Challenges of Growth 2013

Task 6: The Effect of Air Traffic Network Congestion in 2035
This report is part of the fourth Challenges of Growth study, which aims to deliver the best-achievable information to support long-term planning decisions for aviation in Europe.

Companion reports describe in details the 2035 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 2008, we were able to quantify the number of airports that would be congested, and deduce that this would cause difficulties in the form of delay, but we were not in a position to quantify the delay. For Challenges of Growth 2013, we have been able to make the first steps towards quantifying the impact of airport congestion on network performance in terms of delay.

When we analysed August and September 2012, there were just 6 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 2035 forecast, this climbed to more than 30 airports in 2035. Even for the stricter condition of operating at 80% or more of capacity for 6 hours/day, there were more than 20 airports congested in 2035, compared to just three today. Normally, a small hiccup (late bags, missing passenger etc) might cause departure delay that is caught-up en-route. With this future level of congestion, it becomes difficult to accommodate minor deviations from plan, and delays begin to accumulate rapidly.

Delays are classified as primary (delays to this flight) and reactionary (knock-on delays incurred by this aircraft on previous flights). It is through reactionary delay that problems at one airport propagate through the network. In 2012, airport-related primary delays were only 0.9 minutes out of an average of 5.7 minutes of primary delay per flight and of 10 minutes/flight total including reactionary (Ref 1). Airport-related delay is made up of air traffic flow and capacity management (ATFCM) regulations at airports responding to capacity shortfalls, and of other airport causes (ramp congestion, runway closures, etc). So, on average airports are a relatively minor cause of delay, and on only a few days in the year are a more major cause. It is airline-related causes that remain the biggest proportion of primary delays overall (typically 50%).

For this study we have adapted our tools, originally focused on ATFCM delays and nearer-term capacity planning, and which simulate the algorithm used by the Network Manager to respond to constraints. The key changes were to model how reactionary delays propagate from flight to flight during the day; and to calibrate the model using data on delays from all causes, provided by airlines to EUROCONTROL/CODA (Ref 1). The analysis is based on modelling and comparing two summer months in the 2012 baseline year, and in 2035. For 2035, traffic was grown using the most-likely forecast scenario.

Congestion in the network affects day-to-day delays, but it also influences our ability to respond to an unusual event. So, in addition to these busy months in 2035, we also modelled the effects of two ‘disturbances’: a ‘security’ scenario in which on this day Heathrow capacity falls to zero for two hours due to a security issue, recovering back to full capacity by hour 4; we also modelled a ‘weather’ disturbance that is more geographically widespread.

The new modelling is focused on ATFCM (airport) delay, and reactionary delay. At a highly congested airport, running near its capacity limit, it might be expected that other classes of delay would be liable to increase, such as airline or government (security, immigration) ones. These have not been modelled for this study. Secondly, we assume that delays in en-route airspace do not increase. This is consistent with the assumption of each Challenges study that en-route is not the constraint – it may be challenging to deliver the capacity there, but not insuperably so. Consequently, the results here are likely to be a low estimate, and for this reason, we do not report on the share of airport delay in the face of the network congestion of 2035.
The 2035 forecast shows a growing delay challenge at airports for the summer period. In the simulated current days the delay per flight is around 1.12/minutes (slightly higher than the whole year which is 0.9 min/flight). This jumps up to 5.6 minutes per flight for the 2035 case.

In the external disturbances cases, average delays jump to 5.8 and 6.4 minutes per flight in the weather scenario and up to 9.1 minutes per flight for the scenario with a security problem.

Under the expected 2035 airport level of congestion, the network ability to recover from disrupted states is reduced which is observed in a much longer time to recover. The effects of external disturbances propagate rapidly across the network and their impact is aggravated, notably in terms of severity in performance degradation.

In reality we would except that airlines will react to delays by flight cancellations after applying flight priorities according to their policy (e.g. favouring on-time performance or to ensure passengers connectivity) causing additional unaccommodated demand. This illustrates again the constant trade-off that drives the air transport network between demand, capacity and delays.
CONTENTS

1 Introduction 7

2. Introducing Congestion 8
   2.1 Level of congestion 8
   2.2 The network response assessment 9

3. Methodology 10
   3.1 Modelling Approach 10
   3.2 Scenarios 11
   3.3 Future traffic samples 12
   3.4 Delay model 13

4. Simulation results and analysis 14
   4.1 A congested network in 2035: the context 14
   4.2 Airport congestion brings delays to the network 17
   4.3 Congested network and external disturbances 20

5. Conclusion 23
   5.1 Findings 23
   5.2 Future lines of work 23

A. Delay figures and tables 24

B. The ASTAAC model 27

C. CODA reference delay 29

D. Glossary 30

E. References 30

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<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Airport Level Congestion.</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Modelling approach.</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Scenario description summary.</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>Traffic Increase Process.</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>Reactionary delay mechanism.</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>Total traffic increase by 2035 (Scenario C).</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>Airport daily (H24) level of congestion distribution.</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>Increased airport congestion in 2035.</td>
<td>15</td>
</tr>
<tr>
<td>9</td>
<td>Top 15 airports daily congestion profile (congestion= use of available capacity).</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>Increasing number of airports with summer delay (in minutes/flight).</td>
<td>17</td>
</tr>
<tr>
<td>11</td>
<td>Daily evolution of total delay.</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>Growing reactionary and ATFCM (Airport) delay.</td>
<td>19</td>
</tr>
<tr>
<td>13</td>
<td>Total delay distribution.</td>
<td>19</td>
</tr>
<tr>
<td>14</td>
<td>Weather disturbances impact on delays in 2035.</td>
<td>21</td>
</tr>
<tr>
<td>15</td>
<td>Security threat impact on delays in 2035.</td>
<td>22</td>
</tr>
<tr>
<td>16</td>
<td>Baseline delays for August/September 2012.</td>
<td>24</td>
</tr>
<tr>
<td>17</td>
<td>2035 simulated delays.</td>
<td>24</td>
</tr>
<tr>
<td>18</td>
<td>MET.1 2035 weather scenario delays.</td>
<td>24</td>
</tr>
<tr>
<td>19</td>
<td>MET.2 2035 weather scenario delays.</td>
<td>24</td>
</tr>
<tr>
<td>20</td>
<td>2035 Security scenario delays.</td>
<td>24</td>
</tr>
<tr>
<td>21</td>
<td>Reactionary delay distribution.</td>
<td>25</td>
</tr>
<tr>
<td>22</td>
<td>ATFCM (Airport) delay distribution.</td>
<td>25</td>
</tr>
<tr>
<td>23</td>
<td>Non-ATFCM delay distribution.</td>
<td>26</td>
</tr>
<tr>
<td>24</td>
<td>CODA delay breakdown.</td>
<td>29</td>
</tr>
</tbody>
</table>
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 three studies, in 2001, 2004 and 2008. This report is part of the fourth study, Challenges of Growth 2013 (CG13), which overall addresses the following question:

What are the challenges of growth for commercial aviation in Europe between now and both 2035 and 2050?

The main analysis of CG13 is in the traffic forecasts (tasks 4 Ref. 2 and 7 Ref. 3) and mitigation (task 5, Ref 4). These tasks explore how aviation might look in 2035 and 2050, investigating the expected lack of airport capacity.

The forecast comprises four scenarios, each describing a possible future:

- **A**: strong *Global Growth*;
- **C**: moderate *Growth Regulated* (considered the most-likely);
- **C’**: like C but with fragile Europe adapting to *Happy Localism* (i.e. looking inwards);
- **D**: a *Fragmenting World* (i.e. increased regional tensions).

In the most-likely scenario C, demand for 1.9 million flights cannot be accommodated in 2035. Those reports discuss how the air transport industry might handle this capacity gap.

However, 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:

- In the Strategic phase, in theory, an airport can keep some free slots out of its maximum capacity to act as contingency. It will reduce the emergence of delays but will also increase the unaccommodated demand. In practice, commercial pressures will push the number of contingency slots to near zero.

- In Tactical phase, during the day of operations, airlines will react to delays by requesting flight cancellations after applying flight priorities rules according to their policy (e.g. favouring on-time performance or to ensure passengers connectivity).

The aim of the task here, Task 6 congestion modelling, is to further analyse the 2035 situation by quantifying the impact of airport congestion on network performance in terms of delay.

For a summary of the traffic forecast, see the 2035 forecast report (Ref 2).
A congested network appears when, to accommodate the traffic demand, a number of airports operate simultaneously at or close to their peak capacity. In 2008, we discussed the number of airports that would be congested but we were not in a position to quantify the associated difficulties in terms of delay and network performance degradation. This time we have been able to make the first step towards quantifying the impact of congestion on network performance in order to study how the network will respond when more and more airports will face serious congestion issues.

2.1 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 as illustrated in Figure 1 below.

A congested network appears when the scheduling to accommodate the traffic demand implies that a number of airports 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 airport 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, along the day or a one-day average level of congestion (for a 24-hour time period or only during the airport opening hours).

- Congestion over percentile X, that provides the number of airports operating at X% or greater of capacity.

Figure 1: Airport Level Congestion
The network response assessment

In order to assess the situation of the 2035 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 diffusion of the traffic.
- Internal disturbances to the air transport processes.
- External disturbances or unexpected events.

The variations implied by the existence of internal and external disturbances can be locally absorbed or can cause the emergence of performance degradation. The degradation is characterised by the deviation of one or several performance indicators. A typical degradation is the appearance of flight delays superior to 15 minutes.
3. METHODOLOGY

The appearance of delays that characterise the degradation of the air transport network performance, can result from capacity shortfalls within the network infrastructure (ATFCM delays), or be caused by events external to the system (non-ATFCM delays). Those delays can follow one aircraft all along the day of operations (reactionary delays). For Challenges of Growth 2013, we have modelled the different nature of delays by updating our tools, originally focused on ATFCM delays, which simulate the algorithm used by the network Manager to respond to network constraints, and calibrated against CODA statistics to replicate non-ATM related delays. A specific algorithm to link the flights and to track the reactionary delays has been developed.

3.1 Modelling Approach

Most of the simulations related to the ATM (Air Traffic Management) field 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 accordance to model the network behaviour with its associated performance indicators. The simulations have been carried out by using the ASTAAC (Arithmetic Simulation Tool for ATFCM and Advanced Concepts) tool. ASTAAC 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 and ECAC (European Civil Aviation Conference) network capacity planning assessment. For a complete description of the tool see Annex B.

Figure 2 presents the global approach used for the modelling and assessment activities.
3.2 Scenarios

The study of the network behaviour under the level of congestion expected by the 2035 forecast (i.e. scenario C most likely) has been addressed through the definition of several scenarios defined hereafter.

Baseline

A baseline scenario used to calibrate the delay model and to measure reference performance indicators in order to assess the impact of the traffic growth. The reference period in this scenario is built from 61 days of traffic in summer 2012 starting from 1 August 2012. See Annex C: CODA reference delay.

2035 Network in nominal conditions

Within the 2035 scenario, the number of movements has been increased, with respect to the Scenario C forecast (i.e. around 50%). Hourly capacities obtained from the survey of 108 airports* have been used.

2035 Network under unusual conditions

To assess the global performance of a congested network when facing unexpected events (i.e. external disturbances), two categories of perturbations have been modelled: meteorological phenomena and a severe local security threat.

Meteorological phenomenon

The meteorological phenomenon under study is a storm causing capacity shortfall in a certain European region and affecting progressively more airports. Two scenarios have been defined.

Scenario MET.1:

A storm is affecting one airport in Central Europe (i.e. Vienna) producing a 30% reduction in capacity starting at 09:00 a.m. with duration of 3 hours. By the next hour the storm affects a wider area producing a 30% capacity shortfall in two neighbour airports with duration of 3 hours. One hour later (i.e. 11:00 a.m.) the storm evolves impacting 4 additional airports in Central Europe.

Scenario MET.2:

This scenario is based on the previous one but affecting North-West Europe as well. A storm is affecting one airport in Central Europe (i.e. Vienna) producing a 30% reduction in capacity starting at 09:00 a.m. with duration of 3 hours. By the next hour the storm evolves rapidly affecting a wider area producing a 30% capacity shortfall in two neighbour airports with duration of 3 hours. One hour later (i.e. 11:00 a.m.) the storm evolves impacting 4 additional airports in Central Europe with a capacity shortfall of 15% with duration of 3 hours.

Local security threat

The security threat that is studied is the impact of a severe terrorist threat at Heathrow airport. The threat level at the airport is raised to “severe – an attack is highly likely” causing the closure of the airport starting at 09.00 a.m. with duration of 2 hours. The airport recovers to full capacity by next 2 hours.

Figure 3 presents a summary of the modelled scenarios.

* The 2035 traffic forecast used a fully refreshed set of airport capacity figures covering some 108 airports.
### Table: Scenario Description Summary

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Number Airports Impacted</th>
<th>Severity of the Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td><strong>August - September 2012</strong> (61 days). Used to calibrate the model.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>2035 under nominal condition</strong></td>
<td>Increased traffic (+50%) using <strong>Scenario C (most likely)</strong> of 2035 forecast.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>MET.1</strong></td>
<td>Storm in Europe Central</td>
<td>7</td>
<td>30% capacity reduction</td>
</tr>
<tr>
<td><strong>MET.2</strong></td>
<td>Storm in Central Europe and North-Western Europe</td>
<td>7 Central Europe</td>
<td>30% capacity reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 North-West Europe</td>
<td>15% capacity reduction</td>
</tr>
<tr>
<td><strong>Security</strong></td>
<td>Security threat at Heathrow airport</td>
<td>1</td>
<td><strong>2h Airport closure</strong> starting at 09.00 a.m. then recovering at full capacity by 4 hours later.</td>
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</tbody>
</table>

#### 3.3 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 1 August 2012.

Growth figures are then applied to the baseline traffic sample, which respect the 2035 traffic forecast (Scenario C, the most-likely), prepared by Task 4 of the Challenges of Growth 2013 study (Ref. 2).

Another major component of the modelling environment is the airport capacity.
3.4 Delay model

The ASTAAC tool combines, for a simulated day of operations, the expected flight demand and the available airport and/or en-route capacity. The tool simulates network operations and allows us to observe the appearance 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 system (non-ATFCM). As a knock-on effect, the delays can follow one aircraft through the day of operations (reactionary).

For this study, we have adapted our tool, originally focused on ATFCM delays and nearer-term capacity planning activities. 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 thanks to ASTAAC network delay assessment capabilities. The tool emulates the CASA (Computer Assisted Slot Allocation) algorithm used by the Network Manager to respond to network constraints.

**Primary, non-ATFCM** delays are mostly generated by internal disturbances, as defined in section 2.2, 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 data on delays from all causes, provided by airlines to EUROCONTROL/CODA. 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 allocated to the flights.

The affected random delay can not be lower than 5 minutes and can not exceed 30 minutes.

**Reactionary** delays are incurred by delays affecting previous flights and using the same aircraft. 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/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 an average turn-around time of 53 minutes.
- 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, 85% of the flights have been linked.

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

**Figure 5: Reactionary delay mechanism**
With 14.4 million flights in Europe in 2035, the estimated traffic growth will create pressure on airport capacity and have an impact on the global network performance. For Challenges of Growth 2013, we have made the first estimates in terms of delay by analysing two busy summer months. In scenario C, 20 airports operate at 80% or more of their capacity for more than 6 hours per day, compared to 3 in 2012. This drives the ATFCM delay from around 1 minute per flight, as in today operations, up to 5.6 minutes. This increase by a factor 5 raises the ATFCM contribution to delay from a minor role, just above 10% in 2012, to being a major contributor of the total delay in 2035. Associated with the high level of congestion in Europe, delays showed considerable inertia keeping high values even in the latest hours of the day, when the congestion levels have already decreased.

4.1 A congested network in 2035: the context

To study the impact of network congestion on delays in the year 2035, the retained 2035 forecast scenario is the most-likely, Scenario C. This scenario depicted a regulated traffic growth until the target year with moderate economic growth and regulation reconciling the environmental, social and economic demands to address the growing global sustainability concerns.

According to the forecast, after 1.9 million flights can not be accommodated due to lack of capacity, there will be 14.4 million flights in Europe in 2035, representing 1.5 times the 2012 volume. 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 the FIPS tool, we have been able to reproduce the same busy period for the 2035 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 2012 summer period starting from 1 August 2012.

Figure 6 represents the increase in number of movements at each hour bringing the average daily traffic from 32,600 flights up to around 49,000 in 2035, for these summer months.
One of the indicators that represent the level of congestion of the network is the number of airports with a level of traffic over a certain ratio of their capacity. When analysing the number of airports that have a level of congestion above 80% for 3 consecutive hours or more (airports considered saturated), it is found that in August and September 2012 (i.e. baseline scenario) just 6 airports correspond to that criteria. In Scenario C, this climbed to more than 30 airports in 2035. Even with a stricter condition of operating at 80% or more of capacity for 6 consecutive hours or more, there were more than 20 airports congested in 2035 compared to 3 in 2012 (see Figure 8).

Figure 7 highlights the increased number of airports suffering congestion. By 2035 half of the studied airports will experience a daily capacity usage equal or greater than 50%.

Figure 7: Airport daily (H24) level of congestion distribution

![Airport Daily (H24) Level of congestion distribution]

- 2012
- 2035

Figure 8: Increased airport congestion in 2035

![Increased airport congestion in 2035]

- 2012
- 2035

Congestion (%)
Another figure that characterises congestion over the network is the evolution of the average level of congestion. Figure 9 represents the daily profile of the congestion level for the top 15 Airports by slice of 4 hours. In 2035 the network starts being heavily used since early in the morning with the first rotation. We observe, as well, a significant increase in the first and last 4 hour slices of the day, which may bring some environmental issues related to the extra noise generated.

![Top 15 airports daily congestion profile](image)

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 2013 study that showed a lower increase in planned capacity (i.e. 17% increase in total capacity up to 2035), compared to the 38% increase between 2008 and 2030 reported by the airports for Challenges of Growth 2008.

This cut-back in capacity growth plans associated with the 50% increase in traffic demand explains the high level of congestion present across the whole European air transport network in 2035.
4.2 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. For the first time, compared to the previous Challenges of Growth studies, we have been able to make a step toward evaluating the impact of airport congestion on network performance in terms of delay.

As explained in section 3.4, delays have been classified as primary (i.e. ATFCM and non-ATFCM delays) and reactionary (i.e. knock-on delays incurred by previous flights). For this study we have adapted our tool (i.e. AASTAC), originally focused on ATFCM delays assessment, to capture the reactionary and non-ATFCM delays. We also assumed that en-route capacity will not be the constraint, so all of the ATFCM delays mentioned here are airport ATFCM. The capacity en-route improvement identified by SESAR would be sufficient to manage the expected traffic increase by the 2035 time horizon. Delivering this en-route improvement may be challenging and consequently the results presented here are likely to be low estimate.

In 2012, the airport ATFCM primary delays were only 0.9 minutes out of an average of 5.7 minutes of primary delay per flight and out of 10 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.

Within a network where 20 airports operate at 80% or more of capacity during 6 consecutive hours or more, it is likely to expect that any deviation (e.g. late bags, missing passengers) from the plan will generate delays that will accumulate rapidly along the day.

Figure 10 shows the growing delay challenge at airports for the summer months, where for 2012 only a minority of them suffer delays greater than 5 minutes per flight (simulation of August and September 2012). This is reflected in the 1.12 minutes/flight of ATFCM delay measured, that is slightly higher than the whole year value of 0.9 mentioned above. In 2035, the picture is drastically different with high level of delay present across the network and a significant number of airports that present total delays greater than 20 minutes per flight.

In the simulation for 2035, the airport ATFCM related delay jumps from around 1 minute per flight to 5.6 minutes, bringing the total delay from 8.75 minutes in 2012 up to near 15 minutes (14.2 minutes per flight to be precise). This raises the ATFCM contribution to delay from a minor role in 2012, to being a major contributor to delays.

Figure 11 compares the daily evolution of the total delay across the airport network for 2012 and 2035. Today, the average level of congestion is relatively low for all the European regions. Accordingly, longer departure delays are present during the busiest hours where there is less capacity to re-accommodate flights that have missed their slots. At the end of the day, the network recovers well from the deviations occurred during the day. In 2035, the spread of high level of congestion in Europe turns into serious delay early in the morning.
In this situation there is no room for recovery during the day. The delays show considerable inertia, keeping high values even in the latest hours of the day, when the congestion levels have already decreased (see Figure 9).

Figure 11: Daily evolution of total delay
Figure 12 shows the quick increase in delays for 2035 (upper line) once the first rotation starts around 06:00 UTC, and propagating rapidly across the network through the evolution of the reactionary delay.

In terms of delay per delayed flight, the increase is not as high but still significant, the delay jumps from around 19 minutes per delayed flight up to 23.6 minutes. The negative effect is diluted because a higher proportion of flights are delayed. This is illustrated in the Figure 13 below.

The 50% increase in traffic 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 a high level of predicted delay it is expected that, at the tactical level, on the day of operations, airlines will react to delays by requesting flight cancellations after applying flight priorities rules according to their policy (e.g. favouring on-time performance or to ensure passengers connectivity). This was not modelled for this study.

The complete set of delay figures is described in Annex A.
4.3 Congested network and external disturbances

Congestion in the network affects day-to-day delays, but it also influences our ability to respond to an unusual event. This section explores the combined effect of congestion and the occurrence of external events decreasing the capacity of some airports for a given period of time. In addition to the nominal 2035 situation, we modelled two additional scenarios:

- **A meteorological phenomenon**, using two sub-scenarios, a storm has been simulated. This phenomenon causes airport capacity shortfall and affects progressively more airports in Central Europe and later in North-West Europe.
  
  **In sub-scenario MET.1,** a storm is affecting one airport in Central Europe (i.e. Vienna) producing a 30% reduction in capacity starting at 09:00 a.m. with duration of 3 hours. By the next hour the storm affects a wider area producing a 30% capacity shortfall in two neighbour airports with duration of 3 hours. One hour later (i.e. 11:00 a.m.) the storm evolves impacting 4 additional airports.

  **In sub-scenario MET.2,** a storm is affecting one airport in Central Europe producing a 30% reduction in capacity starting at 09:00 a.m. with duration of 3 hours. By the next hour the storm evolves rapidly affecting a wider area producing a 30% capacity shortfall in two neighbour airports with duration of 3 hours. One hour later (i.e. 11:00 a.m.) the storm evolves impacting 4 additional airports in the same region with a capacity reduction of 30% and 5 additional airports in the North-Western part of Europe with a capacity shortfall of 15% with duration of 3 hours.

- **A severe security threat** at Heathrow airport. The threat level at the airport is raised to “severe – an attack is highly likely” causing the closure of the airport starting at 09:00 a.m. with duration of 2 hours. The airport recovers to full capacity over the following 2 hours, i.e. by 11:00 p.m.

4.3.1 Bad weather conditions

When studying the combined effects of airport congestion and the occurrence of a storm, it is observed that the impact on global performance of the external event is different according to the levels of congestion.

Performance degradation caused by the storm affecting airports with severe level of congestion is stronger. Airport congestion acts as a catalyst for the storm impact, resulting in the effects being more widely spread than the case when congestion is less severe. This is shown by comparing scenarios MET.1 and MET.2. The storm in MET.1 affects airports with medium level of congestion in Central Europe, slightly degrading the network performance. The 30% decrease in capacity being translated in an increase of 2.6% in terms of ATFCM delay with 5.75 minutes per flight instead of 5.6 minutes. On the other hand, when the storm evolved in MET.2 starting to affect a region where the level of congestion is higher (i.e. North-West Europe), the effect on network performance is more severe. In this scenario, the ATFCM delay reaches 6.43 minutes per flight.

A high level of congestion obstructs the network mechanisms that help recovery from the storm impact. The performance degradation is observable at network level soon after the start of the external event and this is unchanged by the severity of the event. In the scenario MET.1, there is a recovery after the end of the storm. This is noticeable in the evolution of the ATFCM and reactionary delay in Figure 14. As the region impacted by the storm suffers higher level of congestion, the higher network performance degradation are more spread over the day. This is shown by the evolution of ATFCM delay in scenario MET.2 where recovery arrives only at the end of the day when traffic in the network is much lower.

An emergent observed effect is that the external event is at the origin of waves of performance degradation (see Figure 14) at global level causing instability to the network. Even after the disappearance of the ATFCM degradation in scenario MET.1, it takes two more hours to retrieve the nominal level of reactionary delay.
Figure 14: Weather disturbances impact on delays in 2035

Weather disturbance impact on reactionary delay

Weather disturbance impact on ATFCM delay
4.3.2 Security threat

Previous alternative scenarios explore the network impact of bad weather conditions that are likely to happen in day-to-day operations; but what will happen when faced with a severe disruption? This is what we try to capture with this security scenario where we hypothetically close Heathrow airport during two hours in the morning.

In this scenario the average ATFCM delay jumps to 9.1 minutes per flight. Delays start to propagate rapidly across the network. With the existing level of congestion there is no room for the network to recover. This is shown by the profile of ATFCM delay in Figure 15 where delays jump rapidly after the start of the event and are still present at the end of the day. It is noticeable that the increase in reactionary delay is higher in this security scenario with one airport impacted than the MET.2 scenario where 12 airports suffer capacity reduction due to the storm.

Figure 15: Security threat impact on delays in 2035
5. CONCLUSION

5.1 Findings

For this task of Challenges of Growth we have evaluated the impact of air traffic congestion on the network performances at the 2035 time horizon. According to the forecast (i.e. 2035 forecast scenario C), there will be 14.4 million flights in Europe in 2035, representing 1.5 times the 2012 volume. 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 the summer period 2012, there were 6 airports that were “congested” in a sense of operating at 80% or more of their capacity for more than 3 hours per day. In the scenario C, this climbed to 30 airports in 2035. Even with a stricter condition of operating at 80% or more of capacity for more than 6 consecutive hours, there were more than 20 airports congested in 2035 compared to 3 in 2012. The observation of the capacity usage in 2035 showed that the network starts being heavily used since early in the morning with the first rotation with a significant increase in the first and last 4 hour period of the day, which may bring some environmental issues related to the extra noise generated.

In such a state, it is likely to except that any deviation (e.g. late bags, missing passengers) from the plan will generate delays. In the 2035 simulation, a high level of delay was observed across the entire network. The ATFCM delay jumped from around 1 minute per flight, as in today operations, up to 5.6 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.

A high level of congestion obstructs the network mechanisms that support recovery from external events. The analysis of the storm and security scenarios showed that the performance degradation is observable at network level soon after the start of the external event causing instability to the network. The ability of the network to recover from disrupted state is clearly weakened.

In reality we would except that airlines will react to delays by requesting flight cancellations after applying flight priorities rules according to their policy (e.g. favouring on-time performance or to ensure passengers connectivity) causing additional unaccommodated demand illustrating the constant trade-off that drives the air transport network between demand, capacity and delays.

5.2 Future lines of work

The present network congestion study has allowed us to construct the first model being 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 2035 where the network is totally congested. This limited scope has not allowed an exhaustive analysis of the evolution of the network congestion up to 2035. The study of intermediate levels of congestion and its incorporation in the decision making process is of important to better trigger future investment in more capacity when and where necessary.

- An obvious future line of research is the enlargement of the scope of case studied like the modelling of different periods of the year and a variety of external events (i.e. snow in winter).

- The mitigation task of the Challenges of Growth evaluates different ways to recover a part of the expected unaccommodated demand (i.e. 1.9 million in 2035 forecast, scenario C). 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 the current attempt to capture reactionary delays, an average turn-around process has been simulated in all airports. A way forward to improve the model can be to go down in details by modelling specific turn-around process for the major airports in Europe. A need for accurate data on turn-around and taxi times is of utmost importance.
## A. DELAY FIGURES AND TABLES

**Figure 16: Baseline delays for August/September 2012.**

<table>
<thead>
<tr>
<th>2012 (August – September)</th>
<th>ATFCM</th>
<th>Non-ATFCM</th>
<th>Reactionary</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay per Flight (min)</td>
<td>1.12</td>
<td>3.72</td>
<td>3.91</td>
<td>8.75</td>
</tr>
<tr>
<td>Delay per Delayed Flight (min)</td>
<td>2.44</td>
<td>8.12</td>
<td>8.54</td>
<td>19.1</td>
</tr>
</tbody>
</table>

**Figure 17: 2035 simulated delays.**

<table>
<thead>
<tr>
<th>2035 simulated delays</th>
<th>ATFCM</th>
<th>Non-ATFCM</th>
<th>Reactionary</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay per Flight (min)</td>
<td>5.6</td>
<td>3.81</td>
<td>4.79</td>
<td>14.2</td>
</tr>
<tr>
<td>Delay per Delayed Flight (min)</td>
<td>9.33</td>
<td>6.35</td>
<td>7.98</td>
<td>23.66</td>
</tr>
</tbody>
</table>

**Figure 18: MET.1 2035 weather scenario delays.**

<table>
<thead>
<tr>
<th>2035 MET.1 weather scenario</th>
<th>ATFCM</th>
<th>Non-ATFCM</th>
<th>Reactionary</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay per Flight (min)</td>
<td>5.75</td>
<td>3.75</td>
<td>4.92</td>
<td>14.42</td>
</tr>
<tr>
<td>Delay per Delayed Flight (min)</td>
<td>9.52</td>
<td>6.23</td>
<td>8.14</td>
<td>23.89</td>
</tr>
</tbody>
</table>

**Figure 19: MET.2 2035 weather scenario delays.**

<table>
<thead>
<tr>
<th>2035 MET.2 weather scenario</th>
<th>ATFCM</th>
<th>Non-ATFCM</th>
<th>Reactionary</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay per Flight (min)</td>
<td>6.43</td>
<td>3.76</td>
<td>5.51</td>
<td>15.67</td>
</tr>
<tr>
<td>Delay per Delayed Flight (min)</td>
<td>10.58</td>
<td>6.16</td>
<td>9.06</td>
<td>25.8</td>
</tr>
</tbody>
</table>

**Figure 20: 2035 Security scenario delays.**

<table>
<thead>
<tr>
<th>2035 security scenario</th>
<th>ATFCM</th>
<th>Non-ATFCM</th>
<th>Reactionary</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay per Flight (min)</td>
<td>9.14</td>
<td>3.75</td>
<td>8.53</td>
<td>21.42</td>
</tr>
<tr>
<td>Delay per Delayed Flight (min)</td>
<td>15.23</td>
<td>6.24</td>
<td>14.22</td>
<td>35.69</td>
</tr>
</tbody>
</table>
Figure 21: Reactionary delay distribution

Reactionary Delay Hourly Distribution

Time (UTC Hours)

Delay (min)

2012 — 2035 — 2035 (Security) — 2035 (Weather Sc1) — 2035 (Weather Sc2)

Figure 22: ATFCM (Airport) delay distribution

ATFCM (Airport) Delay Hourly Distribution

Time (UTC Hours)

Delay (min)

2012 — 2035 — 2035 (Security) — 2035 (Weather Sc1) — 2035 (Weather Sc2)
Figure 23 above illustrates the daily evolution of the non-ATFCM delays as modelled in ASTAAE tool. To capture such delays we build a statistical model based on observed CODA data. In our observation, 25% of the total flights suffered such delays. For the study we decided to keep the same observed assumption for all the 2035 simulations. As the non-ATFCM delays have been applied to a fixed part of the traffic, the evolution of the delay reflects the evolution of the traffic demand itself.
B. THE ASTAAC MODEL

ASTAAC is a prototype tool dedicated to research activities for pre-evaluating advanced ATFCM concepts. ASTAAC is a stand-alone desktop application which combines powerful airspace design capabilities and capacity planning analysis functionalities.

ASTAAC 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.

ASTAAC can be used to emulate Area Control Centres (ACC) or airports for strategic planning and network level assessment. ASTAAC 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.

Modelling

ASTAAC is scenario based: users can make changes to the original dataset or reference scenario to model an unlimited number of different operational planning options. Future projects can be selected and combined as required using the layer system.

- Traffic demand can be based on past data, or increased according to the selected traffic forecast.
- 4D trajectories can reflect actual flight trajectories, or be regenerated on customised route networks, according to shortest, cheapest or optimum routings.
- 3D airspaces, sector capacities and configurations, as well as the route network, restrictions, and flight level constraints can be edited.
- Impact of airspace changes on sector capacities can be estimated using built-in workload calculations.
- Traffic volumes monitored for regulation can be refined by adjusting captured flows.
- The number of available controllers can be adjusted to model scenarios such as degraded operations at reduced capacity.
- ASTAAC can optimise opening schemes according to resources available

- ASTAAC can identify bottlenecks and the related causes. Solutions can then be proposed and evaluated.
- ASTAAC can model free route operations in a given area and analyse the possible benefit.

Simulation Algorithms

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

- 4D traffic distribution
  
  ASTAAC 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.

- Configuration optimiser

  ASTAAC 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

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

- Delay simulation

  ASTAAC can calculate ATFCM delays over an entire day for any scenario, taking into account the network effect.
■ Performance indicators

Global indicators including route length extension for flight efficiency, fuel consumption, capacity baselines, ATFCM delay, route charges, CO₂ and NOx emissions can be evaluated individually or combined to provide composite indicators. Large quantities of data spanning multiple years can be evaluated, Strategic view allowing users to detect trends or carry out detailed analysis.

■ Reports

All analysis data can be exported in the form of customised reports which can also be fed into external tools or templates for further analysis. ASTAAC is provided with ready-to-use study templates and can automate frequently used tasks and create dynamically new data computing activities.
## Figure 24: CODA delay breakdown

<table>
<thead>
<tr>
<th>CODA delay breakdown</th>
<th>(August-September 2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Period</strong></td>
<td><strong>Class</strong></td>
</tr>
<tr>
<td>August</td>
<td>Primary</td>
</tr>
<tr>
<td></td>
<td>ATFCM Airport</td>
</tr>
<tr>
<td></td>
<td>ATFCM En-Rte</td>
</tr>
<tr>
<td></td>
<td>ATFCM Weather</td>
</tr>
<tr>
<td></td>
<td>Airline</td>
</tr>
<tr>
<td></td>
<td>Government</td>
</tr>
<tr>
<td></td>
<td>Misc.</td>
</tr>
<tr>
<td></td>
<td>Other Airport</td>
</tr>
<tr>
<td></td>
<td>Other Weather</td>
</tr>
<tr>
<td></td>
<td>Reactionary</td>
</tr>
<tr>
<td>September</td>
<td>Primary</td>
</tr>
<tr>
<td></td>
<td>ATFCM Airport</td>
</tr>
<tr>
<td></td>
<td>ATFCM En-Rte</td>
</tr>
<tr>
<td></td>
<td>ATFCM Weather</td>
</tr>
<tr>
<td></td>
<td>Airline</td>
</tr>
<tr>
<td></td>
<td>Government</td>
</tr>
<tr>
<td></td>
<td>Misc.</td>
</tr>
<tr>
<td></td>
<td>Other Airport</td>
</tr>
<tr>
<td></td>
<td>Other Weather</td>
</tr>
<tr>
<td></td>
<td>Reactionary</td>
</tr>
</tbody>
</table>
**D. GLOSSARY**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>Area Control Centre</td>
</tr>
<tr>
<td>ATA</td>
<td>Actual Time of Arrival</td>
</tr>
<tr>
<td>ATFCM</td>
<td>Air Traffic Flow and Capacity Management</td>
</tr>
<tr>
<td>ATM</td>
<td>Air Traffic Management</td>
</tr>
<tr>
<td>ASTAAC</td>
<td>Arithmetic Simulation Tool for ATFCM Advanced Concept</td>
</tr>
<tr>
<td>CASA</td>
<td>Computed Assisted Slot Allocation</td>
</tr>
<tr>
<td>CG08, CG13</td>
<td>Challenges of Growth 2008, 2013</td>
</tr>
<tr>
<td>ECAC</td>
<td>European Civil Aviation Conference</td>
</tr>
<tr>
<td>EOBT</td>
<td>Estimated Off-Block Time</td>
</tr>
<tr>
<td>ETOT</td>
<td>Estimated Take-Off Time</td>
</tr>
<tr>
<td>ETA</td>
<td>Estimated Time of Arrival</td>
</tr>
<tr>
<td>FIPS</td>
<td>Flight Increase Process</td>
</tr>
<tr>
<td>ScA</td>
<td>Scenario A (similarly C, C’, D)</td>
</tr>
<tr>
<td>SESAR</td>
<td>Single European Sky ATM Research</td>
</tr>
<tr>
<td>SID</td>
<td>Standard Instrument Departure (Route)</td>
</tr>
<tr>
<td>STATFOR</td>
<td>Statistics and Forecast Service of EUROCONTROL</td>
</tr>
<tr>
<td>STAR</td>
<td>Standard Terminal Arrival Route</td>
</tr>
</tbody>
</table>

**E. REFERENCES**

Published reports from the current and previous Challenges of Growth studies are available at [www.eurocontrol.int/articles/challenges-growth](http://www.eurocontrol.int/articles/challenges-growth)

1. **All-causes delay 2012**, CODA Digest, EUROCONTROL Feb 2013

2. **Challenges of Growth 2013 Task 4: European Air Traffic in 2035**, EUROCONTROL June 2013


4. **Challenges of Growth 2013 Task 5: Mitigation of the Challenges**, EUROCONTROL June 2013

**Unaccommodated demand** - the forecast flights that exceed an airport’s reported capacity.

**UTC** - Universal Time Coordinated