A Review of the DfT Aviation Fleet Mix Model

Report for Department for Transport

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Executive summary

Ricardo Energy and Environment, supported by our partners Systra Ltd., Gaia Capital Ltd., Michael Mann, Bethan Owen and Prof. David Lee, have been contracted to provide input to an update of the marginal abatement cost (MAC) curves for the UK aviation sector.

This document provides a review of the existing Fleet Mix Model, which is a key part of the DfT UK aviation modelling framework. The review was intended to assess any changes required for the study to update the MAC Curve model and also to provide recommendations for future developments of the model.

Overall, the model was found to be fit for purpose (for current applications), though a number of recommendations have been made for checks on, and updates of, the assumptions and data. These recommendations include:

For immediate update:

- Some in-production aircraft types appear to continue in production for several years after their replacement aircraft types enter service. The reasons for these apparent anomalies should be checked and, if necessary, the out-of-production dates of the existing types should be brought forward.

- The entry into service dates for some new aircraft types should be revised in the light of recent developments.

- One aircraft type has an out-of-production date that is earlier than seems likely. This should be checked and, if necessary, updated.

- The base year data for one aircraft type that has been out of production for a number of years indicate a number of aircraft with ages significantly lower than expected. These data should be reviewed and amended as necessary. If the age data are valid, a note on the reasons for the apparent anomalies should be included in the model.

For future development

- Some comparisons have been made of the aircraft retirement ages in the model with the age profiles of the air traffic movements in the base year. Although these comparisons showed some differences, it is recognised that the age profiles in the base year data are based on limited data and that analyses based on them are not a robust basis for recommendations for changes to an important parameter such as the retirement age. Therefore, it is recommended that the existing retirement ages in the model should continue to be used.

- As the retirement age is an important parameter in the model, it is recommended that future developments should include a comprehensive review of the age profiles of aircraft operating from UK airports to identify improved estimates of the retirement ages for use in the model. This review should recognise that the “retirement” ages in the model should represent typical ages at which the aircraft cease to be used on operations from the UK, noting that this is not the same as when the aircraft is finally removed from service.

- The approach to setting the market shares for aircraft types in the supply pool generally assigns equal market share to each aircraft type (within a seat class), unless more detailed information is available. This can give rise to some cases where a smaller manufacturer has more deliveries than a larger manufacturer because of the larger number of sub-models included. Consideration should be given to an alternative approach, in which the manufacturers have equal market shares (unless more specific information is known regarding future deliveries).

These manufacturer market shares can then be divided equally between the models offered by the manufacturer within the seat class.

In addition, some recommendations are given for future development of the model to implement best practices, improve usability and make it easier for new users to use. These recommendations include:

- The model should be restructured to include:
  - A cover sheet, including a description of what the model does and specifications of the calculations performed on each sheet.
  - A history of changes sheet to allow the specification of the latest version to be easily identified, including its current intended application(s).
  - All base year ATM data on a single sheet to simplify updates.
  - All user inputs (base year, end year, aircraft retirement ages, etc.) on a single sheet or a small number of dedicated “user input” sheets. Some of these input data elements (e.g. retirement ages, supply pool percentages) may be quite large when there are a number of aircraft types in each seat class, so they may need their own sheet.
  - The individual calculation sheets (one per seat class) should then only contain calculated values or links to the input data sheets. The format of these sheets should be updated to align data so that values for a given year all occur in the same column.
- A significant proportion of the values on the individual seat class sheets are calculated when the VBA macros included in the model have been run and hence appear as fixed values in the cells, with no indication that these values have been calculated by the model. Colour coding of the cells (and/or the text font) should be used to identify values calculated by macros. This approach should be extended to other sheets that contain the results of the macro calculations.
- The version of the FMM that was provided by DfT was accompanied by a Users’ Guide. Further developments to the model should also include updates to the guide to make the FMM easier to understand and use for someone with little or no prior knowledge of the model.

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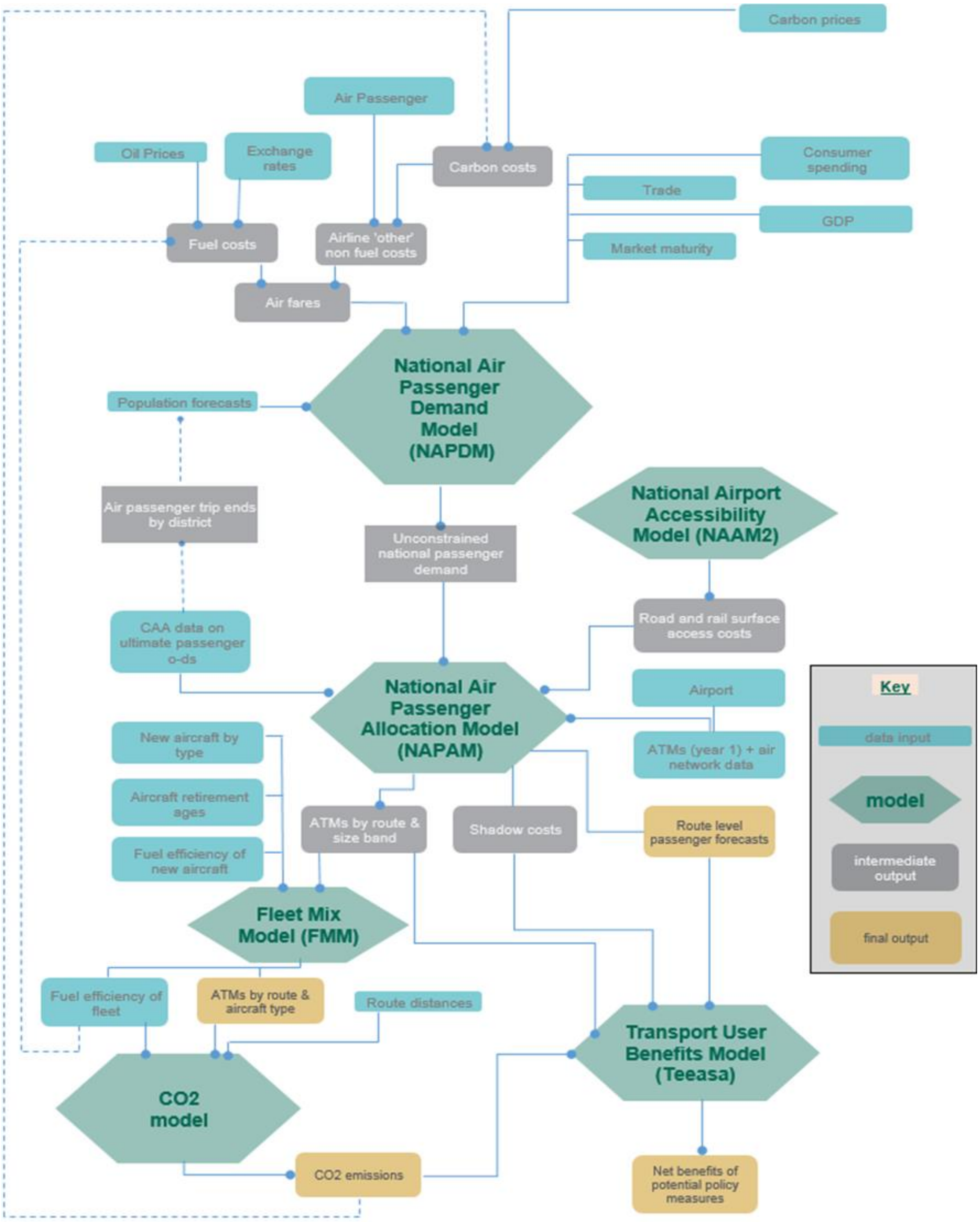
1 Introduction

Ricardo Energy & Environment, supported by our partners Systra Ltd., Gaia Capital Ltd., Michael Mann, Bethan Owen and Prof. David Lee, have been contracted to provide input to an update of the CO_2 marginal abatement cost (MAC) curves for the UK aviation sector. As part of this work, Ricardo has been tasked with carrying out a review of the DfT's Fleet Mix Model (FMM) for the UK aviation sector.

The FMM is a key element of the DfT's aviation modelling suite (as shown in figure 1-1)

Figure 1-1 Structure of DfT aviation modelling suite



Based on specifications of demand and aircraft type availability, the FMM provides definitions of the mix of aircraft types that will be used to deliver services on individual routes. The mix of aircraft types that is calculated by the FMM uses individual aircraft types, mostly current in-production types, though some are notional future aircraft types. This definition of the fleet mix using individual aircraft types allows highly detailed calculations of fuel burn and emissions on individual routes, which is important when analysing the impact of policies that affect the aircraft types used on routes within, from and to the UK in the future.

This document presents the results of our review of the FMM. It gives a brief overview of the model structure and assesses the aircraft types available and their selection for use on flights. It also includes a brief assessment of the usability of the FMM and recommendations for future developments to ease its use.

2 Model overview

The purpose of the FMM is to define the mix of aircraft types that will perform the air traffic movements (ATMs – i.e. flights) in future years. It provides this information separately for the different seat classes that are included in the CO_2 forecasting model. These include three categories of flights (Scheduled (Sch), Charter (Ch) and Low-Cost Carriers (LCC) (referred to in the model as No-Frills Carriers (NFC)), together with six ranges of seat number, as shown in Table 2-1.

Table 2-1 Range of seat numbers for each aircraft size class

Aircraft size class	Range of seats
1	Up to 70 seats
2	71 – 150 seats
3	151 – 250 seats
4	251 – 350 seats
5	351 – 500 seats
6	Over 500 seats

Thus, the model calculates the future fleet mix separately for 18 different seat classes.

Within each seat class, the model starts from the number of movements by each aircraft type in the base year (currently 2015). Aircraft types for which there are less than 1,000 movements in the base year (in each seat class) are excluded from the analysis; these are long-standing low-use types for which any increase in use is considered unlikely. The number of aircraft types for which movements are defined in the base year ranges from 1 (c6Sch and c2NFC) to 18 (c1Sch). There are also a number of seat classes for which there are no movements in the base year (c5Ch, c6Ch, c1NFC, c4NFC, c5NFC and c6NFC). The calculation proceeds on a year-by-year basis from the base year to the final analysis year.

In each year, the model identifies the number of ATMs from the previous year that should be "retired", based on the aircraft age profile and the number of aircraft that have reached the assumed retirement age. These retired ATMs are then replaced by aircraft from the supply pool. This selection is based on the aircraft types that are specified to be in production in the relevant year. The percentages of the replacement ATMs that are performed by the different in-production aircraft types is specified by the user as part of the input data. The ATMs performed by these aircraft are added to the set of ATMs for the year with an aircraft age of zero.

The FMM itself does not include any future growth in demand. This growth is derived by the passenger demand model and is then applied by the ATM forecasting modules to all ATMs, including those performed by the aircraft that have survived from the previous year. This approach is different to that applied in other studies (for example, the analyses of future standards performed by the International Civil Aviation Organisation (ICAO) Committee on Aviation Environmental Protection (CAEP) working groups), in which the new aircraft deliveries are used for all replacement and all growth ATMs. This difference was raised during the previous aviation MAC Curve study in 2011 and it was confirmed that the aim is to capture the effects of both the delivery of new aircraft and the increased utilisation of existing in-service aircraft to meet the increased demand. This remains a valid concept for the DfT's forecasting of aviation CO_2 emissions; however, care should be taken if it is to be applied to scenarios including high levels of demand growth, as, with assumed service lives of over 20 years, the implied utilisation of aircraft nearing the end of their life could be excessive and the modelling may underestimate the penetration of new technology into future fleets.

The outputs from the FMM are the set of aircraft types (with percentages) by seat class used to deliver the ATMs in future years, which are used with the aircraft fuel burn models in the CO_2 model to calculate overall fuel burn and CO_2 emissions.

3 Aircraft types included in the FMM

The analysis of the FMM has identified the following aircraft types that are considered to be in production (i.e. available for inclusion in the supply pool) at some years between 2015 and 2050.

Table 3-1 In-production aircraft types identified in FMM

Code	Aircraft Type	Seat Classes	Production Years	Comments
NDH	AEROSPATIALE AS365 DAUPHIN N3	c1Ch	2015 – 2055	Little forward visibility of future helicopter types, so continued inclusion is supported
AGH	AGUSTA A139	c1Ch	2015 – 2033	Little forward visibility of future helicopter types, so continued inclusion is supported
319	AIRBUS A319	c2Sch, c3Sch, c3NFC	2015 – 2025	2025 out-of-production date (in c3NFC) is late, given that the A319neo enters service ten years previously
19N	AIRBUS A319NEO	c2Sch, c2Ch, c2NFC	2015 - 2045	Not evident why this is not employed in C3NFC
320	AIRBUS A320-100/200	c2Sch, c3Sch, c3Ch, c3NFC	2015 – 2021	
20N	AIRBUS A320NEO	c3Sch, c3Ch, c3NFC	2016 – 2045	
321	AIRBUS A321	c3Sch, c3Ch	2015 – 2018	

Code	Aircraft Type	Seat Classes	Production Years	Comments
21N	AIRBUS A321NEO	c3Sch, c3Ch, c3NFC	2016 – 2045	First example was delivered to customer (Virgin America) in April 2017, so 2016 EIS is early (should be 2017 or 2018)
332	AIRBUS A330-200	c3Sch, c4Sch, c4Ch	2015 – 2022	
333	AIRBUS A330-300	c4Sch	2015 – 2023	
338	AIRBUS A330-800NEO	c4Sch, c4Ch	2019 – 2041	
339	AIRBUS A330-900NEO	c4Sch, c4Ch	2019 – 2041	
351	AIRBUS A350-1000	c5Sch	2018 – 2039	
359	AIRBUS A350-900	c4Sch, c4Ch	2017 – 2041	First scheduled operations to UK were in late 2016, so inclusion in supply pool from 2017 is supported.
380	AIRBUS A380-800	c5Sch, c6Sch	2015 – 2034	
AT5	ATR42-500/600	c1Sch	2015 – 2055	Is used to represent all future demand for turboprops in this class. Represents a small proportion of overall demand, so lack of future development in the model is not a concern.
AT7	ATR72 200/500/600	c1Sch, c2Sch	2015 – 2034	
S61	AW189	c1Ch	2015 – 2033	Little forward visibility of future helicopter types, so continued inclusion is supported
3GM	BOEING 737 MAX 7	c2Sch, c2Ch, c2NFC	2016 – 2045	Not expected to enter into service until 2019 (http://www.b737.org.uk/737max.htm#max)
38M	BOEING 737 MAX 8	c3Sch, c3Ch, c3NFC	2017 – 2045	
39M	BOEING 737 MAX 9	c3Sch, c3Ch, c3NFC	2017 – 2045	Expected EIS 2018 (http://www.b737.org.uk/737max.htm#max)
73G	BOEING 737-700	c2Sch, c2Ch	2015 – 2017	Need to retain in supply pool to 2019 due to late EIS of 737-7
738	BOEING 737-800	c3Sch, c3Ch, c3NFC	2015 – 2025	This is retained in the supply pool eight years after EIS of 737-8. Evidence for continued production to that date? Otherwise, should go out of production in 2019.
739	BOEING 737-900	c3Sch	2015 – 2022	
748	BOEING 747-8	c4Sch	2015 – 2022	
77W	BOEING 777-300ER	c4Sch, c5Sch	2015 – 2024	
78X	BOEING 777-8X	c5Sch	2021 – 2039	
79X	BOEING 777-9X	c5Sch	2021 – 2039	

Code	Aircraft Type	Seat Classes	Production Years	Comments
78J	BOEING 787-10 DREAMLINER	c4Sch, c4Ch	2019 – 2041	
788	BOEING 787-800 DREAMLINER	c3Sch, c4Sch, c4Ch	2015 – 2041	
789	BOEING 787-900 DREAMLINER	c4Sch	2015 – 2025	Comparatively early removal of aircraft type from supply pool, only about 10 years after EIS.
CS1	BOMBARDIER CS100	c2Sch	2015 – 2042	
CS3	BOMBARDIER CS300	c2Sch	2018 – 2042	
CR2	BOMBARDIER REGIONAL JET CRJ900	c2Sch	2015 – 2030	
DH4	DE HAVILLAND DASH 8 Q400	c2Sch	2015 – 2055	
DHT	DE HAVILLAND DH6 TWIN OTTER	c1Sch	2015 – 2030	
D28	DORNIER 228-100/200/NG	c1Sch	2022 – 2030	
E70	EMB ERJ170 (170-100)	c2Sch	2015 – 2026	
E75	EMB ERJ175 (170-200)	c2Sch	2015 – 2018	
175	EMBRAER E175-E2	c2Sch	2019 – 2042	
E90	EMBRAER ERJ190	c2Sch, c2Ch	2015 – 2022	
190	EMBRAER E190-E2	c2Sch	2019 – 2042	
E95	EMBRAER ERJ195	c2Sch	2015 – 2018	
195	EMBRAER E195-E2	c2Sch	2019 – 2042	
ER3	EMBRAER RJ135	c1Sch	2015 – 2020	
ER4	EMBRAER RJ145	c1Sch, c1Ch	2015 – 2032	
EC3	EUROCOPTER EC155 B1 (H155)	c1Ch	2015 - 2055	Little forward visibility of future helicopter types, so continued inclusion is supported
EC3	EUROCOPTER EC225 (H225)	c1Ch	2015 – 2055	Little forward visibility of future helicopter types, so continued inclusion is supported
L4T	LET 410	c1Sch	2015 – 2021	LET-410NG is due to be certificated in 2017
S76	SIKORSKY S76 SPIRIT	c1Ch	2015 – 2033	Little forward visibility of future helicopter types, so continued inclusion is supported
S92	SIKORSKY S92	c1Ch	2015 – 2055	Little forward visibility of future helicopter types, so continued inclusion is supported
U95	SUKHOI SUPERJET 100-95	c2Sch	2015 – 2042	
G21	New G2 Post 2030 CL1	c1Sch, c1Ch	2030 – 2048	
G22	New G2 Post 2030 CL2	c2Sch, c2Ch, c2NFC	2034 – 2055	

Code	Aircraft Type	Seat Classes	Production Years	Comments
G23	New G2 Post 2030 CL3	c3Sch, c3Ch, c3NFC	2035 – 2055	
G24	New G2 Post 2030 CL4	c4Sch, c4Ch	2031 – 2055	
G25	New G2 Post 2030 CL5	c5Sch	2031 – 2049	
G26	New G2 Post 2030 CL6	c6Sch	2036 – 2055	
G31	New G3 Post 2040 CL1	c1Sch, c1Ch	2040 – 2055	
G32	New G3 Post 2040 CL2	c2Sch, c2Ch, c2NFC	2045 – 2055	
G33	New G3 Post 2040 CL3	c3Sch, c3Ch, c3NFC	2045 – 2055	
G34	New G3 Post 2040 CL4	c4Sch, c4Ch	2041 – 2055	
G35	New G3 Post 2040 CL5	c5Sch	2041 – 2055	
G36	New G3 Post 2040 CL6	c6Sch	2046 – 2055	
G16	New G1 Post 2026 CL6	c6Sch	2026 – 2044	

Several aircraft types are available for application to multiple seat classes. In these cases, the “Production Years” values cover the period from the earliest availability (for any seat class) to the latest availability (for any seat class).

As can be seen in Table 3-1, the review supports the inclusion of these aircraft types and, for the majority of types, the years for which they are available in the supply pool. The few exceptions are:

- Airbus A319 is currently included in the supply pool for c3NFC through to 2025. As this is ten years after the EIS of the A319neo, it is not clear that deliveries of the older type would continue to that date. As of 30 April 2017, Airbus data indicate only 28 orders for the type remain to be fulfilled. An out-of-production date of 2019 or 2020 might be more appropriate.

- The A319 is specified for c3NFC, while the A319neo is specified for c2NFC. It is not clear that the newer type would only be used by NFCs with the reduced number of seats. It is recommended that the A319neo should also be available in seat class c3NFC.

- The first delivery of an A321neo was in April 2017 (to a US operator). As such, the 2016 EIS is early. It would be more accurate to assume an EIS date of 2017 or 2018.

- The Boeing 737-7 (Max) is not expected to enter service until 2019, so the type should only be available in the supply pool from that date. The availability of the 737-700 should be extended to 2019 to match.

- The 737-800 is retained in the supply pool (for c3NFC) until 2025. This is eight years after the EIS of the 737-8 (Max); an earlier removal of the 737-800 from the supply pool (e.g. 2019) is recommended.

- The Boeing 787-9 is taken out of production (in c4Sch) in 2025. This aircraft type currently has more orders than the 787-8 (641 compared to 423 as of April 2017[1]). Consideration should be given to extending the production life of this aircraft type to at least 2031, when the next generation of aircraft types in this seat class enters service.

In addition to the aircraft types that are currently in production, or will be in the future, the model contains the following aircraft types with air traffic movements (ATMs) in the base year (2015), but which are already out of production.

Table 3-2 Out-of-production aircraft types identified in model

Code	Aircraft Type
APH	AEROSPATIALE AS332 SUPER PUMA C1E
343	AIRBUS A340-300
346	AIRBUS A340-600
AT4	ATR42-300
AR1	AVROLINER RJ100/115
AR8	AVROLINER RJ85/QT
J32	BAE JETSTREAM 31/32
J41	BAE JETSTREAM 41
733	BOEING 737-300
734	BOEING 737-400
736	BOEING 737-600
744	BOEING 747-400
752	BOEING 757-200
753	BOEING 757-300
763	BOEING 767-300
763	BOEING 767-300ER/F
764	BOEING 767-400ER
772	BOEING 777-200
772	BOEING 777-200ER
919	COMAC C919
D38	DORNIER 328
FRJ	DORNIER 328 JET
100	FOKKER 100
F50	FOKKER 50
F70	FOKKER 70
BNI	PILATUS BN-2A ISLANDER
BNT	PILATUS BN-2A TRISLANDER MK3
S20	SAAB 2000

[1] See http://active.boeing.com/commercial/orders/displaystandardreport.cfm?cboCurrentModel=787&optReportType=AllModels&cboAllModel=787&ViewReportF=View+Report, accessed 11/05/2017

Code	Aircraft Type
SF3	SAAB FAIRCHILD 340

The identification of these aircraft types as being out of production is supported, except for the COMAC C919. This is included in the "AcData" sheet of the model, but is not assigned to the supply pool in any of the seat classes. As a Chinese medium-range airliner that is yet to enter production (its first flight was on 5th May 2017[2]), it is unlikely to have a significant presence in the European market; therefore it would be preferable to remove any reference to it from the FMM.

3.1 Retirement ages

As noted above, the selection of which percentage of the ATMs in a given year should be retired for the next year is based on the aircraft age profile and assumed retirement ages. It should be noted that, in the context of a model of UK aviation, the term "retirement" does not necessarily mean that the aircraft are removed from service entirely. In many cases, an aircraft is sold by the airline (or returned to the leasing company and the re-leased) to an airline elsewhere in the world. This view of the UK in (relative) isolation has implications for the retirement ages derived and implemented in the model, as aircraft are often sold-on for service outside the UK with a significant part of their service life still available and, hence, the UK has a relatively young fleet on average.

The retirement ages currently assumed in the model vary by flight category as shown in Table 3-3.

Table 3-3 Retirement age by flight category, extracted from FMM

Flight category	Retirement age
Scheduled	22
Charter	25
No-Frills Carrier	22

In general, the DfT model uses a single retirement age per category, although there are some examples of individual aircraft types being allocated different retirement ages.

Table 3-4 Aircraft types with non-default retirement ages

Seat Class	Aircraft Type	Retirement Age (years)
c2Sch	Fokker 70	15
c3Sch	Boeing 757-200	20

[2] https://www.nytimes.com/2017/05/05/business/china-airplane-boeing-airbus.html?_r=0

c3Sch	Boeing 737-400	18

It is worth noting that these three aircraft types have all been out of production for a number of years, so there are few ATMs in the base year performed by aircraft of less than the retirement age. The ATMs performed by these types will, therefore, largely disappear within the first year of the FMM (i.e. 2016) and these different retirement ages will have very little effect thereafter.

An exception to this concerns the Boeing 757-200. The base year fleet data in the FMM (in sheet "Population_Sch") includes 158 aircraft of this type with an age of zero (i.e. delivered in 2015) plus a small number with ages between 6 and 10 years. The number of ATMs performed by these aircraft (in class c3Sch) is small; however, it is recommended that these input data should be checked to ensure that they represent new aircraft to which the specified retirement age should be applied.

An investigation was made of the potential to validate the retirement age assumptions in the model by analysing the base year age profiles defined in the "Population…" sheets. However, it was identified that the data presented in those sheets are based on sets of average and standard deviation values, together with assumptions regarding age profiles. As such, they do not form a robust basis for recommending changes to the retirement age assumptions. As the retirement age is an important parameter in the model, it is recommended that future developments should include a comprehensive review of the age profiles of aircraft operating from UK airports to identify improved estimates of the retirement ages for use in the model. This review should recognise that the "retirement" ages in the model should represent typical ages at which the aircraft cease to be used on operations from the UK, noting that this is not the same as when the aircraft is finally removed from service.

3.2 Supply pool

The percentages of each aircraft type in the supply pools have been examined. In the long-term, the data generally assume an equal split across the major competing aircraft types, with gradual transitions as new (future) aircraft types are introduced (replacing the previous generation of types). Given the close competition that exists between the major manufacturers and the uncertainty over future developments in the market, this approach is generally supported.

One aspect that could be considered for an update relates to the distribution between manufacturers and models. This is exemplified by seat class c2Sch. In this seat class, between 2020 and 2030, the modelled deliveries are dominated by eight aircraft types. These include one model from Airbus (the A319neo), one from Boeing (the 737 Max 7), two from Bombardier (the CS100 and CS300), three from Embraer (the E175E2, E190E2 and E195E2) and one from Sukhoi (the Superjet 100-95). As these eight aircraft types are all given an (essentially) equal market share, Embraer are given three times as much market share as Airbus (and Boeing). This seems unlikely, given the current share of the fleet of the different manufacturers and the strong drive for commonality across types for some major airlines. There may be merit in altering the market share approach in cases such as this to divide the market equally between manufacturers, then equally amongst products from a manufacturer. In this particular case, it is recommended that the Sukhoi aircraft is allocated only a small market share (e.g. 5%) as there is no evidence of a large demand from European airlines for this type.

4 Model operation and coding

Ricardo Energy & Environment has recently developed a toolbar add-in for Microsoft Excel for assisting with the quality assurance (QA) of Excel workbooks. It does not, at present, analyse VBA coding, but it analyses and presents other aspects of a model's complexity, including, for example, a list of unique formulae in the model (i.e. those formulae which do not represent copies of those in other cells). This QA analysis has been applied to the FMM.

The QA checks did not identify any evident errors in the formulae implemented in the cells in the model. It was noted that cell B40 on sheet c6Sch is blank, whereas the cells above and below (i.e. B39 and B41) both point to cells further up the sheet (B5 and B7 respectively) which contain the names of aircraft types. As cell B6 is blank (as is B7 and cells below), due to the limited number of aircraft type in the seat class, this does not cause any errors in the current model; however, it would not update automatically if the number of aircraft types was increased.

It was noted that the tables containing the percentage share of the supply pool taken by each aircraft type (rows 36 to 65 in each seat class sheet) sometimes contain formulae relating the percentage in one year to that for the same type in other years or to the sum of the percentages allocated to the other aircraft types in the seat class (thus ensuring the total percentage is 100% in each year). As the allocation of these percentages to the aircraft types needs to take account of the expected changes in the market (e.g. one aircraft type replacing another in production, but gradually rather than immediately), it is inevitably a manual process and the constants and formulae will vary between the seat classes. However, it is often not clear how the formulae have been derived; some additional notes (e.g. “aircraft B replaces aircraft A over a period of five years starting in 2022”) would improve the ability to check this aspect of the model.

The main calculations within the model are performed by a set of three macros, written in VBA code. The macros included in the model are:

- Main routine
- Ac_population
- RunAll
- SupplyPoolDump

The VBA coding does include some comments on the calculations being performed, but they are not as comprehensive as would be considered best practice. The routines include some redundant code (related to the efficiency calculation, which is no longer required); ideally, this redundant code should be removed.

The main routine defines many of the variables used and sets the values of some constants. These constants include some parameters such as the base year and the last year of the analysis (set to 2015 and 2055 respectively in the current model). These values are also set in the main workbook (on several sheets); it would reduce the risk of errors occurring if values such as these were set once (e.g. on an “Input Data” sheet) and referred to in all other locations (including the macros). It is worth noting that the macro Ac_population picks up the start year and final year values from the active sheet at the time it is run.

5 Model usability

In addition to the detailed review of the data and calculations in the model, a brief review has been undertaken of the usability of the model. This was performed by a member of staff with no prior experience of the model to give a view on the ease of understanding and manipulating the model inputs and outputs.

The key points noted from this review are presented below.

5.1 Documentation

The Fleet Mix Model (FMM) is accompanied by the Fleet Mix Model Update 2017 document (referred to here as the Users' Guide) which provides scope, specification and user information. The document is relatively easy to read and understand. However, the inputs and outputs are not clearly defined. Furthermore, the Users' Guide was not sufficiently clear for someone with no prior experience of using the FMM to help them understand how the model works. Therefore, clearly outlining the inputs (variables and hard-coded data) and outputs, and providing more depth to the Users' Guide is recommended. These aspects would ideally also be reflected in the workbook, on a summary worksheet.

5.2 Structure and clarity

The Users' Guide includes a map of the aviation model and the location of the FMM; however, it does not include a map of the FMM. As such, we recommend that a model map for the FMM should be presented in the Users' Guide. The FMM has a uniform worksheet structure that is applied consistently for all sub-model sheets. However, the model lacks titles, labels and units throughout. The addition of these items is recommended, including titles for each worksheet and table, legends to explain colour formatting, units of data, and written explanation of the macro icons. The macro icons in particular are difficult to understand without knowledge of VBA, so a clear definition of their functions is needed. The colour formatting currently highlights input variables, but further colour coding should be used to identify hard coded input, and output.

Furthermore, all this information should also be presented in a summary or title worksheet, which would help the user understand the different tabs and the overall structure of the workbook. The tabs themselves should be colour coded to clearly distinguish between sub-models, input, and output.

While the worksheets have a uniform structure, it is not clear initially that there is additional information further down the spreadsheet. It is recommended that the summary sheet should present a generic layout of the 18 sub-model sheets, so that the user has a clear picture of what is included in each sheet.

For each given sub-model, the columns do not align for a given year the whole way down the sheet. It would add clarity if all tables were aligned (same year in the same column). It was sometimes difficult to work out what inputs the lower tables use to calculate their data, as this is carried out through VBA rather than cell formulae. A short explanation of the data used above each table would help clarify this.

5.3 Data Validation

The possible input variables are indicated by yellow highlighting, however limits for these values have not been defined. It is recommended that minimum and maximum values are defined for these fields, as currently the model reports an error if a value is given outside of these limits.

Furthermore, column H of each sub-model has a broken cell reference for the 'Check Effcy Lookup'. It is understood that the efficiency calculations have been removed from this latest version; it is recommended that this check is removed if it is no longer relevant.

5.4 Data and assumptions

The data and assumptions are presented in the Users' Guide, including the source for hard coded data, and the assumptions used for aircraft data, range, retirement, phasing out, production status and supply pool and population. It would be helpful if this information was also given in a legend within the workbook, especially regarding the labelling of aircraft types and range. For example, it is not immediately obvious what S, L and B stand for, and this could easily be presented at the top of the table as well as in the Users' Guide.

Similarly, it is not clear where the data for the output weighted age and weighted ATMs tabs comes from. It would be helpful to explain what calculations have been made, as well as the weightings used.

5.5 Quality Assurance

The FMM currently lacks a version log, which is considered an important aspect of quality assurance. Such a log would enable users to track the changes made to the model in each version, giving greater transparency into any development the model undergoes.

6 Conclusions and recommendations for further changes

A review of the latest version of the FMM has been performed. Overall, the model is considered fit for its current purpose; no significant issues were identified with its operation that would need correcting for its use in the MAC Curve study or its application for other DfT studies in the near future. However, a number of observations have been made with suggestions for adjusting or verifying the assumptions. These include:

For immediate update:

- Some in-production aircraft types appear to continue in production for several years after their replacement aircraft types enter service. The reasons for these should be checked and, if necessary, the out-of-production dates of the existing types brought forward.

- The entry into service dates and out-of-production dates for some aircraft types should be revised in the light of recent developments.

- The base year data for the Boeing 757-200 aircraft indicate a number of aircraft with ages significantly lower than expected (as the aircraft type has been out of production for some years). These data should be reviewed and amended as necessary. If the age data are valid, a note on the reasons should be included in the model.

For future development:

- Consideration should be given to modifying the market share approach in the model to assign equal market shares to manufacturers (unless more specific information is known regarding future deliveries). These manufacturer market shares can then be divided equally between the models offered by the manufacturer.

- It is recommended that future developments should include a comprehensive review of the ages of aircraft operating from the UK. Improved estimates should be derived for the retirement ages in the model, recognising that the retirement ages should represent typical ages at which the aircraft cease to be used from the UK, noting that this is not the same as when the aircraft is finally removed from service.

In addition to the above recommendations regarding the assumptions in the existing model, recommendations are presented below for the future development of the FMM.

The model should be restructured to include:

- A cover sheet and a history of changes sheet.
- All base year ATM data on a single sheet to simplify updates.
- All user inputs (base year, end year, aircraft retirement ages, etc.) on a single sheet or a small number of dedicated “user input” sheets.
- The individual seat class calculation sheets should align data so that values for a given year all occur in the same column.

Colour coding of the cells in the calculations sheets (and/or different text fonts) should be used to identify values calculated by macros as opposed to cell formula.

Further developments to the FMM should also include updates to the Users’ Guide to make the FMM easier to understand and use for someone with little or no prior knowledge of the model.

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