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Review of DfT model aircraft size and route threshold assumptions

Airports Commission

Final report

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Contents

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Scope

As part of PwC's support on analysis and strategy to the Airports Commission, we were asked to review and document the assumptions used to control route start-up and aircraft size selection within the Department for Transport aviation model. We were asked to produce a report reviewing the "Larame graph" and "route start-up threshold" assumptions used within the model, assessing their intuitive credibility and explicitly comparing them to outturn data.

The scope of this analysis:

- Historical analysis relating to aircraft size and identify drivers of aircraft size for different market segments
- Determine the effect of operational and physical constraints at different airports on the aircraft available for use at these sites
- Compare the results of the DfT assumptions of route 'start-up thresholds' in comparison to historical data of new routes beginning from 2000-2012
- Review the behaviour of different airlines and its differentiation between different service types, and how these behaviours can be reflected in the assumptions used in DfT model

This paper details the approach, methodology and results of this analysis.

Introduction

Executive summary

The DfT aviation model uses a number of complex and inter-relating assumptions to drive the start-up of routes and choice of aircraft size used for each route. These can vary by type of carrier (scheduled, charter or low cost), airport and destination zone (up to 31 domestic routes and 48 international zones). The DfT aviation model primarily uses a procedure known as 'Larame graphs' to determine the effect of these assumptions and their interactions.

These assumptions have evolved over a number of years in response to the calibration needs of the model. As noted by the 2011 peer review of the model[1], it would now be helpful to review and document these assumptions to ensure that they can each still be justified and are supported by underlying data and evidence. At the time of conducting this analysis, there were 244 different Larame graphs determining route start up thresholds and aircraft size for each modelled route. This report has been produced in order to examine the assumptions present in the DfT aviation model, specifically relating to the use of the Larame graphs and route start-up thresholds. Note that given the large number of individual assumptions across each of the 244 Larame graphs, along with a suite of override assumptions, PwC and the Airports Commission Secretariat agreed that the performance of the assumptions be assessed as opposed to a review of each of the graphs themselves. This report summarises the assessment of the credibility of these assumptions by comparing the model outputs to historical out-turn data.

Key findings:

- Historical origin-destination passenger demand data is similar to the DfT forecasts for new route start-up thresholds. The historical data indicates that approximately 80% of new routes are switched on with 27,000 first-year passengers (one way). The DfT thresholds are somewhat more conservative, which is deemed reasonable due to a large number of routes switching on at lower thresholds.
- Fleet order analysis indicates an approximate increase of seats per air traffic movement (ATM) of 2.8% in the short-medium term (5-10 years). This growth is driven predominantly by British Airways and easyJet fleet orders.
- We estimated a linear regression model using historical airport data from 2000 to 2011 to determine the drivers of aircraft size, using average seats per ATM as the independent variable. Depending on market segment, the coefficients and regression fits of the identified drivers varied, with the closest regression fit giving an R^2 value of 0.78 for international scheduled flights, with an overall R^2 of 0.72 across all routes.
- The results of the 2000-2011 regression model were applied to 2012 data, to determine the ability of the model to predict average aircraft size in 2012. Comparison of the model results to the current Larame graph results suggests that the regression model provides a better fit than the Larame graphs for all segments (excluding domestic scheduled).
- At an aggregate level, the Larame graphs appear to perform adequately, producing results that are comparable to outturn data. However, when looking at a more detailed level, there is substantial variation between modelled and actual and some forecasts results do not always seem intuitive.

Purpose of document

This report summarises our review of the assumptions used to control route start-up and aircraft size selection within the DfT aviation model[2]. The review covers the Larame graph and route start-up threshold assumptions and assesses their intuitive credibility and compares them to available outturn data. In this report, we also

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4506/review-napalm.pdf

[2] All DfT model assumptions and outputs are as at July 2013.

demonstrate an alternative approach to the Larame graph, a regression analysis model incorporating key variables which determine future aircraft size for routes in different market segments.

There are a number of different factors that influence route start-up within the DfT aviation model. This project is solely focused on Larame and route start-up threshold assumptions. The logit parameters, airport level fare adjusters and the algorithm itself are out of scope, and this project does not consider the impact that changes in these assumptions have on the forecast.

Structure of the report

- **Historical Evidence –** Analyses of historical airport capacity and aircraft size drivers broken down by route.
- **Route Start-Up Thresholds –** Analyses of DfT forecast passenger threshold credibility.
- **Aircraft Size Trends –** Regression analyses of historical data used to forecast future sizes compared to Larame forecasts.
- **Future Fleet Analysis –** Bottom-up analysis of fleet orders for key UK-operating airlines.
- **Appendix**

Historical evidence

Introduction

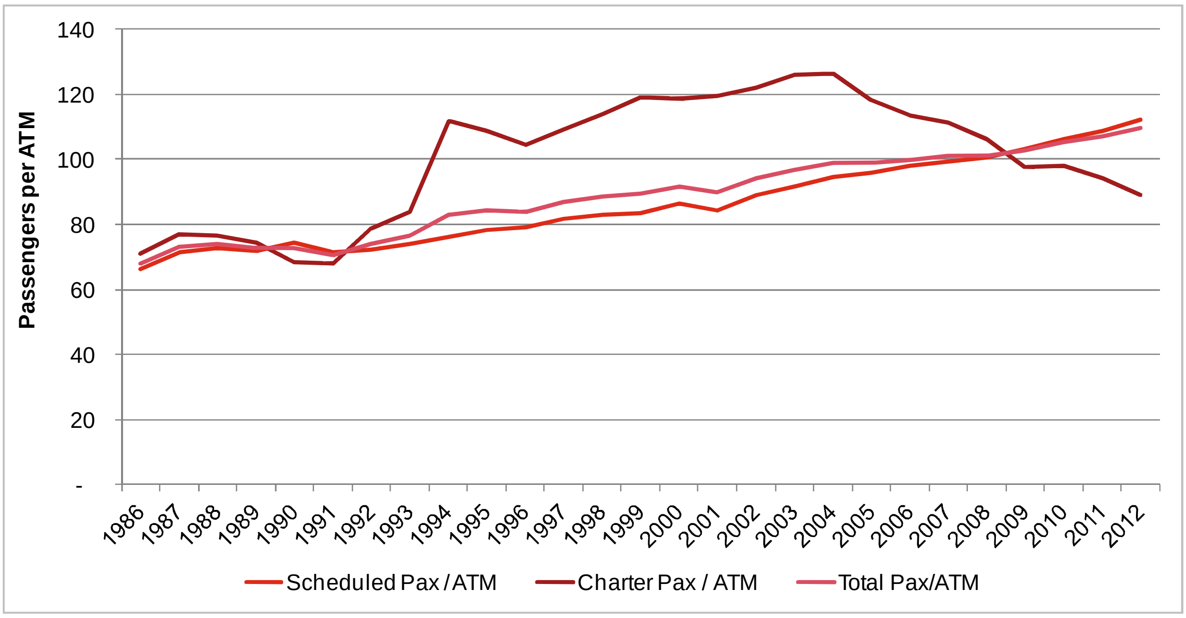
This chapter of the report summarises PwC's analysis of historical data relating to load factors, size of aircraft and route thresholds on routes operated from UK airports between 2000 and 2013. The operational and physical constraints as well as characteristics are also considered to assess how these affect the type of aircraft and load factors. The analysis also considers the type of airline carriers and how these differ. We also look at the trends in size of aircraft and route viability where new aircraft have come into the market over the last decade and how future fleet developments are likely to change the market in the future.

Historical analysis of capacity

Total UK market

Average passengers per air traffic movement (ATM) have been increasing over the last few decades as shown in Figure 2-1. Passengers per movement are a function of aircraft size and seat load factors. An airline's choice of aircraft to serve a particular route, and therefore the resulting average aircraft size is driven by a range of factors. Airline fleets and new aircraft types entering service will have an impact on how the average size of aircraft changes over time. The A380 has made a significant impact on the average size of aircraft, but once the impact of this aircraft entering the market has been felt, there is unlikely to be other significantly larger aircraft coming into the market in the foreseeable future. New aircraft types are more likely to be more operationally efficient than existing variants rather than having significantly higher capacity. For example, the most significant new aircraft types (based on orders) coming into the market are the narrow body aircraft from Boeing (the Boeing 737Max) and Airbus (the A320 neo) as well as new wide body variants such as the Boeing 777-300ER. These aircraft will be more operationally efficient than their incumbents, but they will have little effect on the average seat capacity.

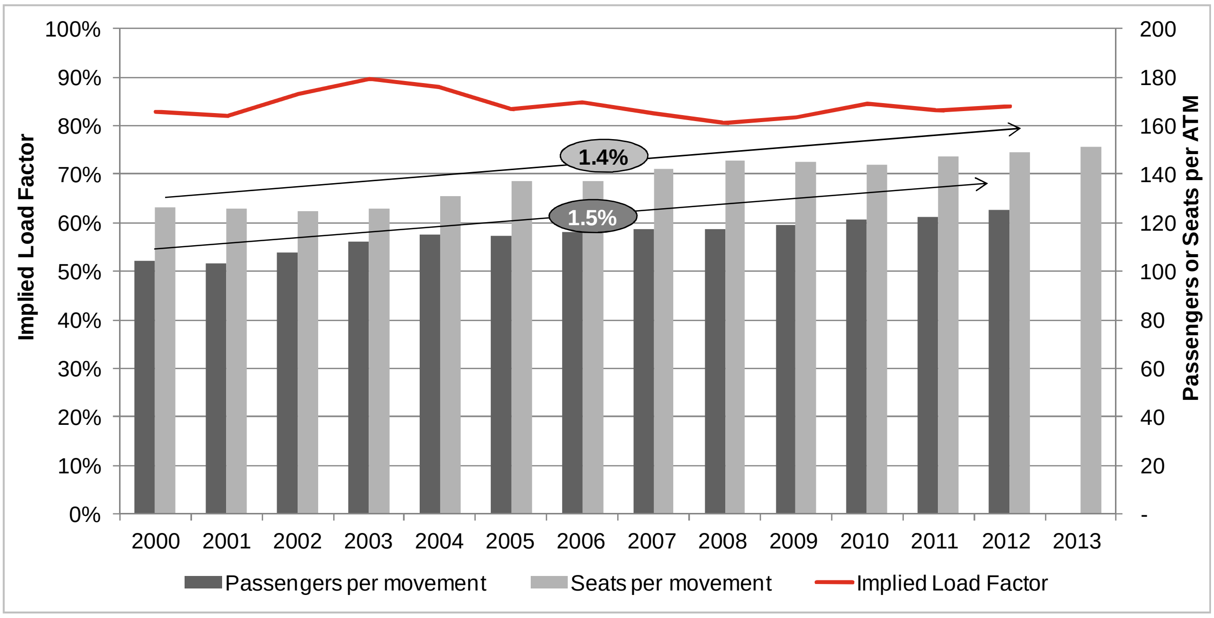
Figure 2-1 – Passengers per air transport movement at all UK airports 1986 to 2012



Source: CAA airport statistics

Figure 1-2 shows the change in passengers per ATM and seat capacity per ATM for all 31 airports included in the DfT aviation model. Between 2000 and 2012 passengers per ATM increased from 105 to 125, representing a compound average annual growth rate of 1.5 per cent. Seat capacity per movement increased by 1.4 per cent per annum from 125 to 149. Average implied load factors remained at just over 80%.

Figure 1-2 – Total passengers and seats per air transport movement



Source: Passengers are based on CAA airport statistics (total reporting UK airports), seat capacity is based on scheduled seat capacity based on Sabre Airport Data Intelligence, Implied load factors are calculated

Drivers of aircraft size

There are a range of considerations airlines make when determining what type of aircraft will serve a particular route. Firstly, the availability of aircraft is an obvious driver and airlines with different operating models tend to have a different fleet composition. For example, full service carriers have a range of different aircraft types available to serve a diverse network; low cost carriers tend to only serve short-haul markets and prefer a homogeneous fleet to minimise operating costs (e.g. maintenance, crew training); and charter airlines typically serve short-medium haul seasonal markets and procure aircraft suitable for serving these destinations. Different aircraft types have different ranges, so distance will be an important factor. Airline economics, i.e. choosing the aircraft type that optimises airline profitability, is a key factor; however, this is difficult to measure and varies by route and aircraft type. The key drivers of aircraft size we consider here are:

- Size of origin airport
- Size of destination airport
- Route distance
- Number of competing airlines on the route (more competition will drive frequency)
- Growth of the destination airport / economy (developed vs emerging)

Size of origin airport

Given different routes served, levels of demand and airport runway constraints, different airports in the UK have different average seat capacity and passengers per movement as shown in Figure 2-3. We have grouped UK airports into 5 categories based on annual terminal passengers in 2012. Hub, which is defined as more than 40 million passengers, only includes London Heathrow; large includes Gatwick, Manchester and Stansted, all at above 15 million passengers; medium is above 5 million passengers; and small and extra small are 1 – 5 million annual passengers and less than 1 million passengers respectively. The airports which report statistics to the CAA but are not among the 31 airports included in the DfT aviation model have been classified in 'other'. These airports, with the exception of Jersey which catered for 1.4 million passengers in 2012, all have less than 1 million passengers per annum.

Figure 2-3 – Size categorisation of airports in the UK and British Isles

Category	Airport Size[3]	Airports
Hub	>40 mppa, >20% transfer	LHR
Large	15-40 mppa	LGW, MAN, STN
Medium	5 – 15 mppa	LTN, EDI, BHX, GLA, BRS
Small	1-5 mppa	LPL, NCL, BFS, EMA, ABZ, LCY, LBA, BHD, SOU, PIK, CWL
Very Small	<1 mppa	EXT, DSA, BOH, SEN, INV, NWI, BLK, HUY, NQY, MME, CVT
Other	<1 mppa	JER, GCI, IOM, LDY, SCS, LSI, KOI, SYY, ISC, ACI, PZE, DND, LEQ, BEB, WIC, TSO, ILY, GLO, BRR, CAL, MSE, TRE, OXF, LWK, CBG, ESH, LYX

Source: Passengers are based on CAA airport statistics (total reporting UK airports)

Size of destination airport

The size of the destination airport was measured by using the destination airport's annual terminal passengers as the determining factor. We have not categorised destination airports into size categories.

Route distance

The route distance places a limiting factor on the aircraft able to operate on the route. Shorter haul routes tend to operate smaller aircraft at a higher frequency, and the range of smaller aircraft often renders them unsuitable for use on long haul routes. We have grouped routes based on distance into two categories, short haul and medium/long haul. Medium and long haul routes are combined due to the majority of routes falling under the short haul classification. Routes of a length of less than 2000 miles are classed as short haul, and routes of more than 2000 miles are classed as medium/long haul.

Competing airlines on route

Airline competition on routes is a key driver of aircraft size. In order to attract passengers, airlines will either offer larger aircraft or increased frequencies on routes with high competition. Aircraft operated on routes will also vary depending on individual airlines' business models and fleet objectives.

Growth of the destination airport/economy

Growth of the destination airport drives route aircraft size by identifying potential demand on routes. It will also help determine the required flight frequency by identifying the business demand on routes.

Data sources

We have used a combination of data sources to conduct this analysis.

- Aggregate passenger and aircraft movement data for UK airports is based on CAA airport statistics
- Capacity data and route length is based on schedule information from Sabre Airport Data Intelligence
- Implied load factors have been calculated based on seat capacity and passengers using a combination of CAA statistics and Sabre Airport Data Intelligence
- We obtained airline current fleet and orders from published Flight Global profiles which contains data based on the ACAS fleet database.

[3] Based on 2012 Terminal passengers.

Route start-up thresholds

Introduction

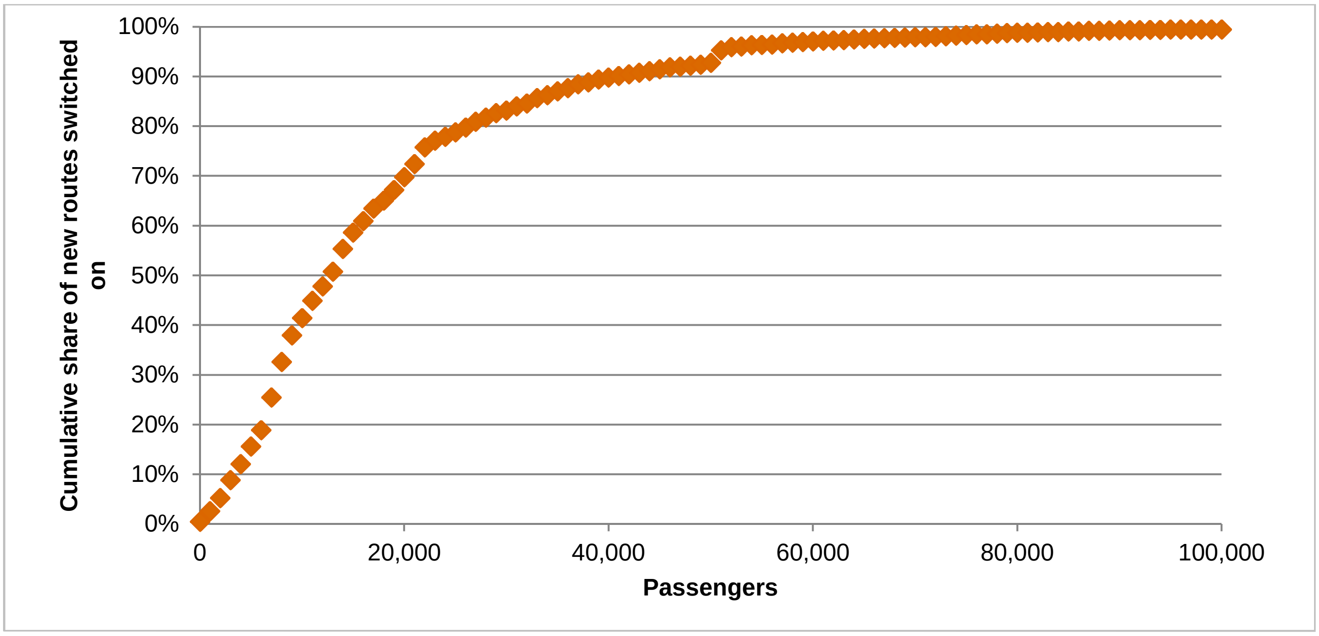
The DfT aviation model has the inherent assumption that a new route requires a minimum number of passengers before it will be commercially viable for an airline to operate. This concept, referred to as 'route start-up thresholds', is a two-way test, and modelled routes can be opened or closed based on these thresholds. Airports are tested jointly for each new route to allow evaluation of competition. Based on these thresholds, the DfT aviation model can subsequently be used to forecast appropriate aircraft size, load factor, and frequency for these new routes. Forecasts are derived statistically from historical data.

In order to determine the credibility of the start-up thresholds produced by the DfT aviation model, we first analysed the historical start-up thresholds for new routes to assess the distribution of the thresholds. This demonstrated a clear distribution trend, so we broke down the new routes into short and medium/long haul routes, to determine whether thresholds differed relative to route length. The approach is detailed below.

Historical start-up thresholds

We first analysed route pairs for the UK airports included in the DfT aviation model[4]. This analysis utilised data from Sabre Airport Data Intelligence, and provided capacity data for origin-destination pairs for routes which commenced in the period 2001-2012. The seat capacity on these routes was annualised over the year in which the route began to adjust for the impact of seasonal variation in passenger numbers, and also for routes which only operated for part of the year. Passenger numbers were estimated based on an assumed load factor of 75%[5]. We then subsequently assessed the level of passengers at which the route commenced to determine start-up threshold distributions. This is displayed in Figure 3-1.

Figure 3-1 – Distribution of first year passenger thresholds for new routes "switched on"



Source: Sabre Airport Data Intelligence, PwC analysis

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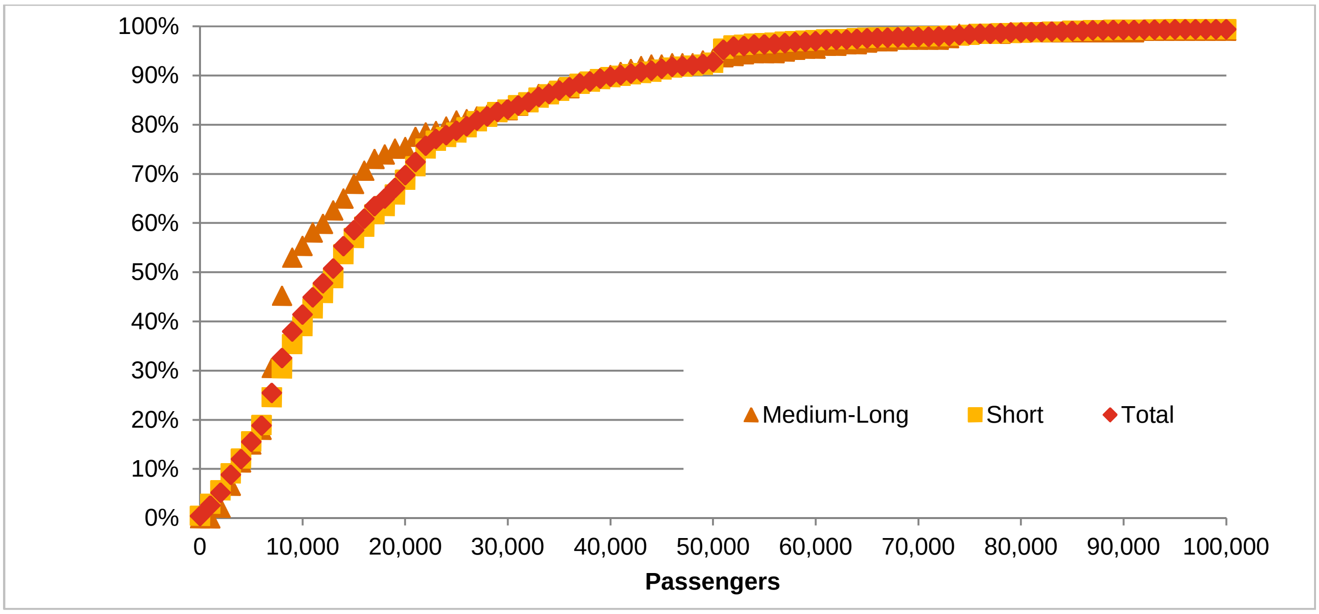
[4] See Figure 2-3.

[5] A typical seat load factor of 75% has been applied to available seat capacity to estimate the level of passengers for a new route starting up. This load factor is broadly consistent with the UK market and the assumptions contained in the Larame graphs, the majority of which range from 70-80%.

The results of this assessment revealed that around 80% of new routes from 2001-2012 had commenced operation with annualised first year passenger numbers of 27,000 or less (one-way). The remaining 20% of routes commenced with increasingly large passenger numbers, with 100% of routes commencing by the point at which first year passenger numbers had reached 100,000.

Subsequently, the individual routes were classified to be either short haul or medium/long haul routes. As noted above, routes shorter than 2000 miles were classified as short haul, and greater than or equal to 2000 mile routes were classified as medium/long haul. The distribution by haul length is shown in Figure 3-2.

Figure 3-2 – Distribution of first year passenger thresholds for short and medium/long haul new routes "switched on"



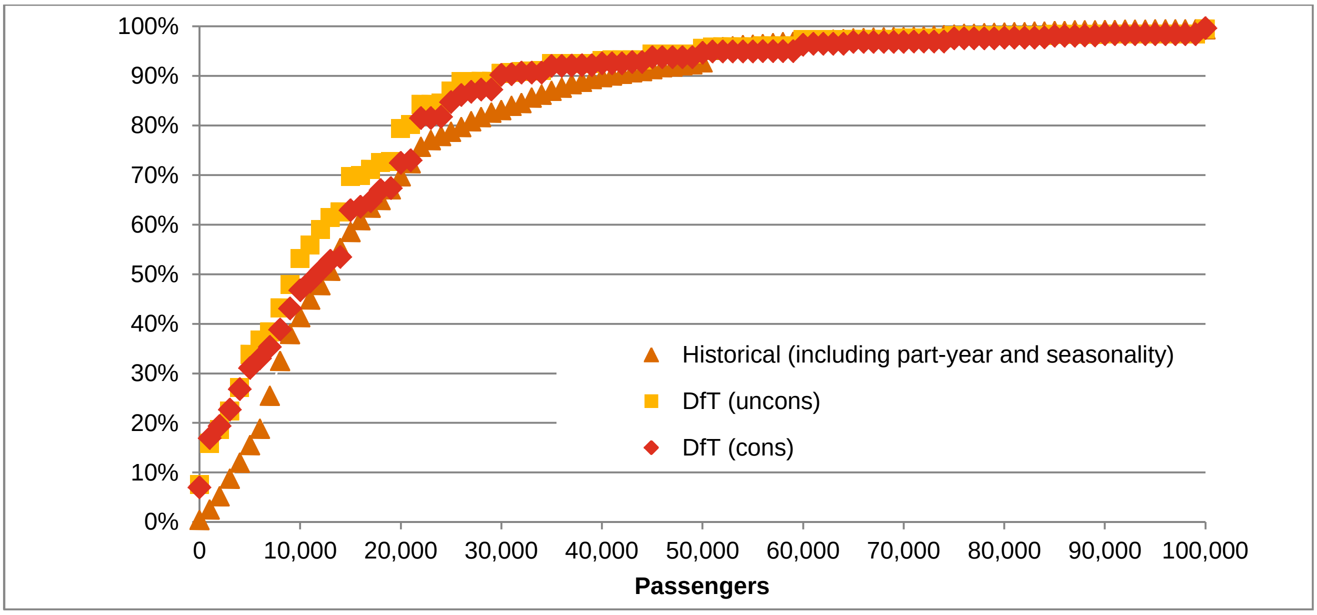
Source: Sabre Airport Data Intelligence, PwC analysis.

For this analysis, the majority of routes switched on were short haul, and thus medium and long haul routes were grouped into a single profile. Short haul routes still maintain the profile of 80% of routes switching on at 27,000 passengers. Medium/long haul routes had somewhat lower thresholds on average, with 80% of routes switching on at 25,000 passengers. However, there are a greater proportion of medium/long haul routes at the higher end of the threshold curve than short haul routes. Overall, the profiles of short and medium/long haul routes are generally comparable in aggregate.

Credibility of DfT route threshold model

In order to determine whether the DfT aviation model can predict credible passenger thresholds for new routes, the distribution of the predicted route thresholds was examined. Using the same approach as for historical route thresholds, the DfT aviation model predicted thresholds were analysed for route segments international LCC, international scheduled and domestic scheduled. The thresholds used were the constrained and unconstrained minimum passenger requirements, and override assumptions were also included. The DfT forecasts were compared to the historical data from 2001 to 2012, to determine the credibility of the thresholds. The results of these analyses are shown in Figure3-3.

Figure 3-3 – Comparison of DfT constrained and unconstrained[6] threshold forecast distribution and historical passenger demand distribution



Source: DfT aviation model outputs, Sabre Airport Data Intelligence

The results of this analysis demonstrate that DfT forecast thresholds are, in aggregate, generally comparable to historical data. The DfT assumptions for start-up thresholds are more conservative than the historical start-up values, with more routes beginning at the lower end of passenger numbers. This seems reasonable, as low thresholds would result in a higher number of routes being switched on.

London City Airport forecast case study

In order to examine the credibility of the DfT route threshold assumptions at a more detailed level, we examined the constrained and unconstrained forecasts for London City Airport (LCY). Forecast routes operating out of LCY were examined up to 2050, and compared against historical routes in 2010 and 2011. These forecast assumptions excluded charter routes.

The constrained assumptions for LCY until 2050 show several key trends. As shown in Figure 3-4, the trend for routes operating out of LCY is for increasing numbers of routes until 2030, then subsequently consolidation and reduction of routes. This trend, when compared to Figure 3-6, reveals that the decrease in actual route numbers is matched by passenger share increasing, creating fewer routes but with deeper capacity. Some key routes which are forecast to switch on are routes to Rome Fiumicino (Europe's 6th busiest airport) increasing connectivity, and other large airports such as Porto Fransisco de Sá Carneiro and Pisa Galileo Galilei. However, several routes which are switched off in these assumptions are anomalous, most significantly routes to Edinburgh, Amsterdam, Frankfurt, Dublin, Rotterdam, Copenhagen, Barcelona, Nice, Stockholm and Milan. These are among the top 20 routes operating out of LCY, and in these assumptions show strong decline and subsequently are switched off by 2050. Our conclusion is that these routes are declining in the model due to the 'pull' demonstrated by London Heathrow, prioritising passengers to existing and new large capacity routes at this airport. In practice, we suspect that these key routes will be maintained, due to the important business position of LCY.

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[6] The unconstrained forecast represents underlying estimates of demand in the absence of airport capacity constraints. Constrained forecasts take into account the effect of the limitations to runway and terminal capacity at UK airports, and are formed by inputting the unconstrained forecasts output into the DfT air passenger allocation model.

Figure 3-4 – Number of LCY routes operated in DfT model outputs (constrained)

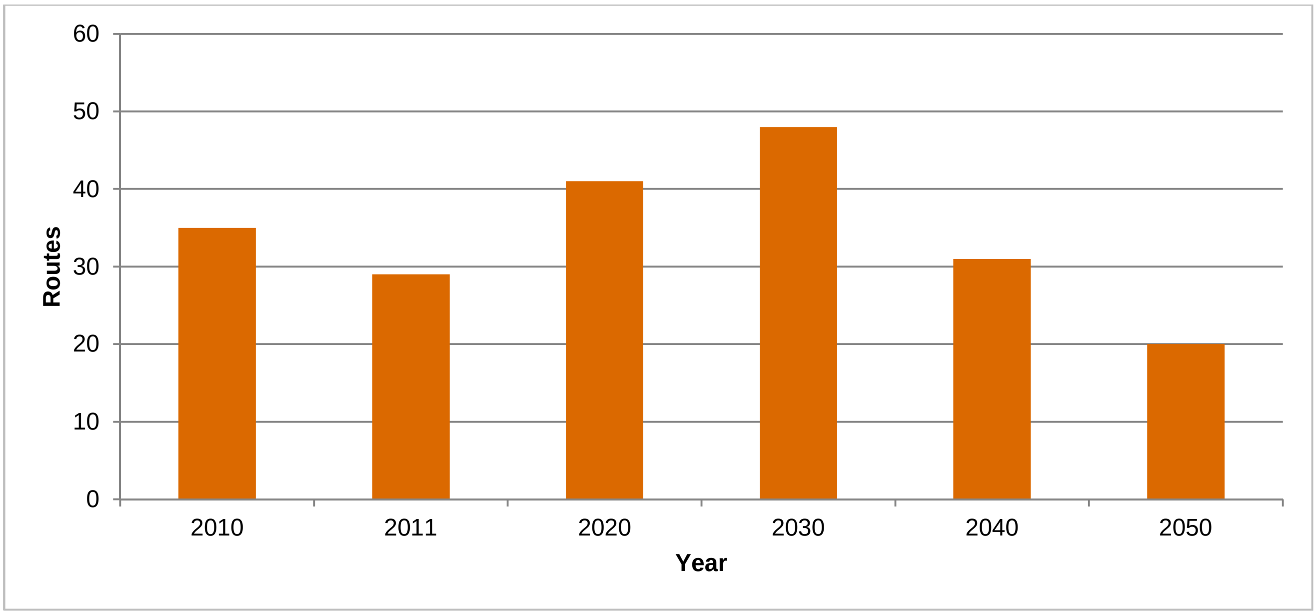
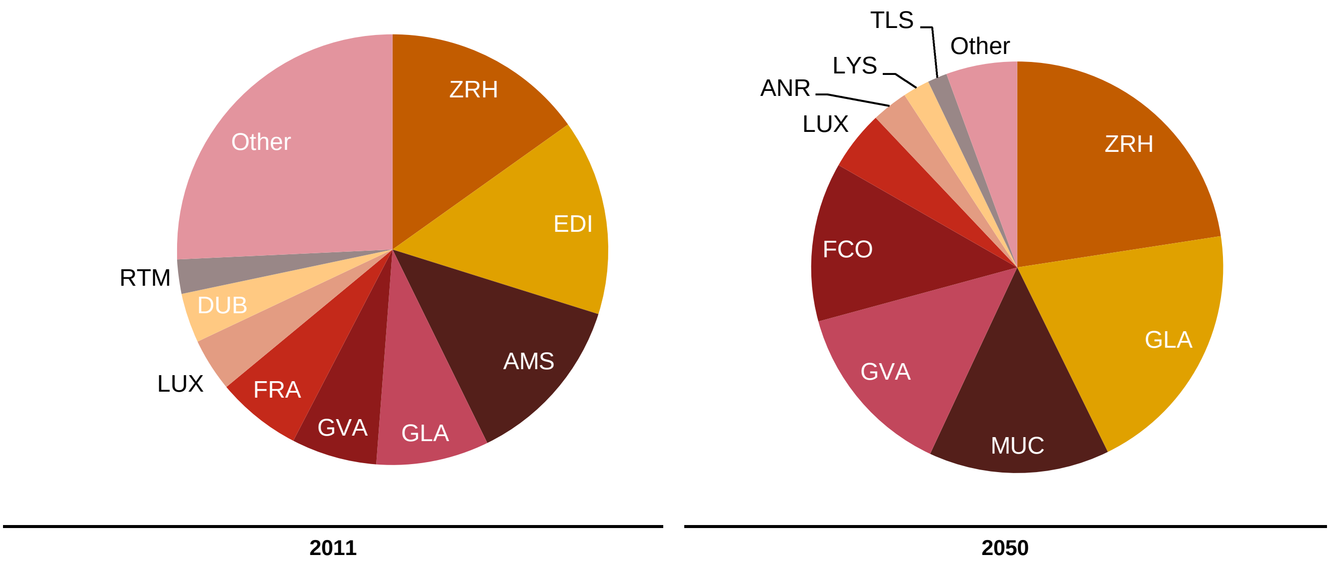


Figure 3-5 – LCY routes switched on and off by 2050 (constrained)

Origin Airport	Routes switched on	Routes switched off
LCY	AVN, BES, BTS, EGC, FCO, FLR, GCI, LIG, LRH, MJV, NTE, OPO, PSA, RNS, SZG	**AGP**, **AMS**, **ARN**, BCN, BCN, BUD, CPH, **DUB**, **EDI**, EIN, FAO, **FRA**, JER, LIN, MAD, **NCE**, PRG, RTM, ALC, BLQ, GIB, GRQ, MAH, MLH, MXP, NAP, PMI, VCE

Figure 3-6 – Share of LCY passengers by route (constrained)



The following analysis looks at the unconstrained capacity scenario from the DfT aviation model. The unconstrained forecast assumptions for LCY show a very different trend, with route numbers decreasing slightly from 2011 to 2020, then subsequently increasing consistently until 2050. The number of routes assumed to switch on increases, and the profile changes to include longer haul airports such as Moscow Domodedovo and Warsaw Chopin. The unconstrained assumptions do show some similar anomalies to the constrained, specifically the loss of Frankfurt, Dublin, Barcelona, Stockholm, Nice and Milan, and also changing to include the loss of Madrid and Oslo. As with the unconstrained forecast assumptions, we believe that in practice these routes would be maintained due to the position of LCY as a key business airport.

Figure 3-7 – LCY routes switched on and off by 2050 (unconstrained)

Origin Airport	Routes switched on	Routes switched off
LCY	AVN, BES, BIO, BRI, BTS, CTA, DME, EGC, FNC, GCI, GOA, GRQ, IBZ, KSC, LCG, LEI, LIG, LRH, MJV, NTE, OPO, RNS, SZG, TRN, VRN, WAW	ARN, BCN, BLQ, DUB, FLR, FRA, LIN, MAD, NAP, NCE, OSL, PSA

Figure 3-8 – Share of LCY passengers by route (unconstrained)

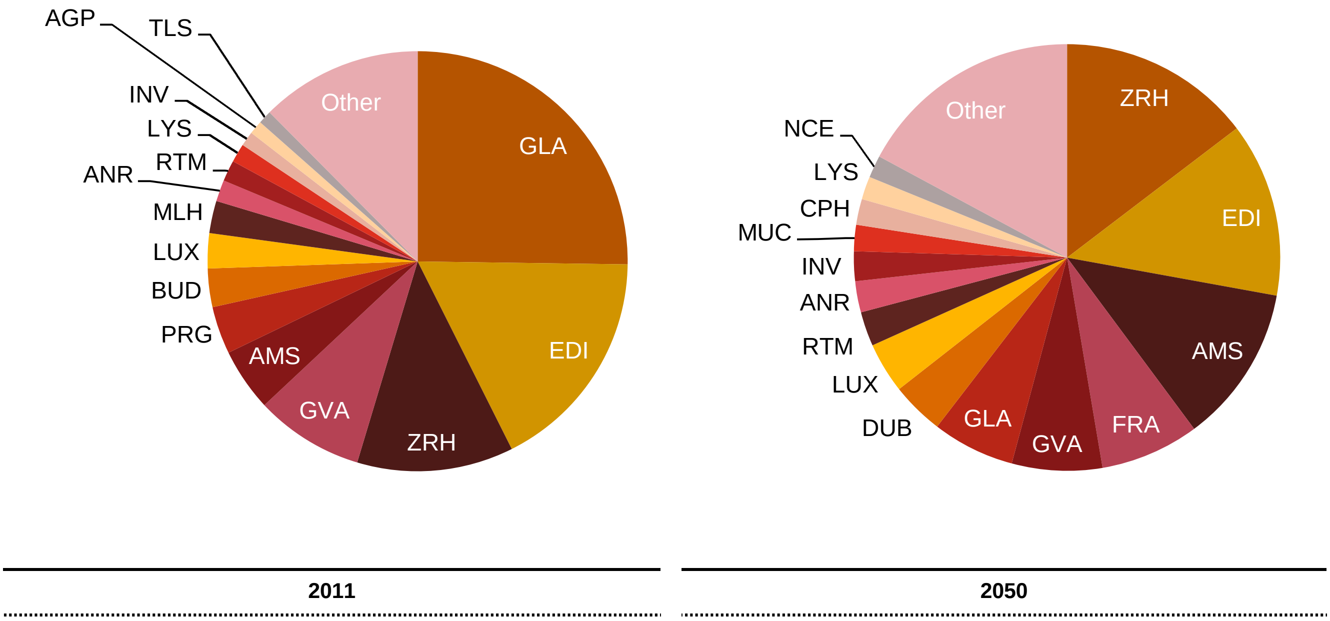
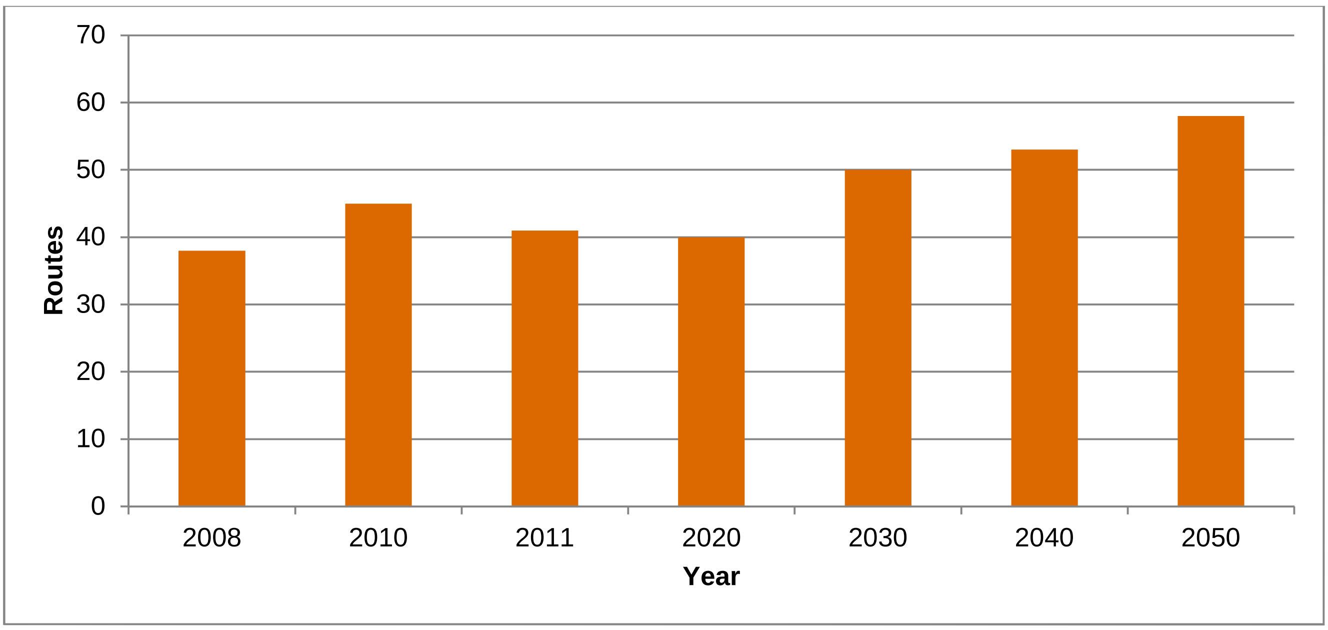


Figure 3-9 – Number of LCY routes operated in the DfT aviation model outputs (unconstrained)



Conclusion

Although this approach produces results which are generally comparable to the historical data, certain drawbacks become apparent upon detailed analysis at a route level. Although the trend seen in the route start-up threshold forecasts closely matches historical route start-ups in aggregate, this comparison breaks down somewhat as the routes are analysed at individual airports. As seen in the London City Airport case study, although certain routes are switched on at unremarkable levels, there are a number of anomalous route start-ups and switch-offs that were detailed above. This indicates that although the DfT route start-up threshold model can be reliable in aggregate, discrepancies occur at individual airport levels.

Data sources

We have used a combination of data sources to conduct this analysis. One-way origin-destination passenger and aircraft movement data for UK airports are based on schedule and capacity data from Sabre Airport Data Intelligence. DfT unconstrained and constrained forecast data was obtained from the DfT aviation model outputs as at July 2013.

Aircraft Size Trends

Introduction

Another key assumption for the DfT aviation model is the size of aircraft serving each route. The Larame graphs contain assumptions on aircraft size and load factors at different levels of frequency to meet passenger demand. The aircraft size and load factor assumptions are used to estimate passengers per movement which are applied to route-level passenger demand to estimate aircraft movements. Since capacity constraints in the London area are primarily driven by runway capacity, assumptions driving aircraft movement forecasts are likely to be highly scrutinised.

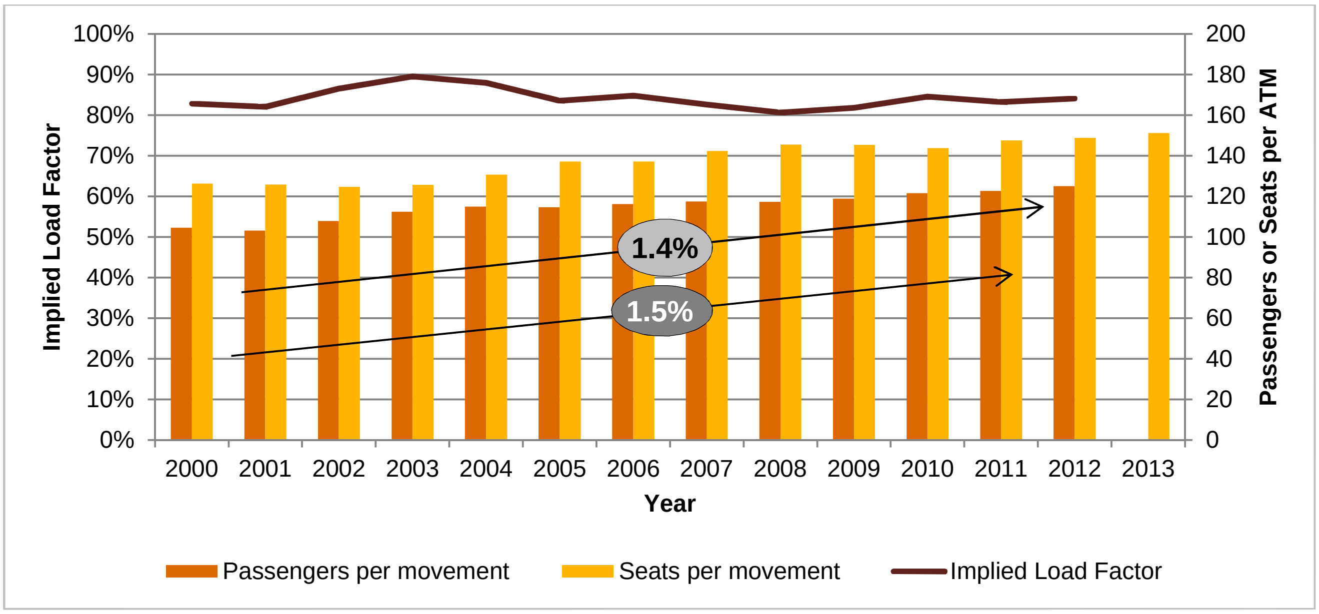
In order to test the credibility of the Larame graph assumptions for aircraft size, we first examined CAA statistics for UK airports of historical passengers and capacity per aircraft movement, and the implied load factor. We also examined DfT aviation model forecasts for average passengers per aircraft movement and average forecast load factor. These data are used to act as sense checks for the modelled future aircraft sizes. We subsequently analysed a number of different variables, and used a linear regression model to determine their effect on average seats per movement for over 10 million aircraft movements (2000-2011 movements by route pair). We determined that segment passengers, route distance, the size of the origin (UK) airport (based on passengers handled) and whether or not the route was operated by a low cost carrier (LCC) were all significant. The regression analysis was replicated for individual market segments and the performance of this model was tested against actual data for 2012 and compared with the performance of the DfT Larame graph assumptions on actual data for 2012.

Historical/forecast passengers and capacity per ATM

We obtained the historical data for passengers and capacity per ATM at UK airports from reported CAA statistics and the Sabre Airport Data Intelligence. We assessed the average annual passengers per aircraft movement against the average annual capacity per aircraft movement, and from this determined the annual implied average load factor. We also obtained the forecast passengers and capacity data per aircraft movement from the DfT aviation model outputs.

Figure 4-1 shows that the trend in aircraft size and load factor over the period of 2000-2012 was fora steady year-on-year increase. There was a drop in average aircraft size operating in 2009 which continued into 2010, but average aircraft size increased again in 2011 to pre-financial crisis levels. Average implied load factors have fluctuated during this time, but have remained within the 80-90% range. Over the whole period, average aircraft capacity increased from 126 to 149 (CAGR of 1.4%) and average passengers per aircraft movement increased from 105 to 125 (CAGR of 1.5%).

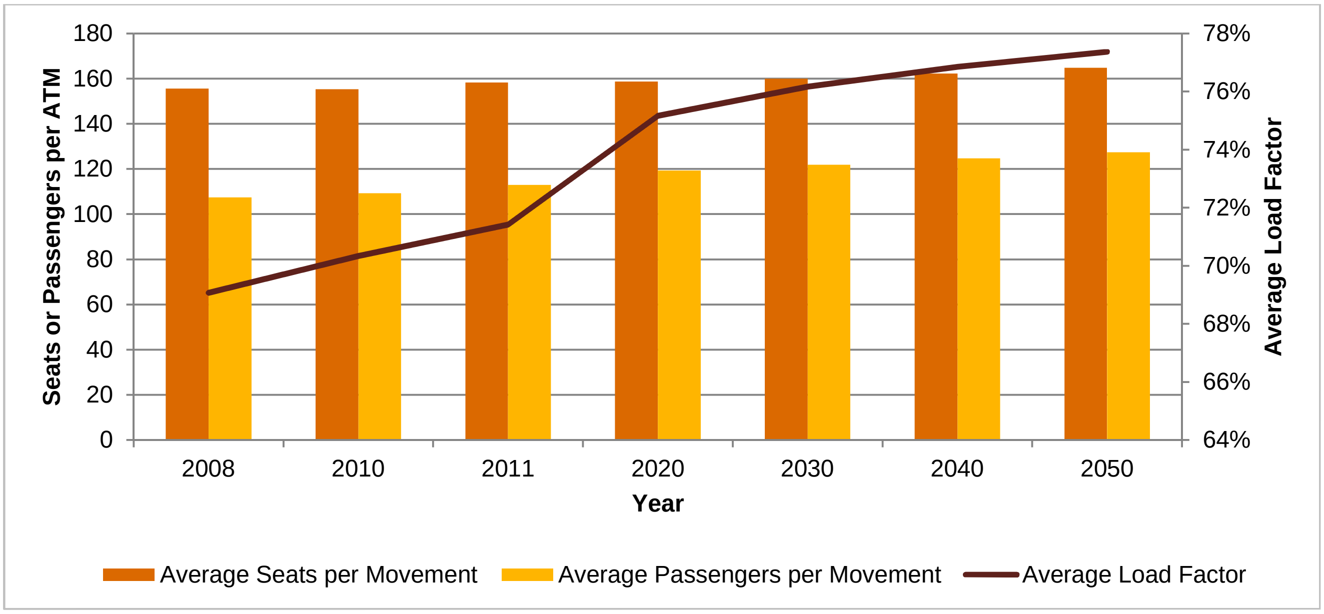
Figure 4-1 – Average annual passengers/capacity per aircraft movement at UK airports



Source: CAA statistics (passengers per movement) and Sabre Airport Data Intelligence (seats per movement)

Figure 4-2 shows the DfT aviation model assumptions and forecasts for average seats and passengers per movement, along with load factors. The DfT aviation model forecasts this growth rate to continue between 2020 and 2050. The DfT forecasts the average aircraft capacity per ATM to increase from 158 in 2008 to 165 in 2050[7].

Figure 4-2 – Forecast average seats and passengers per aircraft movement at UK airports



Source: Constrained DfT aviation model outputs

[7] The discrepancy between reported average aircraft size of the CAA and Sabre data and the DfT published data is likely due to the inclusion of different market segments in the DfT forecast data, and the Sabre data being derived from different sources.

Linear regression analysis of aircraft size drivers

A range of factors that influence the choice of aircraft size on a particular route have been identified. These factors include:

- Airline economics
- Route yields
- Demand
- Fleet availability
- Distance (range of aircraft)
- Airport infrastructure constraints
- Competition level
- Business or leisure domination of route
- Low cost carrier (LCC) or full service carrier (FSC)
- Reliance of transfer passengers

We determined that of these factors, several were measurable drivers of aircraft size, and performed a regression analysis to identify the effect of these factors on the average number of seats per aircraft movement across all routes operating out of the 31 UK airports included in the DfT aviation model. The dependent variable in this regression analysis was the average number of seats per aircraft movement. The independent variables were the number of segment passengers, the size of the UK origin airport in terms of annual passengers[8], whether the carrier was an LCC, whether the destination airport was within the EU, the route distance, the origin airport seat capacity and destination airport seat capacity. The EU and LCC status variables are not continuous, and instead a dummy variable of 1 or 0 is used (1 indicating that the airport or carrier is in the EU or is an LCC respectively, 0 indicating the opposite).

Figure 4-3 – Total results of regression analysis of all route pairs operating out of UK airports 2000-2011

Number	10730574
F(4,7496)	852.43
Prob>F	0
R-squared	0.7218
Root MSE	39.448

(Std. Err. Adjusted for 7497 clusters in route id)

Average seats per movement	Coef.	Robust Std. Err.	T	P>[t]	[95% Conf. Interval]	
Segment passengers	0.0001561	1.23E-05	12.64	0	0.000132	0.0001803
Route distance	0.0263752	0.000566	46.63	0	0.025266	0.0274839
UK airport capacity	0.6382063	0.045041	14.17	0	0.549913	0.7264994
LCC status	31.02737	2.026079	15.31	0	27.05569	34.99906
Base aircraft size	58.28688	1.867668	31.21	0	54.62573	61.94804

The result of the regression analysis performed is shown above in Figure 4-3. We performed a number of regressions to test the significance of each variable as well as testing for correlation between variables. This analysis revealed that of the independent variables tested, four were found to have a statistically significant effect on the average seats per movement operating on a given route. These variables were segment passengers,

[8] Source: CAA UK airport statistics.

route distance, size of the origin airport, and whether the carrier is an LCC or not, and their impact on average seats per movement is shown in Figure 4-3 in the coefficient column. Three independent variables tested were discarded, and not used as part of the model. Origin airport seat capacity data was found to be comparable to the data used for origin airport size, destination airport size was excluded to simplify the regression analysis (the analysis was found to be just as robust with this data excluded), and the EU status of the destination airport was found to be insignificant when combined with the other variables.

The combination of the coefficients produced the following model for calculation of average seats per movement:

Average Seats per Movement = $\underbrace{58.237}_{\text{Base Seat Capacity}}$ + 1.56×10^{-4}(Segment Passengers) + 0.026(Route Distance) + 0.638(origin airport size) + $\underbrace{31.027}_{\text{Added if carrier is an LCC}}$

The coefficient of determination for this regression analysis was 0.722. As this was the regression analysis for all market segments combined, we performed regression analyses on each market segment to identify the accuracy of the model produced. Regression analyses were performed on the following market segments: International Scheduled, International LCC, Domestic Scheduled, and Domestic LCC. The results are summarised in Figure 4-4 below.

Figure 4-4 – Summary of R^2 and coefficients for each independent variable over individual market segment

	Total	**International scheduled**	**International LCC**	**Domestic scheduled**	**Domestic LCC**
R-squared	0.722	0.781	0.321	0.532	0.417
Coefficients:					
Segment Passengers	1.56*10-4	1.11*10-4	2.07*10-4	1.89*10-4	3.31*10-4
Route Distance	0.026	0.025	0.032	0.057	0.079
UK Airport Size	0.638	0.617	0.266	0.731	-0.137
Carrier LCC Status[9]	31.027	0.000	0.000	0.000	0.000
Base Seat Capacity	58.287	70.276	95.120	34.905	46.983

The results of the individual regression analyses determined that of the market segments, the International Scheduled segment has the highest coefficient of determination, which is likely due to a higher level of variation in the flights and routes operated in the market segment. Given that LCCs typically use similar sized aircraft, there was less variation in the data and therefore the predictability of the model is lower.

Comparison of regression analyses and Larame graph assumptions

In order to test the credibility of the Larame graph assumptions used in the DfT aviation model, we applied the results of the regression analyses of 2000-2011 two-way routes to 2012 data, in order to determine how effectively the statistical regression model can predict aircraft size based on actual passengers[10] for the origin airport, route distance, carrier type and segment passengers on each route. Subsequently, the results of this analysis were compared with a regression analysis of the fit of the Larame graph assumptions for 2012 against actual 2012 data.

[9] The LCC status dummy variable was omitted for individual market segment analysis, as each segment will be either entirely LCC or entirely scheduled carriers.

[10] Source: CAA UK aviation statistics

Figure 4-5 – Comparison of regression analyses of statistical model 2012 prediction fit vs. fit of Larame graph 2012 assumptions

Segment	R^2 for regression model	Regression Model Mean % Variance[1)]	R^2 for Larame	Larame Mean % Variance[1)]
Total	**0.682**	**31%**	**0.358**	**27%**
International scheduled	0.774	19%	0.488	25%
International LCC	0.147	20%	-0.002	35%
Domestic scheduled	0.507	44%	0.620	19%
Domestic LCC[11]	0.448	27%	n/a	n/a

[1] *Weighted based on flight frequency*

We found that generally the statistical regression model provided a better fit than the Larame graph assumptions for all market segments with the exception of the domestic scheduled market. Generally, the statistical regression model provides an acceptable coefficient of determination for each market segment, but the international LCC segment has a rather poor fit. We suggest that this is due to the very low level of variation in aircraft size for services within the market segment. Because of this, both the model and Larame graph assumptions do not provide significantly improved accuracy compared to taking the mean of aircraft size across the route.

The overall weighted average variance between the predicted aircraft size in 2012 based on Larame graph assumptions and the actual scheduled aircraft sizes for 2012 is small at 2%. This is somewhat misleading as sometimes large variances in predicted aircraft size compared with the actual size in both directions averaged out. Some Larame graphs performed better than others. The Larame graphs with the most impact on average aircraft size due to frequency of flights and their respective variances are shown in Figure 4-6.

Figure 4-6 – Comparison of predicted (Larame) average aircraft size vs. actual average aircraft size in 2012 (Top 15 Larame graphs by frequency)

Larame graph	Times larame graph used	Flight Frequency	Average aircraft size (Larame)	Average aircraft size (Actual)	Variance (%)
30	202	203,503	158	154	3%
82	23	20,517	156	151	3%
65	26	18,581	29	44	(34%)
44	3	18,535	126	142	(11%)
81	20	18,466	156	149	5%
45	4	17,499	159	150	6%
48	4	14,343	144	132	9%
112	4	13,158	144	157	(8%)
117	4	13,065	190	163	16%
154	7	12,732	165	154	7%
96	12	12,264	189	176	8%
64	18	12,048	78	81	(4%)

[11] Larame assumption coefficient of determination for the domestic LCC market segment is not shown, as Larame graphs are not available for this market segment.

Larame graph	Times larame graph used	Flight Frequency	Average aircraft size (Larame)	Average aircraft size (Actual)	Variance (%)
58	8	11,813	50	63	(20%)
77	9	11,640	153	156	(2%)
110	5	11,277	126	154	(18%)
Average	**6**	**5,362**	**139**	**143**	**(2%)**

Note: Excludes charter

Source: DfT aviation model outputs, actual average aircraft size and flight frequency are based on capacity data from Sabre Airport Data Intelligence

The variance seen in Figure 4-6 shows that although the average Larame graph variance was -2%, this varied in the top 15 graphs between -32% and +16% from actual average sizes (see Appendix B for full Larame assumptions vs. actual table).

Future fleet analysis

Introduction

A key assumption in the DfT aviation model is the average passengers per movement, which is driven by the size of aircraft and seat load factors. With new aircraft entering the market and airlines replacing their fleets, the average size of aircraft has been increasing. Given runway capacity constraints, being able to operate higher capacity aircraft will be key to enabling continued growth in passengers, at a time when aircraft movements cannot increase. The DfT aviation model forecasts a slowing of growth in average passengers per movement compared to previous decades (see Figure 5-1 below).

Figure 5-1 shows historical and forecast average annual increases in passengers per aircraft movement. The growth in average passengers per movement is forecast to slow compared to historical growth rates. In order to assess the reasonableness of forecast assumptions in terms of aircraft size for the DfT aviation model, we have conducted bottom-up analysis of fleet orders for key airlines operating at UK airports to understand the types of aircraft that will be operating in the short to medium term. We have also considered Boeing and Airbus long term forecasts to understand trends in types and size of aircraft for the European market.

Figure 5-1: Annual change in passengers per air transport movement

Year Range	CAGR
1970 – 1980	1.5%
1980 – 1990	2.4%
1990 – 2000	1.1%
2000 – 2010	1.4%
2010 – 2020	*0.7%*
2020 – 2030	*0.1%*
2030 – 2040	*0.2%*
2040 – 2050	*0.2%*

Source: Historical data based on CAA statistics, Forecasts based on the DfT aviation model.

Data sources

- Data on fleet make up for all airlines has come from FlightGlobalpro which obtains fleet data from ACAS
- FlightGlobalpro provides a breakdown of what category (narrow body, wide body, regional) of aircraft each airline has in use today, as well as providing data on the number of each model of aircraft that each airline has both in service and on order

Major airlines operating at UK airports

In terms of passenger frequency in the UK, the five airlines offering the highest service frequency at UK airports are British Airways, easyJet, Flybe, Ryanair and Aer Lingus, as shown in Figure 5-2.

Figure 5-2: Top 20 airlines operating at UK airports based on scheduled aircraft movements

Airline	Scheduled Movements in 2013	Share
British Airways	**164,511**	**18.7%**
easyJet	**147,689**	**16.8%**

Airline	Scheduled Movements in 2013	Share
Flybe	**107,558**	**12.3%**
Ryanair	**95,590**	**10.9%**
Aer Lingus	**23,712**	**2.7%**
Jet2	18,030	2.1%
Monarch Airlines	17,395	2.0%
Eastern Airways	16,980	1.9%
Cityjet	16,374	1.9%
Lufthansa	16,089	1.8%
BA Cityflyer	15,219	1.7%
Loganair Limited	13,705	1.6%
KLM Cityhopper	12,875	1.5%
bmi Regional	12,456	1.4%
Aer Arann Express	11,612	1.3%
Virgin Atlantic	**10,440**	**1.2%**
Wizz Air	9,930	1.1%
SAS	9,378	1.1%
SWISS	9,336	1.1%
KLM	8,721	1.0%
Other	139,811	15.9%
Total	**877,431**	**100.0%**

Source: Sabre Data Intelligence

We will give a brief summary of each of these top five airlines' fleets, as well as providing a similar commentary on Virgin Atlantic given that it is based in the UK and operates primarily long haul, high capacity aircraft. These six airlines make up 62.6% of movements at UK airports, and therefore are key drivers of future fleet mix.

Fleet orders[12]

In order to meet forecast growth in demand, European-based airlines have the aircraft shown in Figure 5-3 on order (including form orders and options):

Figure 5-3: Fleet orders for top 20 airlines operating from UK airports

Airline	Share	Aircraft on order	Impact on UK seat capacity	Comments
British Airways	18.7%	11 A380, 9 A320, 18 A350, 22 787, 2 773	10% increase	A380 replace 747, 787 and A350 replace 767
easyJet	16.8%	48 A320, 100 A320neo, 1 A321	No change	Higher share of 320/similar to A319
Flybe	12.3%	26 E175	3% increase	Replace DHC8-400

[12] Information regarding existing fleet and orders current as at July 2013.

Airline	Share	Aircraft on order	Impact on UK seat capacity	Comments
Ryanair	10.9%	175 737-800	No change	Consistent with existing fleet
Aer Lingus	2.7%	9 A350s	No change	No change to short haul fleet
Jet2	2.1%	0	No change	No aircraft on order
Monarch Airlines	2.0%	2 A321	No change	Comparable to existing fleet
Eastern Airways	1.9%	0	No change	No aircraft on order
Cityjet	1.9%	0	No change	No aircraft on order
Lufthansa	1.8%	166 Long and Short Haul	No change	No change to short haul
BA Cityflyer	1.7%	0	No change	No aircraft on order
Loganair	1.6%	0	No change	No aircraft on order
KLM Cityhopper	1.5%	0	No change	No aircraft on order
bmi Regional	1.4%	0	No change	No aircraft on order
Aer Arann Regional	1.3%	7 ATR72-600	No change	Comparable to existing fleet
Virgin Atlantic	1.2%	6 A380, 15 787-900	1% increase	A380s to replace older 747s, 787 to replace A340
Wizz Air	1.1%	70 A320	No change	Consistent with existing fleet
SAS	1.1%	30 A320neo, 2 737-800, 6 ATR72	9% increase	Neos likely to replace 737s
SWISS	1.1%	30 CS100, 6 777, 1 A320, 1 A321	No change	Comparable to existing fleet
KLM	1.0%	2 777	No change	No change to short haul
Other	15.9%			
Total	**100.0%**		**2.8% increase**	

Source: Flightglobalpro, Sabre Airport Data Intelligence, airline websites, PwC analysis.

British Airways

BA currently have 322 aircraft either in service or on order, but it is important to remember that by the time the 62 on standby actually become active, a number of the 260 aircraft currently in service will have been retired. At the present time, the BA fleet is split evenly between Narrow body (50.4%) and Wide body (49.6%) aircraft. Moving forward, it is clear that BA are looking to expand their long haul fleet with the British Flag Carrier now having 11 A380-800 on order, each with a capacity of 467. It is rare for an airline to operate both the A380 and the Dreamliner (Boeing 787), but this demonstrates BA's commitment to growing their long haul business.

easyJet

The low cost carrier only operates narrow body aircraft, and judging by their order of 149 further narrow body aircraft, it would appear that they are not shifting from their current strategy of solely providing short haul flights in small aircraft. Two thirds of their orders are for the Airbus A320-200neo which have more fuel efficient engines than the current aircraft they have in operation (Airbus A319-100 and the A320-200).

Flybe

This low cost carrier currently has 67 aircraft in service, all of which are regional aircraft. These are split 66%-34% in favour of turboprops over regional jets. Their recent order of 26 Embraer 175-200ST aircraft will increase the size of their fleet, although it is not yet stated as to which of Flybe's current fleet is to be retired. Their recent order highlights how they intend to remain in the short haul market.

Ryanair

This ultra-low cost carrier has ordered 175 Boeing 737-800 aircraft, which will considerably increase their fleet, even after allowing for the retiring of some of their existing aircraft. This model is the only one that they currently have in service and on order, and thus they have shown faith in their tried and tested narrow body aircraft. According to their website, the new order cost around £15.6bn, and will allow the airline to grow at 5% each year, for the next five years. By March 2019, they intend to serve more than 100m passengers each year within Europe.

Aer Lingus

Of their current fleet, Aer Lingus have an 85%-15% split in favour of narrow body over wide body aircraft. However, a recent order of 9 A350's highlights that the airline is looking to expand its long haul network. As with easyJet, Aer Lingus only operate Airbus aircraft.

Virgin Atlantic

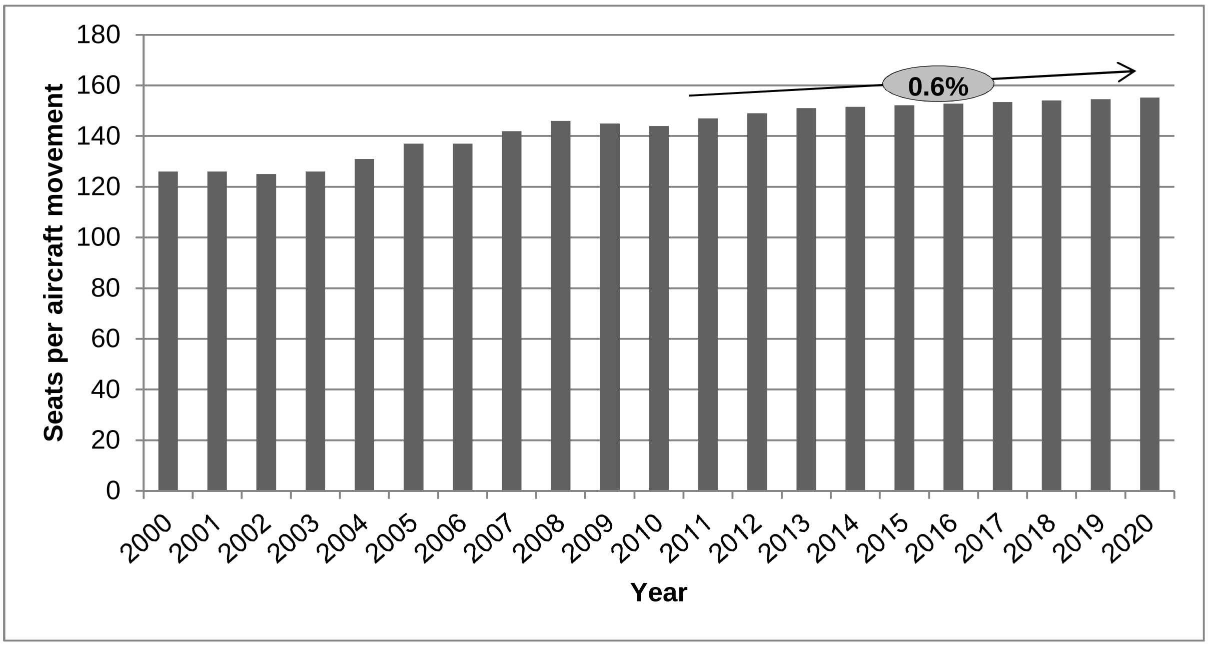
Virgin Atlantic is primarily a long haul carrier with only 10% of their current fleet being narrow bodied, and the remainder being wide bodied. Furthermore, orders of 6 A380-800's and 15 Boeing 787-9's will increase the number of aircraft they have that are capable of operating transatlantic flights.

Short term fleet analysis

2011-2020 forecast capacity increase

Our analysis of average seats per movement shows a steady increase between 2000 and 2011 with a CAGR of 1.3%. Our analysis of historical and forecast aircraft sizes implies that future growth will occur, although at a reduced rate compared with historical growth. An annual growth rate of 0.6% is predicted from 2011, with average seat capacity reaching 155 seats per ATM in 2020. This fits with the assumptions provided by the DfT's passengers per aircraft movement model. The end result of this trend is expected to be an overall increase in European seat capacity of 2.8% over the next 5-10 years.

Figure 5-4 – Historical and Estimated Seats per Movement Based on Fleet Order Analysis



Source: Capacity to 2013 based on Sabre data, future growth based on Boeing and Airbus market forecasts

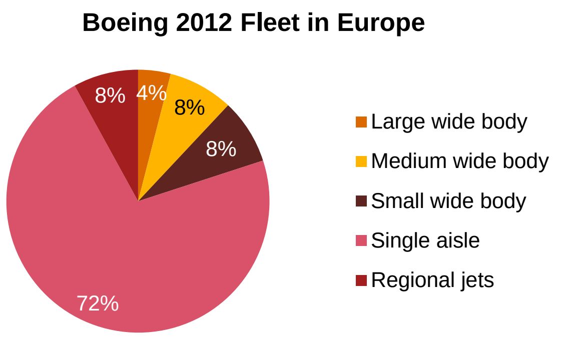
Longer term outlook

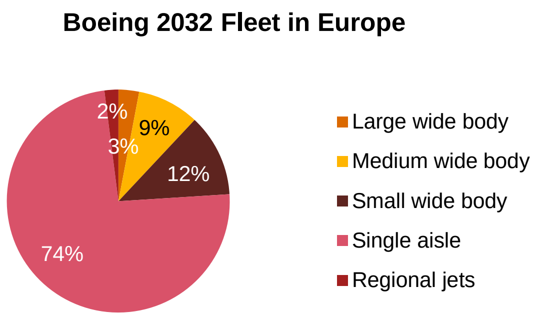
The following section looks at longer term fleet forecasts for aircraft manufactures Boeing and Airbus.

Boeing

Boeing's fleet forecast, shown in Figure 5-4, suggests that the overall make up of their fleet will not undergo serious change over the next 20 years. The proportion of the fleet comprising their smaller capacity aircraft (single aisle and regional jets) is expected to decrease during this time frame from 80% to 76%. Large and medium wide body aircraft are also expected to decrease their overall contribution to the entire fleet drop (12% – 5%). Small wide body aircraft (in between, size wise, medium wide body and single aisle) are expected to maintain their current level within the fleet (8%-9%). Therefore, the data shows that there will be a small increase in smaller capacity aircraft, at the expense of larger capacity aircraft, although the degree to which this shift is expected to occur is small.

Figure 5-4 – Current and Forecast Fleet Mix for Europe (Boeing)





Source: Boeing Current Market Outlook

Figure 5-5 – Boeing forecasts delivery of 7,460 aircraft

Aircraft Type	Forecast Delivery
Regional jets	224
Single aisle	5,595
Small wide body	821
Medium wide body	671
Large wide body	149

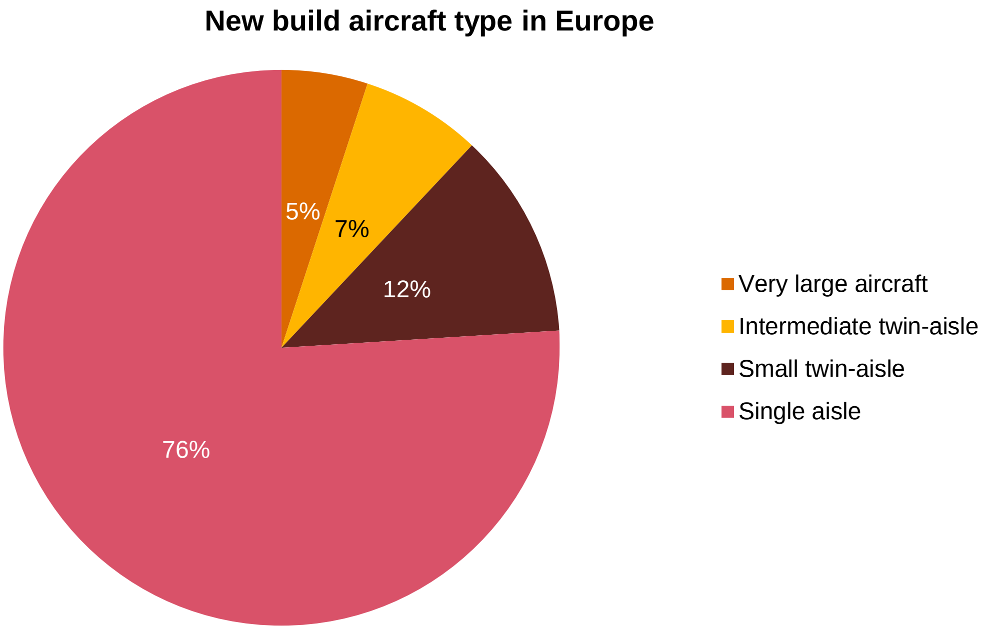
Source: Boeing Current Market Outlook

Boeing has also forecast that of these 7,460 delivered aircraft, 3,620 will be designated for fleet expansion, with the remaining 3,840 designated for replacements for aircraft which will be retired or leased/sold outside Europe.

Airbus

According to Airbus, they will almost double their current European fleet over the next 20 years. Their current fleet stands at 3,840, but this is scheduled to increase to 7,266 by 2031. This includes 5,701 newly built aircraft, of which 40% will be replacements, and the remaining 60% will be for growth. Of these 5,701 newly built aircraft, 76% will be single aisle design.

Figure 5-6 – Airbus Forecast for New Build Aircraft in Europe



Source: Airbus Global Market Forecast 2012 – 2031

Appendices

Appendix A

This appendix provides further detail of elements of the DfT aviation model in order to help understand the scale and nature of the task. However, it is anticipated that a wider reaching teach-in would be required to better inform those working on this project of how their work fits in with the model more broadly.

What level of disaggregation does the DfT allocation model work at?

Passengers are allocated at each airport in the model to 48 international zones. In practice, the most popular destinations such as other Western European hubs may be in a zone on their own (e.g. Paris Charles de Gaulle). However, in order to make computation possible on a standard desktop PC, the model must aggregate some destination airports into groups known as "zone groups". For example, zone group 525 includes airport destinations in Hong Kong, China, Thailand, Malaysia, Singapore, South Korea and others. A zone group may include up to 20 destination airports.

For the purposes of this note a "route" should be considered one UK airport- foreign airport pair. This means that a UK airport may serve a number of routes from a single zone group.

What is a Larame graph?

Zone Group
Route 1
Route 2
Route 3
Route 4

Larame graphs are a procedure[13] to relate passenger numbers on a route to the number of flights, taking into account the size of aircraft likely to be used and load factors. They may be thought of as converting seat forecasts into ATM[14] forecasts. As ATM frequencies have a powerful effect on the overall allocation of passengers to airports, the definition and application of Larame graphs to routes can have a significant impact on the airport forecasts.

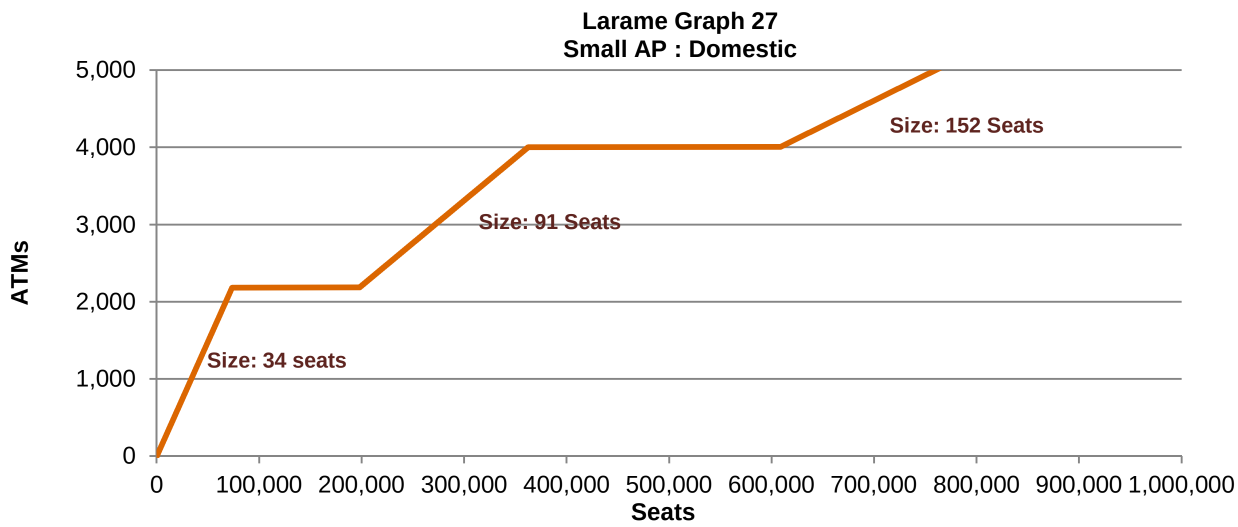
At present NAPAM includes a suite of more than 240 graphs. This allows rich variation in the behaviour of airlines according to their type (e.g. Low Cost vs. full service vs. charter), the airport they're flying from and the destination they're flying to.

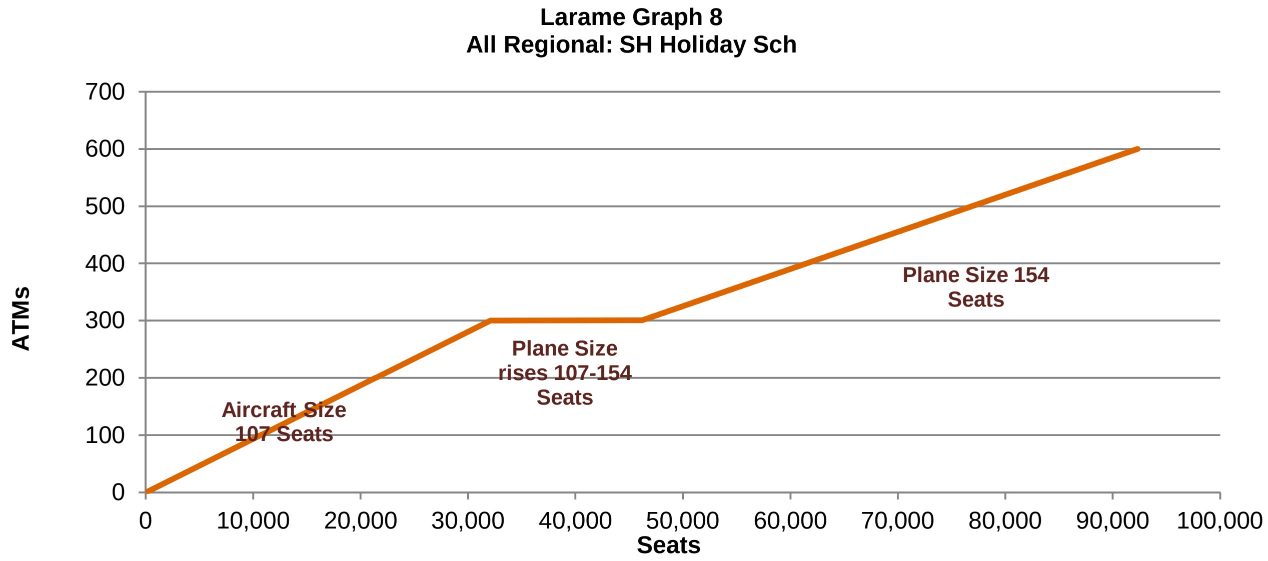
They usually (but not necessarily) include steps which represent the transition between aircraft sizes, as illustrated in the example graphs below. The commercial principle modelled by the graphs is that as demand for seats increases, route frequencies (ATMs) increase until a step is reached where extra passengers are accommodated by switching to larger aircraft sizes; when all aircraft on the route are of the larger size, frequencies will continue to grow to accommodate extra demand. The graphs can be extended beyond those illustrated to include further aircraft size transitions.

[13] They are used in NATS' SPAM model. See NATS FAG Paper 1, *SPAM Larame Graphs*.

[14] Air Transport Movement

Figure A-1 – Example Larame Graphs 8 and 27





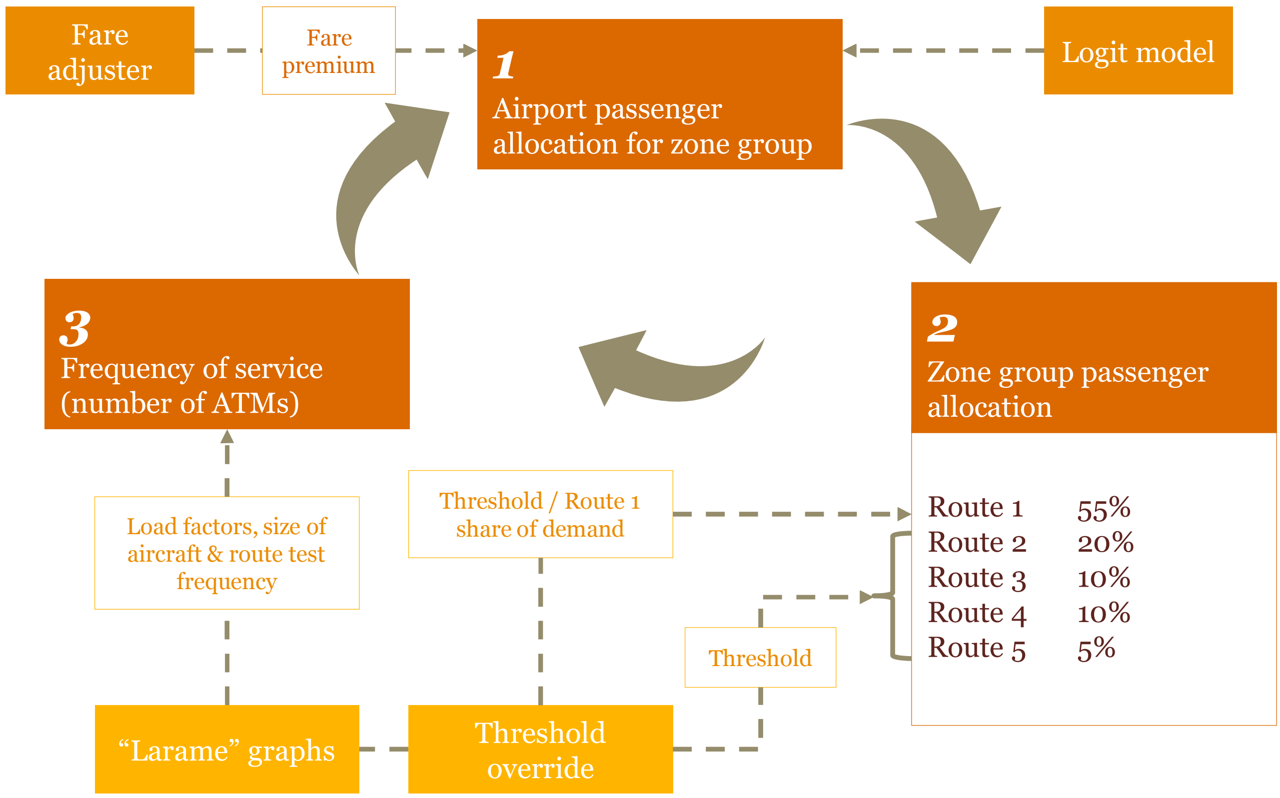
In the bottom graph above (Graph 8) as demand for seats grows, frequencies are added until the demand has reached 32,000 seats per year. At this point the size of the aircraft (or mix of aircraft sizes) operating the routes expands so that the growth in passengers up to 46,000 seats is accommodated without an increase in frequency. For demand above 46,000, frequencies are increased. In some graphs ATM maximum thresholds may trigger the switch to a 'larger' graph.

NAPAM makes provision for Larame graphs to '**increase**' year on year. This represents the probability of technological change allowing larger aircraft within the group of aircraft implicitly represented by each graph and for future year constraints to increase commercial assumptions about load factors. Therefore the Larame graphs are redefined for each year of the period 1998-2030 to incorporate growth assumptions and each page must be a valid year [1998], [1999] etc. Each Larame graph also contains a start-up "test frequency" for new routes and minimum passenger thresholds which are used in the route start-up algorithm.

How are routes started up or closed down in the model?

There are a number of factors influencing the start-up of a route within the model. These are outlined in Figure A-2 below:

Figure A-2 – Factors influencing route start-up thresholds



The model solves iteratively for each year:

- The first iteration uses the frequency of service from the previous year for those routes that already exist, it then adds in all possible routes at all airports using a minimum "test frequency" set from within the Larame graph inputs.
- An initial allocation of passengers to airports is completed on the basis of these frequencies being fed into a set of passenger allocation Logit models (with "fare adjusters" used as a manually adjusted additional cost to help align the model to latest outturn data during the validation process).
- This passenger allocation for each zone is then compared against a minimum threshold for numbers of passengers to make services to the zone viable. This threshold is either drawn from the Larame graphs or a threshold override input (used to help with calibration as it allows more detailed differentiation). Within Zone Groups this test is completed at a route by route level of disaggregation.
- Services between any airport and destination zones or zone groups where no route met the minimum threshold are then removed and the allocation process repeated.
- The passenger allocations for surviving destination zones and individual routes within zone groups are then fed back into the Larame graphs to see how many flights per year this equates to which gives a new frequency of service. This will result in a new allocation and a new round of iteration if required.

Appendix B

Figure B-1 – Larame 2012 Average Aircraft Size Assumptions vs. Actual

Larame Graph	Times used	Flight Frequency	Average aircraft Size (Larame)	Average aircraft Size (Actual)	Difference
1	2	1,173	30	57	-48.1%
2	11	6,620	24	102	-76.8%
3	13	9,008	67	141	-52.3%
4	1	5,155	170	164	3.5%
5	6	1,488	21	101	-79.6%
6	14	1,697	30	96	-68.7%
7	10	4,239	77	163	-52.7%
8	13	2,683	125	187	-33.1%
9	1	23	154	230	-33.1%
10	21	3,284	30	127	-76.6%
11	42	10,958	94	159	-40.7%
12	1	208	113	132	-14.1%
27	29	5,885	34	85	-60.4%
28	6	9,826	59	94	-36.8%
29	1	1	97	88	10.2%
30	202	203,503	158	154	2.6%
31	5	2,718	189	162	16.9%
33	5	5,839	134	133	0.5%
34	4	7,199	134	163	-17.7%
35	7	10,164	134	156	-14.0%
36	11	9,019	134	133	1.1%
38	1	125	89	148	-39.9%
42	1	336	160	235	-31.8%
43	1	3,583	160	181	-11.5%
44	3	18,535	126	142	-11.5%
45	4	17,499	159	150	5.9%
46	2	3,350	126	113	11.6%
47	4	5,786	152	161	-5.8%
48	4	14,343	144	132	8.9%
49	4	8,518	126	109	15.2%

Larame Graph	Times used	Flight Frequency	Average aircraft Size (Larame)	Average aircraft Size (Actual)	Difference
50	1	614	156	180	-13.3%
51	1	1,762	156	165	-5.4%
52	5	2,403	189	192	-1.7%
55	1	119	166	50	232.0%
56	4	2,206	50	74	-32.8%
57	5	1,404	50	53	-6.2%
58	8	11,813	50	63	-20.3%
59	4	6,214	64	86	-26.0%
60	5	7,473	88	100	-12.4%
61	2	6,238	31	80	-61.3%
63	22	10,094	78	70	11.4%
64	18	12,048	78	81	-4.1%
65	26	18,581	29	44	-34.1%
66	4	2,228	50	55	-9.2%
67	2	293	29	32	-10.6%
69	13	8,518	149	148	0.7%
70	10	4,796	149	142	5.2%
71	10	4,201	149	133	11.8%
72	10	6,196	149	156	-4.7%
73	3	589	149	137	9.1%
74	8	5,419	149	125	19.4%
75	1	706	153	156	-1.9%
76	5	1,645	153	156	-1.8%
77	9	11,640	153	156	-1.8%
78	4	9,329	153	154	-0.4%
79	2	1,544	153	158	-3.0%
81	20	18,466	156	149	4.6%
82	23	20,517	156	151	3.0%
83	12	10,712	156	155	0.4%
84	3	2,551	156	159	-1.9%
87	4	1,220	142	88	60.8%
88	8	8,334	142	114	24.1%
89	6	4,067	142	132	7.5%
90	10	4,672	142	118	20.7%
91	7	2,549	142	99	43.6%

Larame Graph	Times used	Flight Frequency	Average aircraft Size (Larame)	Average aircraft Size (Actual)	Difference
92	2	469	142	78	82.1%
93	1	515	142	39	265.0%
94	3	913	189	200	-5.3%
95	10	5,784	189	164	15.5%
96	12	12,264	189	176	7.6%
97	8	4,706	189	167	13.0%
98	9	5,084	189	168	12.5%
99	11	5,751	189	108	75.5%
100	3	3,923	179	169	6.0%
101	11	8,731	179	157	13.9%
102	1	110	179	148	21.2%
104	4	3,780	166	137	21.6%
105	1	69	166	148	12.2%
106	1	36	166	177	-6.3%
108	1	66	50	141	-64.5%
109	3	7,875	50	134	-62.6%
110	5	11,277	126	154	-18.1%
111	3	8,257	126	157	-19.6%
112	4	13,158	144	157	-8.3%
113	3	7,327	126	147	-14.1%
114	1	721	152	190	-20.0%
115	2	3,959	176	176	-0.3%
116	1	2,907	190	164	15.7%
117	4	13,065	190	163	16.4%
118	1	184	154	207	-25.6%
119	1	1,429	199	187	6.3%
121	1	925	210	313	-32.9%
122	1	2,278	270	248	8.7%
123	2	4,550	320	302	6.1%
124	1	6,688	320	286	12.1%
125	2	2,279	249	281	-11.4%
127	1	3,428	350	371	-5.6%
128	1	1,927	225	288	-21.9%
130	1	1,447	370	317	16.6%
131	1	428	270	303	-11.0%

Larame Graph	Times used	Flight Frequency	Average aircraft Size (Larame)	Average aircraft Size (Actual)	Difference
132	2	217	280	301	-7.0%
133	1	509	230	228	0.9%
134	1	90	220	270	-18.6%
136	1	1,095	370	353	4.8%
137	5	4,895	134	156	-14.0%
138	1	37	134	156	-14.1%
139	1	2,962	200	169	18.0%
141	4	3,335	160	173	-7.5%
143	1	925	189	207	-8.9%
144	1	60	189	148	28.0%
146	1	3,429	89	126	-29.6%
147	1	21	270	333	-19.0%
148	2	1,385	148	171	-13.4%
149	3	4,724	186	156	19.3%
150	7	7,200	173	134	29.6%
151	3	1,277	148	102	44.7%
152	7	6,706	149	137	8.5%
153	8	4,802	149	165	-9.9%
154	7	12,732	165	154	6.8%
155	1	23	220	230	-4.4%
156	7	3,948	220	191	15.4%
157	3	982	220	179	22.6%
158	1	126	220	149	47.9%
159	3	721	67	107	-37.4%
161	3	911	67	82	-18.3%
163	4	1,607	58	72	-19.6%
164	5	3,697	66	71	-6.8%
166	1	614	180	180	0.0%
167	1	147	180	189	-4.8%
169	1	2,224	50	55	-8.3%
170	1	3,492	50	87	-42.4%
171	1	2,007	50	50	0.0%
172	1	2,129	50	66	-24.6%
174	6	4,603	106	88	20.1%
176	6	3,635	113	144	-21.8%

Larame Graph	Times used	Flight Frequency	Average aircraft Size (Larame)	Average aircraft Size (Actual)	Difference
177	1	105	98	149	-34.1%
178	6	6,457	115	91	27.2%
179	2	353	78	177	-55.8%
180	8	1,604	78	148	-47.5%
181	10	4,181	78	82	-5.2%
182	11	5,281	78	87	-10.3%
183	1	223	78	41	89.0%
185	2	426	49	156	-68.6%
186	4	1,818	49	85	-42.3%
187	8	4,366	49	78	-37.1%
188	3	2,617	49	90	-45.4%
192	1	150	177	189	-6.3%
193	5	6,653	92	105	-12.7%
194	6	6,681	92	114	-19.3%
196	1	1,278	92	84	10.0%
197	3	369	240	270	-11.2%
198	1	364	240	307	-21.7%
199	1	47	270	342	-21.1%
200	1	25	270	309	-12.5%
201	1	579	430	328	31.0%
202	2	1,824	402	381	5.5%
203	6	3,587	214	175	21.8%
204	1	415	189	188	0.6%
207	1	231	37	156	-76.3%
219	2	404	222	216	3.0%
220	1	1,040	242	214	13.3%
240	2	137	102	139	-26.9%
Total	**1,015**	**868,718**	**139**	**143**	**-2.5%**

Appendix C

Regression analyses of individual market segments 2000-2011

Figure C-1 – International Scheduled Segment

Number of observations	4641338
F(3, 3842)	990.78
Prob > F	0
R-squared	0.7812
Root MSE	40.705

(Std. Err. Adjusted for 3843 clusters in routeid)

	Coef.	Std.	Err.	t	P>|t|	[95% Conf. Interval]
Segment passengers	0.0001111	1.45E-05	7.67	0	8.27E-05	0.00014
Route distance	0.0249556	0.000586	42.58	0	0.023807	0.026105
UK airport size	0.6166375	0.056348	10.94	0	0.506164	0.727111
Carrier status	0	(omitted)				
Base seat number	70.27604	1.989319	*35.33*	0	66.37581	74.17626

Figure C-2 – International LCC Segment

Number of observations	2155754
F(3, 2036)	45.09
Prob > F	0
R-squared	0.3205
Root MSE	36.011

(Std. Err. Adjusted for 3843 clusters in routeid)

	Coef.	Std.	Err.	t	P>|t|	[95% Conf. Interval]
Segment passengers	0.000207	3.82E-05	5.43	0	0.000132	0.000282
Route distance	0.032261	0.002834	11.38	0	0.026703	0.037818
UK airport size	0.265557	0.134153	1.98	0.048	0.002465	0.528649
Carrier status	0	(omitted)				
Base seat number	95.12032	5.927275	16.05	0	83.49616	106.7445

Figure C-3 – Domestic Scheduled Segment

Number of observations	2289141
F(3, 1055)	94.58
Prob > F	0
R-squared	0.5318
Root MSE	35.689

(Std. Err. Adjusted for 3843 clusters in routeid)

	Coef.	**Std.**	**Err.**	**t**	**P>|t|**	**[95% Conf. Interval]**
Segment passengers	0.000189	2.74E-05	6.88	0	0.000135	0.000243
Route distance	0.056653	0.016534	3.43	0.001	0.02421	0.089096
UK airport size	0.730623	0.094378	7.74	0	0.545433	0.915814
Carrier status	0	(omitted)				
Base seat number	34.90527	6.493191	5.38	0	22.16424	47.64631

Figure C-4 – Domestic LCC Segment

Number of observations	1644341
F(3, 560)	118.71
Prob > F	0
R-squared	0.4171
Root MSE	32.66

(Std. Err. Adjusted for 3843 clusters in routeid)

	Coef.	**Std.**	**Err.**	**t**	**P>|t|**	**[95% Conf. Interval]**
Segment passengers	0.000331	2.68E-05	12.36	0	0.000279	0.000384
Route distance	0.078699	0.01366	5.76	0	0.051869	0.105529
UK airport size	-0.13668	0.125903	-1.09	0.278	-0.38398	0.110621
Carrier status	0	(omitted)				
Base seat number	46.98347	5.330195	8.81	0	36.51385	57.45309