Airports Commission

Economy:
Delay Impacts Assessment

November 2014

An independent commission appointed by Government

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Glossary

AC	Airports Commission
Arrival holding	The practise of holding a flight in an airborne stack, waiting to land
ATFM	Air Transport Flow Management
ATM	Air Transport Movement
Block hours	The industry standard measure of aircraft utilisation, or the time spent by the aircraft flying, taxiing or landing
Carbon-traded	Modelling scenario where CO_2 emissions are part of an emissions trading scheme, but not limited to any target
CO_2	Carbon dioxide
Constrained forecasts	Modelling case where passenger and ATM demand must fit available future capacity where no significant additional runway or terminal capacity is added
DECC	Department for Energy and Climate Change
DfT	Department for Transport
Do Minimum	The base case with no airport capacity expansion
Do Something	The scheme case with proposed airport capacity expansion
EU	European Union
Ground holding	The practise of holding a flight on the ground, ready to depart
Helios paper	UK CAA Runway Resilience Study
LGW	London Gatwick
LGW 2R	London Gatwick Second Runway
LHR	London Heathrow
LHR ENR	London Heathrow Extended Northern Runway
LHR NWR	London Heathrow North West Runway
PV	Present Value
Shadow Cost	The extra cost of flying required to reduce passenger demand to within an airport's runway or terminal capacity. It can be thought of as a congestion premium, representing a fare increase to passengers or general inconvienience of using an overloaded airport
Taxiing	The practise of holding an aircraft on ground, ready to depart
TEAM	Tactically Enhanced Arrival Management
TEE	Transport Economic Efficiency
UoW paper	'European airline delay cost reference values' study conducted by University of Westminster
VoT	Value of time
WebTAG	Department for Transport Appraisal Guidance

1. Introduction

1.1 This paper sets out the background to and explains the analysis that has been undertaken to estimate the benefits for airlines, passengers and carbon emissions due to reduction in delays in the UK airport system[1] under the different scheme options.

1.2 This work builds upon preliminary work undertaken for the Airports Commission's (AC) *Interim Report*.[2] This previous analysis considered the delay costs associated with a constrained airport system compared to an unconstrained airport system to an airlines operating and passenger experience costs, which were estimated at £5.1 billion (in Present Value) between 2021 and 2080.[3] The analysis has been refined further since the Interim Report, and now includes a larger set of airports, monetisation of passenger value of time, carbon costs and a distinction between summer and winter delay times.

1.3 In its *Interim Report*, the AC recognised that emerging problems for UK airports cannot be addressed without new infrastructure, but there are opportunities to make better use of existing capacity in the short-term. The suggested optimisation strategy to reduce delays had an estimated NPV of £2.3 billion between 2014 and 2030. To this end, progress has been made by HMG on implementing some measures such as time based separation, airport collaborative decision-making and the establishment of a Senior Delivery Group. However, the Government has yet to make a decision on other key measures such as an early morning smoothing trial or further operational freedoms, reflecting the political difficulties associated with these measures to reduce delays.

1.4 The benefits of reduced delays at airports due to expansion of runway capacity are additional to other benefits captured in the appraisal framework, in particular the direct transport economic efficiency (TEE) and frequency benefits. TEE benefits in the appraisal are the benefits to passengers from reduction in shadow costs. Frequency benefits capture the convenience benefits of increased frequency of flights which allows users to be better matched to their preferred travel times.

1 For the purpose of this analysis, we only consider airports which fill up to 80% of their runway capacity up to 2050. These include Heathrow, Gatwick, Stansted, Luton, London City, Aberdeen, Belfast City, Birmingham, Edinburgh, Manchester, Newquay and Southend.

2 Airports Commission (Dec 2013) *Airports Commission: Interim Report.*

3 Our new estimate is smaller in all do something scenarios because we use more robust and in some cases used lower assumptions of delay times. Work undertaken for the Interim Report was based on the costs associated with a capacity constraint when compared to a capacity unconstrained system. The analysis undertaken in this appraisal is based on the benefit of relasing capacity at one location compared to the constrained 'do minimum' which drives the difference in scale of impact.

2. Background

Impacts of delays

2.1 Delays, cancellations and unreliability impose costs on passengers and airlines and also lead to environmental costs. These are especially acute at airports which run under constraints to runway capacity in relation to demand.

2.2 Longer flight times leave passengers spending time in the air that could be used more productively or enjoyably. Cancelled flights cause frustration and wasted journeys. Uncertainty about arrival and departure times leads to inconvenience and can leave travellers stranded on the runway or in the departure lounge. This will lead to the need for increased terminal capacity and better facilities to house delayed passengers.

2.3 Delays in the system force airlines to account for them and build in buffers in their flight schedules. This creates additional operational costs to the airlines. Under a low cost carrier model, for example, airlines use their aircrafts intensively and plan for several round-trips between destinations. Delays can severely limit this agility and in some cases lead to cancelled flights, leaving airlines and passengers with additional cost and inconvenience. For airlines operating a hub model, unreliability reduces the ability of airlines to schedule connecting flights effectively, which can lead to reduced performance of the airport as an effective hub.

2.4 Delays also have environmental consequences, for example in terms of increased emissions as aircrafts are required to spend time taxiing or in holding stacks awaiting the opportunity to land. They may also have noise impacts on local residents. At Heathrow, for instance, respite from noise is reduced when both runways have to be used for arrivals and departures in order to recover from delays. Gatwick, which uses its runway for mixed mode operations, does not have this flexibility.

2.5 Large numbers of delays on a regular basis, also reduce an airports resilience to withstand and recover from day-to-day perturbations and large scale disruptions.

2.6 Delays to a particular flight at a particular airport can also have second round impacts through upstream and downstream impacts on other airlines and airports. Furthermore, regular delays at an airport can ultimately lead to a reduced number of departures and arrivals planned per hour and further decrease capacity at the airport.

Types of delays

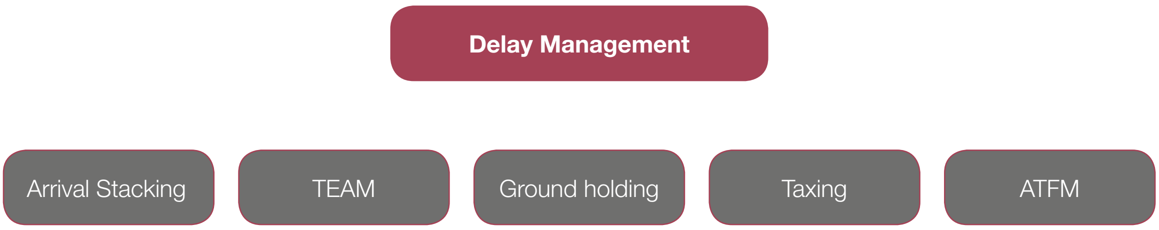
2.7 Delays are usually categorised into two types – strategic and tactical. Strategic delays are those accounted for in advance and often embedded within flight schedules. Tactical delays are those incurred on the day of operations and not accounted for in schedules.

2.8 Strategic and tactical delays are not independent since recurring tactical delays, as can be expected in a capacity constrained airport with little resilience and spare capacity to absorb unexpected delays, will encourage airlines to build in larger buffer times in their flight schedules.

Managing delays

2.9 The runway represents a pinch point in the air traffic network and where demand is approaching capacity, queues can build up.

2.10 Airports optimise existing capacity using several capacity management techniques. Some common measures include the following:



2.11 Arrival stacking is the practise of managing arrival queues by creating airborne holding stacks. They are used to moderate the demand for the runway, to allow air traffic controllers to sequence aircrafts to optimise the throughput of the runway.

2.12 Tactically enhanced arrivals management, or TEAM, is a temporary measure applied at Heathrow to boost arrivals capacity by allowing a proportion of the arriving aircrafts to use the departure runway.

2.13 The departure flow is moderated similarly by managing the queue to optimise the throughput of the departure runway. Departures are sequenced by managing the time that the aircraft is pushed back (ground holding) and by managing its passage from its stand to the runway after it has pushed back (taxiing) to provide the optimum sequence of aircrafts at the departure runway.

2.14 Air Traffic Flow Management (ATFM) is the practice whereby aircraft that plan to arrive during a period of congestion are held upstream on the ground at their departure airports until the downstream capacity constraint is alleviated. The ATFM system is centrally managed by the Eurocontrol Central Flow Management Unit and is usually restricted to departures from Europe. This regulation imposes an ATFM delay on the affected aircraft which is the difference between the scheduled take-off time as per the aircraft's flight plan and the calculated take-off time.

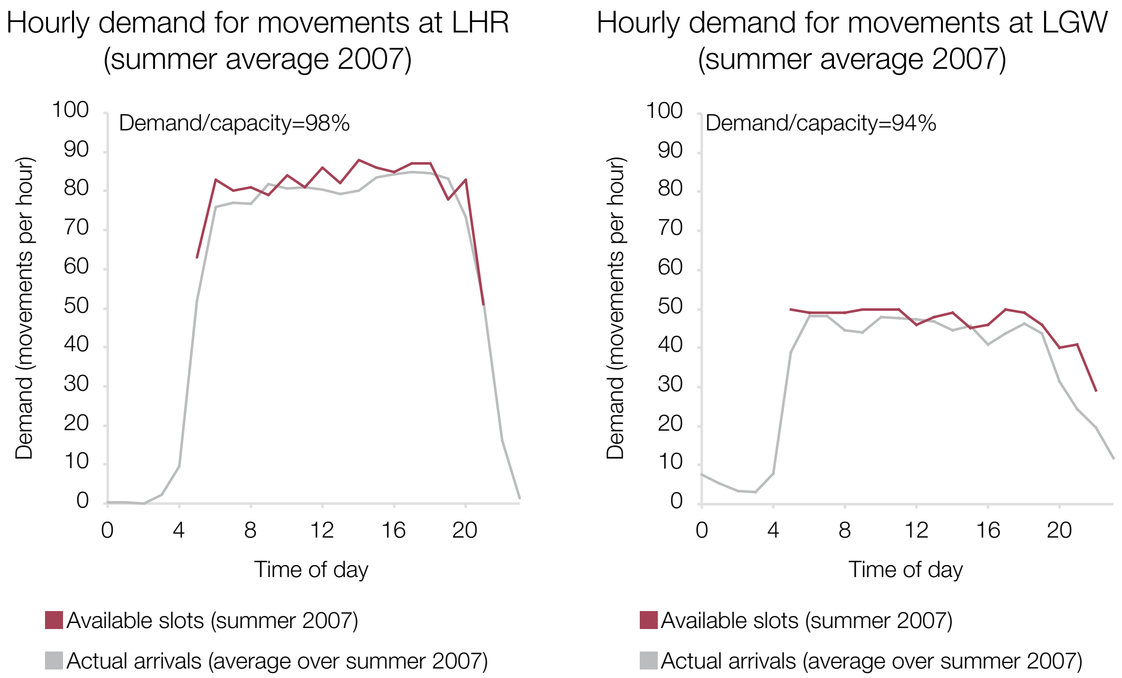
Heathrow and Gatwick performance

2.15 Heathrow is one of the world's biggest international airports and Gatwick is cited as the busiest single runway airport in the world. The figures 1 and 2 show the capacity utilisation at Heathrow and Gatwick over the summer and winter seasons in 2007/08.

2.16 In 2007, Heathrow had a demand to capacity ratio of 98% in the summer months and 97% in the winter months. Over the summer months, Heathrow faced two peaks during the day – early morning and evening. At about 8am and 6pm, demand exceeded the available capacity. There were similar peaks in the winter season and at about 9pm, demand exceeded available capacity.

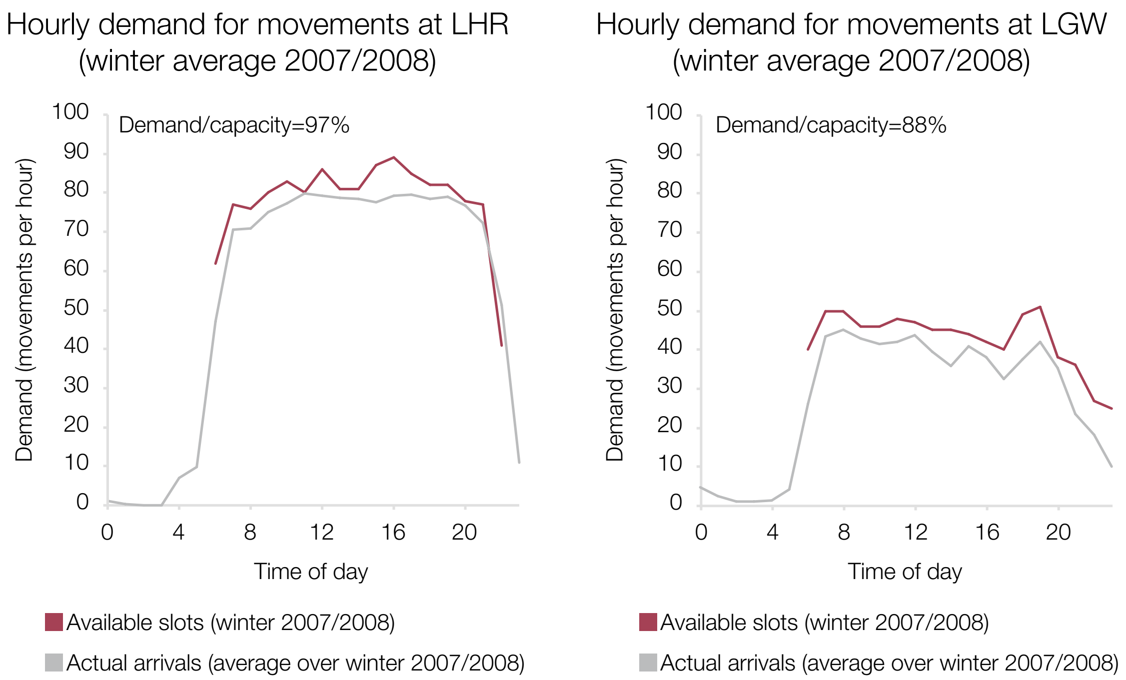
2.17 Gatwick had a demand to capacity ratio of 94% in the summer months and 88% in the winter months. Over the summer months, Gatwick faced three peaks – early morning, late-morning and evening. Demand exceeded capacity about noon. While it faced further several peaks during the day in the winter months, demand stayed slightly further below capacity. The number of peaks at Gatwick are symptomatic of the low cost carrier model operated by airlines that served the airport in 2007/08.

Figure 1: Actual utilisation and available slots at Heathrow and Gatwick in the summer season, 2007



Source: UK CAA Runway Resilience Study (2008)

Figure 2: Actual utilisation and available slots at Heathrow and Gatwick in the summer season, 2007



Source: UK CAA Runway Resilience Study, 2008

2.18 These demand to capacity figures gave rise to significant delays, especially at Heathrow. Tables 1 and 2 describe the delays felt at Heathrow and Gatwick in summer 2007 and winter 2007/08.[4]

4 ICF International (Dec 2008) *UK CAA Runway Resilience Study Final Report.*

Table 1: Delay times at Heathrow in 2007/08, split by management techniques

(minutes)		Stack	ATFM	Ground	Pre-startup
Summer	Average	5.3	2.8	10.0	4.6
	Top-range	10-15	15-25	14-22	19
Winter	Average	6.0	5.3	9.2	4.4
	Top-range	15-20	35-45	14-22	18

Source: UK CAA Runway Resilience Study (2008).

Table 2: Delay times at Gatwick in 2007/08, split by management techniques

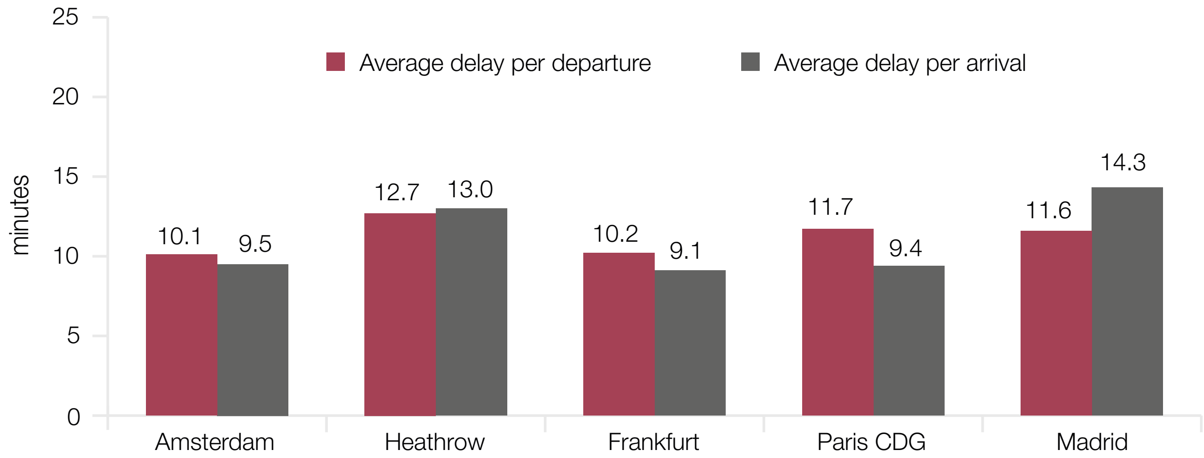
(minutes)		Stack	ATFM	Ground	Pre-startup
summer	Average	1.2	0.4	7-8	2.2
	Top-range	-	-	12-18	12
winter	Average	0.8	1.0	6.9	2.2
	Top-range	-	0-12	12-18	12

Source: UK CAA Runway Resilience Study (2008).

2.19 Data from 2007/08 suggests that delays are much larger at Heathrow than at Gatwick, especially at arrival. As can be seen in the figure 3, average delays at Heathrow are higher than its other competitor European hubs, apart from average arrival delays at Madrid.

Figure 3: Average delays at selected European hubs, 2012

Average delay per departure and arrival, selected European hubs in 2012



Source: CODA (December 2013) by Eurocontrol.

3. Previous work

3.1 Although it is widely accepted that delays can mount up at capacity constrained airports creating additional costs for airlines, passengers and the environment, the literature on the subject is limited.

3.2 The DfT WebTAG Aviation Appraisal unit A5.22[5] recognises the costs to passengers of increased journey times from delays at airports, but does not discuss costs of delays to airlines. Thus, the methodology used for the calculation of total delay costs is constructed using the following papers.

UK CAA Runway Resilience Study[6] (Helios paper)

3.3 This study, conducted by Helios, XPX Consulting and SH&E Ltd, investigates the runway resilience of Heathrow and Gatwick using data from 2007/08. It conducted operational modelling to determine delay distributions and their relationship with demand to capacity ratios.

3.4 We have used the relationship this study derives between demand to capacity ratios and expected delays at Heathrow to estimate the delay profiles at various airports under the different expansion schemes.

European airline delay cost reference values[7] (UoW paper)

3.5 This study, conducted by the Department for Transport Studies at University of Westminster, is a reference guide for European costs of delays (strategic, tactical and ATFM) to airlines estimated using data on operating costs per block hour.

3.6 We have used the costs estimated in this study to predict the costs to airlines and carbon costs due to strategic delays under different expansion schemes.

3.7 Other sources used in our work include assumptions and outputs from the DfT aviation model. More detail on this is included in the following sections.

5 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/275398/webtag-tag-unit-a5-2-aviation-appraisal.pdf

6 ICF International (Dec 2008) *UK CAA Runway Resilience Study Financial Report.*

7 University of Westminster (Mar 2011) *European airline delay cost reference values Final Report (Version 3.2).*

4. Methodology

4.1 The analysis considers the impacts of delays on the UK airport system, focusing on airports that reach demand to runway capacity ratios of over 80%[8] up to 2050 under any of the expansion schemes. As per our analysis, these are – Heathrow, Gatwick, Stansted, Luton, London City, Aberdeen, Belfast City, Birmingham, Edinburgh, Southend, Manchester and Newquay airports.

4.2 This analysis focuses on benefits of reduced delays for airlines, passengers and carbon emissions from strategic delays. Any assessment of the impacts on noise respite, air-quality impacts or any resilience or reliability benefit from having an airport with extra capacity is out of scope of this analysis.

4.3 For the purpose of this analysis, arrival and departure delay time resulting from capacity constraints refers to the phases of a flight when an airline is held in a stack, waiting to land (arrival holding) or on the ground, ready to depart (ground holding). Other delays caused by for instance, ATFM and at gate holding have not been included in this analysis.

4.4 Since evidence on realised delay times does not allow one to distinguish between strategic and tactical delays, it is usually[9] assumed that any recurring average annual delay is factored into airline and passenger schedules. Likewise, the following analysis assumes all delay time to be strategic.

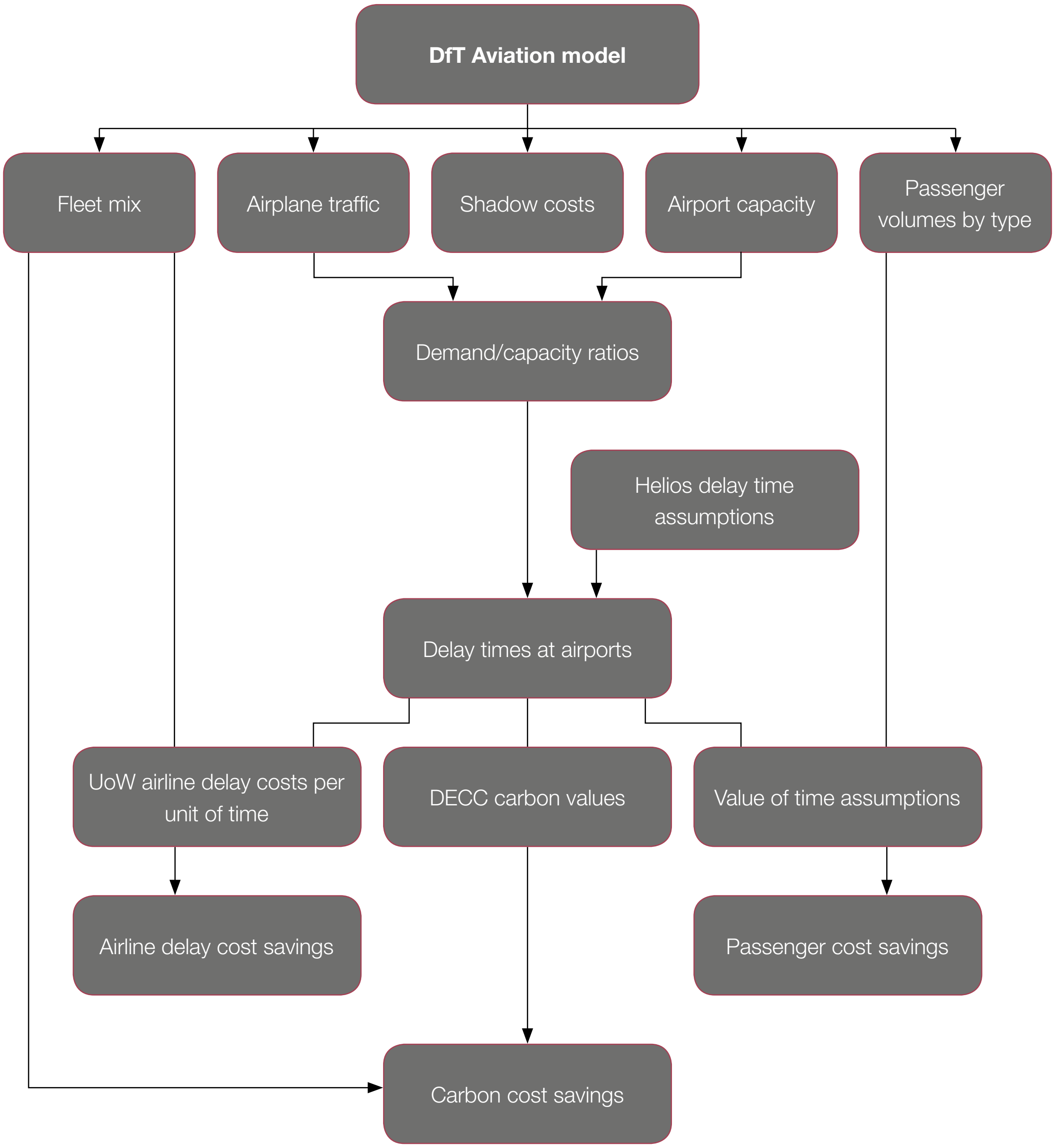
4.5 Due to these limitations, the benefits of reduced delays from this analysis are likely to be an underestimate and should therefore, be considered a lower bound.

4.6 The following flowchart gives a pictorial representation of the methodology used.[10]

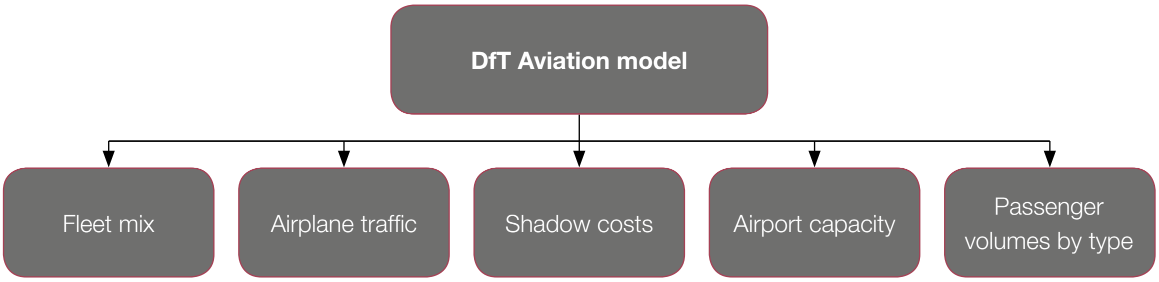
8 This is the threshold of demand to capacity ratios at which ground holding delay times begin to kick in – see delay time assumption below.

9 ICF International (Dec 2008) *UK CAA Runway Resilience Study Financial Report.*

10 Arrows represent direct inputs/outputs. Solid lines represent linkages.


DfT Aviation model
Fleet mix
Airplane traffic
Shadow costs
Airport capacity
Passenger volumes by type
Demand/capacity ratios
Helios delay time assumptions
Delay times at airports
UoW airline delay costs per unit of time
DECC carbon values
Value of time assumptions
Airline delay cost savings
Passenger cost savings
Carbon cost savings

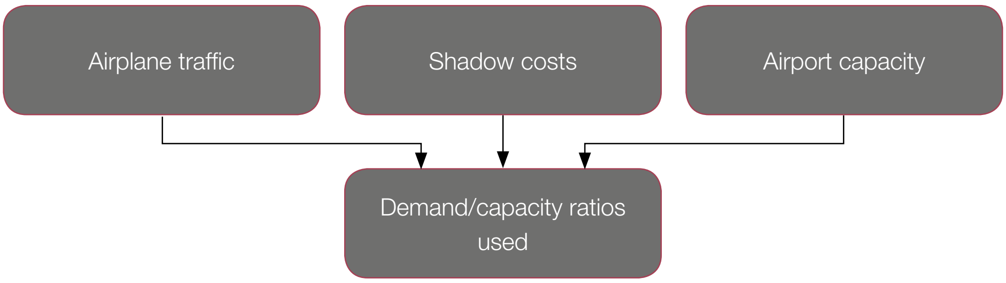
Outputs from the DfT aviation model



4.7 As shown in the flowchart above, the DfT aviation model[11] provides capacity constrained forecasts of airplane traffic, fleet mixes, shadow costs, passenger volumes split by types of passengers[12] and airport capacity from 2025 to 2085 for all carbon-traded global scenarios.[13]

4.8 Traffic forecasts have been split into summer (seven months) and winter (five months) seasons to make it consistent with previous studies which suggest that the delay time impacts of capacity constraints differ in the two seasons due to differences in scheduling limits,[14] which inform the scheduling process and the variation in weather between the two seasons.

Demand to capacity ratios



4.9 As shown in the flowchart above, the forecasts of airplane traffic (ATMs) and the airport capacity at all airports is used to calculate the demand to capacity ratio at each airport. The demand to capacity ratio is determined to be 1 if any airport shadow costs begin to build up, because of either runway or terminal capacity being full.

4.10 We use ATMs as an indicator of demand as opposed to passenger numbers. This is because passenger numbers alone will overestimate capacity constraints without

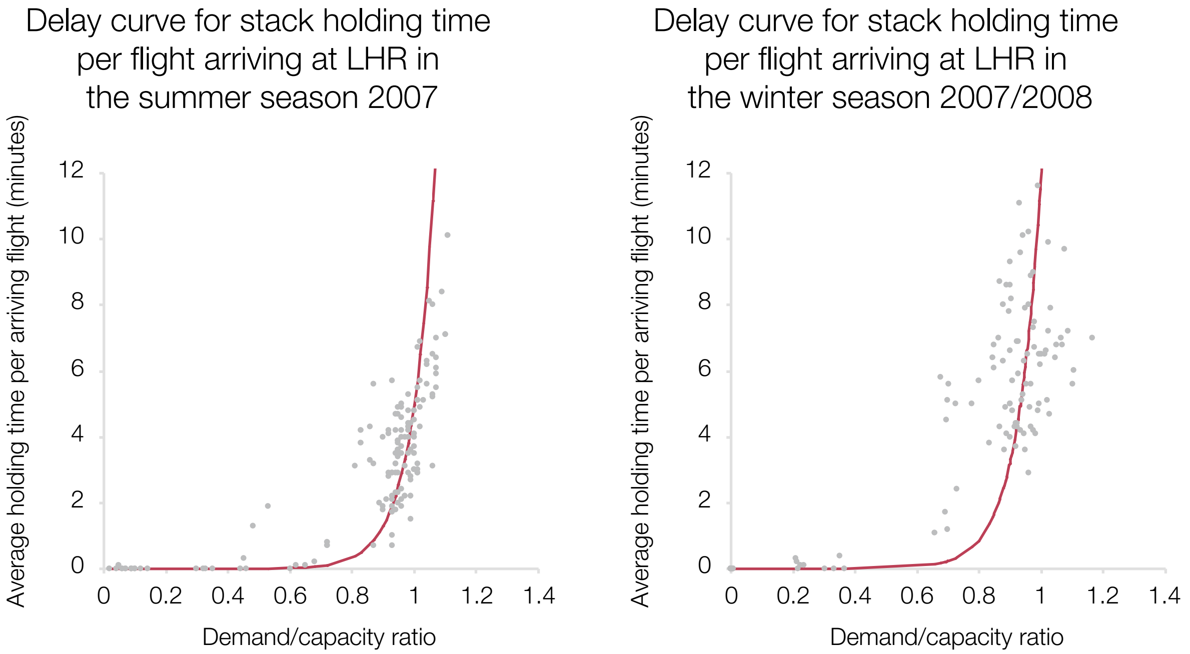
11 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223839/aviation-forecasts.pdf
12 The various types of passengers considered are UK business, UK leisure, foreign business, foreign leisure and international to international (connecting).
13 Details on scenarios in Appendix B.
14 The maximum number of movements per hour and the effective planned capacity of the runways.

the appropriate fleet mix considerations which could be used to serve the excess passenger demand.

Delays time assumptions

4.11 Assumptions around the relationships between i) average stack holding and demand/capacity ratio, and ii) average ground holding time and demand/capacity ratio are based on the Helios report are shown in figure 4.

Figure 4: Relationship between demand to capacity ratios and average stack holding time at Heathrow



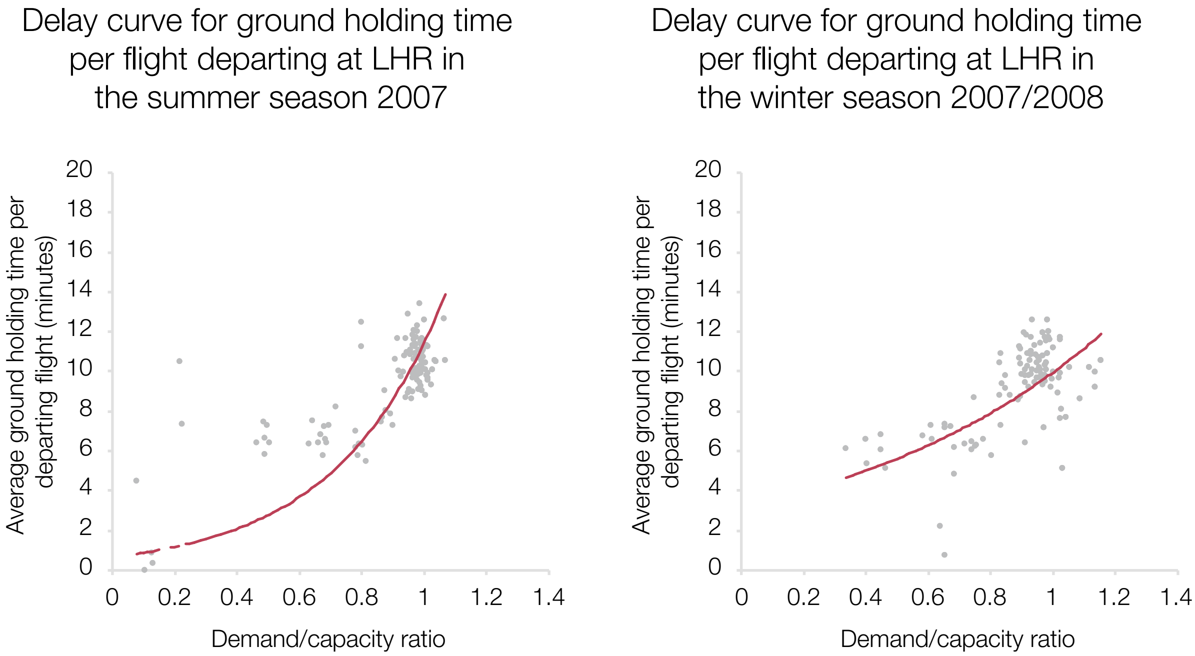
Source: UK CAA Runway Resilience Study (2008)

4.12 Figure 4 shows the relationship between the average stack holding time per flight in minutes (Y-axis) and the demand/capacity ratio (X-axis) at Heathrow in the summer and winter season 2007/08.

4.13 Based upon this evidence, it is assumed that arrival delays only occur when an airport's capacity is above or equal to 80%. Further, we have assumed that in summer, there is 0.5 minutes of delay at a demand to capacity ratio of 0.8 which builds up linearly to a maximum delay time of 6 minutes at demand to capacity ratio of 1. Over the winter, the delay times are between 1 minute to 12 minutes.

4.14 The following figure 5 shows the relationship between average ground holding time per flight (defined as the difference between actual and perfect taxi time[15]) and the demand/capacity ratio.

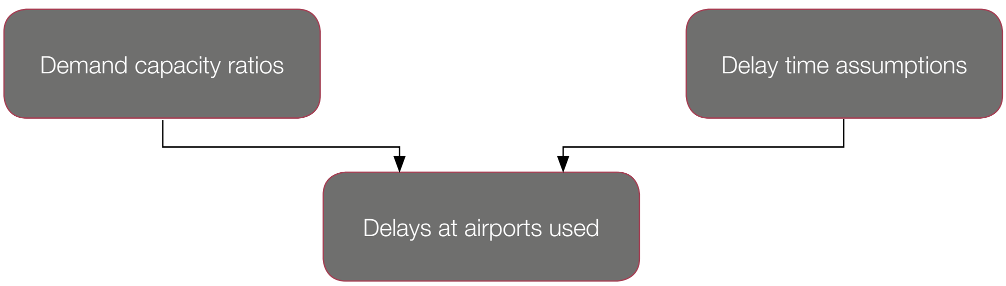
Figure 5: Relationship between demand to capacity ratios and average ground holding time



Source: UK CAA Runway Resilience Study (2008)

4.15 Based on this, the relationship between average ground holding time per flight and the demand/capacity ratio assumes that departure delays builds up consistently from a base of 0.6 and 3.1 minutes in the summer and winter respectively.

Delay times at airports



4.16 We then take the average delay time per flight at a fully capacity constrained airport, defined as when the demand to capacity ratio is equal to one for the purpose of this analysis. These times are outlined in the table 3.

15 Perfect taxi time is the time taken by an airline to taxi from its gate to the runway with no disruption.

Table 3: Average delay times at a fully capacity constrained airport

	Summer	Winter
Arrival	4.8	6.3
Departure	7.2	6.8

Source: Development and Assessment of Airport Capacity Options Short Term Options: Technical Report (2013)

4.17 These delay times are applied equally across all airports that experience a capacity constraint and are based upon evidence of delay times at Heathrow in 2008 after the application of the short term options[16] as found by LeighFisher in their December 2013 report[17] to the Airports Commission.

4.18 The delay times in table 3 are averages across all inbound and outbound traffic. It includes flights that experience no delay (i.e. 0 minutes) as well as flights that experience significantly greater arrival or departure delay. For instance, the arrival delay time that might be expected at the top-end of the range of a capacity constrained airport are two to three times greater; being around 10 to 15 minute in summer and 15 to 20 minutes in winter. Similarly departure delay in the top-end would be two times greater than the average.

4.19 Combining these assumptions with estimates of average delay time at airports (as in table 3), we derived average delay times for airports with different demand/capacity ratios. This is presented in table 4:

Table 4: Delay time and demand/capacity ratio

Demand/ Capacity ratio	Summer (minutes)		Winter (minutes)	
	Arrival	Departure	Arrival	Departure
0.1	0.0	0.0	0.0	0.1
0.2	0.0	0.0	0.0	0.8
0.3	0.0	0.0	0.0	1.6
0.4	0.0	1.0	0.0	2.3
0.5	0.0	2.0	0.0	3.1
0.6	0.0	3.1	0.0	3.8
0.7	0.0	4.1	0.0	4.6
0.8	0.5	5.1	1.0	5.3
0.9	3.3	6.2	6.5	6.1
1.0	6.0	7.2	12.0	6.8

16 Please note that not all of the recommended short term measures have been implemented and so the delay time savings for each scheme compared to the 'do minimum' is likely to be an underestimate.

17 LeighFisher (Dec 2013) *Development and Assessment of Airport Capacity Options Short Term Options: Technical Report (December 2013).*

4.20 This was used to calculate the delay times at each airport[18] under each scenario for the various expansion schemes as well as for the do minimum as a comparison.

4.21 The delay times under each scheme is combined with the airline, passenger and carbon costs per unit (explained below) at each airport to determine the total benefits of any reduction of delays.

Airline cost savings

4.22 Capacity constrained airports lead to an expectation of delays by the airlines, as explained in paragraph 2.3 above. Based on the experience of stack holding and taxiing time during the day at each airport, airlines build a 'buffer' in their schedules.

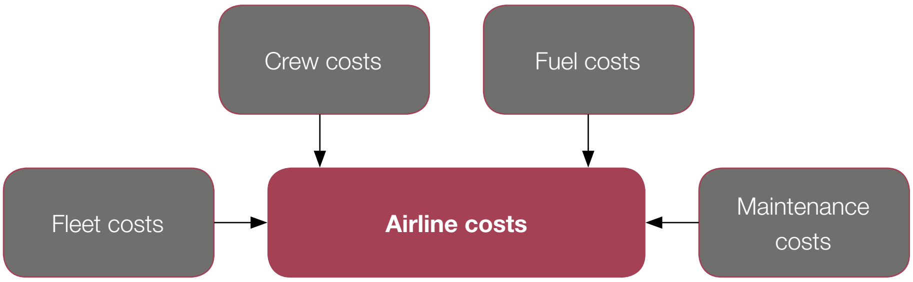
4.23 Airline costs are the costs accrued by airlines from adding a buffer to their schedules. These costs, termed costs of prevention, include costs at the planning stage such as need for extra crew and aircrafts as well as at the operational stage such as cost of excess fuel consumption during stacking and taxiing.

4.24 The methodology and data used is based on the base case in the UoW paper. The various elements of the airline costs (paragraph 4.25 to 4.28 below) have been calculated for delays at arrivals and departures.

4.25 Fuel costs are the costs of excess fuel consumption during stack holding and taxiing as well as fuel carriage penalty (see Carbon Costs below). The UoW study provides the best available data on rates of fuel burn and fuel costs. It has sourced its data on fuel burn based on aircraft and engine type from the ICAO Aircraft Engine Emissions Databank and specific engine suppliers. Adjustments had to be made to align the aircraft types considered in the study to the DfT's forecast fleet mix. It is assumed that next generation aircrafts are 10% more fuel efficient than current aircrafts, and next but one generation aircrafts are 50% more efficient, in line with EU objectives. Data on cost of fuel is based on 2009 'Rotterdam' spot prices.

18 For the purpose of this analysis, these include Heathrow, Gatwick, Stansted, Luton, London City, Aberdeen, Belfast City, Birmingham, Edinburgh, Southend, Manchester and Newquay.

4.26 Maintenance costs are costs to airlines from additional wear and tear of the aircrafts and leased equipment, which are estimated by calculating the cost per block hour and then redistributing it across the departure, en-route and arrival stages of a flight. These are based on data collected through interviews with airlines.

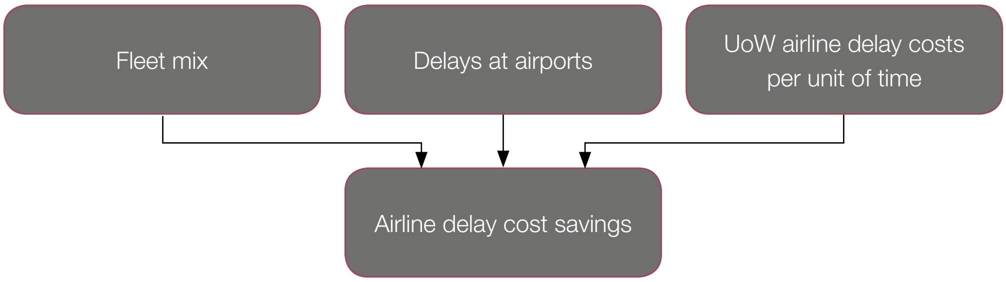


4.27 Fleet costs are the costs of financing the extra aircrafts needed, including depreciation, rentals and leases of flight equipment. These values are sourced from airline interviews, Airclaims data and other literature.

4.28 Crew costs arise from the need to hold additional crew, both on-board and ground, to service the additional flying time. These are derived in a similar way to maintenance costs per block hour from pay deals information from airlines.

4.29 Further assumptions have been applied to the costs in the UoW study such that maintenance costs are decreased by 20% with each new generation of aircrafts. A conservative approach is taken to the other parameters which remain the same over time as new aircraft enter the fleet but fleet and crew costs decrease by 50% in 2050 due to expectations of productivity increases.

4.30 All costs available from the UoW study are in Euros and so have been converted to GBP using a conversion rate of 0.8 GBP to 1 Euro. They have been calculated for 12 aircraft types, which had to be aligned with the DfT forecast fleet mix.



4.31 Airline costs per unit time are then combined with delay times per airport and traffic forecasts to derive total cost savings to airlines over the appraisal period[19] against the do minimum as shown in the flowchart above.

4.32 Although this analysis has tried to cover as much of the costs to airlines as possible, due to lack of available evidence, it has not been able to cover some other airline costs of delays such as those associated with freighter operations. Further, airport charges have been ignored since previous studies show that these are marginal in the context of delays.

4.33 As explained earlier, these costs to airlines only include the costs of strategic delays. There are also likely to be costs to airlines from tactical delays.

Passenger cost savings

4.34 Passenger costs are the costs to existing[20] passengers from increased journey times due to the extra time spent on flights in stack holding and/or taxiing as a result of delays. These benefits capture the traditional journey time savings from transport improvements.

4.35 Passengers value this extra time which could have been used for other activities such as additional working or leisure time. This value is different for different types of passengers, most notably leisure and business travellers. They are estimated using willingness-to-pay techniques where people (and employers for business travellers) are asked how much they would be willing to pay to save an additional unit of time during travel.

4.36 The leisure value of time (VoT) comes from the DfT aviation model. Business passenger values of time are further broken down into UK and foreign resident values of time and are based on 2011 survey data from 32 UK airports. This is the most comprehensive collection of survey results. A growth index for each VoT (also

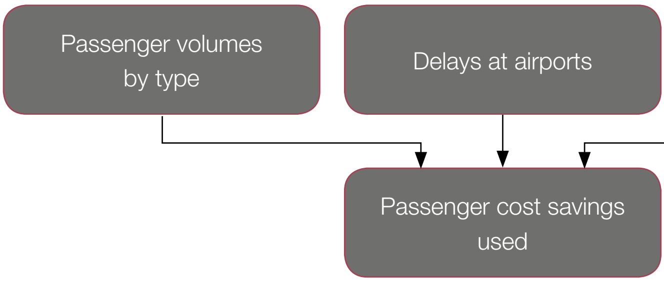
19 We take a standard 60 year appraisal period starting in 2025 for Gatwick and 2026 for Heathrow schemes.
20 Only costs to existing passengers are considered since new passengers already account for delay costs in deciding whether to travel or not.

from the DfT aviation model) is then applied to account for increase in GDP and inflation. Standard HMT GDP deflators are used to get VoT in 2014 prices.

4.37 The values used are presented in **Table 5**:

Table 5: Values of time split by type of passenger (2014 prices)

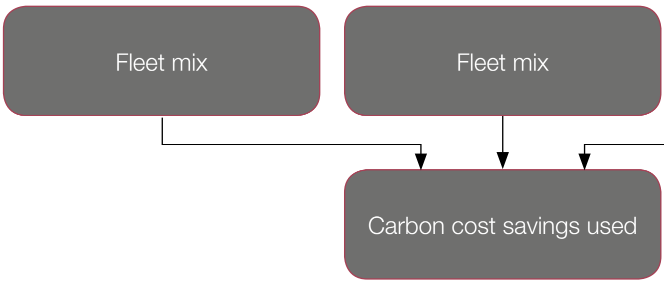
Passenger type	Value of time (£/hour)
Leisure passengers	6.60
UK Business passengers	49.20
Foreign business passengers	46.80



4.38 As per the flowchart above, the value of time assumptions, passenger volumes and delay times are combined to calculate the benefits to passengers from reduction in delays against the do minimum.

Carbon cost savings

4.39 Carbon costs capture the environmental costs of emissions from excess fuel consumption when a flight experiences departure delay. This includes not just the direct fuel burn due departure management in the form of stack holding, but also a fuel carriage penalty. This is the additional fuel burn which arises from carrying excess fuel between the origin and destination due to the expectation of arrival management at destination.



4.40 Data on the rate of fuel burn for stack holding and taxiing has been taken from the UoW study which has sourced its data based on aircraft and engine type from the ICAO Aircraft Engine Emissions Databank and specific engine suppliers.

Adjustments had to be made to align the aircraft types considered in the study to the DfT fleet mix.

4.41 Fuel burn is then converted to CO_2 emissions based on assumptions in DfT Aviation forecasts which assume that each additional kilogram of jet fuel (kerosene) emits 3.15kg of CO_2.

4.42 It is assumed that next generation aircrafts are 10% more fuel efficient (fed in through rates of fuel burn) than current aircrafts, and next but one generation aircrafts are 50% more efficient, in line with EU objectives[21].

4.43 The monetised costs of emissions are based on carbon values from DECC's supplementary green book guidance[22], as used in the DfT aviation model. The carbon costs savings are calculated with relation to the do minimum.

Scheme assessment

4.44 An assessment of the delay benefits for each of the scheme proposals, compared to the do minimum, is made based on the methodology described above.

4.45 All benefits are presented in real terms, discounted[23] to 2014 prices using standard Green Book discount rates.

4.46 The appraisal period is based on the estimated opening year of the individual schemes and standard DfT appraisal period of 60 years. For a second runway at Gatwick, this is 2025 – 2084 and for the two Heathrow schemes, it is the period 2026 – 2085.

21 Flightpath (2050) http://ec.europa.eu/transport/modes/air/doc/flightpath2050.pdf
22 https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal
23 Costs and benefits that occur in future years are discounted in order to reflect people's preferences for current consumption over future consumption.

5. Analysis of results

5.1 Table 6 gives an indication of the total delay savings for the various expansion schemes under the different scenarios.

Table 6: Delay benefits under different scenarios (PV in £billion, 2014 prices)

Total savings (£ billion)	LGW 2R	LHR ENR	LHR NWR
Assessment of need	£1.04	£0.61	£0.77
Global Growth	£0.73	£0.62	£0.83
Relative decline of Europe	£1.81	£1.48	£2.21
Low Cost is King	£1.13	£1.00	£1.40
Global Fragmentation	£1.63	£1.47	£2.11

5.2 The total benefits can be further broken down into savings for airlines and passengers and carbon savings – as seen in table 7 for the *assessment of need* scenario. Please note that the total savings do not include the benefits to transfer passengers.

Table 7: Delay benefits in *assessment of need* (PV in £billion, 2014 prices)

		LGW 2R	LHR ENR	LHR NWR
Passenger savings	UK Business	0.10	0.05	0.08
	UK Leisure	0.05	0.04	0.05
	Foreign Business	0.04	0.03	0.01
	Foreign Leisure	0.01	0.01	0.01
	Total passenger	0.19	0.13	0.14
Airline savings		0.84	0.47	0.61
Carbon savings		0.01	0.00	0.01
Total savings		**1.04**	**0.61**	**0.77**

5.3 Similar results on the other scenarios (1-4) are available in Appendix A.

5.4 Under the *assessment of need* and *global growth* scenario, a majority of the benefits accrue to airlines. In all other scenarios, the maximum benefits accrue to passengers.

5.5 It is helpful to see these in relation to the passenger numbers under the different scenarios, as seen in table 8.

Table 8: UK passenger numbers (2050) under different scenarios

Total passengers (million)	LGW 2R	LHR ENR	LHR NWR
Assessment of need	426	430	435
Global growth	488	491	496
Relative decline of Europe	441	432	435
Low-cost is king	502	489	494
Global fragmentation	406	415	420

5.6 Delay benefits are driven mainly by delay time savings and the demand, given by passenger and ATM volumes. There is an inverse relationship between demand and delay time savings, which is particularly driven by how fast the additional capacity delivered by the scheme fills up and thus, delays start to build up at the airports in the system. These savings will accrue to a higher number of people based on the demand. Further discussion on individual schemes is included below.

5.7 These benefits to passengers, airlines and society (through reduction in carbon emissions) are a result of reduction in strategic delays in both arrival and departure due to airport expansion.

5.8 Due to limitations of data available, this analysis considers all times of the day equally which could potentially be underestimating the costs of strategic delays since delays at peak times can be significantly larger. For instance, delay times in the top end of the range can be two to three times greater than the average. The costs of higher delays at each instance could be exponentially higher.

5.9 There are additional, and arguably larger, cost of tactical delays which this analysis does not cover. There is a similar story of delays due to ATFM regulations, which is felt is particularly by flights from other European destinations. This analysis ignores these costs due to limitations of evidence of reasons for actual delay times at airports.

5.10 Further, costs to airports of needing to increase terminal capacity and better facilities to house delayed passengers have been ignored due to lack of available evidence. On the passenger side, the benefits of reduction in delays to connecting passengers have also not been included.

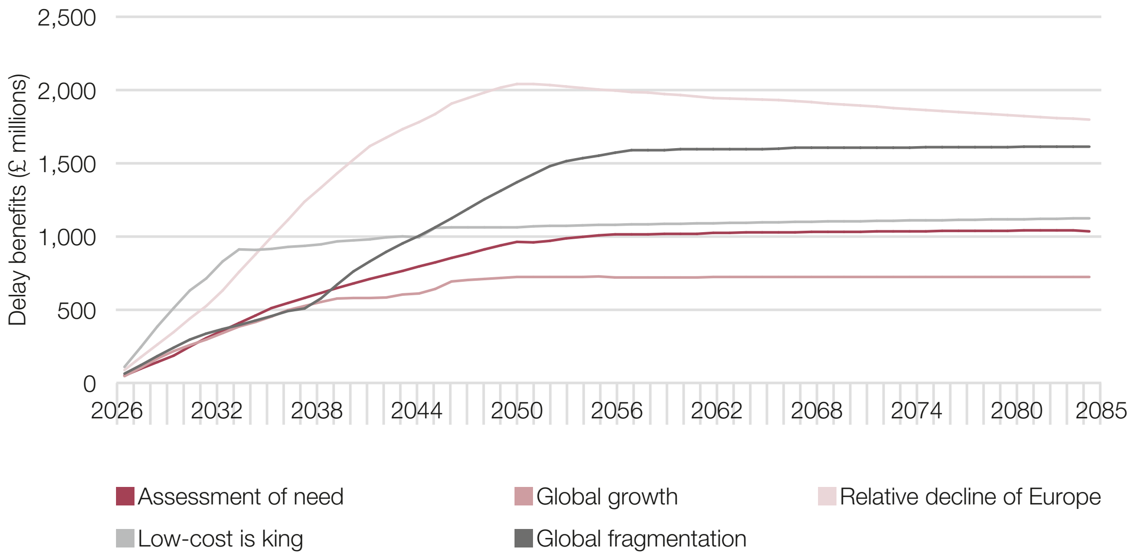
5.11 We have considered delay times at fully-capacity constrained airports after the application of all short term measures recommended by the Commission in its Interim Report. However, since the Government is yet to make a decision on some of these measures the benefits from airport capacity expansion on reduction of delays is underestimated if these short term measures are not fully implemented before the schemes open.

5.12 As such, the benefits from reduced delays estimated in this analysis should be considered a lower bound.

Gatwick Airport Second Runway

5.13 The delay savings under the Gatwick Airport Second Runway expansion scheme are between £0.7 billion and £1.8 billion, depending on the demand scenario under consideration, as seen in the figure 6.

Figure 6: Delay benefits (cumulative) across scenarios



5.14 As shown above, the benefits from reduced delays are highest in the *relative decline of Europe* scenario where passenger benefits account for 61% of the total benefits (figure 8). This follows on from the delay time savings as seen in figure 7. Due to discounting, delay time savings in later years feed into the delay benefits to a lesser extent.

Figure 7: Delay time savings, *assessment of need*

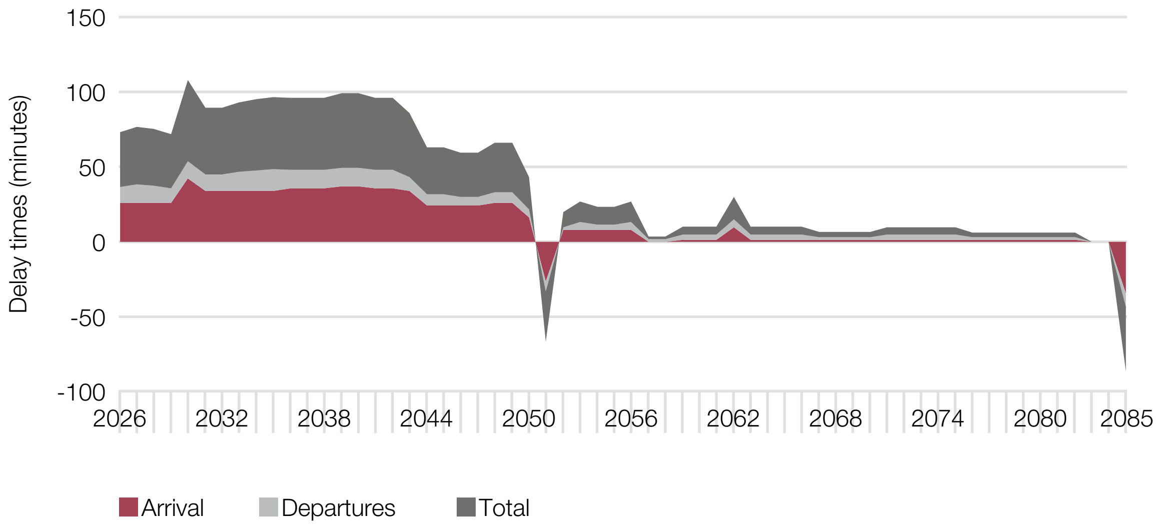
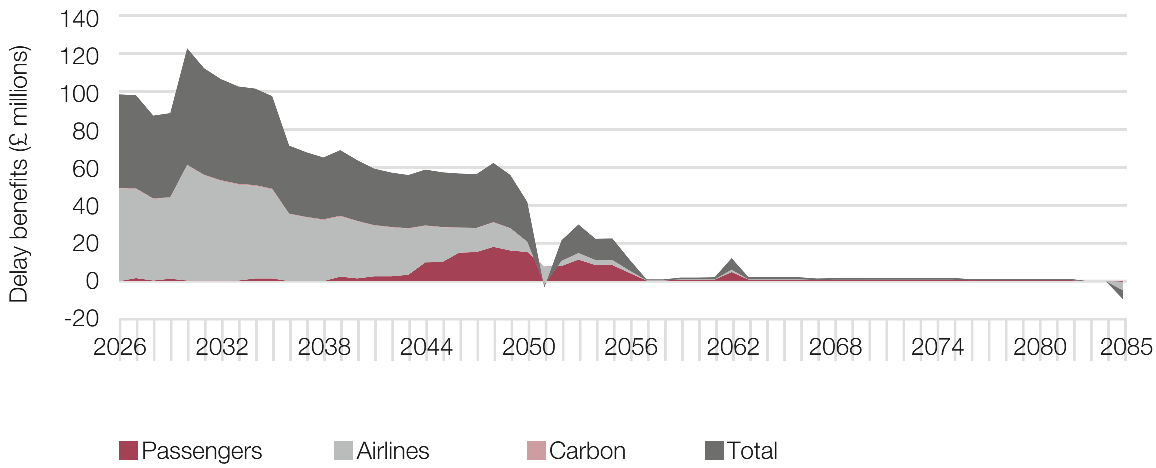


Figure 8: Delay benefits, *assessment of need*

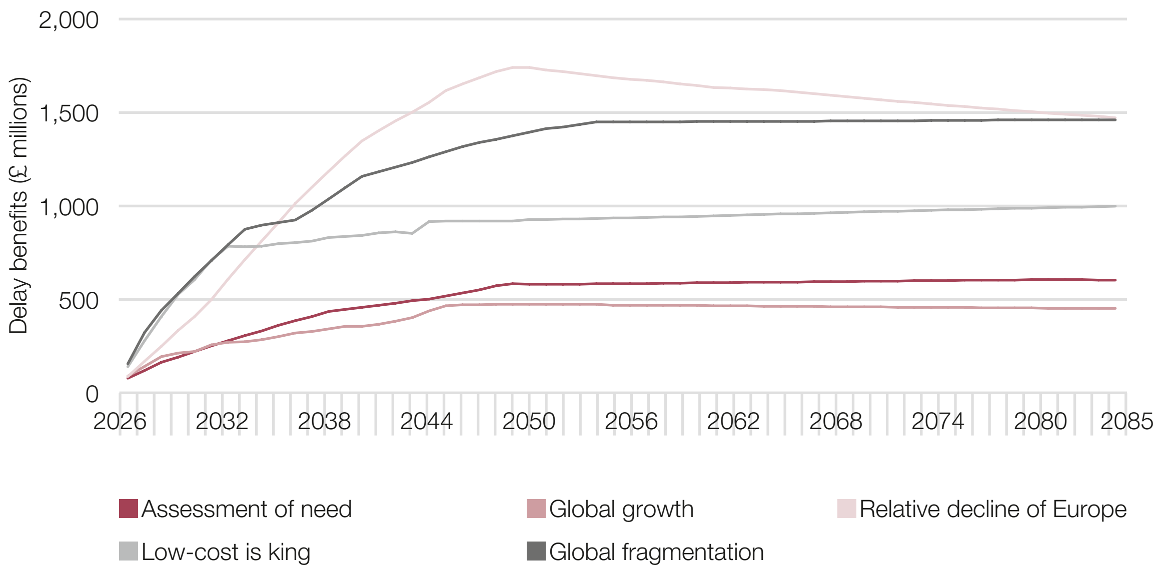


5.15 As mentioned earlier, delay benefits are driven by a combination of delay time savings and the number of passengers or ATMs that these savings accrue to. Delay time savings are higher when the additional capacity remains spare longer and so delays do not start to build up. This is the reason benefits from reduced delays are lowest for the *global growth* scenario where large number of passengers lead to the additional capacity filling up quickly, causing delays to occur earlier than in other scenarios.

Heathrow Airport Extended Northern Runway

5.16 The delay savings under the Heathrow Airport Extended Northern Runway expansion scheme are between £0.6 billion and £1.5 billion, depending on the demand scenario under consideration.

Figure 9: Delay benefits (cumulative) across scenarios



5.17 As shown above, the benefits from reduced delays are highest in the *relative decline of Europe* and *global fragmentation* scenarios where passenger benefits account for 58% and 61% of the total benefits (figure 11). This follows on from the delay time savings as seen in figure 10. Due to discounting, delay time savings in later years feed into the delay benefits to a lesser extent.

Figure 10: Delay time savings, *assessment of need*

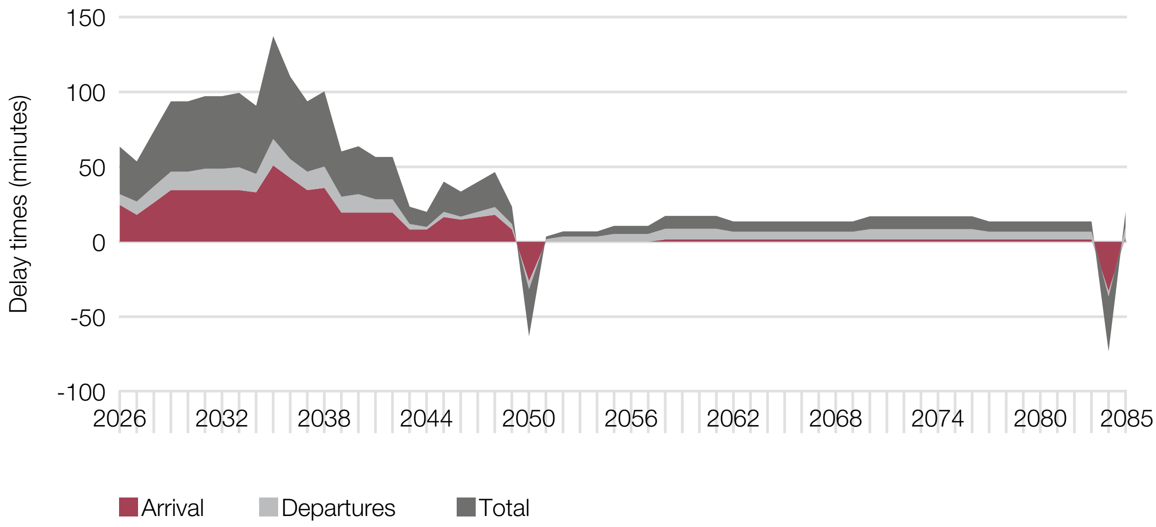
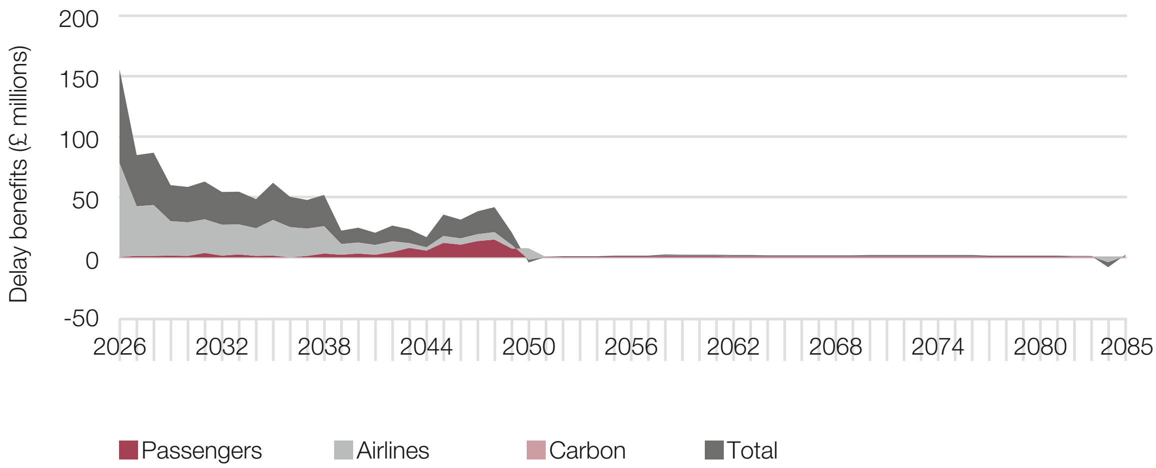


Figure 11: Delay benefits, *assessment of need*

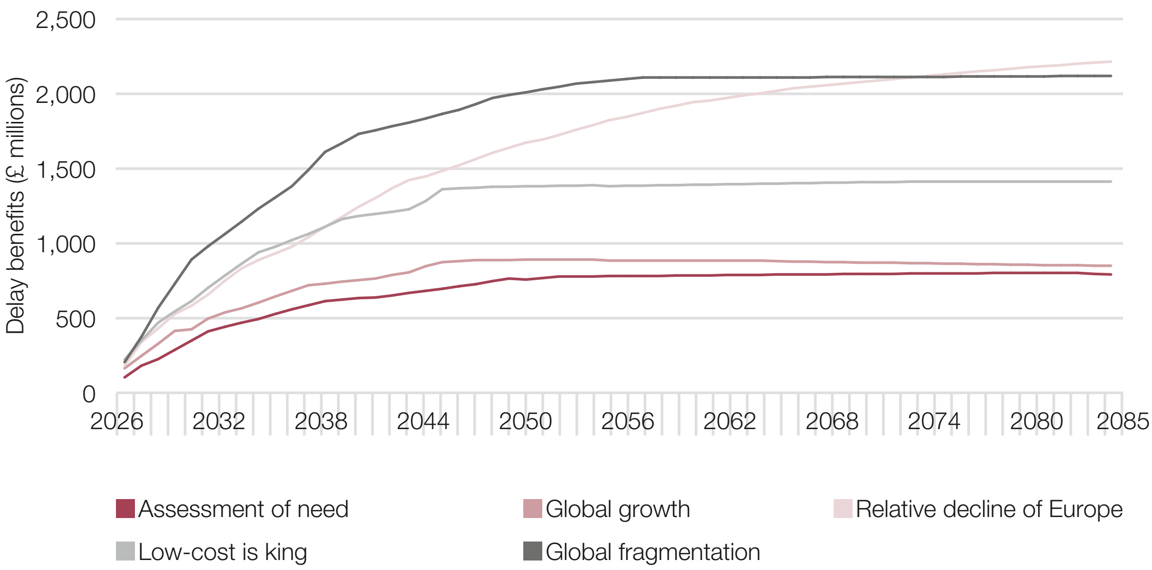


5.18 As mentioned earlier, delay benefits are driven by a combination of delay time savings and the number of passengers or ATMs that these savings accrue to. Delay time savings are higher when the additional capacity remains spare longer and so delays do not start to build up. This is the reason benefits from reduced delays are low for the *global growth* scenario where large number of passengers lead to the additional capacity filling up quickly, causing delays to occur earlier than in other scenarios.

Heathrow Airport North West Runway

5.19 The delay savings under the Heathrow North West Runway expansion scheme are between £0.8 billion and £2.2 billion, depending on the demand scenario under consideration.

Figure 12: Delay benefits (cumulative) across scenarios



5.20 As shown above, the benefits from reduced delays are highest in the *relative decline of Europe* scenario where passenger benefits account for 68% of the total benefits (figure 14). This follows on from the delay time savings as seen in figure 13 but is also affected by volumes of passengers. Due to discounting, delays in later years feed into the delay benefits to a lesser extent.

Figure 13: Delay time savings, *assessment of need*

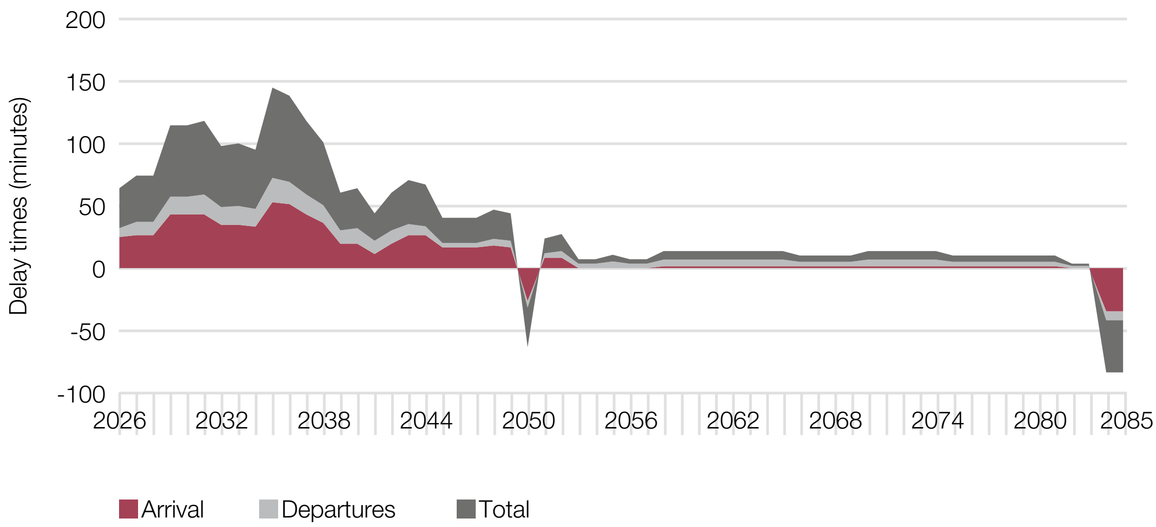
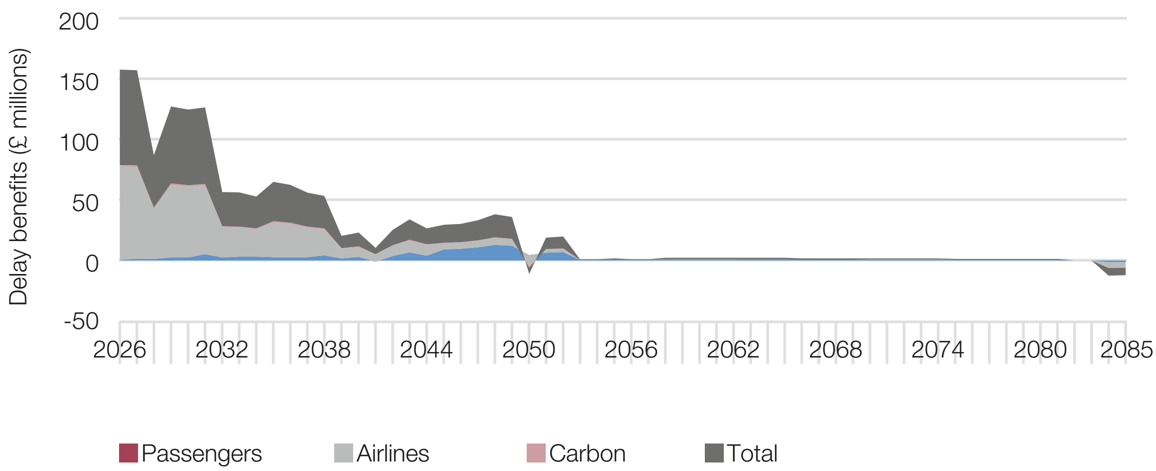


Figure 14: Delay benefits, *assessment of need*



5.21 As mentioned earlier, delay benefits are driven by a combination of delay time savings and the number of passengers or ATMs that these savings accrue to. Delay time savings are higher when the additional capacity remains spare longer and so delays do not start to build up. This is the reason benefits from reduced delays are low for the *global growth* scenario where large number of passengers lead to the additional capacity filling up quickly, causing delays to occur earlier than in other scenarios.

6. Conclusions

6.1 A review of literature on implications of delays suggests that delays at airports that function close to their capacity impose cost to airlines, passengers and the environment. Any increase in runway capacity in the UK airport system is likely to lead to a reduction in delays at airports and thus provide benefits in addition to the transport economic efficiency and frequency benefits.

6.2 Using a methodology derived from the UK CAA Runway Resilience Study and European airline delay cost reference values paper and inputs from the Department for Transport's Aviation model, we have estimated the benefits accruing to airlines, passengers and the environment through reduction in delay times at airports.

6.3 We have found that the benefits of delays are mainly driven by time savings from reduced delays compared to the base case of no capacity expansion and the demand, given by passenger and ATM volumes. There is an inverse relationship between demand and delay time savings, which is particularly driven by how fast the additional capacity delivered by the scheme fills up and thus, delays start to build up at the airports in the system. These savings will accrue to a larger number of passengers based on the demand.

6.4 Based on the demand scenario under consideration, the benefits of reduced delays from the Gatwick second runway expansion scheme are between £0.7 billion and £1.8 billion. These benefits are between £0.6 billion and £1.5 billion for the Heathrow Airport Extended Northern Runway scheme and £0.8 billion and £2.2 billion for Heathrow Airport North West Runway scheme.

6.5 It is important to consider that these estimates are likely to be a lower bound for benefits of reduction in delays since we have ignored potential benefits due to limitations in data. These include benefits from reduction in tactical and ATFM delays and reduction in costs to airports from need of lower terminal capacity amongst other things. Another area worth exploring would be the resilience of airports in adverse conditions which is affected by airports operating near capacity.

7. Annex A

Delay benefits for different global scenarios

Table A1: Delay benefits in *assessment of need* (PV in £billion, 2014 prices)

		LGW 2R	LHR ENR	LHR NWR
Passenger savings	UK Business	0.10	0.05	0.08
	UK Leisure	0.05	0.04	0.05
	Foreign Business	0.04	0.03	0.01
	Foreign Leisure	0.11	0.01	0.01
	Total passenger	0.01	0.13	0.14
Airline savings		0.19	0.47	0.61
Carbon savings		0.01	0.00	0.01
Total savings		**1.04**	**0.61**	**0.77**

Table A2: Delay benefits in *global growth* (PV in £billion, 2014 prices)

		LGW 2R	LHR ENR	LHR NWR
Passenger savings	UK Business	0.05	0.18	0.18
	UK Leisure	0.02	0.01	0.08
	Foreign Business	0.02	0.02	0.08
	Foreign Leisure	0.01	0.00	0.02
	Total passenger	0.10	0.21	0.35
Airline savings		0.62	0.40	0.47
Carbon savings		0.01	0.00	0.01
Total savings		**0.73**	**0.62**	**0.83**

Table A3: Delay benefits in *relative decline of Europe* (PV in £billion, 2014 prices)

		LGW 2R	LHR ENR	LHR NWR
Passenger savings	UK Business	0.42	0.29	0.76
	UK Leisure	0.30	0.29	0.34
	Foreign Business	0.28	0.20	0.29
	Foreign Leisure	0.11	0.08	0.11
	Total passenger	1.10	0.87	1.50
Airline savings		0.71	0.61	0.70
Carbon savings		0.01	0.01	0.01
Total savings		**1.81**	**1.48**	**2.21**

Table A4: Delay benefits in *low-cost is king* (PV in £billion, 2014 prices)

		LGW 2R	LHR ENR	LHR NWR
Passenger savings	UK Business	0.28	0.26	0.40
	UK Leisure	0.18	0.17	0.21
	Foreign Business	0.14	0.12	0.18
	Foreign Leisure	0.06	0.05	0.06
	Total passenger	0.66	0.60	0.86
Airline savings		0.47	0.40	0.53
Carbon savings		0.00	0.00	0.01
Total savings		**1.13**	**1.00**	**1.40**

Table A5: Delay benefits in *global fragmentation* (PV in £billion, 2014 prices)

		LGW 2R	LHR ENR	LHR NWR
Passenger savings	UK Business	0.42	0.41	0.60
	UK Leisure	0.35	0.20	0.26
	Foreign Business	0.18	0.22	0.33
	Foreign Leisure	0.08	0.07	0.10
	Total passenger	1.03	0.90	1.29
Airline savings		0.59	0.57	0.80
Carbon savings		0.01	0.01	0.02
Total savings		**1.63**	**1.47**	**2.11**

8. Annex B

A1. Five possible scenarios of future demand are considered and are briefly described below.

Assessment of need	This scenario is consistent with the forecasts underpinning the Commission's *assessment of need*. Future demand is primarily determined by past trends and the central projections published by sources such as the Office for Budget Responsibility, OECD and IMF.
Global growth	This scenario sees higher *global growth* in demand for air travel in the future. It adopts higher passenger demand from all world regions, coupled with lower operating costs and assumes any actions to manage carbon emissions from aviation (see below) are taken at the global level.
Relative decline of Europe	This scenario sees higher relative growth of passenger demand in emerging economies in the future compared to the growth in the developed world. It adopts higher passenger demand from newly industrialised and developing countries, a strengthened position of Far and Middle Eastern aviation hubs and airlines, and assumes any actions to manage carbon emissions from aviation are taken at the global level.
Low-cost is king	This scenario sees the low cost carriers strengthening their position in the short-haul market and capturing a substantial share of the long-haul market. As with *global growth*, it also sees higher passenger demand from all world regions, lower operating costs, and assumes any actions to manage carbon emissions from aviation are taken at the global level.
Global fragmentation	This scenario sees economies close themselves off by adopting more conditional and interventionist national policies. As a result, there is a decline in passenger demand from all world regions, coupled with higher operating costs and no global carbon agreement is reached, leading to UK introducing unilateral measures on carbon emissions from aviation.

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