘scheduled’, ‘no-frills’ and charter),
    - route level comparison of forecast international ATMs against CAA reported outturns for each airline segment,
    - route level comparison of forecast international aircraft loads (passengers per ATM) against CAA reported outturns for each airline segment,
    - route level passenger, ATM and load comparisons for internal domestic flights, and

---

[107] The NAPALM modelling effectively has two base years. The first base refers to the input year of the initial base demand and supply inputs. The second year is the year in which the modelled forecasts are validated against detailed outturn data. This is because it is only in the second year that the model’s ATM and ATM load forecasting modules are active and validation of this year provides a more stringent test of overall model performance.

[108] Further detail of the model validation is available in a technical note available on request.

- comparisons of forecast passengers transferring flights at hubs compared with those recorded in 2009 CAA passenger interview surveys.

NAPALM forecasting scope and structure

E.9 The National Air Passenger Allocation Model computer program has been extended to produce detailed annual passenger, ATM and shadow cost forecasts between a base year of 2008 and a final year of 2050. Previously the model only operated between 2004 and 2030. Although NAPALM is now capable of reaching 2050 it will only do so if the combination of input unconstrained demand and airport runway and terminal capacity permit.

E.10 The segmentation of the domestic market into scheduled and no-frills carriers has been removed (there is no significant internal domestic charter traffic). This improves the analytical power of the model. Previously no-frills domestic flights had been treated as an airport to airport add-in which did not represent demand between the ultimate district passenger origin and destination. This improvement means that all internal domestic passengers are now modelled using the full geographical scope of the model (455 district zones) and competition with surface modes for internal UK demand can also be better represented. The space vacated in model outputs is also used to provide better business/leisure split output data for domestic passengers.

Extension of forecasts when NAPALM runs do not reach 2050

E.11 An ‘ATM synthesis’ module has been added to allow the extrapolation of more detailed capacity restrained ATM by airline type, route and seat band class outputs for use in the Fleet Mix and CO_2 models where NAPALM runs have failed to complete (see chapter 2).

E.12 Reliable CO_2 forecasts are driven by projections of passengers and ATMs by destinations and of the type of aircraft likely to be in use on each route in each year. In producing previous published forecasts the DfT extrapolated the detailed UK terminal passengers and ATMs output by the National Air Passenger Allocation Model to 2030 onwards to 2080. The method used to extrapolate the forecasts is described in *UK Air Passenger Demand and* CO_2 Forecasts, 2009.[109] These extrapolation methods are still required when the National Air Passenger Allocation Model completes its final year of detailed forecasting. However, they have shortcomings for CO_2 forecasting in that they do not provide details of ATMs by destination and by seat band, and so cannot be used with the Fleet Mix Model.

E.13 The extension of the NAPALM programme to 2050 helps to reduce the need for such extrapolation. Where the National Air Passenger Allocation Model cannot run to 2050, because the level of demand is to

---

[109] See *UK Air Passenger Demand and* CO_2 *Forecasts, 2009,* p.58

great relative to the assumed airport capacity, an improved extrapolation ('ATM synthesis') technique has been developed. This uses the earlier post-2030 methodology described above to create ATM growth factors. These factors, constrained to individual airport capacities and by airline type, can be applied to the final available National Air Passenger Allocation Model output of ATMs by route and aircraft seat band size to create equivalent outputs for subsequent years. These synthesised ATM outputs provide inputs to the Fleet Mix Model which in turn provides the required aircraft and route detail for the CO_2 Model – see chapter 3 for more detail on these models.

E.14 Where syntheses of ATM or passenger forecasts prior to 2050 have been required they have been marked in grey in this document. They are an effective method of providing airport constrained, route level, size band ATM forecasts. However they can introduce some discontinuity between comparable options where synthesis has been required in different years.[110]

Base airport capacities

E.15 Changes in the max use ('s02') capacities since *UK Air Passenger Demand and CO_2 Forecasts* 2009 have been limited to a reduction of the terminal capacity at Gatwick from 46.5mppa to 42mppa and of the runway capacity at Birmingham from 192,000 to 189,000 ATMs.[111] These do not have a material impact on the forecasts.

E.16 The same set of 31 airports is modelled (with one reserved spare slot). However in the validated base Coventry is now assumed to be closed to passenger traffic but has the potential to re-open in later years to its previous capacity in the max use capacity scenario, if justified by demand. Plymouth is assumed to be open, but since model runs have been undertaken the owners have indicated that it will close to passenger traffic.

NAPALM airport choice parameters

E.17 All the parameters which explain passenger choice of airport (see annex D) have been reviewed using all the available CAA passenger interview data from the period 2000-2008. The choice model uses a series of multinomial logit equations that use as inputs projections of the variables that a calibration process has found to determine passenger airport

---

[110] The main discontinuity has been that the synthesised ATM forecasts may project slightly lower levels of passengers and therefore ATMs than a full National Air Passenger Allocation Model run. This is because the extrapolation method cannot fully account for all the complexities of passenger reallocation to other neighbouring airports when a specific airport reaches it capacity ceiling. In practice the National Air Passenger Allocation Model works more efficiently to fit constrained passengers into the system.

[111] The Gatwick capacity reduction is nominal because the input annual runway capacity of 260,000 effectively controls the airport capacity and the terminal capacity ceiling is not reached in the forecasts. At Birmingham the capacity was adjusted after consultation with the airport to better represent the impact of the proposed runway extension.

choice. This is the first full review of airport parameters since before the Air Transport White Paper.[112]

Surface access to airport modelling

E.18 The model that provides ‘skims’ of road vehicle travel times and operating costs and rail times, waiting times, interchanges and fares has been modernised and its source switched to the DfT’s Long Distance Model (LDM). These skims provide generalised composite costs of getting from each district to every modelled airport in the model and for travelling by surface modes between each pair of districts for modelling competition between air and surface modes in the domestic air market. Using the LDM updates the base year network definition to 2008 and allows the inclusion of the recently published High Speed Rail schemes (London-Birmingham via Old Oak Common for Heathrow in 2026 and extensions to Manchester and Leeds in 2033).

E.19 The LDM inputs to NAPALM are:

- Highway - Drive time (minutes)
- Highway - Distance (kms)
- PT - In-vehicle time
- PT - Fare
- PT - Wait time
- PT - Number of interchanges

E.20 2008 base year highway travel costs are assumed to be held constant into the future (i.e. infrastructure improvements offset any deterioration in operating conditions caused by traffic growth), while public transport times are held constant until the introduction of HSR in 2026.[113]

Regional Growth Adjustments

E.21 There has been a significant upgrade to the Distgrowth demand interface between the NAPDM and NAPALM which allows input of local variations to district growth rates while making compensating adjustments in the other districts to control the overall national demand to the level output by the NAPDM. The upgrade allows:

- the input of district or regional growth rates compatible with TEMPRO (NTEM) and its underlying demographic and income forecasts;

---

[112] A paper describing the estimation of the new multi-nomial logit models estimated is available on request. See also the Peer Review by John Bates.

[113] A technical note comparing the specification, changes and performance of the LDM compared to its predecessor NAPALM input, the National Airport Accessibility Model (NAAM) is available on request.

- the calibration of different weighting for each explanatory demographic variable by air passenger purpose;
- retention of more of the geographic detail of the econometric national forecasts (i.e. weighted splits into short haul, long haul OECD, NIC or LDC in each district); and
- retention of more of the purpose data associated with forecasts of no-frills passengers[114]

E.22 Tests were made with different versions of NTEM (5.4 and 6.1) demographic and income data. There was little difference in the district level forecasts of air passengers or airport shadow costs resulting. This model version uses NTEM 6.1 inputs.[115]

E.23 Distgrowth also allows an interface between NAPDM and NAPALM which can override inaccuracies in the NAPDM outputs before demand is modelled at airports. In this context Distgrowth is now used to:

- impose 2010 national outturns where the econometric models under-forecast the loss of traffic associated with the economic recession and volcanic ash disruption;
- re-instates in all forecasts for 2011 the exceptional traffic loss of around 4.8mppa passengers lost from the 2010 forecast due to volcanic ash disruption; and
- adjust the forecasts to reflect a ‘bounce-back’ in demand following the exceptional loss in passengers following the financial crisis (see section 2.2 for details). This bounce-back correction is only applied in the high demand scenarios.

NAPALM parameter inputs

E.24 All NAPALM parameter inputs have been reviewed for this generation of the model. The material changes are:

- all time-dimensioned inputs (notably airport capacities, values of time, demand growth factors) have been extended to cover the period 2008-2050;
- new multi-nomial logit passenger to airport choice parameters following the re-estimation process are in use;[116]
- values of time (VoT) have been reviewed and are consistent with the newly estimated airport choice logit parameters. There are no ‘official’ published UK air passenger VoTs. Resource leisure times for appraisal are Webtag compliant, but behavioural leisure times for passenger airport choice remain based on the previous versions (in

---

[114] A technical note (10/03) gives more detail of the scope of the upgrade and a further note (10/20) describes the calibration of the input parameters for the demographic modelling. Both notes are available on request.

[115] These NTEM tests are described in technical note(10/21)

[116] A technical note (10/014) gives full details of all the new settings and is available on request.

turn based on CAA research) and updated in line with Webtag growth in VoT. Business VoTs, both resource and behavioural, are based on the latest data collected by the CAA in the 2008 passenger interview survey;[117]

- vehicle operating costs and occupancies for surface access generalised costs have been updated in line with Webtag 3.5.6, (Feb 2010, Draft) and latest CAA interview data on car-borne passenger group sizes; and
- the generalised cost demand suppression elasticities which remove excess demand were reviewed and changed to the generally lower values of the fare elasticities by passenger purpose resulting from the econometric estimation process described in chapter 2 and annex A.[118]

---

[117] A technical note (10/005) gives full details of all the review of appraisal and behavioural value of times and their current settings and is available on request.

[118] A technical note (10/007) describes the process and effect of changing these parameters and is available on request.

Fleet Mix Model

E.25 The Fleet Mix Model (FMM) is used to convert generic seat-banded ATMs by airline category output by NAPALM into specific aircraft types in each forecast year.[119] The dimensions of the Fleet Mix Model (FMM) have been expanded to allow the model to operate out to 2050 and to allow a maximum of 30 aircraft types over the forecasting period in each airline type seat band up to an overall maximum of 150 aircraft types. Previously only 70 present and future aircraft types had been possible.

E.26 The definition of present and future types were adjusted initially in line with recommendations in chapter 6 of the QinetiQ Report *Future Aircraft Fuel Efficiencies – Review of Forecast Method Final Report.*[120] Subsequently some further additions of new post 2020, 2030 and 2040 generic types were added on the recommendations of the technology experts working on the MAC curve study, to define distinct fleets for the low, central and high forecasts.

E.27 The supply pool of replacement aircraft and the expectations for the length of time existing types remain in the supply pool have been modified in line with the QinetiQ March 2010 report recommendations. In particular, Airbus A340-300 and 600 models were removed from the supply pool after 2008 and 2012 respectively; the B777 (except the extended range models) were removed from supply pools after 2020; the entry of the B787 and Bombardier C Series aircraft into the supply pool were delayed until 2011 and 2013 respectively; and second generation A320 and B737 series aircraft were assumed to start entering service after 2016.

---

[119] NAPALM outputs ATMs broken down into six seat band categories (1-70, 71-150, 151-250, 251-350, 351-500 and 500+ seats) separately for full service scheduled, no-frills and charter airline types.

[120] *Future Aircraft Fuel Efficiencies – Review of Forecast Method Final Report,* QinetiQ, March 2010 (available at www.dft.gov.uk)

CO_2 model

E.28 The CO_2 model is used to convert route level ATM outputs from NAPALM to estimates of departing aircraft CO_2 emissions on a route by route basis for each year in the forecast period. As part of this process it applies the FMM to convert NAPALM's seat-banded ATM outputs to specific aircraft types for each forecast year. The model is described in detail in chapter 3.

E.29 The main changes since the previous version are:

- new ATM demand forecasts described above and in chapter 2 are used;
- the emissions validation base year is updated to 2008;
- the model is extended to forecast in detail through to 2050 (previously 2030);
- the size of the residual ('unmodellable') CO_2 has been reviewed and considerably reduced[121]; and,
- the CORINAIR based fuel burn rates (see chapter 3) have been modified in line with the recommendations of the QinetiQ March 2010 report.

E.30 The final two bullet points outlined above require further explanation. In *UK Air Passenger Demand and CO_2 Forecasts* 2009, a residual of some 5mtCO_2 emissions had been used to reconcile the Tier 3 calculated CO_2 from that model base year with DECC's estimate of CO_2 emissions for 2005 based on bunker fuel returns. The scope of an audit of probable sources of this gap covered :

- comparison of 2005 modelled ATM-kms by aircraft type against actual equivalent data recorded in detailed CAA statistics;
- examination of the aggregation of individual destinations into model route groups;
- aircraft stopping and refuelling patterns and 'tankering';
- a comparison of the prediction of aircraft types from seat-banded output by the 2005 FMM with CAA recorded actuals;
- improvements to the modelling of freighter emission rates using new data made available to DfT by the CAA;
- detailed estimates of classes of air movements not included in the DfT modelling including business jets, positioning flights and other miscellaneous air traffic movements;
- movements to and from minor airports not included in the 31 main DfT modelled airports;

---

[121] The residual is the gap between the route level CO_2 emissions (calculated by the model using the IPCC specified Tier 3 method) and the DECC CO_2 estimate of emissions based on bunker fuel returns at UK airports.

- suitability of the CORINAIR fuel burn rates (see below);
- impacts of load factors by route; and
- a review of the assumptions about air traffic management operational efficiency gains being applied.

The audit was informed by discussions with airlines and airport fuel suppliers. The audit found that the shortfall was attributable to a sum of several small factors. In the list above the inclusion of estimates of business jets and other unmodelled aircraft movements, the review of CORINAIR modelling and improved data on freighter movements proved the most significant.[122]

E.31 The current version of the CO_2 model has reduced the residual of unexplained aviation emissions against bunker fuel returns to under $0.5mtCO_2$ in a 2008 base year. This significant improvement has been attributable to implementation of items listed above wherever it was possible within the scope of the modelling framework. However, the updating of the model base from 2004/5 to 2008/9 and the re-validation of all route level ATM movements was also a major factor in the reduction of the residual. The previous generation of the model had tended to under-forecast the growth in the proportion of medium and long haul flights as projections were moved forward. This shift to long haul was captured in the re-validated base year.

E.32 The CORINAIR guidebook fuel burn rates are calculated from the PIANO aircraft design software for a subset of representative aircraft types to which all other types are mapped. The QinetiQ review of the DfT modelling[123] checked the mapping of aircraft types to the CORINAIR guidebook representative types, checked the extension of fuel burn rates for longer missions and checked the CORINAIR guidebook rates themselves using data from the AERO2k project which used data on actual missions flown by specific aircraft types rather than the standardised operational settings used in the CORINAIR guidebook. The improvements recommended in chapter 6 of the QinetiQ report have all been implemented.

E.33 The QinetiQ report also recommended significant changes for new aircraft types entering service beyond 2030. These ‘ACARE-compliant’ types were implemented but have subsequently been further reviewed, updated and included in the baselines as part of the MAC Curve project and these changes are documented elsewhere. They are now referred to as ‘FG’ or future generation aircraft rather than ‘ACARE compliant’ aircraft.

---

[122] A technical note (09/005) gives full details of the audit process of the 2005 residual and is available on request.

[123] *Future Aircraft Efficiencies – Final Report,* QinetiQ, March 2010 (available at www.dft.gov.uk)

Annex F: Detailed Validation Results

F.1 Chapter 2 set out some of the results of the model's airport- and route-level validation. This annex reports in more detail:

a) The airport level validation results, for both passengers and ATMs
b) The distribution of passengers by route error band, split between international and domestic flights; and,
c) Scatter plots of actual and fitted passengers, ATMs, and loads, split between international and domestic flights.

a) Airport level: actual vs fitted passengers and ATMs, 2009

	Passengers (mppa)			ATMs (000 pa)		
	Actual	Fitted	Difference	Actual	Fitted	Difference
Heathrow	65.9	66.7	-0.8	461	471	-10
Gatwick	32.4	32.6	-0.2	247	250	-4
Manchester	18.6	20.2	-1.6	162	182	-20
Stansted	19.9	19.4	0.5	157	168	-10
Birmingham	9.1	8.9	0.2	94	95	-1
Luton	9.1	8.6	0.5	78	72	6
Glasgow	7.2	6.8	0.4	78	68	10
Edinburgh	9.0	8.6	0.5	111	106	5
Bristol	5.6	5.6	0.0	54	54	0
Newcastle	4.6	4.4	0.2	50	45	5
Belfast International	4.5	4.5	0.1	45	46	-2
Liverpool	4.9	5.1	-0.2	43	46	-3
Nottingham East Midlands	4.7	4.8	-0.2	60	58	2
Aberdeen	3.0	2.8	0.2	99	89	10
Leeds Bradford	2.6	2.7	-0.2	33	33	0
Prestwick	1.8	1.7	0.1	15	14	1
Belfast City	2.6	2.5	0.1	38	38	0
London City	2.8	2.6	0.2	61	64	-3
Southampton	1.8	1.7	0.1	41	41	0
Cardiff	1.6	1.5	0.1	21	20	1
Durham Tees Valley	0.3	0.2	0.1	6	5	1
Exeter	0.8	0.9	-0.1	14	16	-2
Bournemouth	0.9	0.6	0.2	9	7	2
Coventry	0.0	0.0	0.0	2	2	1
Doncaster Sheffield	0.8	0.9	0.0	7	8	-1
Inverness	0.6	0.6	-0.1	16	11	5
Norwich	0.4	0.5	-0.1	24	20	4
Humberside	0.3	0.3	0.0	15	13	1
Blackpool	0.3	0.3	0.0	12	10	2
Newquay	0.3	0.5	-0.1	13	10	3
Plymouth	0.1	0.2	-0.1	9	8	1

b) Route level distribution of passengers by route error band, 2009

All flights (domestic and international)

Error band	Proportion of routes	Cumulative proportion
0%-5%	55%	55%
5%-10%	22%	77%
10%-20%	12%	89%
20%-30%	5%	94%
30%-40%	3%	98%
40%-50%	1%	98%
50%+	2%	100%

International flights

Error margin	Proportion of routes	Cumulative proportion
0%-5%	54%	54%
5%-10%	26%	80%
10%-20%	13%	93%
20%-30%	4%	97%
30%-40%	2%	99%
40%-50%	1%	99%
50%+	1%	100%

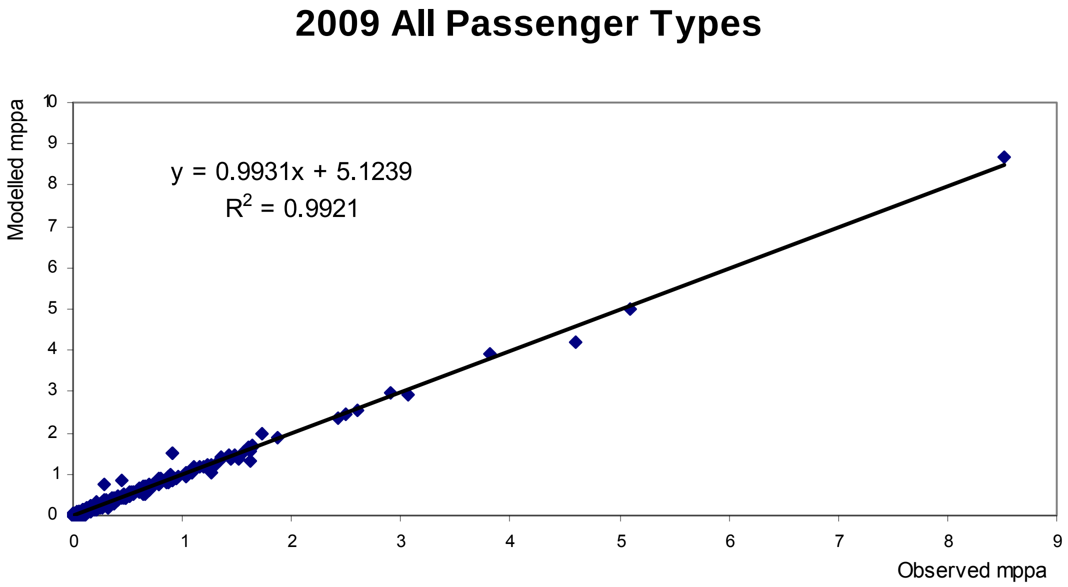
Domestic Flights

Error margin	Proportion of routes	Cumulative proportion
0%-5%	57%	57%
5%-10%	10%	68%
10%-20%	12%	79%
20%-30%	8%	88%
30%-40%	6%	94%
40%-50%	2%	96%
50%+	4%	100%

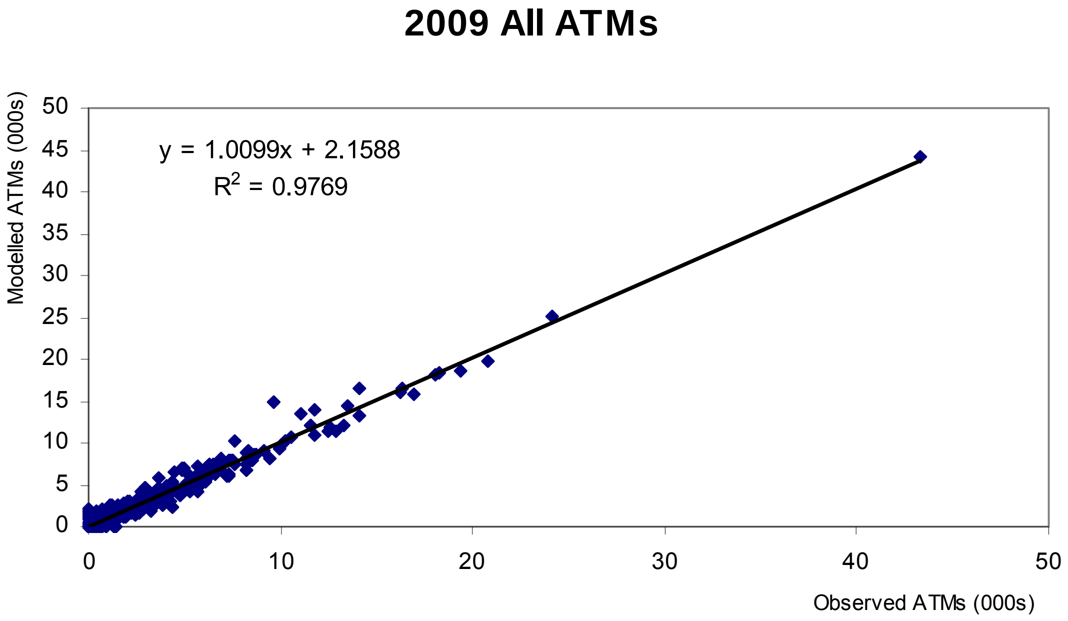
c) Route level scatter plots

All Flights (domestic and international)

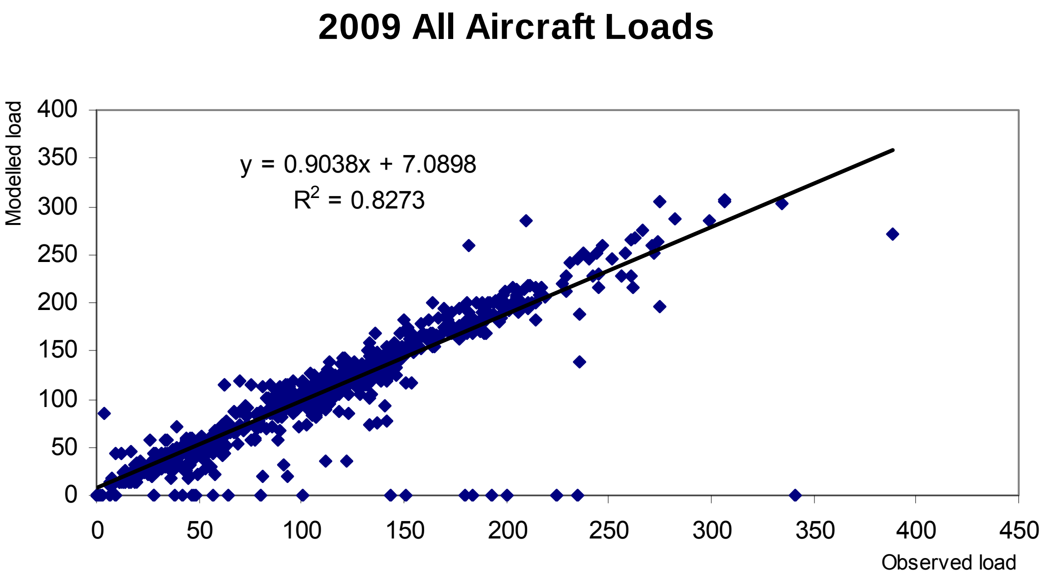
Passengers



ATMs

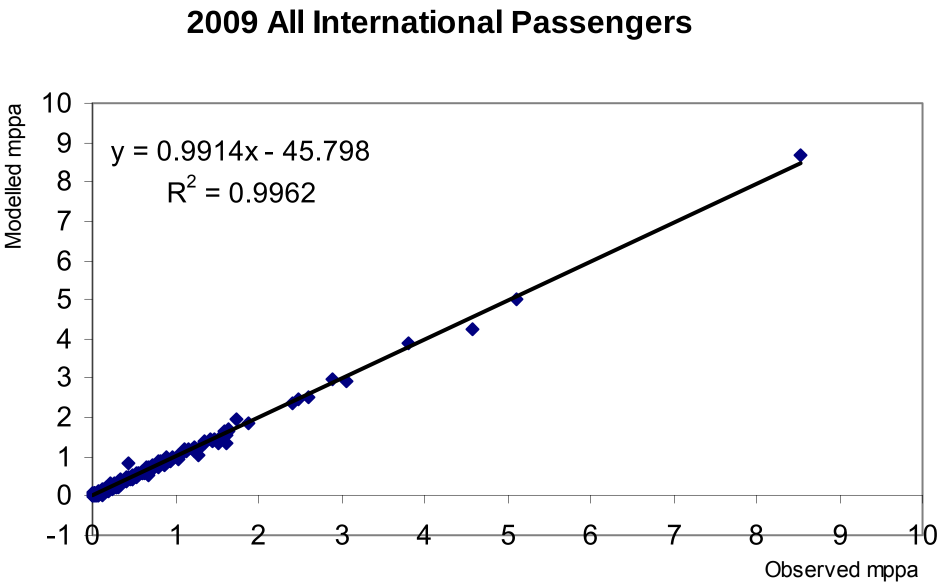


Loads

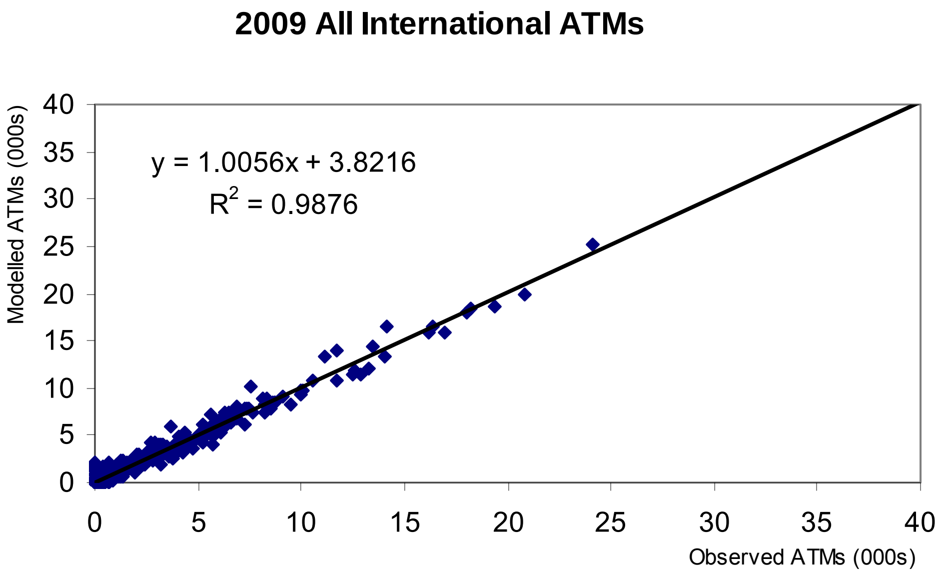


International flights

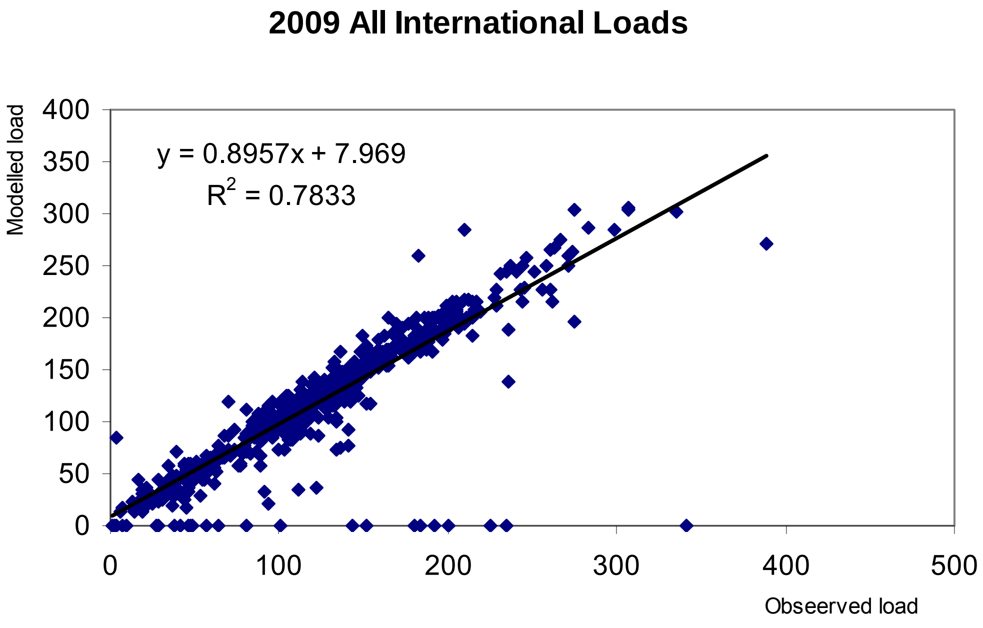
Passengers



ATMs

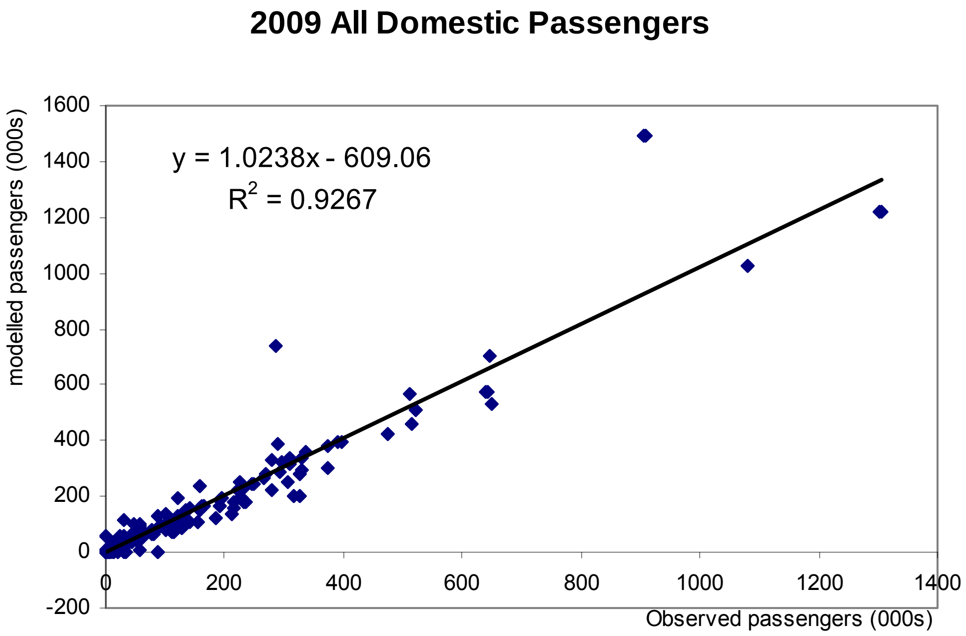

2009 All International ATMs
y = 1.0056x + 3.8216
R2 = 0.9876
Modelled ATMs (000s)
0
5
10
15
20
25
30
35
40
Observed ATMs (000s)
0
5
10
15
20
25
30
35
40

Loads

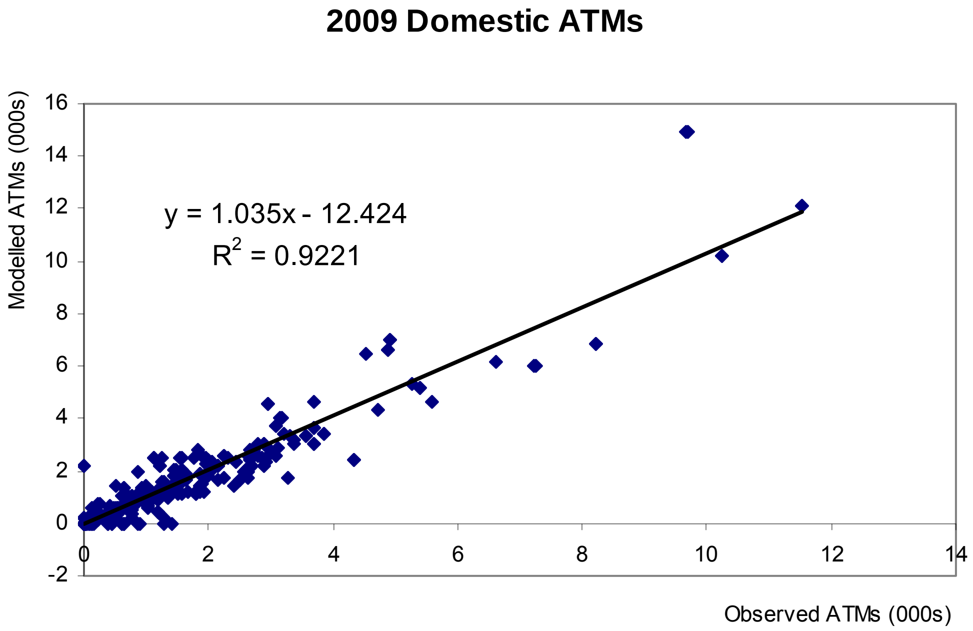

2009 All International Loads
y = 0.8957x + 7.969
R2 = 0.7833
Modelled load
0
50
100
150
200
250
300
350
400
Obseerved load
0
100
200
300
400
500

Domestic flights (scheduled)

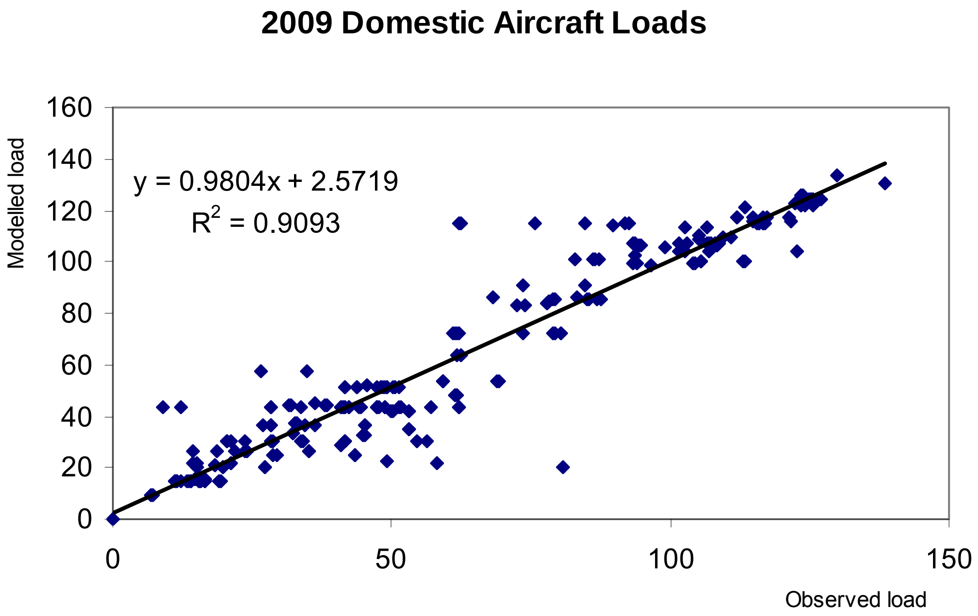
Passengers



ATMs



Loads


2009 Domestic Aircraft Loads
y = 0.9804x + 2.5719
R^2 = 0.9093
Modelled load
Observed load
0
20
40
60
80
100
120
140
160
0
50
100
150

Annex G: Detailed Passenger Forecasts

Table G.1: Unconstrained (NAPDM) forecasts of passengers by purpose and world region (mppa)

(mppa)		2020			2030			2040			2050		
	2008 Base	Low	Central	High	Low	Central	High	Low	Central	High	Low	Central	High
						INTERNATIONAL							
UK Business													
Short Haul	14	18	20	19	20	25	26	24	31	33	26	37	42
OECD	3	3	3	4	3	4	4	4	5	5	4	5	6
NIC	1	1	1	1	1	2	2	2	2	3	2	3	5
LDC	3	4	5	5	6	7	8	7	9	13	9	13	21
All Long Haul	6	8	9	10	10	13	15	13	16	21	15	21	31
All UK Business	20	26	29	29	31	38	41	36	47	55	42	58	73
UK Leisure													
Scheduled Short Haul	55	77	84	79	92	106	108	108	133	142	124	167	189
OECD	10	15	14	12	17	18	16	20	22	20	23	27	26
NIC	2	3	3	2	4	4	3	5	5	4	5	6	6
LDC	12	22	20	14	28	27	21	34	38	31	42	52	46
All Scheduled Long Haul	23	39	37	28	49	49	40	59	65	56	70	85	77
Short Haul Charter	24	11	12	11	13	15	15	15	19	20	18	24	27
Long Haul Charter	5	7	7	5	8	8	7	9	10	9	10	13	12
All Charter	28	18	19	16	21	23	22	25	29	29	28	37	38
All Short Haul	78	88	96	91	106	121	123	123	152	162	142	191	216
All Long Haul	28	46	43	33	57	57	47	69	75	65	81	98	89
All UK Leisure	106	134	140	123	163	178	169	192	227	226	223	289	305
Foreign Business													
Short Haul	11	14	15	15	16	19	20	18	22	24	21	27	30
OECD	2	3	3	3	3	3	4	3	4	4	4	4	4
NIC	0	0	0	1	1	1	1	1	1	2	1	1	3
LDC	2	2	2	2	2	2	2	2	3	3	3	3	4
All Long Haul	4	5	5	5	6	6	7	6	7	9	7	8	11
All Foreign Business	15	19	21	20	22	25	26	25	30	33	28	35	41
Foreign Leisure													
Short Haul	24	33	30	23	40	37	30	47	46	38	54	56	50
OECD	6	8	8	8	8	8	8	9	9	9	9	10	10
NIC	0	1	1	1	1	1	1	2	2	3	2	2	4
LDC	3	4	4	4	5	5	5	6	6	9	7	7	15
All Long Haul	10	13	13	12	15	15	15	17	17	21	19	19	29
All Foreign Leisure	34	47	44	35	55	52	45	64	62	59	73	75	79
International to International Transfer	22	31	30	26	36	35	32	39	39	36	42	44	41
Total UK International	127	160	169	153	193	215	210	228	274	281	265	347	378
Total Foreign International	72	97	94	81	113	112	103	128	131	128	142	154	161
Total International	**199**	**257**	**263**	**234**	**306**	**327**	**313**	**356**	**406**	**409**	**407**	**501**	**539**
						DOMESTIC (Internal "end to end")							
Business	16	18	19	20	20	24	26	24	29	34	27	35	44
Leisure	18	20	23	25	24	31	39	28	41	60	32	53	88
Miscellaneous	1	1	2	2	2	2	2	2	3	3	2	3	5
Total Domestic	**36**	**39**	**44**	**46**	**46**	**57**	**68**	**54**	**73**	**97**	**61**	**91**	**137**
GRAND TOTAL	**235**	**296**	**306**	**280**	**352**	**384**	**381**	**409**	**478**	**506**	**468**	**592**	**675**

Table Notes

1. International figures are terminal passengers and count domestic interlining passengers changing at hub airports.
2. These figures are based on 2008 terminal passenger units from econometric results, when demand is allocated to airports in forecast years the numbers of terminal passengers will vary with the levels of connections at UK hubs
3. Scheduled figures include both "full service" and "no frills" airlines.
4. Domestic passengers exclude those using domestic flights to connect to international flights at a hub airport.
5. Miscellaneous includes passengers at minor airports not surveyed in the source data and other non-surveyed passengers such as domestic charters, oil rig traffic etc., most, but not all, will be domestic.

Table G.2: Constrained terminal passenger forecasts, UK airports (central forecast)

mppa

Airport	**2010**	2020	2030	2040	2050
Heathrow	**65**	80	85	85	85
Gatwick	**30**	35	40	40	40
Manchester	**20**	25	35	55	55
Stansted	**20**	25	35	35	30
Birmingham	**9**	20	25	25	25
Glasgow	**7**	7	10	12	20
Luton	**9**	12	15	15	15
Edinburgh	**9**	13	15	20	20
Bristol	**6**	6	9	12	12
Newcastle	**4**	5	6	7	10
Belfast International	**4**	6	8	10	11
Liverpool	**5**	5	6	8	20
Nottingham East Midlands	**4**	3	4	14	25
Leeds/Bradford	**3**	3	4	7	12
Aberdeen	**3**	3	4	5	6
Prestwick	**2**	2	2	3	4
Belfast City	**3**	3	4	4	4
London City	**3**	7	7	7	7
Southampton	**2**	2	6	7	6
Cardiff	**1**	1	2	3	12
Durham Tees Valley	**<1**	<1	<1	<1	<1
Bournemouth	**<1**	<1	2	6	6
Exeter	**<1**	1	2	3	11
Inverness	**<1**	1	<1	<1	<1
Coventry	**<1**	<1	<1	<1	2
Doncaster Sheffield	**<1**	1	1	2	2
Norwich	**<1**	<1	<1	3	3
Humberside	**<1**	<1	2	2	12
Newquay	**<1**	<1	<1	<1	1
Blackpool	**<1**	<1	<1	<1	<1
Plymouth	**<1**	<1	<1	1	2

Table Notes

1. 2010 figures are CAA actuals.
2. Central demand case
3. Modelled results Core s02 scenario (max use of existing runways).
4. If throughput greater than 15m, throughput mrounded to nearest 5m.
5. Individual airport totals capped strictly to capacity,
   modelling constraint tolerances removed, model output totals may differ slightly.

Table G.3: Constrained terminal passengers, overall forecast range, 2030 & 2050

mppa	Low		**Central**		High	
Airport	2030	2050	**2030**	**2050**	2030	2050
Heathrow	85	85	**85**	**85**	85	85
Gatwick	35	40	**40**	**40**	40	40
Manchester	30	45	**35**	**55**	35	55
Stansted	30	35	**35**	**30**	35	35
Birmingham	20	25	**25**	**25**	25	25
Glasgow	8	11	**10**	**20**	10	20
Luton	14	15	**15**	**15**	15	15
Edinburgh	14	20	**15**	**20**	15	20
Bristol	7	12	**9**	**12**	9	12
Newcastle	5	6	**6**	**10**	6	20
Belfast International	7	9	**8**	**11**	8	25
Liverpool	6	8	**6**	**20**	6	20
Nottingham East Midlands	3	11	**4**	**25**	4	25
Leeds/Bradford	4	7	**4**	**12**	4	12
Aberdeen	4	4	**4**	**6**	4	10
Prestwick	2	2	**2**	**4**	2	9
Belfast City	3	4	**4**	**4**	4	4
London City	7	6	**7**	**7**	7	8
Southampton	4	7	**6**	**6**	6	7
Cardiff	2	3	**2**	**12**	2	12
Durham Tees Valley	<1	<1	**<1**	**<1**	<1	<1
Bournemouth	<1	6	**2**	**6**	2	6
Exeter	1	4	**2**	**11**	2	12
Inverness	<1	<1	**<1**	**<1**	<1	3
Coventry	<1	<1	**<1**	**2**	<1	<1
Doncaster Sheffield	1	2	**1**	**2**	1	2
Norwich	<1	2	**<1**	**3**	<1	3
Humberside	1	2	**2**	**12**	2	6
Newquay	<1	<1	**<1**	**1**	<1	3
Blackpool	<1	<1	**<1**	**<1**	<1	<1
Plymouth	<1	<1	**<1**	**2**	<1	4

Table Notes

1. 2010 figures are CAA actuals.
2. Range is underlying demand scenarios, not runway constraint options.
3. Modelled results Core s02 scenario (max use of existing runways).
4. If throughput greater than 15m, throughput mrounded to nearest 5m.
5. Individual airport totals capped strictly to capacity,
   modelling constraint tolerances removed, model output totals may differ slightly.
6. High demand case required extrapolation to 2040-2050.

Table G.4: Constrained terminal passenger forecasts by world destination, excluding transfers (central forecast)

mppa	2010	2020	2030	2040	2050
Domestic	29	39	50	62	76
Europe (SH)	115	152	189	232	274
Rest of Africa	6	7	9	12	14
United States and Canada	13	18	23	28	34
Caribbean & South America	3	4	5	7	8
Middle East	5	7	9	11	14
Indian Sub-continent	3	4	5	6	7
Far East	4	6	8	10	12
Australasia	2	2	3	3	4
Total (exc. Transfers)	179	240	300	370	442

Notes
1. Modelled results from the core "s02" max use of existing runways scenario
2. Europe SH includes African Mediterranean holidays destinations, excl Egypt and Israel
3. Passengers beginning or ending their journeys in the UK, i.e. excluding international-international transfers

Table G.5: Constrained transfer passengers (central forecast)

mppa	Hub	2010	2020	2030	2040	2050
Domestic-international transfers	Heathrow	6.1	2.6	1.7	0.9	0.2
	Gatwick	1.3	0.7	0.8	0.1	0.0
	Other UK	0.6	0.8	1.4	0.8	0.0
Total		8.0	4.1	3.9	1.8	0.2
UK transfers at overseas hubs	European Hub	2.4	0.7	0.7	1.2	2.1
	Middle East	1.5	0.5	0.6	1.0	1.0
Total		3.9	1.2	1.3	2.1	3.0
International-International transfers	Heathrow	18.6	22.7	25.3	25.8	20.2
	Gatwick	1.7	1.8	1.6	0.6	0.4
	Other UK	1.4	1.4	2.6	4.9	7.9
Total		21.6	25.9	29.5	31.4	28.4
Grand total		33.5	31.2	34.7	35.3	31.7

Notes
1. Modelled results from the core "s02" max use of existing runways scenario
2. Domestic-international transfers at UK airports count each passenger *2 at the UK hub, but not at the UK originating airport
3. Domestic international transfers at overseas airport count each passenger *1 at UK originating airport
4. Proxy European airport hubs in model are Amsterdam, Paris CDG and Frankfurt
5. Proxy Middle East hub is Dubai
6. Transfers at other airports e.g. US or Far East hubs are not modelled
7. International-international transfers have use UK hubs, but have ultimate origin or destination outside the UK
8. 2010 figures are modelled, not actuals

Table G.6: Constrained terminal passengers, regional origins and surface journeys (central forecast)

	max use				
Surface to SE Airports	2010	2020	2030	2040	2050
Northern Ireland	0	0	0	0	0
Scotland	0	0	0	0	0
North	1	1	1	1	0
Midlands	6	7	8	5	2
Wales	1	1	1	1	0
South West	5	6	7	6	3
Regional Total	13	15	16	13	5
SE Passengers	85	114	140	159	166
Total Surface Passengers at SE Airports	***98***	***130***	***157***	***172***	***172***
Other Airports					
Northern Ireland	6	9	11	15	18
Scotland	20	27	33	40	50
North	29	38	48	61	74
Midlands	14	18	24	34	45
Wales	3	4	6	8	11
South West	7	11	15	21	29
Regional Total	79	106	136	179	228
SE Passengers	2	4	7	19	42
Total Surface Passengers at Other Airports	***81***	***110***	***143***	***198***	***270***
I to I Interliners at SE Airports	21	25	28	27	21
I to I Interliners at Regional Airports	0	0	1	4	8
Domestic Interliners at SE Airports	8	4	4	2	0
Domestic Interliners at Regional Airports	0	0	0	0	0
Grand Total	***208***	***269***	***333***	***403***	***470***
Passengers with Regional O-Ds					
Northern Ireland	6	9	11	15	18
Scotland	20	27	33	40	50
North	30	39	49	61	74
Midlands	19	25	31	39	47
Wales	5	6	7	9	11
South West	12	17	21	26	32
South East	87	118	147	179	209
Total Surface Passengers	***179***	***239***	***300***	***370***	***442***

Notes

1. SE Regional Airports: Heathrow, Gatwick, Stansted, Luton, London City, Southampton and Norwich.
2. SE Passengers are from London, South East and Eastern Regions.
3. Domestic Interliners are counted as surface passengers to first airport and interliners (*2) at the hub.
4. Passengers may not total exactly as a result of rounding to nearest million.
5. 2010 Figures are modelled.
6. All Figures include only the 31 modelled UK airports.

Table G.7: Constrained terminal passengers by journey purpose at South East airports (central forecast)

2010	Heathrow		Gatwick		Stansted		Luton		London City		Total London		Other Airports		National	
UK Business	8	18%	3	9%	2	14%	1	15%	1	24%	15	14%	14	17%	29	15%
UK Leisure	21	45%	20	65%	9	52%	4	59%	1	35%	54	53%	56	67%	110	59%
Foreign Business	6	13%	1	5%	1	8%	0	5%	0	14%	9	9%	3	4%	13	7%
Foreign Leisure	11	24%	6	22%	5	26%	2	21%	1	28%	25	24%	11	13%	35	19%
International-International Transfer	19		2		1		0		0		21		0		22	

2020	Heathrow		Gatwick		Stansted		Luton		London City		Total London		Other Airports		National	
UK Business	11	19%	4	10%	3	13%	2	17%	2	25%	21	16%	20	17%	41	17%
UK Leisure	26	46%	21	63%	12	55%	6	54%	3	43%	68	52%	74	65%	142	58%
Foreign Business	7	13%	2	5%	2	7%	1	7%	1	12%	12	9%	4	4%	17	7%
Foreign Leisure	12	22%	8	22%	6	25%	3	22%	1	20%	29	22%	15	14%	45	18%
International-International Transfer	23		2		1		0		0		25		0		26	

2030	Heathrow		Gatwick		Stansted		Luton		London City		Total London		Other Airports		National	
UK Business	12	21%	4	11%	5	15%	2	14%	2	27%	25	17%	26	17%	52	17%
UK Leisure	27	46%	24	64%	18	53%	10	56%	3	39%	81	53%	98	65%	179	59%
Foreign Business	8	13%	2	5%	2	7%	1	7%	1	14%	14	9%	6	4%	20	7%
Foreign Leisure	12	20%	7	20%	8	24%	4	23%	1	20%	33	21%	20	13%	53	17%
International-International Transfer	25		2		1		0		0		28		1		30	

2040	Heathrow		Gatwick		Stansted		Luton		London City		Total London		Other Airports		National	
UK Business	14	22%	5	12%	5	14%	3	18%	2	33%	29	18%	34	17%	64	17%
UK Leisure	30	46%	24	62%	19	53%	9	51%	2	36%	84	51%	137	66%	221	59%
Foreign Business	9	13%	2	6%	3	8%	1	8%	1	15%	16	10%	8	4%	24	6%
Foreign Leisure	13	19%	7	19%	9	25%	4	23%	1	16%	34	21%	29	14%	63	17%
International-International Transfer	26		1		1		0		0		27		4		31	

2050	Heathrow		Gatwick		Stansted		Luton		London City		Total London		Other Airports		National	
UK Business	16	25%	5	12%	5	16%	4	26%	2	30%	33	20%	44	16%	77	17%
UK Leisure	26	40%	27	65%	16	51%	7	45%	3	39%	79	49%	183	66%	262	59%
Foreign Business	11	16%	2	5%	3	8%	1	9%	1	17%	18	11%	11	4%	28	6%
Foreign Leisure	13	19%	8	18%	8	25%	3	21%	1	14%	33	20%	41	15%	74	17%
International-International Transfer	20		0		0		0		0		21		8		28	

Table Notes

1. All figures are modelled, including 2010.
2. Modelled results from the core "s02" max use of existing runways scenario
3. International-international interliners are not split by purpose in the modelling, but in the base year were around 73% leisure purposes
4. Direct model output, airport totals may marginally exceed capacity and totals shown in G.2/G.3

Table G.8: Constrained terminal passengers by international/domestic, scheduled/charter and year (central forecast)

mppa	Heathrow	Gatwick	Stansted	Luton	London City	London total	London share	Other Airports	Total
2010									
International Scheduled	62	24	17	6	2	111	70%	47	158
International Charter	0	6	1	0	0	7	33%	15	22
Domestic (excl. Transfers)	3	2	1	1	0	7	24%	22	29
2020									
International Scheduled	76	29	21	10	5	141	67%	68	210
International Charter	0	5	0	0	0	6	26%	16	21
Domestic (excl. Transfers)	3	2	2	2	1	9	23%	30	39
2030									
International Scheduled	82	30	30	16	6	164	64%	94	258
International Charter	0	6	0	0	0	7	25%	20	26
Domestic (excl. Transfers)	3	2	4	2	1	11	22%	39	50
2040									
International Scheduled	89	30	33	14	6	171	55%	138	309
International Charter	0	6	0	0	0	6	19%	26	33
Domestic (excl. Transfers)	2	3	4	3	1	13	21%	49	62
2050									
International Scheduled	84	31	27	11	7	161	45%	195	356
International Charter	0	6	0	0	0	6	16%	33	39
Domestic (excl. Transfers)	2	4	5	5	0	16	21%	60	76

Table Notes

1. Passengers are counted at the 31 UK airports included in the DfT model.
2. All figures are modelled, including 2010.
3. Modelled results from the core "s02" max use of existing runways scenario
4. International passengers include transfer passengers counted as additional arrivals and departures at the hub airport
5. Domestic passengers are those starting and finishing the journey in the UK..
6. Direct model output, airport totals may marginally exceed capacity and totals shown in G.2/ G.3

Table G.9: Constrained terminal passengers, by domestic/short haul/long haul, South East airports (central forecast)

mppa	Heathrow	Gatwick	Stansted	Luton	Total
2010					
Long Haul	34	6	0	0	41
Short Haul	28	24	17	6	75
Domestic	3	2	1	1	6
Long Haul Share	*53%*	*20%*	*1%*	*0%*	*33%*
2020					
Long Haul	45	5	0	0	50
Short Haul	31	29	21	10	91
Domestic	3	2	2	2	8
Long Haul Share	*57%*	*15%*	*0%*	*0%*	*34%*
2030					
Long Haul	53	7	0	0	60
Short Haul	29	30	30	16	105
Domestic	3	2	4	2	10
Long Haul Share	*63%*	*18%*	*0%*	*0%*	*34%*
2040					
Long Haul	62	6	0	0	68
Short Haul	27	30	33	14	104
Domestic	2	3	4	3	12
Long Haul Share	*68%*	*16%*	*0%*	*0%*	*37%*
2050					
Long Haul	55	8	0	0	63
Short Haul	29	30	27	11	98
Domestic	2	4	5	5	16
Long Haul Share	*64%*	*18%*	*0%*	*0%*	*36%*

Table Notes

1. All figures are modelled, including 2010.
2. Modelled results from the core "s02" max use of existing runways scenario
3. Long haul includes medium haul e.g. United States and Middle East but excludes Eastern Europe and Russia
4. Direct model output, airport totals may marginally exceed capacity and totals shown in G.2/G.3

Table G.10 Constrained terminal passengers, journey purpose and destination detail, main airports (central forecast)

2010	Domestic (Excl. intl transfers)					Short Haul						Long Haul						Grand
mppa	UKBus	UKLei	FoBus	FoLei	Total	UKBus	UKLei	FoBus	FoLei	I to I	Total	UKBus	UKLei	FoBus	FoLei	I to I	Total	Total
Heathrow	1	1	0	0	2	4	8	3	5	7	28	3	11	3	6	11	34	65
Gatwick	1	1	0	0	2	2	14	1	5	1	24	0	4	0	1	0	6	32
Stansted	1	1	0	0	1	2	8	1	5	1	17	0	0	0	0	0	0	19
Luton	0	0	0	0	1	1	4	0	2	0	6	0	0	0	0	0	0	7
London City	0	0	0	0	0	0	1	0	1	0	2	0	0	0	0	0	0	3
London Total	3	3	0	0	7	9	35	7	17	10	77	3	16	3	7	12	41	125
Manchester	1	1	0	0	1	1	9	1	2	0	13	0	4	0	1	0	5	20
Birmingham	1	1	0	0	1	0	5	0	1	0	7	0	1	0	0	0	1	9
Glasgow	1	1	0	0	2	0	2	0	1	0	3	0	1	0	0	0	1	6
Edinburgh	2	2	0	0	4	1	2	0	1	0	4	0	0	0	0	0	0	9
Bristol	0	1	0	0	1	0	3	0	1	0	4	0	0	0	0	0	0	5
Newcastle	0	1	0	0	1	0	2	0	0	0	3	0	0	0	0	0	0	4
Belfast International	1	2	0	0	3	0	1	0	0	0	2	0	0	0	0	0	0	4
Liverpool	0	0	0	0	1	0	3	0	1	0	4	0	0	0	0	0	0	5
East Midlands	0	0	0	0	1	0	3	0	0	0	3	0	0	0	0	0	0	4
Other Airports in Model	3	4	0	0	7	1	7	1	2	0	10	0	0	0	0	0	0	18
Regional Total	10	12	0	0	22	4	38	3	9	0	54	0	6	0	2	0	8	84
National Total	13	15	0	0	29	12	74	9	26	10	131	4	22	3	9	12	49	209

2030	Domestic (Excl. intl transfers)					Short Haul						Long Haul						Grand
mppa	UKBus	UKLei	FoBus	FoLei	Total	UKBus	UKLei	FoBus	FoLei	I to I	Total	UKBus	UKLei	FoBus	FoLei	I to I	Total	Total
Heathrow	1	1	0	0	3	6	6	4	3	10	29	5	20	4	9	15	53	85
Gatwick	1	1	0	0	2	3	18	2	6	1	30	0	5	0	1	1	7	39
Stansted	2	2	0	0	4	3	15	2	8	1	30	0	0	0	0	0	0	34
Luton	1	1	0	0	2	2	9	1	4	0	16	0	0	0	0	0	0	17
London City	0	0	0	0	1	1	2	1	1	0	6	0	0	0	0	0	0	7
London Total	5	6	0	0	11	15	51	10	23	12	110	6	24	4	10	16	60	181
Manchester	1	1	0	0	2	2	17	2	5	1	26	1	5	0	1	0	8	35
Birmingham	1	1	0	0	2	1	12	1	3	0	17	0	5	0	1	0	7	26
Glasgow	3	2	0	0	5	0	2	0	1	0	3	0	1	0	0	0	1	10
Edinburgh	3	3	0	0	6	1	5	1	2	0	9	0	1	0	0	0	1	16
Bristol	1	1	0	0	2	0	6	0	1	0	7	0	0	0	0	0	0	9
Newcastle	1	1	0	0	2	0	3	0	1	0	4	0	0	0	0	0	0	6
Belfast International	2	3	0	0	5	0	3	0	0	0	3	0	0	0	0	0	0	8
Liverpool	0	1	0	0	1	0	4	0	1	0	5	0	0	0	0	0	0	6
East Midlands	1	0	0	0	1	0	2	0	0	0	3	0	0	0	0	0	0	4
Other Airports in Model	5	7	0	0	13	2	13	1	3	0	18	0	1	0	0	0	1	32
Regional Total	17	21	0	1	39	8	65	5	17	1	95	1	13	1	3	0	18	152
National Total	22	26	1	1	50	23	115	15	40	13	206	7	37	5	13	16	78	334

Table G.10 (Continued): Constrained terminal passengers, journey purpose and destination detail, main airports (central forecast)

2050	Domestic (Excl. intl transfers)					Short Haul						Long Haul						Grand
mppa	UKBus	UKLei	FoBus	FoLei	Total	UKBus	UKLei	FoBus	FoLei	I to I	Total	UKBus	UKLei	FoBus	FoLei	I to I	Total	Total
Heathrow	1	1	0	0	2	8	5	5	3	7	29	7	20	5	9	13	55	86
Gatwick	2	2	0	0	4	2	19	2	7	0	30	1	6	0	1	0	8	41
Stansted	2	3	0	0	5	3	14	3	8	0	27	0	0	0	0	0	0	32
Luton	3	3	0	0	5	2	5	1	3	0	11	0	0	0	0	0	0	16
London City	0	0	0	0	0	2	3	1	1	0	7	0	0	0	0	0	0	7
London Total	8	8	0	0	16	17	45	12	23	7	105	8	26	5	10	14	63	183
Manchester	1	2	0	0	3	3	18	2	6	3	32	1	12	1	2	4	20	55
Birmingham	1	1	0	0	3	2	7	1	3	0	13	1	8	0	2	0	11	27
Glasgow	5	4	0	0	9	0	5	0	2	0	8	0	2	0	1	0	2	19
Edinburgh	4	4	0	0	9	1	5	1	2	0	9	0	1	0	0	0	2	20
Bristol	1	1	0	0	2	1	7	0	2	0	10	0	0	0	0	0	0	12
Newcastle	1	1	0	0	3	0	6	0	1	0	7	0	0	0	0	0	0	10
Belfast International	3	4	0	0	7	0	3	0	0	0	4	0	0	0	0	0	0	11
Liverpool	1	2	0	0	2	1	13	1	3	0	17	0	0	0	0	0	0	19
East Midlands	1	1	0	0	2	1	13	1	4	0	19	0	3	0	1	0	4	25
Other Airports in Model	9	11	0	0	21	5	44	3	10	0	61	0	5	0	1	0	6	88
Regional Total	27	31	1	1	60	14	121	9	34	4	181	2	31	1	7	4	45	286
National Total	35	39	1	1	76	32	166	21	56	11	286	10	57	7	16	18	108	470

Table notes

1. Domestic total only includes "end to end" domestic travel and excludes transfers
2. Modelled results from the core "s02" max use of existing runways scenario
3. Long haul includes "medium haul" destinations to Midle East and North America.
4. UK to Channel Isles counted as short haul
5. Direct model output, airport totals may marginally exceed capacity and totals shown in G.2/G.3

Table G.11: Constrained passengers: revenue passenger-kms (billion)

	Low	Central	High
2010	575	575	575
2015	648	660	689
2020	726	763	801
2025	795	855	919
2030	859	943	1,048
2035	923	1,035	1,184
2040	988	1,148	1,383
2045	1,053	1,280	1,553
2050	1,115	1,347	1,753

1. Modelled results from the core "s02" max use of existing runways scenario
2. Revenue Passenger-kms (RPK) counted only for passengers at the 31 UK airports in the model.
3. RPK counts both arriving and departing passengers.

Table G.12: Freighter payload (central forecast)

	Total Air Tonnage (000s)	*Bellyhold tonnage (000s)*	Freighter Tonnage (000s)	Average Freighter Payload (tonnes)	Freighter Average Distance (kms)
2010	2,363	*1,172*	1,192	16	1,627
2015	3,016	*1,443*	1,573	21	1,824
2020	3,849	*1,675*	2,174	24	1,895
2025	4,913	*1,943*	2,970	28	1,918
2030	6,271	*2,131*	4,139	32	1,926
2035	7,777	*2,644*	5,134	37	1,929
2040	9,193	*3,125*	6,068	40	1,929
2045	10,351	*3,518*	6,833	43	1,930
2050	11,097	*3,772*	7,325	45	1,930

Annex H: Detailed ATM and CO_2 Forecasts

Table H.1: Air Transport Movements, by domestic/international, scheduled/charter, passenger/freight, and year (central forecast)

ATM 000s	International Scheduled	International Charter	Domestic	Freight	Total
2010	1,230	120	600	70	2,020
2015	1,390	90	630	70	2,190
2020	1,570	110	710	80	2,470
2025	1,740	120	780	100	2,730
2030	1,910	130	820	110	2,960
2035	2,090	140	870	120	3,220
2040	2,340	160	950	110	3,560
2045	2,600	170	970	70	3,820
2050	2,720	190	1,000	70	3,980

Notes

1. ATMs are counted at the 31 UK airports included in the DfT model.
2. All figures are modelled, including 2010.
3. Modelled results from s02
4. ATMs exclude general aviation, air taxis, positional, diplomatic, military and other miscellaneous flights.
5. ATMs rounded to the nearest 10,000, total may not sum due to this rounding.

Table H.2: Air Transport Movements, by South East airport and year (central forecast)

ATM 000s	Heathrow	Gatwick	Stansted	Luton	London City	Total London	London Share	Other Airports	Total
2010	460	240	160	60	60	990	49%	1,030	2,020
2015	480	250	160	80	80	1,040	48%	1,130	2,170
2020	480	260	180	100	120	1,140	47%	1,310	2,450
2025	480	260	240	120	120	1,230	45%	1,480	2,710
2030	480	260	260	130	120	1,250	43%	1,660	2,910
2035	480	260	260	140	120	1,250	40%	1,900	3,150
2040	480	260	260	140	120	1,250	36%	2,240	3,490
2045	470	250	250	140	120	1,230	33%	2,530	3,760
2050	480	260	230	130	110	1,210	31%	2,720	3,930

Notes

1. Other ATMs are counted at the remaining 26 UK airports included in the DfT model.
2. All figures are modelled, including 2010
3. ATMs rounded to the nearest 10,000, totals may not sum due to this rounding.
4. Model results for the Central Demand Case, s02 scenario (max use)
5. ATMs exclude general aviation, air taxis, positional, diplomatic, military and other miscellaneous flights.
6. Individual airport totals capped strictly to capacity, modelling constraint tolerances removed, model output totals may differ.

Table H.3: ATM forecasts (000s) at UK airports (central forecast)

Airport	**2010**	2020	2030	2040	2050
Heathrow	**450**	480	480	480	480
Gatwick	**230**	260	260	260	260
Manchester	**150**	230	280	400	390
Stansted	**140**	180	260	260	230
Birmingham	**85**	160	210	200	200
Glasgow	**70**	55	75	90	140
Luton	**75**	95	130	140	130
Edinburgh	**100**	170	190	230	180
Bristol	**55**	55	85	120	120
Newcastle	**50**	50	55	65	95
Belfast International	**40**	60	75	95	110
Liverpool	**45**	40	55	65	170
Nottingham East Midlands	**55**	55	75	210	220
Leeds/Bradford	**35**	35	45	65	110
Aberdeen	**90**	90	100	110	120
Prestwick	**15**	20	25	25	30
Belfast City	**40**	50	50	50	50
London City	**65**	120	120	120	110
Southampton	**40**	50	100	130	110
Cardiff	**15**	20	30	50	110
Durham Tees Valley	**5**	<5	<5	<5	10
Bournemouth	**5**	15	25	80	120
Exeter	**15**	25	25	45	100
Inverness	**15**	30	15	15	15
Coventry	**<5**	<5	<5	<5	30
Doncaster Sheffield	**5**	10	10	25	25
Norwich	**20**	30	45	70	50
Humberside	**15**	30	40	45	120
Newquay	**10**	10	15	15	25
Blackpool	**10**	5	5	10	10
Plymouth	**5**	15	15	25	40

Table Notes
1. 2010 figures are CAA actuals.
2. All throughputs rounded to 5 thousand.
and if throughput greater than 100 thousand, throughput rounded to nearest 10,000.
3. Modelled results Core s02 scenario (max use of existing runways).
4. Individual airport totals capped strictly to capacity,
modelling constraint tolerances removed, model output totals may differ slightly.

Table H.4: ATM forecasts (000s) at UK airports, overall forecast range

	Low		**Central**		High	
Airport	2030	2050	**2030**	**2050**	2030	2050
Heathrow	480	480	**480**	**480**	480	480
Gatwick	260	260	**260**	**260**	260	260
Manchester	240	330	**280**	**390**	340	420
Stansted	250	260	**260**	**230**	260	260
Birmingham	180	210	**210**	**200**	210	210
Glasgow	60	85	**75**	**140**	85	230
Luton	120	130	**130**	**130**	130	120
Edinburgh	190	230	**190**	**180**	220	230
Bristol	65	120	**85**	**120**	120	120
Newcastle	50	60	**55**	**95**	65	190
Belfast International	65	90	**75**	**110**	95	260
Liverpool	50	65	**55**	**170**	65	230
Nottingham East Midlands	70	150	**75**	**220**	130	230
Leeds/Bradford	40	65	**45**	**110**	55	150
Aberdeen	90	100	**100**	**120**	110	230
Prestwick	20	20	**25**	**30**	30	75
Belfast City	50	50	**50**	**50**	50	50
London City	120	120	**120**	**110**	120	120
Southampton	65	130	**100**	**110**	130	120
Cardiff	30	40	**30**	**110**	40	230
Durham Tees Valley	<5	<5	**<5**	**10**	<5	10
Bournemouth	15	100	**25**	**120**	95	95
Exeter	25	45	**25**	**100**	50	210
Inverness	10	15	**15**	**15**	15	45
Coventry	<5	<5	**<5**	**30**	<5	<5
Doncaster Sheffield	10	15	**10**	**25**	30	25
Norwich	40	55	**45**	**50**	55	80
Humberside	40	50	**40**	**120**	40	160
Newquay	10	10	**15**	**25**	20	110
Blackpool	5	5	**5**	**10**	10	30
Plymouth	15	15	**15**	**40**	25	80

Table Notes

1. 2010 figures are CAA actuals.
2. Range is underlying demand scenarios, not runway constraint options.
3. All throughputs rounded to 5 thousand.
   and if throughput greater than 100,000, throughput rounded to nearest 10,000.
4. Modelled results Core s02 scenario (max use of existing runways).
5. High demand case required extrapolation to 2040-2050.
6. Individual airport totals capped strictly to capacity,
   modelling constraint tolerances removed, model output totals may differ slightly.

Table H.5: CO_2 emissions by UK airport, 2030/2050, central and overall forecast range

million tonnes CO_2	**2030**			**2050**		
	Low	**Central**	High	Low	**Central**	High
Heathrow	23.5	**23.1**	24.7	16.8	**14.9**	15.5
Birmingham	1.7	**4.3**	2.9	1.8	**4.0**	2.4
Gatwick	3.4	**3.8**	3.6	3.2	**3.7**	3.5
Manchester	3.2	**3.7**	4.5	3.6	**5.9**	6.6
Stansted	1.8	**2.0**	4.2	2.2	**1.8**	2.5
Luton	0.7	**1.0**	0.8	0.8	**0.6**	0.7
Edinburgh	0.9	**1.0**	1.2	1.1	**1.1**	0.9
Glasgow	0.6	**0.7**	0.9	0.6	**1.1**	1.9
Bristol	0.4	**0.6**	0.9	0.8	**0.8**	0.8
London City	0.5	**0.6**	0.6	0.3	**0.6**	0.7
Leeds/Bradford	0.5	**0.5**	0.6	0.6	**1.1**	2.0
Southampton	0.3	**0.4**	0.6	0.4	**0.3**	0.3
Belfast International	0.3	**0.4**	0.5	0.4	**0.5**	1.1
Newcastle	0.3	**0.3**	0.4	0.3	**0.5**	1.0
Liverpool	0.3	**0.3**	0.4	0.4	**1.2**	2.2
East Midlands	0.2	**0.3**	0.6	1.7	**3.3**	3.5
Aberdeen	0.2	**0.3**	0.3	0.2	**0.2**	0.3
Bournemouth	0.1	**0.2**	0.6	0.5	**0.6**	0.6
Humberside	0.2	**0.2**	0.2	0.2	**1.1**	1.9
Prestwick	0.1	**0.2**	0.2	0.2	**0.3**	0.7
Belfast City	0.1	**0.2**	0.2	0.1	**0.2**	0.3
Exeter	0.1	**0.1**	0.3	0.2	**1.1**	3.0
Cardiff	0.1	**0.1**	0.1	0.1	**0.6**	1.8
Doncaster Sheffield	0.1	**0.1**	0.2	0.1	**0.2**	0.2
Norwich	0.0	**0.1**	0.1	0.1	**0.1**	0.1
Inverness	0.0	**0.1**	0.1	0.0	**0.1**	0.1
Newquay	0.0	**0.0**	0.1	0.0	**0.1**	0.1
Plymouth	0.0	**0.0**	0.1	0.0	**0.1**	0.2
Durham Tees Valley	0.0	**0.0**	0.0	0.0	**0.1**	0.0
Blackpool	0.0	**0.0**	0.0	0.0	**0.0**	0.0
Coventry	0.0	**0.0**	0.0	0.0	**0.1**	0.0
Ground (APU)	0.5	**0.6**	0.7	0.6	**0.8**	1.0
Freight	2.2	**1.9**	2.0	1.7	**1.1**	1.6
Residual	0.5	**0.6**	0.7	0.4	**0.6**	0.9
Total	43.2	**47.6**	53.4	39.6	**49.0**	58.4

Notes

1. Low CO_2 assumes low demand scenario
2. High CO_2 assumes high demand scenario
3. All cases are for the option 's02': 'Best case' scenario,
4. Airports sorted on 2030 central CO_2 emissions.
5. CO_2 emissions from UK departures only.
6. APU, freight and residual add-on not allocated to airports.

Table H.6: CO_2 emissions at airport level 2005 2030 and 2050 detailed (central forecast)

	Total CO_2 (mtCO_2) in 2010	Share of 2010 Total CO_2	Total CO2 (mtCO2) in 2030	Share of 2030 Total CO2	Total CO2 (mtCO2) in 2050	Share of 2050 Total CO2
Heathrow	18.9	56.4%	23.1	48.5%	14.9	30.4%
Birmingham	0.9	2.6%	4.3	9.1%	4.0	8.2%
Gatwick	3.8	11.4%	3.8	8.0%	3.7	7.6%
Manchester	2.3	7.0%	3.7	7.8%	5.9	12.0%
Stansted	1.3	3.8%	2.0	4.2%	1.8	3.6%
Luton	0.5	1.6%	1.0	2.1%	0.6	1.3%
Edinburgh	0.5	1.6%	1.0	2.0%	1.1	2.3%
Glasgow	0.5	1.6%	0.7	1.5%	1.1	2.3%
Bristol	0.4	1.1%	0.6	1.3%	0.8	1.7%
London City	0.2	0.6%	0.6	1.2%	0.6	1.2%
Leeds/Bradford	0.2	0.6%	0.5	1.1%	1.1	2.3%
Southampton	0.1	0.3%	0.4	0.9%	0.3	0.6%
Belfast International	0.2	0.7%	0.4	0.8%	0.5	1.1%
Newcastle	0.3	0.9%	0.3	0.7%	0.5	1.1%
Liverpool	0.3	0.8%	0.3	0.7%	1.2	2.4%
Nottingham East Midlands	0.3	0.9%	0.3	0.6%	3.3	6.8%
Aberdeen	0.2	0.5%	0.3	0.5%	0.2	0.5%
Bournemouth	0.1	0.3%	0.2	0.4%	0.6	1.3%
Humberside	0.0	0.1%	0.2	0.4%	1.1	2.2%
Prestwick	0.1	0.3%	0.2	0.4%	0.3	0.6%
Belfast City	0.1	0.3%	0.2	0.3%	0.2	0.5%
Exeter	0.1	0.2%	0.1	0.2%	1.1	2.3%
Cardiff	0.1	0.3%	0.1	0.2%	0.6	1.3%
Doncaster Sheffield	0.1	0.3%	0.1	0.1%	0.2	0.3%
Norwich	0.0	0.1%	0.1	0.1%	0.1	0.3%
Inverness	0.0	0.1%	0.1	0.1%	0.1	0.1%
Newquay	0.0	0.1%	0.0	0.1%	0.1	0.1%
Plymouth	0.0	0.0%	0.0	0.1%	0.1	0.3%
Durham Tees Valley	0.0	0.0%	0.0	0.0%	0.1	0.1%
Blackpool	0.0	0.0%	0.0	0.0%	0.0	0.0%
Coventry	0.0	0.0%	0.0	0.0%	0.1	0.2%
Ground (APU)	0.4	1.2%	0.6	1.2%	0.8	1.6%
Freight	1.1	3.2%	1.9	4.1%	1.1	2.2%
Residual	0.4	1.2%	0.6	1.2%	0.6	1.1%
Total	33.4		47.6		49.0	

Notes

1.Total Includes around residual adjustment to ensure consistency with DECC bunker fuel outturn estimate.

2. CO_2 counted for UK departures only.

3. Option 's02': 'max use' scenario

4. Table sorted by CO_2 in 2030.

5. APU, freight and residual add-on not allocated to airports.

Table H.7: ATMs (short vs long haul), available seat-kms, average flight length, and CO_2 emissions (short vs long haul), by UK airport, 2010 (central forecast)

2010	Short Haul & Domestic ATMs (000s)	Long Haul ATMs (000s)	Available Seat-Kms (m)	Average Flight Length (km)	Short Haul & Domestic CO_2 ($mtCO_2$)	Long Haul CO_2 ($mtCO_2$)	Total CO_2 ($mtCO_2$)
Heathrow	303	157	428,638	3,114	2.3	16.6	18.9
Gatwick	210	29	101,707	1,854	1.7	2.1	3.8
Manchester	158	17	63,834	1,552	1.1	1.3	2.3
Stansted	152	1	38,795	1,299	1.2	0.1	1.3
Birmingham	88	4	24,024	1,263	0.6	0.3	0.9
Glasgow	52	3	13,744	1,148	0.3	0.2	0.5
Luton	57	0	15,778	1,406	0.5	0.0	0.5
Edinburgh	93	2	12,419	839	0.5	0.1	0.5
Bristol	49	1	9,722	1,130	0.3	0.1	0.4
Newcastle	41	1	9,218	1,164	0.3	0.1	0.3
Nottingham East Midlands	36	0	8,820	1,286	0.3	0.0	0.3
Liverpool	38	0	8,270	1,148	0.3	0.0	0.3
Belfast International	38	0	5,907	916	0.2	0.0	0.2
Cardiff	18	0	2,894	949	0.1	0.0	0.1
Leeds/Bradford	30	0	5,211	985	0.2	0.0	0.2
Prestwick	12	0	3,258	1,387	0.1	0.0	0.1
Aberdeen	45	0	3,263	760	0.2	0.0	0.2
London City	58	0	3,971	725	0.2	0.0	0.2
Durham Tees Valley	4	0	212	483	0.0	0.0	0.0
Southampton	38	0	1,689	494	0.1	0.0	0.1
Bournemouth	11	0	2,459	2,002	0.1	0.0	0.1
Coventry	0	0	0		0.0	0.0	0.0
Belfast City	35	0	1,737	420	0.1	0.0	0.1
Exeter	15	0	1,469	763	0.1	0.0	0.1
Doncaster Sheffield	8	0	2,737	1,564	0.1	0.0	0.1
Norwich	9	0	412	489	0.0	0.0	0.0
Humberside	5	0	406	618	0.0	0.0	0.0
Inverness	7	0	454	544	0.0	0.0	0.0
Blackpool	2	0	307	1,181	0.0	0.0	0.0
Newquay	8	0	219	388	0.0	0.0	0.0
Plymouth	7	0	128	364	0.0	0.0	0.0
Total	1,628	216	771,702	1,712	11	21	32
Total CO_2 including freight, ground delay emissions and residual adjustment to DECC 2008 estimate							33.4

Notes

1. Option 's02': 'Max use' scenario
2. Seat-Kms and average distances are next stop only.
3. Distances are Great Circle and uprated by 8% for indirect routeing and stacking.
4. CO_2 emissions from UK departures only.
5. Airport level CO_2 emissions exclude freight and ground (delay) emissions.
6. Airports sorted on descending available seat-kms.
7. "0" means non-zero, or rounds to zero at 0dp.
8. ATMs are direct model output, airport totals may marginally exceed capacity and totals shown in H.2-H.4

Table H.8: ATMs (short vs long haul), available seat-kms, average flight length, and CO_2 emissions (short vs long haul), by UK airport, 2030 (central forecast)

2030	Short Haul & Domestic ATMs (000s)	Long Haul ATMs (000s)	Available Seat-Kms (m)	Average Flight Length (km)	Short Haul & Domestic CO_2 ($mtCO_2$)	Long Haul CO_2 ($mtCO_2$)	Total CO_2 ($mtCO_2$)
Heathrow	276	210	597,269	3,747	2	21	23
Gatwick	237	29	115,729	1,959	2	2	4
Manchester	248	29	108,508	1,682	2	2	4
Stansted	252	0	62,557	1,229	2	0	2
Birmingham	182	27	123,013	2,104	1	3	4
Glasgow	64	4	19,107	1,097	0	0	1
Luton	129	0	29,920	1,198	1	0	1
Edinburgh	139	5	24,041	986	1	0	1
Bristol	84	0	16,742	1,272	1	0	1
Newcastle	56	0	9,894	1,028	0	0	0
Nottingham East Midlands	41	0	6,963	1,207	0	0	0
Liverpool	50	0	10,035	1,130	0	0	0
Belfast International	68	0	10,288	926	0	0	0
Cardiff	22	0	2,261	699	0	0	0
Leeds/Bradford	41	4	13,791	1,435	0	0	1
Prestwick	19	0	5,763	1,540	0	0	0
Aberdeen	61	0	4,438	744	0	0	0
London City	131	0	12,525	855	1	0	1
Durham Tees Valley	3	0	64	338	0	0	0
Southampton	104	0	8,077	755	0	0	0
Bournemouth	27	0	4,522	1,606	0	0	0
Coventry	0	0	0		0	0	0
Belfast City	53	0	2,714	407	0	0	0
Exeter	27	0	2,329	730	0	0	0
Doncaster Sheffield	11	0	2,665	1,065	0	0	0
Norwich	18	0	765	487	0	0	0
Humberside	23	0	4,809	1,878	0	0	0
Inverness	11	0	824	894	0	0	0
Blackpool	1	0	23	220	0	0	0
Newquay	16	0	438	400	0	0	0
Plymouth	14	0	380	398	0	0	0
Total	2,407	309	1,200,455	1,759	16	29	44
Total CO_2 including freight, ground delay emissions and residual adjustment to DECC 2008 estimate							47.6

Notes
1. Option 's02': 'Max use' scenario
2. Seat-Kms and average distances are next stop only.
3. Distances are Great Circle and uprated by 8% for indirect routeing and stacking.
4. CO2 emissions from UK departures only.
5. Airport level CO2 emissions exclude freight and ground (delay) emissions.
6. Airports sorted on descending available seat-kms.
7. "0" means non-zero, or rounds to zero at 0dp.
8. ATMs are direct model output, airport totals may marginally exceed capacity and totals shown in H.2-H.4

Table H.9: ATMs (short vs long haul), available seat-kms, average flight length, and CO_2 emissions (short vs long haul), by UK airport, 2050 (central forecast)

2050	Short Haul & Domestic ATMs (000s)	Long Haul ATMs (000s)	Available Seat-Kms (m)	Average Flight Length (km)	Short Haul & Domestic CO_2 ($mtCO_2$)	Long Haul CO_2 ($mtCO_2$)	Total CO_2 ($mtCO_2$)
Heathrow	261	213	605,504	3,776	2	13	14.9
Gatwick	230	32	132,198	2,159	2	2	3.7
Manchester	312	71	210,924	2,116	2	4	5.9
Stansted	218	0	59,017	1,309	2	0	1.8
Birmingham	155	44	178,695	2,556	1	3	4.0
Glasgow	127	9	42,884	1,266	1	0	1.1
Luton	125	0	18,623	779	1	0	0.6
Edinburgh	152	12	40,038	1,221	1	0	1.1
Bristol	122	0	25,958	1,329	1	0	0.8
Newcastle	92	0	18,101	1,109	1	0	0.5
Nottingham East Midlands	179	19	131,545	2,392	1	2	3.3
Liverpool	168	0	38,314	1,383	1	0	1.2
Belfast International	94	2	15,494	972	0	0	0.5
Cardiff	113	0	21,159	1,161	1	0	0.6
Leeds/Bradford	102	11	38,443	1,587	0	1	1.1
Prestwick	28	0	10,891	1,887	0	0	0.3
Aberdeen	85	0	6,382	765	0	0	0.2
London City	110	0	18,326	1,371	1	0	0.6
Durham Tees Valley	10	0	1,268	1,540	0	0	0.1
Southampton	110	0	6,831	608	0	0	0.3
Bournemouth	118	0	16,026	1,477	1	0	0.6
Coventry	28	0	3,381	884	0	0	0.1
Belfast City	80	0	5,449	493	0	0	0.2
Exeter	82	16	37,932	1,899	1	1	1.1
Doncaster Sheffield	25	0	5,101	1,000	0	0	0.2
Norwich	42	0	3,136	704	0	0	0.1
Humberside	113	0	36,889	1,966	1	0	1.1
Inverness	14	0	1,517	1,049	0	0	0.1
Blackpool	4	0	87	239	0	0	0.0
Newquay	27	0	1,087	467	0	0	0.1
Plymouth	40	0	2,286	680	0	0	0.1
Total	3,366	429	1,733,488	1,821	20	26	47
Total CO_2 including freight, ground delay emissions and residual adjustment to DECC 2008 estimate							49.0

Notes
1. Option 's02': 'Max use' scenario
2. Seat-Kms and average distances are next stop only.
3. Distances are Great Circle and uprated by 8% for indirect routeing and stacking.
4. CO2 emissions from UK departures only.
5. Airport level CO2 emissions exclude freight and ground (delay) emissions.
6. Airports sorted on descending available seat-kms.
7. "0" means non-zero, or rounds to zero at 0dp.
8. ATMs are direct model output, airport totals may marginally exceed capacity and totals shown in H.2-H.4

Annex I: Glossary

ACARE	Advisory Council for Aeronautics Research in Europe
AERO2k	A Greenhouse Gas model developed by QinietiQ
APD	Air Passenger Duty
ATM	Air Transport Movement or Air Traffic Management
ATWP	The Future of Air Transport White Paper (2003)
BCR	Benefit Cost Ratio
BERR	Department for Business, Energy and Regulatory Reform (formerly DTI)
Bounce-back	A modelling scenario: swift recovery from the financial crisis of 2008
CO_2	Carbon Dioxide
CAA	Civil Aviation Authority
CAEP	The ICAO Committee on Aviation Environmental Protection
CANSO	Civil Air Navigation Services Organisation
CCC	Committee on Climate Change
CORINAIR	Part of the European Environment Agency (EEA) Corine programme (Co-ordination of information on the environment) tasked with creating an inventory of European air pollutant emissions – in effect a methodology and databank for calculating aviation emissions by aircraft type.
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DETR	Department of Environmental Transport & Regions (predecessor of DfT in 2000 when a previous set of forecasts were produced.)
DfT	Department for Transport
EU ETS	European Union Emissions Trading Scheme
ExR	Exchange Rates
FG	Future Generation: aircraft not currently in development introduced in decades after 2020
FMM	Fleet Mix Model
GDP	Gross Domestic Product (National Income)
HMT	Her Majesty's Treasury
IATA	International Air Transport Association (Airline trade body)
ICAO	International Civil Aviation Organisation
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPS	International Passenger Survey (ONS)
LDC	Less Developed Countries
LDM	Long Distance Model (a DfT multi-modal model)
MAC	Marginal Abatement Cost
MDS-T	MDS Transmodal (Freight Consultants)
mppa	Million Passengers Per Annum
$MtCO_2$	Million Tonnes of Carbon Dioxide
NAAM	National Airport Accessibility Model (superseded by LDM)
NATS	National Air Traffic Services
NAPALM	National Air Passenger Allocation Model
NAPDM	National Air Passenger Demand Model
NIC	Newly Industrialised Countries
NPV	Net Present Value
OBR	Office for Budget Responsibility
OECD	Organisation for Economic Co-operation and Development (used in this report to refer to members outside the European Union)

OEF	Oxford Economic Forecasting
OLS	Ordinary Least Squares (a method of regression analysis in statistics)
ONS	Office of National Statistics
PED	Price Elasticity of Demand
PIANO(-X)	Aircraft performance and emissions software. Lissys Ltd
RASCO	Regional Air Services Co-ordination Study DfT (2002)
RF or RFI	Radiative Fencing Index – a factor applied to CO_2 to account for other climate change impacts of aviation emissions
RPK	Revenue Passenger-kilometre
SERAS	South East Region Air Services Study DfT (2002)
SESAR	Single European Sky ATM Research (ATM as Air Traffic Management)
s02	The baseline ‘max use’ development scenario
SPASM	Alternative, earlier name for DfT National Air Passenger Allocation Model (NAPALM)
TAG	Transport Analysis Guidance (DfT)
UNFCC	United Nations Framework Convention on Climate Change
WEO	World Economic Outlook (produced by the International Monetary Fund)
YED	Income Elasticity