

02 / European aviation in 2040 - Challenges (OF GROWTH - NETWORK CONGESTION IN 2040	
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SUMMARY

This annex is part of the fifth Challenges of Growth study, which aims to deliver the best-achievable information to support long-term planning decisions for aviation in Europe.

Companion annexes describe in detail the 2040 traffic forecast and the means to mitigate the challenges of that growth. Those reports discuss the lack of airport capacity causing unaccommodated demand, and how the air transport industry might handle this gap. However, even after this unaccommodated demand is removed, there is still a major effect of operating near capacity: delays.

In Challenges of Growth 2013 (CG13), we were able to quantify the number of airports that would be congested, and to make a first step towards quantifying the impact of airport congestion on network performance in terms of delay. In this 2018 iteration of the Challenges of Growth (CG18) study we took the opportunity of updated airport capacity plans and the new long-term traffic forecast to look again at the network behaviour in 2040.

According to the forecast, by 2040 traffic in Europe is expected to grow over 16.2 million flights in the Regulation and Growth scenario (most-likely), 53% more than the 2017 volume. Higher growth is expected in the Global Growth scenario, with around 20 million flights.

This growth in traffic will create pressure on airport capacity and will certainly reduce the number of slots available to act as contingency. When we analysed August and September 2016, there were just 6 airports that were "congested" in the sense of operating at 80% or more of their capacity for more than 6 consecutive hours per day. In the most-likely scenario of the 2040 forecast, this climbed to 16 airports in 2040. That is a small improvement on the 20 congested airports for the same conditions in the most-likely scenario from CG13, since the capacity growth between now and 2040 is now better targeted at the larger airports.

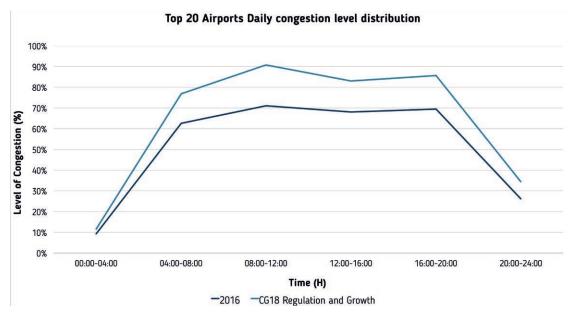


Figure 1 / Daily congestion is expected to increase at Top 20 Airports in the most-likely scenario.

The observation of the airport capacity usage along the day gives us an overview of the global state of the network in 2040. The current 16% planned capacity growth by 111 airports (28% for the top 20 airports) is still not enough to manage the extra demand. By 2040, the top 20 airports will operate close or above 80% of their capacity starting with the first rotations till the end of the day in the most-likely scenario Regulation and Growth. With this future level of congestion, it becomes difficult to accommodate minor deviations from plan, and delays begin to accumulate rapidly.

For this iteration of Challenges of Growth we took the opportunity to update our delay model, originally focused on flow management (ATFCM) delays and nearer-term capacity planning, and which simulates the algorithm used by the Network Manager to respond to constraints. The key changes were to better simulate the distribution of non-ATM delay occurrences along a day of operation using EUROCONTROL/CODA statistics for the summer 2016. We used detailed data on

actual turn-around times at airports to model how reactionary delays propagate from flight to flight during the day and we have been able to evaluate the level of flight cancellations that might be expected in response to strong delays. The analysis is based on modelling and comparing two summer months in the 2016 baseline year, and in 2040. For 2040, traffic was grown using three forecast scenarios Regulation and Growth (most likely), Global Growth and Fragmenting World.

While assuming that delays from causes other than congestion remain constant, our modelling of the interaction of increased traffic and future capacity plans shows flow management delays climb from 1.2 mins/flight in Summer 2016 to 6.2 in 2040. This is because the Network Manager needs to apply more and more flow management regulation to balance demand against the limited capacity. This drives the total delay from 12.3 minutes to 20.1 minutes on average, per flight.

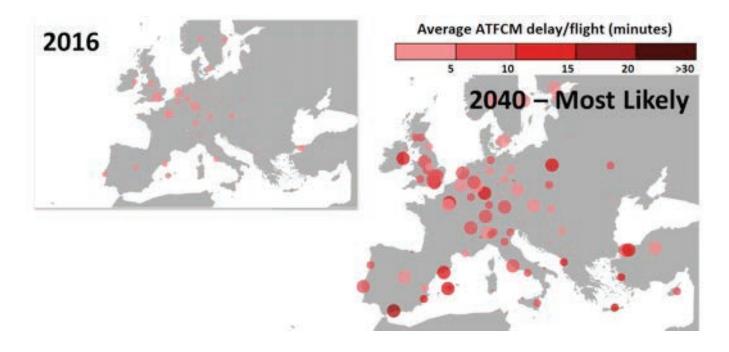


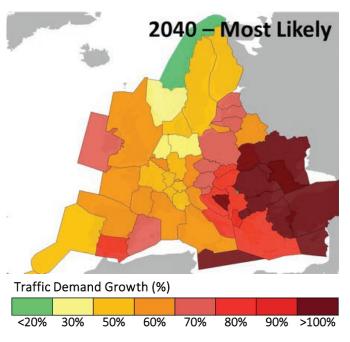
Figure 2 / Increasing number of airports with Summer delay (in minutes/flight).

Airlines and airports adapt to a certain level of congestion, with operating procedures, processes and capital investment to provide a reasonable quality of service to their passengers. However, it is hard to see how quality of service could be maintained if average delays were nearly to double. There is a long tail to the distribution of delays: our modelling shows a significant increase in flights delayed by 60-120 minutes in this situation, with 7 times as many by 2040 in Regulation and Growth. This means around 470,000 passengers each day delayed by 1-2 hours in 2040, compared to around 50,000 today.

Congestion is also a challenge for the airspace. We looked in more detail at where the traffic increases will be. By 2040 in Regulation and Growth, a majority of en-route airspace will face an increase of demand between 50% and 80%, so some airspace will see growth well ahead of the 53% total growth.

For example, at this time horizon, Turkey will face 2.5 times as many flights. This expected growth will directly impact the neighbouring countries, so Romania, Bulgaria, Serbia, Cyprus and Greece will experience high level of traffic demand with expected growth around or greater than 80% compared to 2016. At the other corner of Europe, the south of Spain will have to face a 70% growth in demand, similar to the south-east part of Italy, the Brindisi area being affected by the traffic growth in Turkey.

The European core area will not be exempted from difficulties with an average demand growth between 40% and 55%. To handle this growth where traffic is already dense and complex will surely represent as much of a challenge as higher percentage growth elsewhere.



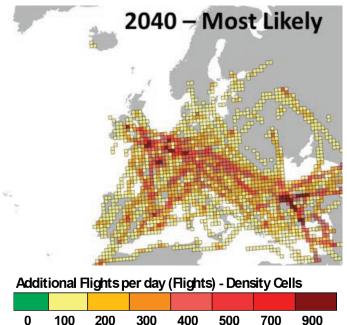


Figure 3 / En-route airspace traffic growth in 2040



INTRODUCTION

The Challenges of Growth series of studies aims to deliver the best-achievable information to support long-term planning decisions for aviation in Europe. EUROCONTROL completed four studies, in 2001, 2004, 2008 and 2013 (Ref. 2, 3, 4, 5). This report is part of the fifth study, Challenges of Growth 2018 (CG18), which overall addresses the following question:

What are the challenges of growth for commercial aviation in Europe between now and 2040?

A series of annex reports supports the summary report "European Aviation in 2040" (CG18, Ref. 1):

- Annex 1, reports in details the forecast of flights to 2040 (Ref. 6) and the effects of capacity constraints at airports.
- Annex 2, reports on the environmental issues (Ref. 7) giving an up-to-dated assessment of the readiness of the aviation industry to adapt to the effects of climate changes.
- Annex 3, explores ways to mitigate the lack of capacity, starting with building more airport capacity, but also how to use differently what capacity there is (Ref. 8).
- Annex 4, this report, discusses the impact of this lack of capacity in terms of congestion and delays over the network.

The forecast comprises four scenarios, each describing a possible future depending on how outward-looking Europe becomes, and how able to adapt to economic, political and environmental challenges it is:

- Strong Global Growth in economic and trade terms as well as traffic, with technology used to mitigate effects of the environmental challenges;
- Regulation and Growth (considered the mostlikely). Moderate growth that balances demand with sustainability issues;
- **Happy Localism** like Regulation and Growth but with fragile Europe adapting, i.e. looking inwards, meaning weaker growth of long-haul;

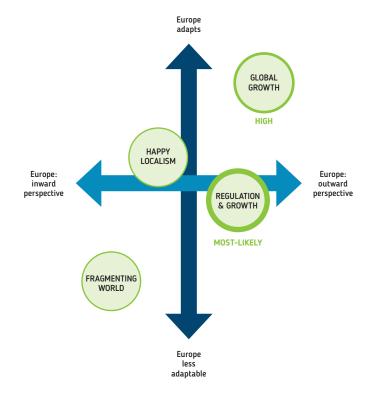
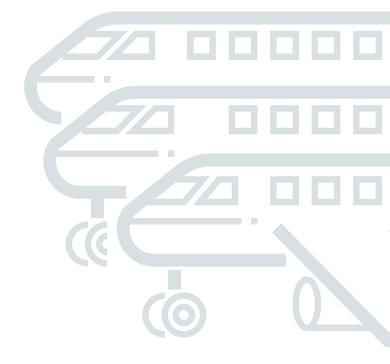


Figure 4 / Four possible futures.



Fragmenting World, i.e. increased regional tensions and reduced globalisation.

With the return of vigorous traffic growth after a long hiatus, Regulation and Growth is considered the most-likely. But for this CG18 iteration we recommend that special attention also be paid to the Global Growth scenario.

In the most-likely scenario, traffic demand in Europe is expected to grow to around 16 million flights by 2040. This growth will create pressure on airport capacity and have an impact on the European network performance.

After a cut back between 2008 and 2013, long-term airport capacity plans are growing again with 111 airports planning a 16% increase in capacity. Given the expected traffic growth, these airport capacity expansion plans are not sufficient; demand for 1.5 million flights cannot be accommodated in the most-likely scenario (see Ref. 6).

Even after this unaccommodated demand is removed, there is still a major effect of operating near capacity: delays. The relationship between capacity, delay and the number of flights involves two trade-offs:

- From several months until the day of operations, in theory, an airport can keep some free slots out of its maximum capacity to act as contingency. That provides a buffer to counter inevitable delays, but also increases the unaccommodated demand. In practice, commercial pressures will push the number of contingency slots to near zero.
- During the day of operations, airlines will react to delays ultimately by cancelling flights after applying flight priority rules according to their policy (e.g. favouring on-time performance or to ensure passenger connectivity).

The aim of this report is to further analyse the 2040 situation by quantifying the impact of airport congestion on network performance in terms of delay.

INTRODUCING CONGESTION

A network becomes congested when, to accommodate the traffic demand, a number of airports or airspaces (i.e. controlled sectors) operate simultaneously close to their peak capacity. In 2013, we discussed the impact of air traffic congestion on network performance in 2035. The analysis of the CG13 forecast showed 20 airports "Heathrow-like" operating at 80% or more of capacity for at least 6 consecutive hours. In such a state, network performance was severely impacted with ATFCM delays that jumped from around 1 minute per flight up to 5.6 minutes. For CG18, with updated airport capacity plans and a new forecast for 2040, we are able to look again at the network situation in order to study how the network will respond when more and more airports will face serious congestion issues.

The network is congested when traffic demand implies that a number of airports or airspace sectors operate simultaneously close to or at that their peak capacity for a significant period of time.

The congested situation of the network is given by the profile of the level of congestion at each location along the day. This congestion situation can be characterised by:

- An average level of congestion that provides the time distribution of the congestion at the network level, against the available capacity for a one-day of operations (for a 24-hour time period or only during the airport opening hours). This is illustrated in Figure 5.
- Congestion over percentile X, that provides the number of airports operating at X% or greater of capacity for a given number of hours per day.

LEVEL OF CONGESTION

The level of congestion at a specific airport for a given period of time is the ratio between the traffic demand and the available capacity illustrated by Figure 5 below.

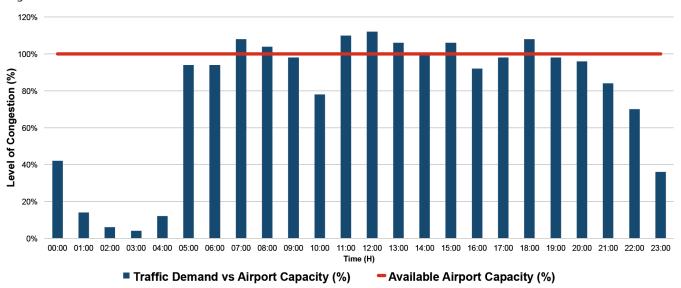


Figure 5 / Airport Level Congestion.

THE NETWORK RESPONSE ASSESSMENT

In order to assess the situation of the 2040 air transport network, it is important to understand which factors have an impact on the network behaviour.

An air traffic network is affected by:

- The capacity of its elements and the traffic pattern from which the network congestion can be evaluated.
- The performance of the air transport processes that manage the distribution of the traffic.
- Internal disturbances to the air transport processes.
- External disturbances.

A disturbance is an event that affects the planned operation of the air transport network processes or its elements. The disturbances can be internal or external:

- Internal disturbances are inherent to the air transport network and appear under normal conditions (e.g. variability of taxi time or late passengers).
- External disturbances are produced by elements which are not part of the air transport network.
 They are events that lead to abnormal operation conditions (e.g. bad weather conditions, security threat).

The variations implied by the existence of internal and external disturbances can be locally absorbed or can degrade performance. The degradation is characterised by the deviation of one or several performance indicators. A typical degradation that is measured is the appearance of flight delays longer than 15 minutes.

METHODOLOGY

The appearance of delays that characterise the degradation of air transport network performance can result from capacity shortfalls within the network infrastructure, or be caused by events external to the system. Those delays can follow one aircraft all along the day of operations. For Challenges of Growth 2018, we have updated our toolset which models the different types of delays by including primary delays (ATFCM and non-ATFCM) and reactionary delays. A specific algorithm to emulate the cancellation of flights in response to strong delays has been developed for this iteration of Challenges of Growth.

Figure 6 / Network congestion modelling approach.



MODEL CALIBRATION

- 2016 Historical data
- CODA Statistics
- Updated Delay Model

MODELLING APPROACH

Most of the simulations related to air traffic management (ATM) have been developed around microscopic and detailed models that allow the aircraft to fly precise 3 dimensional routes, emulating human interventions (e.g. air traffic controllers) to characterise specific performance (e.g. airport or en-route sectors).

The approach adopted for this study can be defined as macroscopic with a high level of detail chosen in order to model the network behaviour with its associated performance indicators. The simulations have been carried out by using the Research Network Strategic tool (RNEST). RNEST is used as a research validation platform developed by EUROCONTROL for prototyping and pre-evaluating advanced ATFCM concepts (e.g. SESAR). The model uses Network Manager data for long term ACC (Area Control Centre) and ECAC (European Civil Aviation Conference) network capacity planning assessment. For a complete description of the tool see Annex "The RNEST Toolset".



BUILDING OF FUTURE TRAFFIC SAMPLES

Growth Forecasts

Future Airport Capacities



PERFORMANCE ASSESSMENT

- Network Congestion
- 2040 Delays
- Cancellation Impacts

MODEL CALIBRATION

The model calibration step serves to update (i.e. fine-tune) the RNEST delay model and to measure reference performance indicators in order to compare and align actual impact with modelled impact of the traffic growth. The reference period in for the study is built from 61 days of traffic in summer 2016 starting from August 1st, ending the 30th of September.

For this iteration of Challenges of Growth, we took the opportunity to update our delay model. EUROCONTROL/CODA compiles and analyses data from airlines and airports describing delays to individual flights from all sources. We used the CODA statistics (See Annex CODA reference delay) for the summer 2016, to better simulate the distribution of non-ATM delay occurrences along a day of operation.

Figure 7 / Traffic Increase Process.

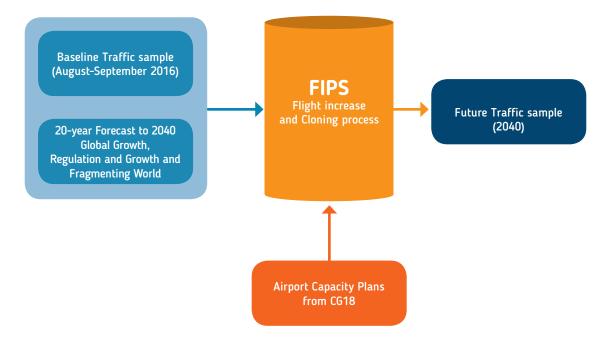
BUILDING OF FUTURE TRAFFIC SAMPLES

The EUROCONTROL Network Research unit has developed a tool (FIPS – Flight Increase Process) which allows future traffic samples to be created that completely respect the temporal distribution of the baseline sample (i.e. the same peaks are observed in the demand distribution at each airport) but take into account the planned airport hourly capacities.

Future traffic samples are constructed directly from the baseline traffic sample, which in our case is a 61 day period starting August, 1 2016.

Growth figures are then applied to the baseline traffic sample, from the 2040 forecast prepared for Challenges of Growth 2018. We modelled three of the four scenarios: Regulation and Growth (most likely), Global Growth and Fragmenting World.

Another major component of the modelling environment is the airport capacities, which were taken from the same source as in the 2040 traffic



NETWORK PERFORMANCE ASSESSMENT

The RNEST tool combines, for a simulated day of operations, the expected flight demand and the available airport and en-route capacity. The tool simulates network operations and allows us to observe the appearance and propagation of delays that characterise the degradation of the network performance. Those delays can result from capacity shortfalls within the network infrastructure (ATFCM), or be caused by events external to the network (non-ATFCM). As a knock-on effect, the delays can follow one aircraft all along the day of operations (reactionary).

Delays have been classified as:

- Primary, delays to this flight.
- Reactionary, knock-on delays incurred by this aircraft on previous flights.

Primary ATFCM delays have been captured by the RNEST network delay assessment capabilities. The tool emulates the CASA (Computer Assisted Slot Allocation) algorithm used by the Network Manager to respond to network constraints, so RNEST regulates traffic in a similar way to real operations.

Primary, non-ATFCM delays are mostly generated by internal disturbances, as described above, and are related to the intrinsic variability associated to air traffic processes (e.g. handling, passengers or baggage problems). Internal disturbances have been modelled by using a probabilistic model developed from CODA data. To model internal disturbances:

- All delays are taking place on ground.
- An empirical distribution of the minutes of delay has been built.
- Based on the observed probability of occurrence (i.e. 25%), a random delay value is applied to the flights.
- This random delay cannot be lower than 5 minutes and cannot exceed 30 minutes. The average is calibrated to match delays in the baseline 2016 data set.

Reactionary delays are incurred by delays affecting previous flights and using the same aircraft¹. It is through reactionary delay that problems at one airport propagate through the network.

To capture the level of reactionary delay we have linked the flights using the following algorithm:

- For every flight, a check on the aircraft registration or flight number has been made. A link for the flights with the same registration number has been made.
- For the rest of the flights, a search is performed at the destination airport for the next departing flight checking the aircraft type, the operator and taking into account a specific average turn-around time per airport or airline. If no information is available for turn-around time at destination airport, an average value of 53 minutes is used.
- When linked, a Rotation Margin is evaluated to assess if the initial delay can be absorbed before the next scheduled flight rotation.

After running the algorithm, 90% of the flights have been linked.

The figure below illustrates the reactionary delay mechanism implemented within the RNEST tool, and the effects of the rotation margin on initial delay.

For this study, our modelling has focused on delays at airports rather than in the airspace.

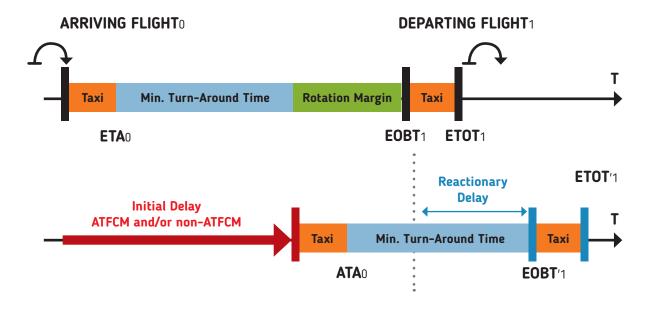


Figure 8 / Reactionary delay mechanism.

NETWORK CONGESTION SIMULATION RESULTS & ANALYSIS

With 16.2 million flights in Europe in 2040 (in the most-likely scenario), the estimated traffic growth will create pressure on airport capacity and have an impact on the global network performance. For Challenges of Growth 2018, we made an estimate in terms of delay by analysing two busy summer months. In the most-likely Regulation and Growth scenario, 16 airports operate at 80% or more of their capacity for more than 6 hours per day, compared to 6 in 2016. This drives the ATFCM delay from around 1 minute per flight today, up to 6.2 minutes. This increase by a factor 5 raises the ATFCM contribution to delay from a minor role, just below 10% in 2016, to being a major contributor responsible for 31% of the total delay in 2040. Associated to the high level of congestion in Europe, delays showed considerable inertia keeping high values even in the last hours of the day, when the congestion levels have already decreased.

A CONGESTED NETWORK IN 2040

According to the forecast, by 2040 traffic in Europe is expected to grow over 16.2 million flights in Regulation and Growth scenario (most-likely), 1.5 times the 2017 volume. Higher growth is expected in Global Growth scenario, with around 20 million flights. Along the year, the traffic is not equally shared among the seasons with the most important traffic peak occurring during the summer period.

By using our toolset, we have been able to model the same busy period for the 2040 time horizon using the predicted forecast to evaluate the expected number of movements. The reference period used for this modelling is 61 days in the 2016 summer period starting from August 1st.

Figure 9 shows the increase in number of movements at each hour for these summer months.

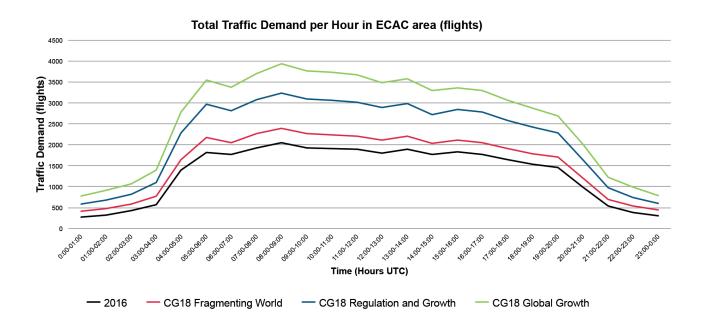


Figure 9 / Total traffic increase by 2040 (three forecast scenarios).

The impact of the 2040 forecast on the average daily demand is significant. The traffic demand is not equally spread over the year with high peaks in summer. In our modelling by focusing on the summer period, the Regulation and Growth scenario (most-likely) shows an increase of 61%, bringing the average daily demand from 32,198 in the sample period in 2016 to around 52,000 flights for the equivalent summer months in 2040. Compared to the summer 2017, that have seen 33,740 flights in average on a daily basis, the Regulation and Growth scenario presents an increase of around 54%.

The Global Growth scenario shows an average daily demand that is nearly doubled compared to summer 2016, with an increase of 93%, bringing the level of daily demand to around 62,000 flights per day in summer period. Relatively to summer 2017, this growth represents an increase in demand by 84%.

Figure 10 presents the average daily demand in 2040 according to the three Challenges of Growth 2018 forecast, Global Growth Scenario, Regulation and Growth scenario (most-likely) and Fragmenting World scenario relatively to the same period for the years 2016 and 2017.

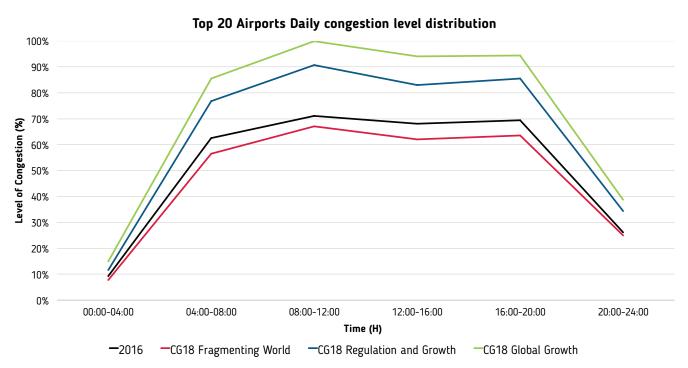
To understand the level of congestion over the ATM network, the analysis of the airport capacity usage along the day gives an overview of the global state of the network. In order to evaluate the mismatch between the expected airport capacities and traffic demand we used the data collected by the EUROCONTROL Airport unit for the Challenges of Growth 2018 study that showed a return of capacity increase in long-term airport capacity plans.

Figure 11 shows the daily profile of the usage of total airport capacity for the top 20 Airports by slice of 4 hours.

	AVERAGE DAILY DEMAND (FLIGHTS)		
2016 (August - September)	32,198		
2017 (August - September)	33,740		
FORECAST SCENARIO (2040)	2040 Average daily demand (flights)	Growth vs 2016 avg. daily demand (%)	Growth vs 2017 avg. daily demand (%)
2040 – Fragmenting World	38,188	19%	13%
2040 – Regulation and Growth	51,970	61%	54%
2040 – Global Growth	62,180	93%	84%

Figure 10 / Average daily demand in 2040 (summer period).

Figure 11 /
Top 20 airports daily congestion profile (congestion= use of available capacity).



As a first observation we see that the growth in the Fragmenting World scenario could easily be managed by the current 16% planned capacity growth by 111 airports. In this scenario, the level of capacity usage along a day of operation remains similar, even lower, than the observed usage in 2016. This is a direct outcome from the planned 28% increase in capacity by the top 20 airports by 2040.

In the Regulation and Growth scenario, the airport capacity expansion plans are not enough to manage the extra demand. Starting from the first rotations of the day, those airports are operating close or above 80% of their capacity till the end of the day. The Global Growth scenario is showing a more dramatic behaviour with the top 20 airports operating really close to their maximum capacity during the full day: the figure of 100% in late morning means that all 20 airports are using all of their capacity.

Another indicator that characterises the level of congestion of the network is the number of airports with a level of traffic over certain ratio of their capacity. Illustrated by the Figure 12, the analysis of the number of airports that have a level of congestion above 80% for 3 consecutive

hours or more (airports considered saturated) shows 8 airports corresponding to that criteria during the summer period 2016 (i.e. in August and September). If we look at a stricter condition of operating at 80% or more of capacity for 6 consecutive hours or more, we have 6 airports.

Level of Airport Congestion in 2016

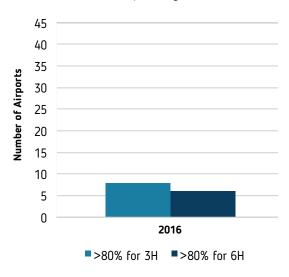
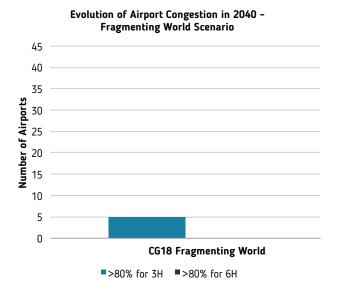
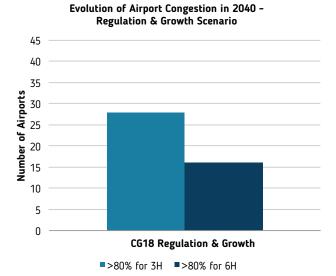


Figure 12 / Level of airport congestion in 2016.





By 2040, as expected, in the most-likely scenario the number of airports that have a level of congestion above 80% for 3 consecutive hours or more is climbing to 28. Even with the stricter condition of operating at 80% or more of capacity for 6 consecutive hours or more, we have 16 airports congested in 2040 compared to 6 in 2016 (see Figure 13). That is a small improvement on the 20 congested airports for the same strict conditions in the most-likely scenario from CG13, since the capacity growth is better targeted at the larger airports.

That the Global Growth scenario means heavy congestion is confirmed. In this dramatic picture we have 43 airports operating at 80% or more of capacity for 3 consecutive hours or more. The 6 consecutive hour condition shows 28 airports, "Heathrow-like", within the ATM network.

Figure 13 summarises the increased number of airports suffering congestion.

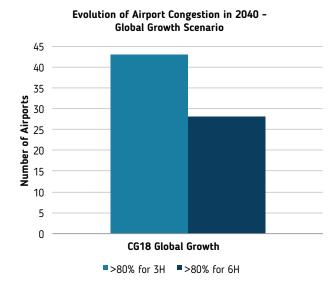


Figure 13 / Level of congestion in 2040.

AIRPORT CONGESTION BRINGS DELAYS TO THE NETWORK

In the previous section we illustrate how the lack of airport capacity will create a congested network, but there is an associated side effect of operating near capacity: delays. As in CG13, we have been able to evaluate the impact of airport congestion on network performance in terms of delay, this time with an improved model of non-ATFCM and reactionary delays.

As explained in section Methodology, delays have been classified as primary (i.e. ATFCM and non-ATFCM delays) and reactionary (i.e. knock-on delays incurred by previous flights). We assume that primary non-ATFCM delays, eg delays in loading baggage, remain similar to today.

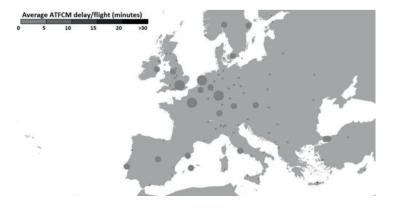
We also assume that en-route capacity will not be the constraint, so all of the ATFCM delays mentioned here are airport ATFCM.

In effect, this means assuming that capacity enroute can be increased in line with the forecast, for example through re-sectorisation or through improvements identified by SESAR. Delivering this en route improvement will be challenging and consequently the results presented here are likely to be a low estimate.

In 2016, the airport ATFCM primary delays were only 1.2 minutes out of an average of 6.3 minutes of primary delay per flight and out of 12.2 minutes per flight of total delay including the reactionary delay. So today, airports are a minor contributor of delays, the main cause and the biggest part of primary delays being related to airline causes. The current situation, for ATFCM delay and all causes of delay is illustrated at airport level in Figure 14.

In the following sections we will explore three out of four Challenges of Growth long-term traffic forecast scenarios to have a look at how the network respond to the corresponding airport congestion level: Regulation and Growth, Global Growth and Fragmenting World.

Happy Localism scenario was not retained for the study, since the traffic increase was close to the most-likely Regulation and Growth, the main differences being in the mix of short- and longhaul flights.



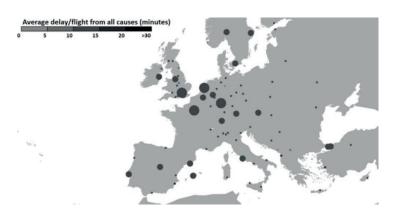


Figure 14 / Airport delay situation in 2016.

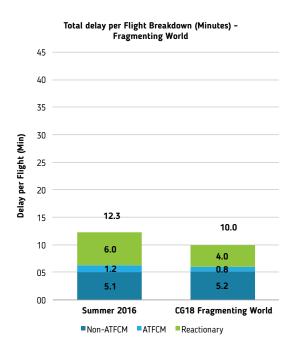
FRAGMENTING WORLD

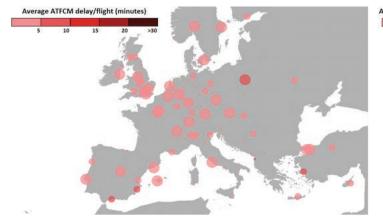
Fragmenting World presents the lowest traffic increase to 2040 in a world of increasing tensions and reduced globalisation. In section "A congested network in 2040", we have seen that the expected 19% increase in traffic demand could easily be managed by the current 16% planned capacity growth. In this scenario the daily congestion profile for the top 20 airports remains close to the observed one in 2016.

As expected, the network simulations performed to study the network performance under those conditions confirmed the operational viability of this scenario Illustrated by Figure 15, the combination of increased traffic and future airport capacity plans show the ATFCM delays go down from 1.2 minutes per flight to 0.8 minutes per flight in 2040. Whether in these traffic circumstances all airports would find delivering their current capacity plans cost-effective is another matter; so actual capacity is likely to be lower and these delay results therefore are optimistic.

Figure 16 shows, for Fragmenting World, network performance for the summer months close to 2016 where, in comparison, only few airports are suffering delays greater than 5 minutes per flight in our modelling.

Figure 15 / In Fragmenting World, summer delays go down from 12 to 10 minutes per flight.





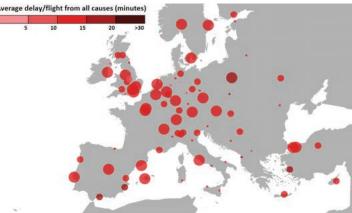
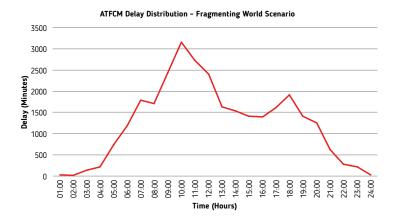


Figure 16 / In the Fragmenting World scenario, a network situation close to today's.

The similar patterns and order of magnitude of the distribution of delays (Figure 18) and the evolution of the ATFCM and reactionary delay over the day indicate network behaviour under control with performance level close to or slightly better than observed in summer 2016.



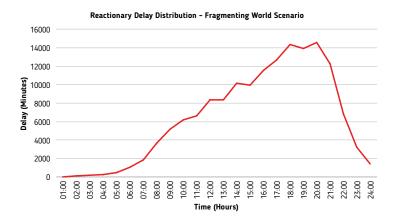


Figure 17 / Similar growing ATFCM (Airport) and reactionary delays than 2016 (Fragmenting World scenario).

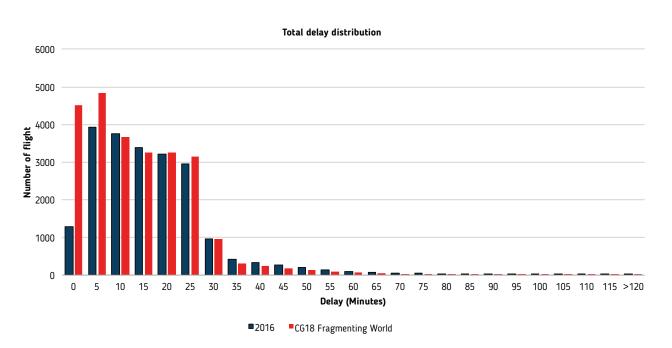


Figure 18 /Total delay distribution (Fragmenting World scenario).

REGULATION AND GROWTH (MOST-LIKELY) SCENARIO

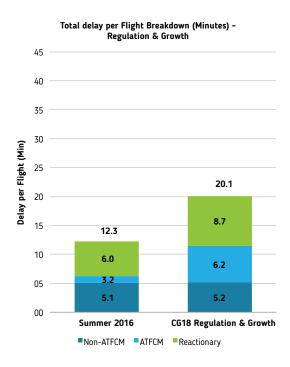
In 2016, there were 6 airports operating at 80% or more of capacity during 6 consecutive hours or more. The forecast is for this to climb to 16 congested, 'Heathrow-like' airports by 2040, in the most-likely scenario.

Within a network where 16 airports operate at 80% or more of capacity during 6 consecutive hours or more, it is likely to expect that any deviations (e.g. late bags, missing passengers) from the plan will generate delays that will accumulate rapidly along the day.

Illustrated by Figure 19, in our modelling, the interaction of increased traffic and future capacity plans show primary flow management delays climb from 1.2 minutes per flight to 6.2 minutes per flight in 2040, in the Regulation and Growth scenario (most-likely), with a knock-on increase in reactionary delays by 45% from 6 minutes per flight to 8.7 minutes per flight. The network's resilience and capacity to absorb additional shocks and the buffers present in the flight scheduling are pushed to the limit by the expected traffic growth.

Figure 20 shows, for the most-likely scenario, the growing delay challenge at airports for the summer months; where for 2016 none of them suffered delays greater than 5 minutes per flight in the simulation of August and September 2106. In 2040, the spread of high level of congestion in Europe turns into serious delays.

Figure 19 /In the most-likely scenario, summer delays jump from 12 to 20 minutes per flight.



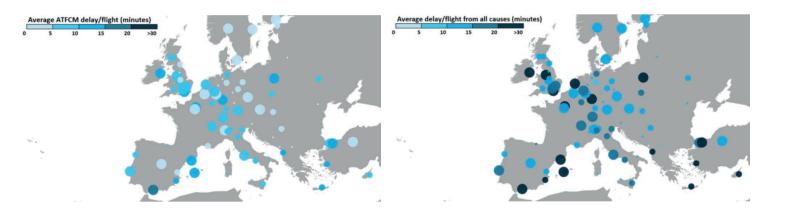
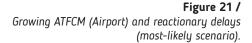


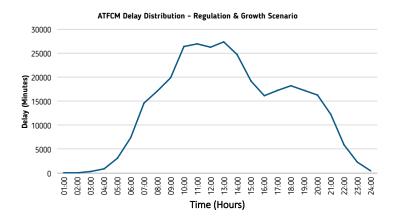
Figure 20 /

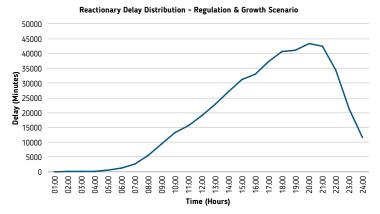
In this situation, with some major airports suffering from high level of delays (all causes), there is no room to recover during the day. The delays show considerable inertia, keeping high values even in the last hours of the day, when congestion level have already decreased (see Figure 11).

Figure 21 shows the quick increase in delays for the 2040 most-likely scenario, once the first rotation starts between 05:00-06:00 UTC, and rapidly propagating across the network through the evolution of the reactionary delay.

In terms of delay per delayed flight, the degradation is also heavy: the delay jumps from around 23 minutes per delayed flight up to 30 minutes.







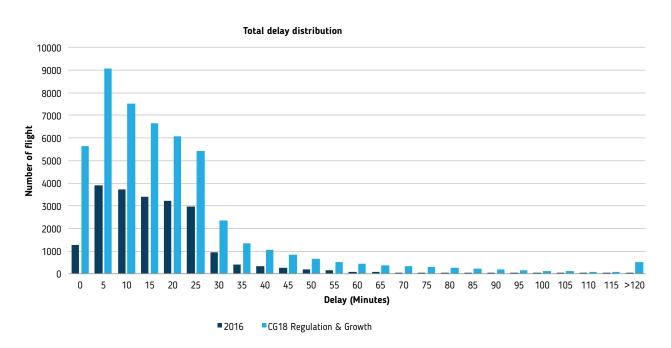


Figure 22 /Total delay distribution, long tail of delay for the most-likely scenario.

The increase in traffic demand is partly responsible for the increase in ATFCM delay at airports increasing by a factor 5, but the critical factor is the number of airports operating near capacity as discussed earlier.

With such long tail in the distribution of delays associated to the high level of predicted delay it is expected that, at the tactical level, on the day of operations, airlines will react to delays by cancellations after applying flight priorities rules according to their policy (e.g. favouring on-time performance or to ensure passengers connectivity), which will vary by airline and also during the day. Without cancellations, our modelling shows a significant increase in flights delayed by 60-120 minutes, that today represents around 1% of the total flight demand, by a factor of 7, in the mostlikely scenario representing 5.8% of the expected 2040 flight demand. This means around 470,000 passengers each day delayed by 1-2 hours in 2040, compared to around 50,000 today.

We have modelled the cancellation of flights in response to strong delays. Impacts and results can be found in the flight cancellation response section.

Total delay per Flight Breakdown (Minutes) -Global Growth 44.7 45 18.6 35 **Œ** 30 Fight 25 **a** 20 15 Delay 20.9 12.3 10 6.0 05 5.2 5.1 00 Summer 2016 CG18 Global Growth Non-ATFCM ATFCM Reactionary

Figure 23 / In the Global Growth scenario, summer delays jump from 12 to 44.7 minutes per flight.

GLOBAL GROWTH

The Global Growth scenario shows an average daily demand that is nearly doubled, with an increase of 93%, bringing the level of daily demand to around 62,000 flights per day in summer period.

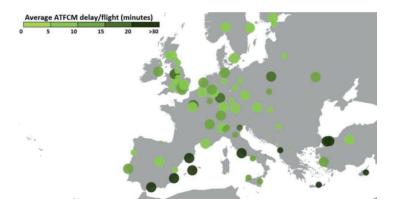
In such conditions, the analysis of the airport congestion profile showed a dramatic picture where 43 airports operate at 80% or more of capacity for 3 consecutive hours or more. With a 6 consecutive hours condition, the forecast show 28 airports "Heathrow-like" within the ATM network. It is hard to see how a plan can be executed in such a situation, given the deviations (e.g. late bags, missing passengers) that would surely occur.

Illustrated by Figure 23, in our modelling, the interaction of increased traffic from the Global Growth scenario and future capacity plans show flow management delays climb from 1.2 minutes per flight to 20.9 minutes per flight in 2040, in the Global Growth scenario.

Figure 24 shows, for this high scenario, the critical delay challenge at airports for the summer months; where for 2016 none of them suffered primary flow management delays greater than 5 minutes per flight in the simulation of August and September 2016. In 2040, the spread of high level of congestion in Europe turns into unsustainable delays across Europe.

Figure 25 shows the quick increase in delays for the 2040 Global Growth scenario, once the first rotation starts between 05:00-06:00 UTC, and rapidly propagating across the network through the evolution of the reactionary delay. Unlike the other scenarios, the network continues to generate high levels of ATFCM delay through to the early evening. At the end of the day, the network is not able to recover with level of delays not so far from their peaks.

In terms of delay per delayed flight, the delay jumps from around 23 minutes per delayed flights up to around 60 minutes.



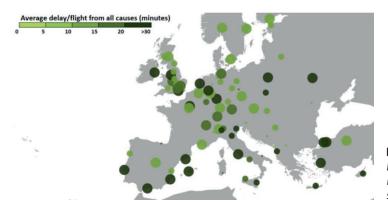
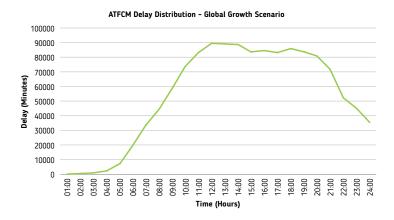


Figure 24 / In the Global Growth scenario, increasing number of airports with summer delay (in minutes/flight).



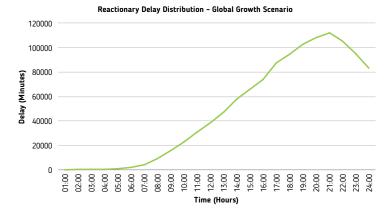


Figure 25 / Growing ATFCM (Airport) and reactionary delays (Global Growth scenario).

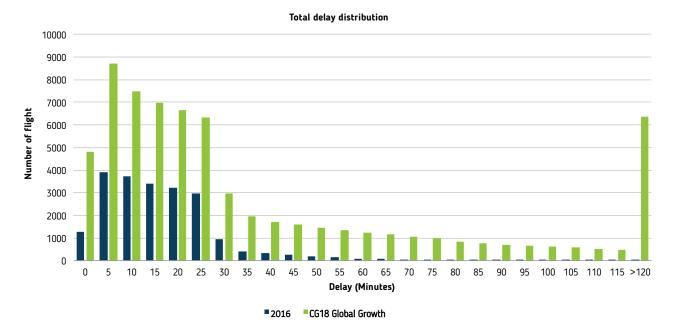


Figure 26 /Total delay distribution, long tail of delay for the Global Growth scenario.

With an increase in traffic demand nearly doubled in comparison to 2016, this scenario is an extreme case. Without a significant increase in airport capacity investment and innovative technology the ATM network will not function properly

FLIGHT CANCELLATION RESPONSE

In 2040 in the most-likely scenario, the level of airport congestion resulting from the traffic demand increase (i.e. around 60% in summer period) will bring the flow management delays from 1.2 minutes per flight up to 6.2 minutes per flight. This will raise the total delay per flight from around 12 minutes per flight in 2016 up to 20.1 minutes.

In response to strong delays, airlines are likely to cancel flights in order to adapt and to provide a reasonable quality of service to their passengers. In this 2018 iteration of the Challenges of Growth study, we attempt for the first time to simulate this behaviour. It allow us to quantify the amount of demand that would be dynamically lost during a day of operation in addition to the

unaccommodated demand, strictly due to capacity and airport slots availability reasons.

The assumptions for our basic flight cancellation model are:

- Flights suffering more than 2h of total delay (including reactionary & ATFCM) are dynamically cancelled during the simulation.
- Cancellation strategy applied to traditional scheduled airlines & low-cost carrier market segments.
- Cargo, military & business aviation are exempted from cancellation.

EFFECT OF FLIGHT CANCELLATIONS OVER THE MOST-LIKELY SCENARIO

We applied this flight cancellation strategy over the most-likely forecast scenario. Our simulations show that, on a daily basis in average 547 flights suffering delays of 2 hours and more have been cancelled along the day of operations. This represents 1.1% of the total expected daily demand in 2040 (most-likely).

As a direct outcome the total delay dropped by 13% to 17.4 minutes of delays, decreasing the level of ATFCM delay to 5.3 minutes. Figure 27 illustrates the outcomes of applying the cancellation model in the most-likely scenario.

This overall reduction of the delay is also observed on the daily distribution of the reactionary and ATFCM delay evolution as illustrated by Figure 28. Cancellation of flights starts to occur in the morning, bringing down the level of delays and allowing the system to better recover at the end of the day.

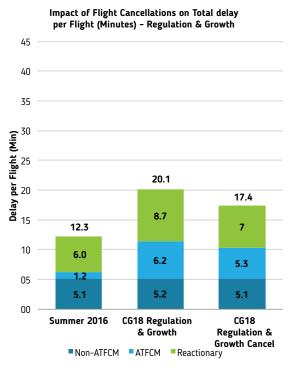
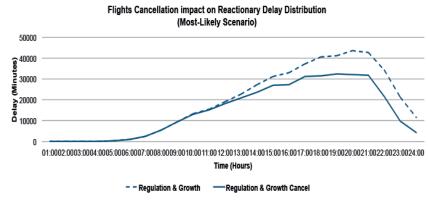


Figure 27 /
Flight cancellations impact on delay in the most-likely scenario, summer delays go down from 20 to around 17 minutes per flight.



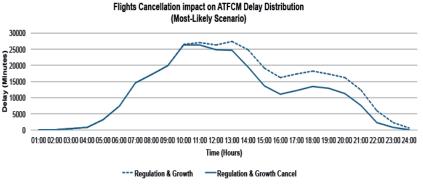


Figure 28 / Flight cancellations impact on delay in the most-likely scenario.

EFFECT OF FLIGHT CANCELLATIONS OVER THE GLOBAL GROWTH SCENARIO

Given the strong growth of the Global Growth scenario (i.e. traffic demand nearly doubled by 2040), to cancel the flights suffering delays greater than 2 hours would have resulted in cancelling nearly all the extra demand between the most-likely scenario and the Global Growth scenario.

To continue to conduct the study we decided to adapt the main assumption that triggers the flight cancellation. The level of delay that serves as a threshold for cancellation was increased from 2 hours up to 3 hours of total delay.

The adapted assumptions applied are:

- Flights suffering more than 3h of total delay (including reactionary & ATFCM) are dynamically cancelled during the simulation.
- Cancellation strategy applied to traditional airlines & low-cost carrier market segments.
- Cargo, military & business aviation are exempted from cancellation.

Our simulations show that, on a daily basis in average 3,500 flights have been cancelled on the day of operations. This represents 6% of the total expected daily demand by 2040 in the Global Growth scenario. A typical rate of cancellations in 2016 was 1%-1.5% on an average day. It is unlikely that such a level of demand would be cancelled by the airline, but as explained this scenario is an extreme case.

As a direct outcome the total delay dropped by 37% to 27.7 minutes of delays, decreasing the level of ATFCM delay to 11.7 minutes. Figure 29 illustrates the outcomes of applying the cancellation model in the most-likely scenario.



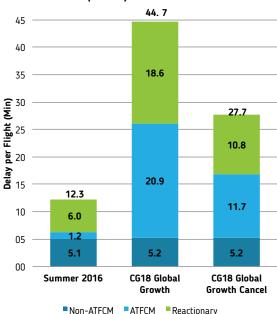
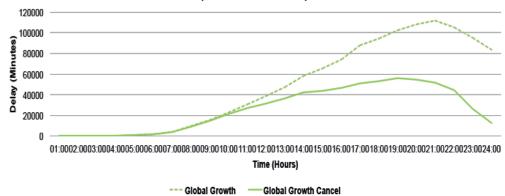
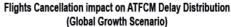


Figure 29 /
Flight cancellations impact on delay in the global growth scenario, summer delays go down from 45 to around 28 minutes per flight.

This overall reduction of the delay is also observed on the daily distribution of the reactionary and ATFCM delay evolution as illustrated by Figure 30, below. Cancellation of flights starts to occur in the morning, bringing down the level of delays and allowing the system to better recover at the end of the day.







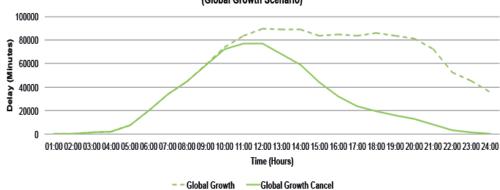


Figure 30 /
Flight cancellations impact
on delay in the Global Growth
scenario.

2040 TRAFFIC INCREASE IMPACT ON EN-ROUTE AIRSPACE

The increase of airport movements has also consequences in the en-route phase of the flights. In this CG18 edition we assume that en-route capacity will not be the constraint, and that the capacity could be expanded for example through additional resources, or through improvements identified by SESAR in a way that would be sufficient to manage the expected traffic increase by the 2040 time horizon.

Nonetheless we can still have a look at how the foreseen increase in traffic demand will impact the European airspace.

As discussed in section "A Congested Network in 2040", the impact of the 2040 forecast on the average daily demand is significant. The Regulation and Growth scenario (most-likely) shows an increase of 61% in summer traffic, bringing the average daily demand in the August and September to around 52,000 flights. The Global Growth scenario shows an average daily demand that is nearly doubled, with an increase of 93%, bringing the level of daily demand to around 62,000 flights per day in summer period. The Fragmenting World scenario presents a relatively small increase in traffic demand of 19% that represent roughly an average 38,000 flights a day.

Figure 31 illustrates that a majority of en-route airspace will face an increase of demand between 50% and 80%. This represents a huge increase in demand compared to today's volume of flights managed by the European airspace management system. The increase in demand for the Global Growth scenario is spread over a larger range comprised between 70% and 140% of extrademand.

But the traffic demand increase is not equally spread over Europe; some regions will receive more extra demand than others. Figure 32 presents in detail the en-route traffic demand increase (in percentage) by 2040 for the forecast scenarios Global Growth, Regulation & Growth (most-likely) and Fragmenting World.

In 2040, Turkey airspace will face a traffic demand multiplied by 2.5 (i.e. around 150% increase in demand) in the most-likely scenario and even by 3 if we look at the high growth scenario. This expected demand growth will directly impact the neighbouring countries, so Romania, Bulgaria, Serbia, Cyprus and Greece will experience high level of traffic demand with expected growth around or greater than 80% compared to 2016.

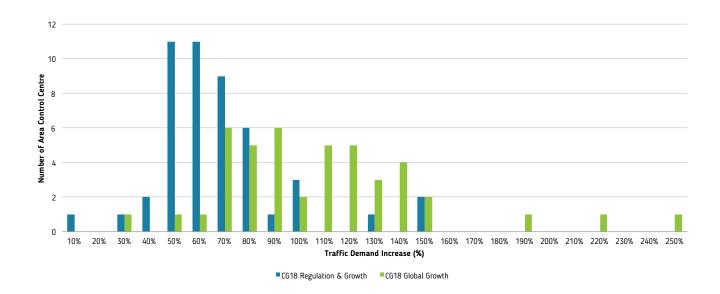


Figure 31 / En-route traffic demand increase distribution by 2040.

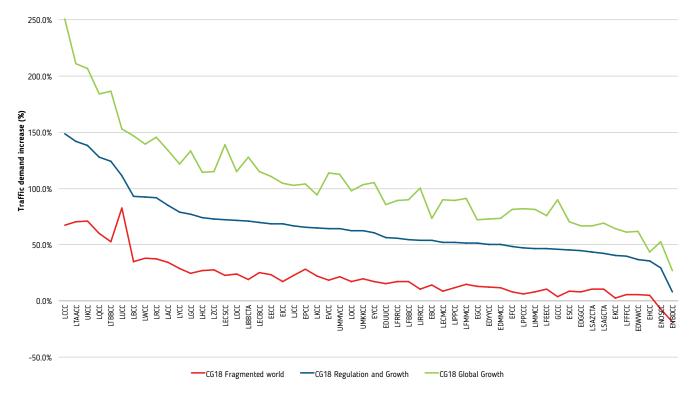


Figure 32 / En-route traffic demand increase by 2040.

Figure 33 / En-route airspace traffic growth in 2040.

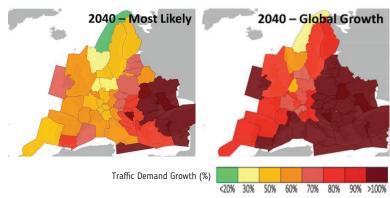
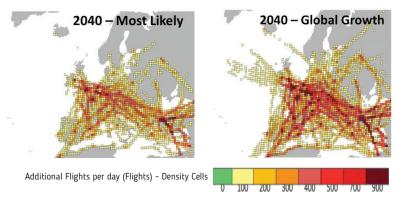


Figure 34 / En-route Additional flights per day in 2040.





CONCLUSION

FINDINGS

For this annex of Challenges of Growth, we have evaluated the impact of air traffic congestion on network performance at the 2040 time horizon. According to the forecast, by 2040 traffic in Europe is expected to grow to over 16.2 million flights in Regulation and Growth scenario (most-likely), 1.5 times the 2017 volume. Higher growth is expected in Global Growth scenario, with around 20 million flights.

This growth in traffic will create pressure on airport capacity and will certainly reduce the number of slots available to act as contingency. When we analysed August and September 2016, there were just 8 airports that were "congested" in the sense of operating at 80% or more of their capacity for more than 3 hours per day. In the most-likely scenario of the 2040 forecast, this climbed to more than 28 airports in 2040. Even for the stricter condition of operating at 80% or more of capacity for 6 hours/day, there were 16 airports congested in 2040, compared to just six today. That is a small improvement on the 20 congested airports for the same strict conditions in the most-likely scenario from CG13, since the capacity growth is better targeted at the larger airports.

Measuring airport capacity usage along the day gave us an overview of the global state of the network in 2040. The current 16% planned capacity growth by 111 airports (28% for the top 20 airports) is still not enough to manage the extra demand. By 2040, the top 20 airports will operate close or above 80% of their capacity starting with the first rotations till the end of the day in the most-likely scenario.

In such a state, it is clear that any deviations (e.g. late bags, missing passengers) from the plan will generate delays. In the 2040 simulation, a high level of delay was observed across the entire network. The ATFCM delay in the most-likely scenario jumped from around 1 minute per flight, as in today operations, up to 6.2 minutes. This increase by a factor 5 raises the ATFCM contribution to delay from a minor role, to being a major contributor. Associated with the spread of high level of congestion in Europe, serious delays start appearing early in the morning and showed considerable inertia keeping high values even in the latest hours of the day, when the congestion levels have already decreased.

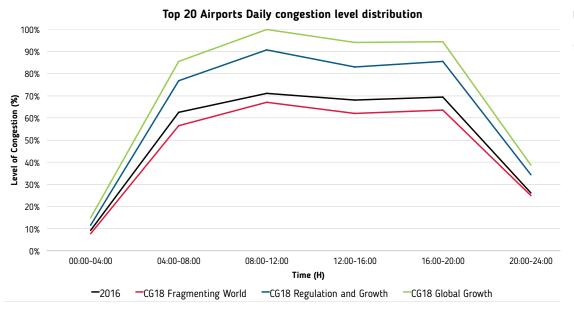


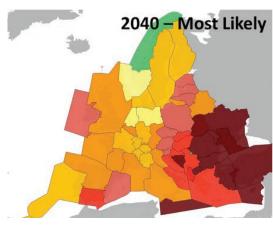
Figure 35 / En-route airspace traffic growth in 2040.

A high level of congestion obstructs the network mechanisms that support recovery from external events. In reality, airlines and airports adapt to a certain level of congestion, with operating procedures, schedules, processes and capital investment to provide a reasonable quality of service to their passengers. However, it is hard to see how quality of service could be maintained if average delays were nearly to double. There is a long tail to the distribution of delays: our modelling shows a significant increase in flights delayed by 60-120 minutes in this situation, with 7 times as many by 2040 in Regulation and Growth. Our modelling showed an additional 1.1% of the total expected daily demand in 2040 (most-likely) lost due to flight cancellation.

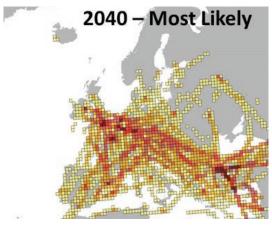
Congestion is also a challenge for the airspace. We looked in more detail at where the traffic increases will be. By 2040 in Regulation and Growth, a majority of en-route airspace will face an increase of demand between 50% and 80%, so some airspace will see growth well ahead of the 53% total growth. For example, at this time horizon, Turkey will face 2.5 times as many flights. This expected growth will directly impact the neighbouring countries, so Romania, Bulgaria, Serbia, Cyprus and Greece will experience high level of traffic demand with expected growth around or greater than 80% compared to 2016. At the other corner of Europe, the south of Spain will have to face a 70% growth in demand, similar to the south-east part of Italy, the Brindisi area being affected by the traffic growth in Turkey.

The European core area will not be exempted from difficulties with an average demand growth between 40% and 55%. To handle this growth where traffic is already dense and complex will surely represent as much of a challenge as higher percentage growth elsewhere.

Figure 36 / En-route airspace traffic growth in 2040







Additional Flights per day (Flights) - Density Cells



FUTURE LINES OF WORK

The present network congestion study has allowed us to continue our modelling refinements to be able to evaluate at the same time the primary (i.e. ATFCM and non-ATFCM) and reactionary delays. The modelling effort and the observed results of the simulations open interesting research routes for the future:

- In the course of the present study, a network situation comparison has been made between today, where the network is well available, and the year 2040 where the network is totally congested. The study of the major forecast scenario (i.e. Global Growth, Regulation and Growth and Fragmenting World) allow an exhaustive analysis of the potential evolution of the network congestion in 2040. But in order to better trigger future investment in more capacity when and where necessary the study of intermediate steps and year between now and 2040 is fundamental.
- An obvious future line of research is the enlargement of the scope to allow the modelling of en-route capacity evolution and associated performance assessment in longer term.
- The mitigation annex of the Challenges of Growth evaluates different ways to recover a part of the expected unaccommodated demand (i.e. 1.5 million in 2040 Regulation and Growth scenario. See Ref. 6). The study of the impact of adding this extra demand to the network can prove to be very useful to arbitrate the constant trade-off between demand, capacity and delays.
- The proposed approach for non-ATFCM model depends highly on the availability of high quality data to support the statistical modelling. The continuous effort from CODA to maintain and improve comprehensive statistical data on delays is of utmost importance for improving the model with more realistic and accurate data.

In front of network congestion, airspace users have specific decision criteria tightly linked to the schedule of operation and their market segment. The cancellation model used in the study was a first attempt to represent airline behaviour using a linear model to trigger flight cancellations. We know it does not represent exactly the reality but it proved to be useful in capturing a network response to flight cancellations. It opens an interesting field of research and improvements for the next iteration of the Challenges of Growth studies.

DELAY FIGURES AND TABLES

Figure 37 / CG18 congestion study delay summary

CC10 ALL CONCECTION CCENARIOS	AVERAGE DELAY PER FLIGHT (MIN)			
CG18 ALL CONGESTION SCENARIOS	ATFCM	Non-ATFCM	Reactionary	Total
2016 (August – September)	1.2	5.1	6.0	12.3
2040 – Fragmenting World	0.8	5.2	4.0	10.0
2040 – Regulation and Growth	6.2	5.2	8.7	20.1
2040 – Global Growth	20.9	5.2	18.6	44.8
2040 – Regulation and Growthwith Flights Cancellationss	5.3	5.1	7.0	17.4
2040 – Global Growth with Flights Cancellations	11.7	5.2	10.8	27.7

Figure 38 / Reactionary delay distribution – Combined Plots

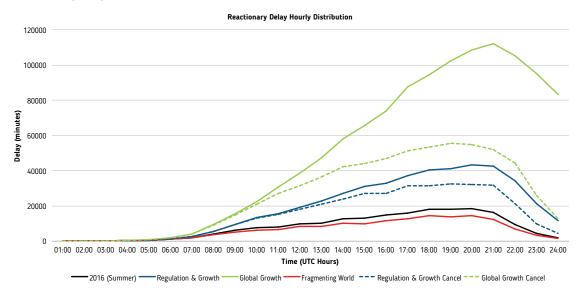


Figure 39 / ATFCM (Airport) delay distribution

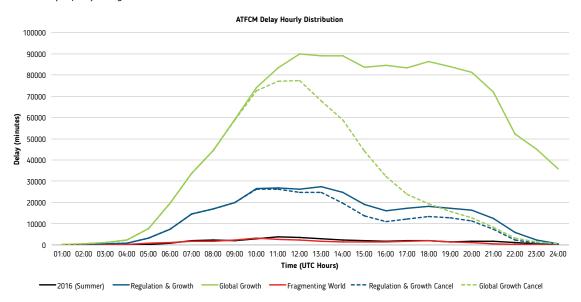
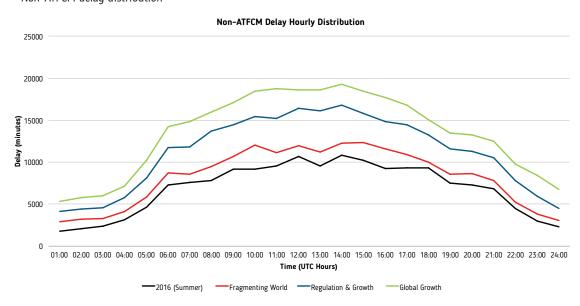


Figure 40 / Non-ATFCM delay distribution



THE RNEST TOOLSET



R-NEST is a model-based simulation tool, sharing the same base as the EUROCONTROL NEST tool. R-NEST is dedicated to research activities for preevaluating advanced ATM concepts. The tool is a stand-alone desktop application combining dynamic ATFCM simulation capabilities with powerful airspace design and capacity planning analysis functionalities.

R-NEST offers an intuitive, planner-orientated interface with a low barrier to entry for new users. It is a powerful scenario-based modelling engine, capable of running a broad range of complex, operationally relevant analyses and optimisation functionalities.

R-NEST can be used to emulate Area Control Centres (ACC) or airports for strategic planning and network level assessment. R-NEST can process and consolidate large quantities of data spanning multiple years, but allows to drill down into the details by analysing and observing 10-minute periods of data.

SIMULATION CAPABILITIES

Delays

R-NEST **dynamically** simulates network operations and allows detection and observation of delays that characterise the degradation of the network performance.

R-NEST is able to capture:

- ATFCM delays, thanks to an emulation of the CASA (Computer Assisted Slot Allocation) algorithm used by the Network Manager to respond to network constraints and an integrated STAM (Short Term ATFCM Measures) model developed following the guidance of the SESAR concept.
- Non-ATFCM delays, mostly generated by internal ATM network disturbances. These delays can result from various causes e.g. handling, passengers or baggage problems. (source: EUROCONTROL/CODA)
- Reactionary delays, incurred by delays affecting previous flights using the same aircraft. It is through reactionary delays that problems at one airport propagate through the network.

Airspace Configuration Optimiser

R-NEST can propose an optimum operational opening scheme according to controller availability, sector configurations and sector or traffic volume capacities. The model balances working time and overloads, based on a customisable optimisation strategy.

Regulation builder

|||||||

R-NEST automatically calculates the period and capacity required to smooth detected overloads. The model can be customised to mimic operational behaviours.

4D traffic distribution

R-NEST can calculate 4D flight trajectories for a given route network, taking into account aircraft performance data, route restrictions and flight level constraints, SID & STAR and military area opening times. The traffic can be distributed via shortest, cheapest (minimising route charges) or optimum (minimising overloads) routes.

Future traffic samples

R-NEST can generate future traffic samples using traffic growth forecasts provided by STATFOR. Airport capacities and curfews can be used to constrain traffic growth.

From Local to Network Performance indicators

R-NEST is able to measure at the Network level the improvements generated by the local implementation of a new ATM concept.

R-NEST offers global indicators evaluation including route length extension for flight efficiency, fuel consumption, ATFCM/Non-ATFCM delays, CO₂ and NOx emissions.

R-NEST can process large quantities of data spanning over multiple years. A strategic view allows users to detect trends or carry out detailed analysis.

Reports

R-NEST is provided with ready-to-use study templates and can automate frequently used tasks and create dynamically new data computing activities.

All analysis data from R-NEST can be exported in the form of customised reports which can also be fed into external tools or templates for further analysis.

CODA REFERENCE DELAY

Figure 41 / CODA All causes of delay breakdown.

Hour STD (Aug-Sept 2016)	Avg All-Causes delay per flight	Avg En-Route ATFM delay per flight	Avg Primary (excl En-Route ATFM) All-Causes delay per flight	Avg Reactionary delay per flight
0	14.5	0.2	8.0	6.3
1	12.8	0.3	6.6	5.8
2	9.5	0.2	6.0	3.4
3	7.0	0.3	4.9	1.8
4	5.5	0.6	4.0	0.8
5	6.2	0.8	4.5	0.9
6	6.9	0.7	4.4	1.8
7	8.9	0.7	4.8	3.4
8	10.2	1.1	5.4	3.7
9	11.2	1.2	5.5	4.5
10	11.7	1.0	5.7	5.0
11	12.3	1.0	6.1	5.3
12	12.3	0.7	5.7	5.9
13	12.1	0.7	5.9	5.5
14	12.0	0.7	5.7	5.6
15	12.0	0.8	5.2	6.0
16	12.3	0.7	5.0	6.6
17	12.8	0.7	4.9	7.3
18	12.9	0.6	4.6	7.7
19	14.6	0.7	5.2	8.6
20	13.8	0.4	5.5	7.8
21	14.4	0.3	6.8	7.3
22	12.3	0.1	7.6	4.6
23	13.9	0.1	7.4	6.4

GLOSSARY

ACC Area Control Centre

ATFCM Air Traffic Flow and Capacity Management

ATM Air Traffic Management

CASA Computed Assisted Slot Allocation

CG08, CG13, CG18 Challenges of Growth 2008, 2013, 2018

ECAC European Civil Aviation Conference

ATA Actual Time of Arrival

EOBT Fstimated Off-Block Time

ETOT Estimated Take-Off Time

ETA Estimated Time of Arrival

FIPS Flight Increase Process

LTF Long-Term Forecast (20 years)

MTF Medium-Term Forecast (7 years)

RNEST Research Network STrategic Tool

SESAR Single European Sky ATM Research

SID Standard Instrument Departure (Route)

STATFOR Statistics and Forecast Service of EUROCONTROL

STAR Standard Terminal Arrival Route

Unaccommodated demand the forecast flights that exceed an airport's reported capacity.

UTC Universal Time Coordinated

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