Medium and Long Term Sustainable Growth in Air Transport

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**TITLE:**
MEDIUM AND LONG TERM SUSTAINABLE GROWTH IN AIR TRANSPORT

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**Abstract:**
This report describes an EEC study which employs long-term traffic and capacity growth predictions as well as an Air Traffic Flow Management simulation of the entire European network in order to determine potential growth constraints and delay evolution.
**Executive Summary**

This study describes a methodology which is capable of predicting the impact of evolutions in the nature of the level of air traffic demand on certain key ATM parameters.

The report considers airport capacity constraints and introduces the notion of “unaccommodated demand” i.e. flights which will be unable to gain access to the system as a result of inability of airports to increase their capacity. A number of alternative scheduling practices impacting both the temporal and spatial demand characteristics are explored and the delay sensitivity for each of these is presented, as is the variation in the level of unaccommodated demand where appropriate.

The report highlights the potential evolution of airports to become constraining factors within the future network both in terms of their potential for delay generation but also the fact that existing scheduling practices could lead to access difficulties for airlines. The scenarios explored in this report are by no means exhaustive and necessarily incorporate a number of simplifications.

The report illustrates a number of differing views concerning the necessity of imposing any kind of restrictions on the level of air traffic growth – such restrictions being ways of adapting the system to the presence of constraints. The alternative view is that the constraints should be addressed directly so as to ensure the unfettered (or at the very least, ‘sustainable’) growth of aviation.

The report is divided into a number of different sections:

1. **Medium Term delay predictions (2006)**

This section is based upon the results of a number of ATFM simulations based on the CFMU slot allocation process. The most recent traffic growth predictions were employed in this analysis. This analysis shows that the level of en-route delay could reach unacceptable levels and is likely to be due to a small number of major bottlenecks. The analysis demonstrates that the slot allocation algorithm employed can lead to large delay levels when there is a poor match between the traffic volume and level of capacity provision.

2. **Longer term performance predictions and comparisons (2015)**

This aim of this analysis is to identify the sensitivity (in terms of delay and airport access) to a number of different scenarios. These scenarios included the following:

- **Do nothing scenario**

  The “do-nothing” scenario represents a baseline for performance comparison. It is derived from the traffic growth predictions for the 2015 time horizon and attempts to respect as closely as possible the temporal distribution of the current demand profile. Therefore it is assumed that there is no significant change to the operational paradigm either in the increased use of less capacity constrained airports, the use of larger aircraft or attempts to schedule flights into the “less attractive” periods of the day.

  *Based on the assumed evolution of the ‘supply-side’ parameters, the study predicts the potential for significant increases in en-route delay per flight with equivalent values due to regulations put in place to protect airports. In addition, a significant amount, almost one quarter, of the unconstrained growth will be unable to gain airport slots at the desired time.*
Schedule smoothing

The impact on airport delay of the presence of localised peaks in demand is analysed in the report. Flights which have slots in congested time periods and which would therefore be subject to delay were moved in time if possible so as to ‘spread the peaks’ and to identify the consequential impact on the level of delay.

The results of the simulation demonstrate a (logical) sensitivity of the airport delay to this strategy. Moving flights in peak periods by only one hour if possible (which impacts less than 0.4% of the total number of flights) generates a reduction in airport delay of around 10%. With a movement of up to three hours, there is a reduction in the level of airport delay of more than 27% when compared to the do-nothing scenario.

A second aim of rescheduling flights can be a means of reducing the unaccommodated demand. For those flights of the “do-nothing” scenario which cannot be accommodated, the less capacity constrained time periods can be used to gain access to the system.

By scheduling flights at up to one hour away from localised peaks in demand, the number of unaccommodated flights can be reduced by around one quarter. This without recourse to the use of alternative airports.

Use of secondary airports

In this scenario, those unaccommodated flights of the “do-nothing” scenario are examined to identify the potential for being scheduled at nearby alternative airports.

This approach represents the most potent way of reducing the level of unaccommodated demand. For the given scenario considered the level of unaccommodated demand was reduced by around three quarters compared to the do-nothing scenario.

Frequency capping

This scenario considers the impact of applying restrictions on the daily frequency of flights between aerodrome pairs. Of all the different scenarios considered, this technique is seen to have the most impact upon the predicted level of delay. This scenario can be seen as an initial simulation of the network effect associated with the migration toward larger aircraft on high density city pairs.

The most stringent scenario (maximum of 10 daily flights in each direction on individual airport pairs) led to a reduction in en-route and airport delay of 34% and 65% respectively compared to the do-nothing scenario.

Substitution and inter-modal transport links

In this scenario, a potential future European High Speed Rail network was considered and based on an estimate of the rail travel time, the potential for some degree of substitution of air services was identified.

Under the replacement hypotheses considered, en-route and airport delay were reduced by 24% and 68% respectively compared to the do-nothing scenario.
3. Environmental analysis

The aim of this section is to provide an insight into the results of a modelling study performed to assess the impact on local noise and global emissions associated with the long term growth in aircraft movements. A study of the evolution of the noise contours at Barcelona airport is presented through to the 2015 time horizon.

The most effective measures to stimulate air traffic growth will probably comprise a concerted effort on all fronts. It may be that in certain geographical areas the construction of new airports or a major extension to existing airport infrastructure may be both possible and desirable. In some markets the potential for collaboration with rail companies may yield significant benefits and on certain city pairs, an evolution toward larger aircraft operating at reduced frequency may be the most reliable way of accommodating the growth in passenger numbers.

Air Navigation Service Providers will also be required to adhere to future capacity plans and to actively participate in a collaborative process of capacity enhancement, with a network-wide view, and embracing new legislation if necessary providing that capacity and safety benefits can be identified.
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## Abbreviations

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<th>Description</th>
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<tr>
<td>ACC</td>
<td>Area Control Centre</td>
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<tr>
<td>ACG</td>
<td>ATM/CNS Consultancy Group</td>
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<td>AMOC</td>
<td>ATFM Modelling Capability</td>
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<td>ATAG</td>
<td>Air Transport Action Group</td>
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<td>ATC</td>
<td>Air Traffic Control</td>
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<td>ATFM</td>
<td>Air Traffic Flow Management</td>
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<td>ATM</td>
<td>Air Traffic Management</td>
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<tr>
<td>ANSP</td>
<td>Air Navigation Service Provider</td>
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<tr>
<td>CASA</td>
<td>Computer Assisted Slot Allocation</td>
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<td>CFMU</td>
<td>Central Flow Management Unit</td>
</tr>
<tr>
<td>CRCO</td>
<td>Central Route Charges Office</td>
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<td>EATMP</td>
<td>European Air Traffic Management Programme</td>
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<td>EUROCONTROL Experimental Centre</td>
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<td>FAP</td>
<td>Future ATM Profile</td>
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<td>IATA</td>
<td>International Air Transport Association</td>
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<tr>
<td>PC</td>
<td>Provisional Council</td>
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<td>Performance Review Commission</td>
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1. Introduction

Over the last 50 years, there has been a considerable increase in air traffic movements throughout the world. Despite a number of periods where growth has reduced due primarily to economic reasons or regional conflicts, the consistent view is that air travel will continue to grow, with Europe perhaps witnessing a near-doubling in air traffic movements by 2015 or shortly after.

There are numerous benefits associated with a continued growth in air travel. Aviation contributes to national and regional economies, supports jobs and enhances standards of living through the creation of increased leisure possibilities.

If demand for air travel continues to grow then increased levels of capacity will be required throughout the Air Traffic Management (ATM) infrastructure, encompassing the entire ‘Gate-to-Gate’ phases of flight. However, changes to infrastructure, particularly airports, do not come without a price. For growth to be ‘sustainable’, it is necessary to strike the correct balance between the social and economic benefits of increased air travel and the negative effects of any development. These negative effects include increased noise and pollution around airports, potential loss of countryside as airports are expanded or created and finally an increased level of emissions contributing to climate change.

One approach to addressing the needs of the future system can be referred to as ‘predict and provide’. This entails predicting the future levels of air traffic demand and then providing the capacity to match. For example, the UK Government has recently issued a series of consultation papers describing the way that air travel demand is predicted to increase in the various regions and detailing a number of potential “solutions” if such demand is to be satisfied. Exactly where the correct balance between unfettered growth (enabled through continued and timely capacity provision) or a more “constrained” growth (enabled through economic regulation or necessitated through the impact of system capacity constraints) is to be found is the question generating the most diverse reaction. For example...

“Finally, competitive pressures within the airline industry may still lead airlines to continue using operations strategies that are vulnerable to delays. These pressures currently motivate airlines to schedule flights that fully use available air transport system capacity during those times of the day in which they perceive consumers most want to fly”
Report to the Ranking minority Member, Committee on Commerce, Science, and Transportation, U.S. Senate.

“Airport charges must be adjusted to deter bunching of flights at certain times of the day.”
Extract from White Paper, European Transport Policy for 2010: Time to Decide.

“An airport charges system is proposed, designed to deter bunching of flights at certain times of the day. This system has been tested and abandoned by most major European airports.”
Address by the AEA Secretary General, to the European Parliament RETT.

“At the current rate of growth, Britain would need capacity equivalent to five new Heathrow airports by 2030, much of it within reach of London. That is clearly untenable. So before Governments embark on new runway construction in crowded regions, such as the southeast of England, more thought should be devoted to making better use of existing capacity and to controlling demand.”
“Assisted Flight” Financial Times – 12 August 2002

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1 both airside and as a result of the increased volume of road traffic in the proximity
2 “The Future Development of Air Transport in the United Kingdom”
The aim of this report is to explore the extent to which existing levels of capacity are being exploited in an optimal manner. The report does not describe changes that would need to be made to the economic regulatory framework for the system to be more efficient\(^3\). Instead, through the use of Air Traffic Flow Management (ATFM) modelling tools and supporting data, the report aims to provide an independent, robust analysis of the impact on ATFM delay and system access arising from potential changes to the scheduling practices and operational strategies of airlines in the future.

The aim is therefore twofold:

- To provide delay predictions at the 2006 time horizon, taking into account the most recent predictions of traffic growth provided by the EUROCONTROL STATFOR unit and;

- Secondly, to extend the time horizon of the study to a longer term (2015) and highlight the sensitivity of the European ATM network to variations in the nature of the demand and capacity provision.

*The report does not promote growth constraints as a means of alleviating capacity shortfalls. Instead, the potential of maintaining profitable operations has been explored under the hypothesis that airlines will adapt their schedules in the face of increasing delays or access difficulties.*

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\(^3\) For example, the low charges at London’s Heathrow and Gatwick airports due to the mechanism employed in the setting of the overall charge levels (single till) has been blamed in some quarters for stimulating congestion and stifling growth at regional airports.
2. The Analytical Environment

The EUROCONTROL Experimental Centre has developed a series of analytical tools and simulation platforms useful for providing performance predictions for the future ATM system. The aim of such tools is to provide a consolidated performance prediction in terms of delay at the European level given a number of potential scenarios concerning the evolution of both capacity and demand.

At the heart of the analytic environment is an ATFM simulator that simulates the slot allocation process of the CFMU. The model therefore takes as input both ‘supply-side’ (capacity) and demand-side (individual flight plans) data and allocates departure slots in the same way as the CFMU. These tools represent the only such European-wide analytical environment capable of faithfully replicating the operations of the CFMU and resultant network interaction.

Future traffic samples are constructed directly from the baseline traffic sample and respecting the growth figures provided by the EUROCONTROL STATFOR unit. The EEC have developed a tool which (through simple parameter setting) allows future traffic samples to be constructed which respect completely the temporal distribution of the baseline sample (i.e. the same peaks are observed in the demand distribution at each airport) or ones which employ more relaxed scheduling practices and growth is seen in those “quieter” periods of the baseline sample.

The analytic environment is indicated in the following diagram:

This report presents predictions concerning the behaviour of two key parameters at the long-term time horizon. These are “unaccommodated demand” (described in detail in Section 4.2) and secondly ATFM delay. The unaccommodated demand is derived in the above environment by careful analysis of the future traffic samples and the assumed hourly airport capacities. The delay is calculated as a result of the ATFM simulation of the future traffic sample and the assumed ‘supply-side’ (capacity) values.

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4 Which in our case is two 14 day periods from July 2000 and July 2001, comprising the complete set of daily flight plans as known to the CFMU
3. Scenarios relating to 2006

Future delay predictions are sensitive to the relationship between the level of capacity offered and the anticipated level of traffic demand. At certain levels of capacity / demand ratio, small increments in the level of demand can generate large increases in the level of delay should the capacity not be increased accordingly. This section provides the results of a simulation of the potential delay situation in 2006. The simulation is based on the actual traffic of a two week period in July 2001 and on the hypothesis that traffic will follow the shortest routes consistent with the route structure and sector configuration of ARNV4. The traffic is assumed to grow beyond the July 2001 level in line with the most recent predictions (February 2002) from STATFOR. According to these predictions, the net annual growth rate over the medium term time horizon is close to 3%.

The adjacent figure indicates the new STATFOR growth predicted for Summer 2002 as compared to actual traffic of Summer 2001, indicating on average a reduction in traffic volume of 0.4% with some local variations considerably more pronounced.

In order to perform the delay prediction, the individual Air Traffic Control Centre (ACC) capacities are assumed to evolve in line with the plans included in the Local Convergence and Implementation Plan (LCIP) documents.

Using the most recent traffic forecasts, the delay in 2006 is predicted to be 2.8 minutes per flight, concentrated in a small number of ACCs as indicated. High levels of delay are predicted in those ACCs whose capacity augmentation plans are poorly adapted to the predicted traffic growth – which is the cause for the relatively high average delay even though the majority of ACCs would appear to have adequate traffic-handling potential in 2006.
4. Long Term Growth

As the time horizon for performance analysis becomes more protracted, the quality of the predictions concerning traffic growth and capacity provision necessarily decrease. More than ever such performance predictions should be considered in the framework of a ‘what-if’ rather than as a prediction of the future state of the ATM network. The principal aim is not to attempt to provide detailed performance predictions, but rather to provide indications of the potential sensitivity of the ATM network to changes in the nature of the demand profile through the use of reliable modelling techniques.

4.1 Development of the “baseline” scenario

The following diagram indicates the essential data and processes used in an Air Traffic Flow Management (ATFM) related performance prediction. As stated above, as the time horizon increases, the quality of the predicted data (demand and capacity) necessarily decreases and so the performance prediction in itself becomes somewhat less valuable. However, the real added value from this process is to be able to illustrate the sensitivity of the European network to changes in the demand and capacity profile (highlighted by the ‘callout’) and thereby be able to provide a realistic comparative analysis.

For this study a ‘baseline’ system derived from certain assumptions concerning the demand and capacity growth has been developed. This baseline is then used as a comparative benchmark for assessing the effect of alternative demand scenarios.

4.1.1 Long-term Demand for ATC Services

In the absence of longer term forecasts concerning passenger demand, and the translation of this demand into aircraft movements, it is probably prudent to consider that the traffic growth will be consistent and that downturns will be compensated for over time. This is coherent with historical observations of the air transport industry. Potential changes in the structure of the market (e.g. the evolution of low cost carriers or a significant change in the operational paradigm) are not captured directly in the demand growth assumptions. Future demand profiles have been constructed based on an annual growth rate of 4% (80% over 15 years).
4.1.2 En-route Capacity Evolution

For the evolution of en-route ATC capacity, no longer-term commitments are available – the normal commitment process extending only over a 5-year time horizon. It was therefore considered most prudent to use the existing commitments and to consider the ACC complexity as a potential indicator of the scope for future increases. In this way it is possible to capture the relative difficulty of increasing capacity through traditional means – sometimes referred to as ‘diminishing returns’.

Work performed by the EEC in collaboration with National Air Traffic Services Ltd of the UK (NATS) has developed complexity measures as a means of supporting the benchmark comparison of different ANSPs. Based on an understanding of the traffic flows, the controller tasks and available technology support, the study concluded with a ranking of each ACC in terms of its complexity, essentially classifying each centre into one of ‘low’, ‘medium’ and ‘high’ complexity. A more detailed description of this work is given in Reference 2.

Based on this ranking, a number of potential capacity growth functions have been determined for each ACC beyond the 5 year time horizon – these functions depending on the complexity of the ACC concerned and calculated as the result of a regression analysis of the predicted evolution in capacity within the time horizon covered by the LCIP. For each complexity category, the following characteristics were applied:

<table>
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<td>Low</td>
<td>Linear growth</td>
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<tr>
<td>Medium</td>
<td>Logarithmic function. More constrained than the linear case</td>
</tr>
<tr>
<td>High Complexity</td>
<td>Power function. Further constrained in the long-term.</td>
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By analysing the expected capacity evolution over the next 5 years and then extrapolating this evolution according to the complexity classification, it is believed that the difficulties of increasing capacity in the more complex ACCs through traditional means is sufficiently well captured so as to ensure the reliability of the modelling results.

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5 this function has already been used for each ACC in Reference 1 and led to a prediction of negligible en-route delay for 2015 based on the hypothesis of 6% annual capacity increase in each ACC.
4.2 Unaccommodated demand

Unaccommodated demand is defined for this study as “those flights which are unable to obtain slots in desired airports at the desired time of the day”. In order to assess the potential future levels of unaccommodated demand, a predicted traffic sample is created which reflects closely the temporal nature of that of today but augmented in line with the EUROCONTROL STATFOR predictions. The aim is to provide an indication of the level of difficulty in obtaining desired slots at the 2015 time horizon as well as to create a benchmark against which other access strategies can be compared.

In order to calculate the level of unaccommodated demand, the predicted (2015) hourly demand profile at each airport is compared with the hourly capacity limits. Many airports in Europe currently achieve hourly throughput figures which exceed the published capacity figures. Indeed, an analysis of the entire European network has shown that when such ‘capacity busts’ are observed, they can exceed the declared capacity levels by on average 8%. Therefore, an additional threshold is set above the predicted capacity and only those flights in hourly periods which exceed this upper threshold are considered to be unaccommodated. Those flights above the capacity limit but below the ‘growth constraint’ threshold are accommodated but are subject to ATFM regulations in the model. In this way, a simultaneous assessment is possible of the level of access difficulties and airport delay evolution.

The overall process for a generic airport is illustrated in the following diagram:

The adjacent diagram indicates at the overall network level the potential demand growth that could not be accommodated at 2006 and 2015.

This figure indicates that some 22.5% of the predicted traffic augmentation beyond 2001 cannot be accommodated by the system as a result of the modelled airport capacity constraints.

In order to better understand the
levels of congestion at airports, the capacity provision versus demand was calculated for each day in the baseline week (July 2000)\(^6\) and then estimated for the years 2006 and 2015 based on the anticipated level of demand at each airport. The average relationship between the capacity and demand was considered although it should be noted that certain airports are more constrained on certain days than on others. In the following table, the average value\(^7\) for the 30 busiest airports in 2000 is presented as well as the projection for the 2006 and 2015 time horizons. Cells in red indicate \((c/d)_{\text{global}} < 1.5\) and those in green are for \((c/d)_{\text{global}} \geq 1.6\).

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<td>1.26</td>
</tr>
<tr>
<td>LTBA</td>
<td>Istanbul Ataturk</td>
<td>2.04</td>
<td>1.42</td>
<td>1.51</td>
</tr>
<tr>
<td>ESSA</td>
<td>Stockholm - Arlanda</td>
<td>3.80</td>
<td>3.01</td>
<td>2.41</td>
</tr>
<tr>
<td>EGSS</td>
<td>Stansted</td>
<td>1.93</td>
<td>1.02</td>
<td>1.08</td>
</tr>
<tr>
<td>LSGG</td>
<td>Geneva</td>
<td>2.34</td>
<td>1.52</td>
<td>1.22</td>
</tr>
<tr>
<td>ENOM</td>
<td>Oslo-Gardermoen</td>
<td>3.94</td>
<td>3.36</td>
<td>2.87</td>
</tr>
<tr>
<td>EDDH</td>
<td>Hamburg - Fuhlsbuett</td>
<td>3.02</td>
<td>1.57</td>
<td>1.34</td>
</tr>
<tr>
<td>LPPT</td>
<td>Lisbon</td>
<td>2.19</td>
<td>1.68</td>
<td>3.88</td>
</tr>
<tr>
<td>EFKH</td>
<td>Helsinki</td>
<td>4.81</td>
<td>2.97</td>
<td>2.43</td>
</tr>
<tr>
<td>EDDS</td>
<td>Stuttgart</td>
<td>2.77</td>
<td>1.43</td>
<td>1.10</td>
</tr>
<tr>
<td>EGBB</td>
<td>Birmingham</td>
<td>2.81</td>
<td>1.52</td>
<td>1.19</td>
</tr>
</tbody>
</table>

If a similar analysis was to be performed using data only from the peak hourly periods then in many cases the capacity versus demand figures would be considerably less. The absolute difference between the peak and daily data would be a measure of the extent to which demand is localised at certain times of the day and the absolute value of the daily data (as indicated above) provides a measure of the available capacity throughout a 24 hour period.

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\(^6\) The capacity figures employed for each airport correspond to the most accurate information known to EUROCONTROL concerning the sustainable declared runway capacity – and do not reflect directly the number of slots made available to the co-ordinator

\(^7\) calculated over a two week period but employing the hourly demand and capacity figures – thereby capturing effects such as night curfews
The derivation of daily capacity versus demand data has in fact been performed for 110 airports included in the study. Considering the average of all airports and the average of the busiest 30 yields the adjacent figure. This indicates the predicted effect of concentration of traffic whereby capacity remains available in certain airports although the busiest hubs and congested gateways provide limited growth and therefore will present increasing access problems for non-incumbent airlines.

The potential for airports to become the principal constraining factor to growth requires further study. This should extend the simple analysis presented here to include more reliable estimates of the likely capacity evolution and the impact of the role of the slot co-ordinator.
5. Long Term demand distribution scenarios

The aim of this section is to explore the effect of constructing future demand schedules but using successively more relaxed parameters than those defined in the definition of the “do-nothing” scenario. In order to maintain consistency and provide data for comparison the results will in each case be presented in terms of delay (en-route and airport) and, where appropriate, in terms of the level of unaccommodated demand.

Given the uncertainty surrounding “what the system will look like” in 2015, a number of different demand distribution scenarios have been considered:

- **Do-nothing scenario**

  The “do-nothing” scenario represents a baseline for performance comparison. It is derived from the traffic growth predictions for the 2015 time horizon but attempts to respect as closely as possible the temporal distribution of the current demand profile. Therefore it is assumed that there is no significant change to the operational paradigm either in the increased use of less capacity constrained airports, the use of larger aircraft or attempts to schedule flights into the “less attractive” periods of the day.

- **Schedule smoothing (“spreading the peaks”)**

  For flights which have slots in congested periods and would therefore be subject to delay, the process can be used as a means of “spreading the peaks” and consequentially the level of delay. In addition, the scheduling of flights in less congested periods presents the potential for a reduction in the levels of unaccommodated demand. Both approaches will be analysed separately in the following sections.

- **Use of secondary airports**

  Those unaccommodated flights of the “do-nothing” scenario may potentially be able to gain access to the system through the use of less congested airports – as is already being seen today in the development strategies of the principal low-cost carriers.

- **Frequency capping**

  In this scenario, the number of daily operations on each airport pair was limited to a defined threshold. The report considers three such thresholds namely 10, 15 and 20 daily flights. This scenario is broadly in line with an evolution towards larger aircraft i.e. satisfying a certain growth in the level of passenger demand without a consequential increase in the number of aircraft movements.

- **Substitution and inter-modal transport links**

  In this scenario, a potential future European High Speed Rail network was employed and from an estimate of the rail travel time, the potential for substitution or complementary operations is considered.

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8 i.e. *inter-alia* to allow flights to be scheduled in less busy periods or to use alternative less congested airports.
5.1 “do-nothing” scenario

The adjacent figure indicates the level of en-route and airport delay assuming that the traffic growth is in line with the discussion in Section 4.1.1, and that each ACC is able to grow capacity in line with the discussion in Section 4.1.2. This analysis also assumes that the temporal and geographical demand distribution remain similar at the 2015 time horizon to that which is currently observed – the so-called “do-nothing” scenario.

For this study, airports have been modelled in two distinct ways :

- As capacity constraining bottlenecks which limit airline access and growth possibilities (unaccommodated demand)
- As potential delay sources i.e. they are seen as airspace volumes with defined capacity limits and for which the model will introduce any necessary regulations.

Delay at airports is currently due to reduced operations due to weather or other operational issues. However in some cases, regulations are put in place in terminal airspace solely as a result of airport capacity constraints – a practice which is likely to extend in the future and which reflects the approach taken in this study.

5.1.1 Delay sensitivity to traffic growth

Given the current uncertainty and pessimism concerning traffic growth in the medium term, it was considered interesting to perform a similar set of delay predictions but based on traffic increases lower than those given by the ‘STATFOR Medium Growth’ (SMG) prediction.

A number of different future traffic samples were constructed by applying successively lower growth on each flow according to the rule : SMG – X%. Three such scenarios were studied whereby the SMG growth predictions (do-nothing scenario) were reduced by 10%, 15% and finally 20%. In terms of total numbers of flights, these scenarios represented respectively a reduction of 3%, 4% and 6% when compared to the traffic volumes derived directly from the SMG scenario\(^9\). As can be expected, there is a reduction in both the en-route delay and the level of unaccommodated demand.

En-route delay reduces by 13%, 20% and 25% for the three scenarios i.e. indicating a delay / demand sensitivity of around 4.5 at constant capacity provision.

Since the en-route ACC capacities represent less of a constraint in these scenarios, there is the potential that the level of airport delay could actually increase due to the reduced level of ‘protection’ offered by ACCs.

\(^9\) The overall traffic volume is not reduced by X% in each scenario due to the constraining effect of some airports – as described in Section 4.2.
5.2 Schedule smoothing

The aim of this section is to consider the effect on delay of moving flights to adjacent non-congested periods (should this be possible) when the airport capacity is approached during peak hours. This technique is referred to as schedule smoothing and can best be considered as “spreading the peaks”. In this particular scenario, no attempt is made to reduce the level of unaccommodated demand. Instead, the effect on delay resulting from a temporal shift in the demand profile is explored.

An ECAC-wide traffic sample was constructed for the 2015 time horizon taking into account the growth rates described in Section 4.1.1 and also the known airport capacity constraints and their evolution. This constitutes what can be referred to as the “do-nothing” forecast. For each scenario (allowable time offset of 1, 2 or 3 hours), flights that were timed to arrive or depart during congested periods were examined in order to determine if an adjacent non-congested ‘slot’ was available. If no such slot was available then the flight was not moved. In this way, an alternative traffic sample was constructed, containing the same volume of flights as the “do-nothing” scenario but with a modified temporal distribution. The following diagram indicates the generic principal which was applied to both arriving and departing aircraft at each airport:

The effect of this action is to reduce the size of the ‘capacity bust’ (the absolute size of the peak) and consequently to broaden the demand into those adjacent periods where sufficient capacity is available. The potential for finding such a period naturally increases with the allowable size of the time offset.

For each scenario, the level of en-route and airport delay was determined through ATFM simulation. The results of the simulation demonstrate a (logical) sensitivity of the airport delay to this strategy. Moving flights in peak periods by only one hour if possible (which impacts less than 0.4% of the total number of flights) generates a reduction in airport delay of around 10%. With a movement of up to three hours, there is a reduction in the level of airport delay of more than 27% when compared to the “do-nothing” scenario.

The reduction in en-route delay, whilst present, is far less significant. By moving flights in peak periods by up to three hours there is a 6% reduction in en-route delay compared to 27% in airports. This would tend to indicate that the presence of local peaks in airport demand does not necessarily translate into demand peaks at the ACC level and in fact the ACC demand is slightly flatter.
5.3 Accommodating flights in less congested time periods

The previous section highlighted the sensitivity of the airports to changes in the temporal nature of the demand. In reality, as has already been seen in the U.S, attempts by the airlines to use less congested periods are likely to result in other airlines rapidly filling any vacated slots. The objective of this section is to therefore explore the scope for reducing the level of unaccommodated demand by allocating those "lost" flights of the do-nothing scenario to periods where the airport capacity/demand profile suggests that such action may be possible. The following diagram illustrates the principal:

Flights can be accommodated at two or three hours offset (not to scale) from centre of peak (growth potential indicated by dotted lines)

The effect of this approach is that the level of unaccommodated demand will be reduced as more flights gain access to the system but as a consequence one would expect that both the airport and en-route delay levels be augmented when compared to the “do-nothing” scenario presented in Section 5.1.

As previously described, when the current temporal nature of the demand is respected in augmenting the traffic i.e. the “do-nothing” scenario, there is the potential that around 22.5% of the desired demand growth will be unable to obtain airport slots at the required time.

However, when attempting to accommodate the future demand, use of slots within a time period of one hour of peak periods would permit a reduction in the unaccommodated demand to 17.3%. As a result of these additional flights being accommodated by the system, the level of delay increases.
5.4 Promotion of secondary airports

Capacity constraints at the major airports are likely to be one of the principal factors in defining the development strategies of the various carriers. Difficulties of access to certain airports means that alternative points of entry to the system will be sought – as has been apparent in the evolution of the various low cost carriers.

In order to understand the likely impact of a more fragmented market, those flights of the “do-nothing” scenario which could not be accommodated due to airport capacity constraints were examined to see if they could be accommodated at a nearby less congested airport. Should this not be possible then the flight remained as a “lost” or “unaccommodated” flight.

In this way, a demand forecast was generated which sought to accommodate the forecast growth for 2015 but which contained a greater number of flights on certain airport pair markets than was the case in the “do-nothing” forecast. Within the scope of this study, it was not possible to take into account specific ‘alternative’ airports that individual airlines may employ in order to seek access to the system. The analysis for this study had to confine itself to considering potential alternative airports as those being within the same STATFOR ‘Origin-destination Zone’ (ODZ)\(^{10}\). However, in order to ensure the integrity of this analysis, no “new” airport-pair markets were created. That is to say that an unaccommodated flight in the do-nothing scenario was only affected to an ‘alternative’ airport if an existing flight in the baseline (real observed) traffic sample was already present on that airport pair\(^{11}\). If this was not possible then the flight remained as unaccommodated.

The adjacent graphic shows the results for this ‘fragmentation’ scenario. The percentage of ‘lost’ flights (i.e. those for which suitable alternative airports could not be found) was found to reduce from 22.5% (constrained “do-nothing” scenario) to 6.5%. As can be expected, there is a notable decrease in the level of airport delay.

Although not included here, it is not unreasonable to consider that a scenario employing both an increased level of fragmentation and an allowable level of time shift to less congested periods would reduce further still the level of unaccommodated demand.

\(^{10}\) The individual ODZ families are of varying granularity (single airport, pairs or small group of airports, through to geographical regions).

\(^{11}\) If this condition is not applied then it may be possible to assign flights to “unrealistic” airport pairs.
5.5 Frequency reduction

“In response to the congestion at most major European airports, airlines must seek to maximise the number of passengers carried per flight and, hence, aircraft size.”
Extract from White Paper, European Transport Policy for 2010: Time to Decide.

“On the issue of airport congestion, I see not a single firm proposal in the area of new airports and new runways. Instead, we the airlines are urged to maximise the number of passengers carried per flight by buying bigger aircraft. So much for more competition and more choice!”
Address by the AEA Secretary General, to the European Parliament RETT.

In order to assess the effect on delay from restricting the daily frequency of operations on certain airport pairs, a demand scenario for the year 2015 was created directly from the “do-nothing” scenario but with a restricted number of movements on certain city pairs. This is consistent with the migration towards the use of larger aircraft as a means of satisfying a growing level of passenger demand without a consequential increase in the number of aircraft movements.

Reference 6, noted that such actions have already been taken in the U.S by Continental Airlines who reduced the number of scheduled flights through the use of larger aircraft at Newark International Airport. Similarly United Airlines began using larger aircraft and scheduling fewer flights to help address persistent delays in San Francisco.

Before presenting the simulation results, it is interesting to observed that the number of city pairs likely to be impacted by such measures is relatively low. Indeed, based on a weekday traffic forecasted at the time horizon 2015, the following chart shows the anticipated level of market concentration. Less than 5% of the city-pairs are likely to have a daily frequency higher than 10 flights per day, and about 1% more than 20.

![Percentage of city pairs with daily frequency >= N](chart)

To analyse the impact of a reduction in daily frequencies on certain city pairs, three simulations were performed in which the number of flights (daily, each way) on any airport-pair was not permitted to exceed a certain threshold. These thresholds were assigned to be 10 flights per day, 15 flights per day and 20 flights per day (referred to as FC10, FC15 and FC20). The reductions in delay are significant, especially at the airport level due notably to the reduction in the number of flights on high traffic density city-pairs such as Barcelona/Madrid or Rome/Milan.
As the upper limit on the number of flights between city pairs becomes more of a constraining factor (FC10), the reduction in the number of movements compared to the "do-nothing" scenario becomes more pronounced. The en-route and airport delay figures are seen to significantly decrease compared to the "do-nothing" scenario by 34% and 65% respectively – this as a result of an overall reduction in traffic volume of 8% at the FC10 level.

Changes in en-route delay in the FC15 and FC20 (the least constraining) scenarios are reduced due to the limited effect on the overall number of movements.

The question of whether such a scenario will be realised may also depend on other actors in the ATM environment. Indeed one could imagine a scenario whereby a number of airports introduce special slots for certain destinations only allowing aircraft with passenger capacity exceeding a given value.
6. Substitution and inter-modal transport links

“Intermodality with rail must produce significant capacity gains by transforming competition between rail and air into complementary between the two modes, with high-speed train connections between cities. We can no longer think of maintaining air links to destinations for which there is a competitive high-speed rail alternative. In this way, capacity should be transferred to routes where no high speed rail service exists.”

Extract from White Paper, European Transport Policy for 2010: Time to Decide.

“…promote intermodality with rail. Yes, there is some potential for co-operation and substitution, but the handful of routes eligible for modal shift from air to rail could not produce anything like the capacity gains expected by the White Paper.”

Address by the AEA Secretary General, to the European Parliament RETT.

Substitution of air transport toward alternative modes of transport may be feasible on certain links within Europe, primarily through the use of High Speed Trains. The extent of this feasibility is clearly open to discussion as illustrated above. Examples of the migration of air passengers toward such links can be either as a result of a conscious decision by the airlines e.g. Air France on the Paris – Brussels link or more indirectly as a result of competition between different modes of transport e.g. Channel Tunnel services competing directly with the available air services.

It is unlikely that rail services represent a viable alternative to air services for journey times in excess of four hours and for certain types of passenger this figure may be somewhat less. Given the difficulties outlined earlier of obtaining slots at certain airports, the sustainable growth of aviation may be dependent on the use of rail transport as a feeder service to and from the airports as well as an alternative mode of transport for certain point to point passengers. This will have the combined effect of freeing up slots for higher revenue medium and long-haul services as well as making more effective use of the available runway capacity. A more integrated transport infrastructure will necessitate regular, convenient services but also facilities such as improved check-in possibilities at the rail terminal, offering passengers a more ‘seamless’ travel experience when connecting between the different modes of transport.

The demand for air services is a complex mix of a number of economic and demographic parameters inter-alia, price, potential alternatives and incentive schemes. This study has not attempted to model this level of interaction but rather to take a potential European rail network at a given time horizon and make certain assertions about the scope of the resultant variation in the number of air movements resulting from this network.

For the purposes of this study, each individual airport pair was considered and the potential for rail substitution was modelled based on the likelihood of there being a high speed rail link within the time horizon of the study and also the estimated rail travel time.

The extent of substitution of passengers on these routes will depend on the efficiency and frequency of the rail link in comparison to the air link as well as the extent to which the rail service is integrated into the airport infrastructure (as in Paris CDG or Frankfurt Main), allowing feeder air services to be replaced by the train.
This study is based on the adjacent map from the UIC-High speed train division. This map represents a potential European high speed rail network at the 2010 time horizon \(^{12}\) (showing new lines and planned upgrades to existing lines as well as the extensions at the 2020 time horizon). This network was therefore considered appropriate for a modelling assessment of the likely situation in 2015 given the delays that are invariably incurred with such large scale infrastructure projects.

Based on an estimate of the rail travel time between each city pair, the volume of air traffic was reduced accordingly as indicated below:

This strategy for substitution and replacement resulted in a reduction of less than 4 percent of the daily number of air movements when compared to the 2015 forecast ("do-nothing"). It could be considered therefore that this level of substitution is somewhat weak. The predicted en-route and airport delay are observed to reduce significantly as a result of this approach.

At the 2015 time horizon, the assumptions described above lead to the following delay results:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Reduction in en-route delay (%) compared to &quot;do-nothing&quot; scenario</th>
<th>Reduction in airport delay (%) compared to &quot;do-nothing&quot; scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>HST substitution</td>
<td>24.2</td>
<td>68.4</td>
</tr>
</tbody>
</table>

\(^{12}\) Based on construction of new lines and improvement to existing infrastructure.
7. Environmental Issues

The analysis in this report has concentrated on issues associated with ATFM delay and airport capacity constraints. However, when considering the future growth in air transport, concerns over environmental issues will never be far from the fore.

The air transport industry, through IATA, has publicised the improvements in past years associated with both noise and emissions. The environmental lobby will also closely monitor the situation in terms of global emissions, airport noise and also the potential for increased pollution levels due to surface transport around airports associated with the future increase in passenger movements. IATA under the auspices of ATAG (Reference 5) is promoting better surface links (e.g. increased use of high speed city centre to airport rail links) as a direct means of addressing pollution issues.

The EUROCONTROL Experimental Centre has devoted considerable effort toward the development of analytical tools able to analyse and predict environmental parameters such as emissions and noise pollutants. It is therefore considered interesting here to provide a ‘first-look’ analysis of issues associated with the evolution of air traffic demand but to also analyse any potential impact that demand management strategies such as those considered in the previous chapters may have on the principal environmental parameters.

7.1 Local study: noise pollution

The EEC has developed facilities to calculate in a detailed manner the noise impact resulting from air traffic around airports, through the use of the Federal Aviation Administration (FAA) Integrated Noise Model (INM) along with the European Harmonised Aircraft Noise Contour Modelling Environment (ENHANCE).

In order to calculate noise contours around a particular point (e.g. an airport), the ENHANCE/INM tool-set requires a detailed knowledge of the profile of each flight to be studied – notably trajectory and speed information. Whilst ATFM simulations rely also on aircraft trajectories for their execution, the required granularity is somewhat less. For this reason, an intermediate filter was built between the data used in the ATFM simulations reported on in previous chapters and that used by ENHANCE/INM. This filter was provided by the Total Airspace and Airport (TAAM) Model.

By adopting this approach, a study of the noise issues associated with changes to the demand volume becomes possible. In the first instance, it was desired to assess these effects at a specific, single airport. The choice of Barcelona airport was made, as it was one where the various "demand shaping" scenarios analysed as part of this report would have an impact. Specifically the following scenarios have been studied (each scenario being derived from the same baseline day of traffic):

1. Baseline year 2000 demand profile
2. Predicted year 2006 demand profile
3. Predicted year 2015 demand profile
4. Predicted year 2015 demand profile but modified to simulate the introduction of high speed rail services coherent with the scenario described in Chapter 6.
7.1.1 Modelling approach

A faithful reproduction of the Barcelona environment has been created including runway configurations, SIDs, STARs and ATC constraints. A slightly simplified gate configuration was built but with sufficient fidelity to ensure realism of the traffic flows.

The following graph shows an example of the ground tracks generated by TAAM. These tracks correspond to the procedures used at Barcelona when operating with the configuration of runway 20 for departures and 25 for arrivals.

By employing the local procedures constructed in the TAAM environment (including ground dispersion) as shown above in conjunction with the standard flight procedures taken from the INM database, it was possible to construct on a flight by flight basis, a 3-D trajectory, including speed and thrust information along the path, in order to calculate the noise contribution (noise footprint) of each, using so-called Noise-Power-Distance (NPD) relationships. These are graphs or tables of noise levels versus slant distance from the aircraft, one for each of a number of different engine power levels (thrust settings).

The noise footprints calculated for each flight of the 24 hours traffic sample were then combined ("summed acoustically") to produce so-called noise contours, according to the \( L_{den} \) indicator (day-evening-night equivalent level). This indicator incorporates in particular a notion of "disturbance" through the application of weighting factors "penalising" (i.e. increasing the noise estimate) of evening and night flights. In this study, the evening period was assumed to be from 6 p.m. until 10 p.m., and the night period from 10 p.m. until 6 a.m. The noise contours were calculated for threshold values from 55 to 85 dB.

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13 The INM standard procedures (used to specify height, speed and thrust along the tracks), are provided by manufacturer for different airframe-engine combinations and — for departures — a set of average takeoff weights (depending on the stage length, a range of trip distances). For this study, medium takeoff weights were generally used, except for aircraft types that usually operate on long-haul flights, for which the "heavy" assumption was made.
7.1.2 Limits of the study

The fleet mix used for the 2006 and 2015 scenarios was the same as for the 2000 baseline scenario. No forecast was indeed available about the aircraft types that will operate at Barcelona airport (function of airline strategies) at these years. Moreover, the INM aircraft database provides noise and performance characteristics only for currently existing aircraft types and does not provide any facility to anticipate on the noise characteristics of future aircraft with new technologies. The scenarios presented therefore should be considered as a “do-nothing” in terms of technological advances associated with engine emission and noise envelope is concerned.

Whilst some improvement concerning the flight profiles is possible (in terms of realism concerning dispersion and different company operating procedures), the profiles are considered sufficiently realistic for comparative analysis – at least as part of a ‘first assessment’.

7.1.3 Results

In this section, the noise contours associated to the different scenarios are presented along with the arrival and departure tracks. Each graph represents an area of 17nm by 19nm and each graduation represents 1nm. The runways are located at the crossing of the 2 axes. The following table indicates the noise level thresholds values associated to the different colours of the contours:

<table>
<thead>
<tr>
<th>Colour</th>
<th>Noise Level (L) range</th>
<th>Colour</th>
<th>Noise Level (L) range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L &gt; 85 dB</td>
<td></td>
<td>65 &lt; L &lt; 70 dB</td>
</tr>
<tr>
<td></td>
<td>80 &lt; L &lt; 85 dB</td>
<td></td>
<td>60 &lt; L &lt; 65 dB</td>
</tr>
<tr>
<td></td>
<td>75 &lt; L &lt; 80 dB</td>
<td></td>
<td>55 &lt; L &lt; 60 dB</td>
</tr>
<tr>
<td></td>
<td>70 &lt; L &lt; 75 dB</td>
<td></td>
<td>50 &lt; L &lt; 70 dB</td>
</tr>
</tbody>
</table>

- **2000 baseline**

The adjacent figure represents the noise contours corresponding to the observed traffic of 17 July 2000.
• 2006 prediction

The noise contours resulting from the 2006 traffic predictions are represented in the adjacent graphic.

For comparative purposes, the envelope of the 2000 contours is also represented to show the increase of the size of the noise contours simply due to the increase in traffic volume.

• 2015 prediction

In this case, the daily traffic increases by 34% compared to 2000. As already said previously, this increase could have been higher regarding the STATFOR predictions but is limited by the airport capacity constraint. However, the noise contours remain larger than in 2006 and this spread is homogenous.
2015 High Speed Train (HST) implementation

The adjacent figure shows the noise contours for the 2015 time horizon but with the assumption of the inclusion of the High-Speed Rail network as described in Section 6. The envelope of the noise contours for the 2015 baseline scenario (no high-speed rail effect) is also included as a means of providing direct comparison.

In the particular case of Barcelona airport, the impact of High Speed Rail stems from the Barcelona / Madrid and Barcelona / Valencia combinations. The substitution strategies employed leads to a reduction in Barcelona of 23% in the number of flights compared to the 2015 “do-nothing” scenario. This in fact reduces the traffic close to the 2006 level.

Even though the total number of flights is close to the one of 2006, the flight distribution is, of course, quite different and close comparison with the 2006 prediction shows some differences in the noise impact.

Most notably, the noise annoyance is reduced significantly compared to the 2015 “do-nothing” prediction although this reduction is not homogenous across the main arrival and departure tracks. The main noise reductions are located at the arrivals on the runway 25 and at departures on the routes going to the South and the West – consistent with the assumed High Speed Rail network.

For ease of comparison, the previous results can be summarised by considering the spreading of the “noisy” area in terms of percentages. The 3 first columns translate the effect of the growth of the demand from 2000 to 2015 whereas the last one translates the new demand shapes due to the High Speed Rail introduction scenario:

<table>
<thead>
<tr>
<th>Noise level range</th>
<th>Noise level according to the year in Km² produced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
</tr>
<tr>
<td>&gt; 75 dB</td>
<td>5.1</td>
</tr>
<tr>
<td>&gt;70 dB</td>
<td>12.3</td>
</tr>
<tr>
<td>&gt; 65 dB</td>
<td>27.7</td>
</tr>
<tr>
<td>&gt; 60 dB</td>
<td>58.4</td>
</tr>
<tr>
<td>&gt; 55 dB</td>
<td>130.9</td>
</tr>
</tbody>
</table>
7.2 Global study: Fuel Burn and Emissions

This section aims to illustrate the impact of air traffic growth in terms of air pollution, notably fuel burn and gas emissions. The Advanced Emission Model (AEM) developed at the EEC and validated against published results from a number of sources was employed for this aspect along with the forecast traffic samples of 2006 and 2015 identical to those used for the delay and access predictions described earlier.

The AEM tool estimates fuel burn and the gas emissions based on 4-D profiles with adjustments for the take-off and landing phases of flight. Emissions are computed in terms of different groups, namely Water Vapour (H$_2$O), Sulphur Oxides (SO$_x$), Nitrous Oxides (NO$_x$) and Carbon Dioxide (CO$_2$).

The following table provides the anticipated global increase for each group at the time horizons of 2006 and 2015 compared to a baseline of 2000. The evolution is the same for the 3 first gases studied but is different for the NO$_x$, during the fact that the latter is primarily emitted during the take-off phase whereas the former are primarily associated with the cruise phase:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$, H$_2$O, SO$_x$</td>
<td>26.64%</td>
<td>42.01%</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>25.96%</td>
<td>40.56%</td>
</tr>
</tbody>
</table>

As with the local noise study for Barcelona, the future traffic samples contain no inherent assumptions concerning the evolution in engine emission technology or regulatory measures that may be introduced over the time frame of the study. The above figures should therefore be considered as indicative of a "do-nothing" scenario.

These results present an initial insight into the type of analysis that can be performed at a local and global level concerning environmental issues associated with the growth in air movements. In terms of a comparative analysis of a "do-nothing" scenario the results are considered to be reliable. The integrity of the analysis can be further enhanced by incorporating more realistic assumptions concerning company fleet mixes in the future as well as engine technology evolutions.
8. Conclusions / Next Steps

The results contained in this note have been derived using traffic growth data provided by EUROCONTROL in conjunction with Member States. Similarly, short-term capacity growth projections have been obtained from the individual ANSPs as well as the EUROCONTROL/ACI database in the case of airports. The longer term en-route capacity projections were estimated based on a complexity classification of individual ACCs in an attempt to capture the relative difficulty that will be faced in maintaining capacity growth in the longer term.

For the longer term time horizon, it makes less sense to provide performance predictions, due to the inherent uncertainty over the growth in both the demand and supply-side parameters. Furthermore, en-route delay is very sensitive to the level of capacity, with small variations in available capacity potentially having a notable effect on the level of observed delay. Furthermore, as has been highlighted in the report, the delay performance of an individual ANSP is not only dependent on the level of capacity provided, but also the level of capacity provision by neighbouring ACCs – the so-called ‘network effect’.

Therefore, the aim of this report has been more to provide a ‘comparative analysis’ where the absolute values are perhaps less important but the sensitivity of the results (in terms of delay and unaccommodated demand) to different potential future strategies is more important. The report has highlighted some differing views concerning the longer term constraints to aviation growth, as well as the necessity or otherwise to adapt the system to these constraints.

Concerning the information provided in the report, the following key points can be retained:

- At the longer term time horizon, 2015, there is a potential for airports to present a major constraint in terms of system access should the geographical and temporal distribution of the demand reflect that of today.

- There is considerable scope for reducing delay due to airport capacity constraints by attempting to reduce the peaks in the temporal profile of the demand. Similarly scheduling flights in less constrained periods will also allow for improved access to the system. Use of less capacity constrained airports provides the most potential for improving system access.

- Reducing the frequency of flights on certain high volume city pairs provides the potential for reduced levels of delay across the entire network. The same can be said of a more extensive, reliable European High Speed rail network which offers a genuine alternative for air travel on certain routes.

As a separate study, the EEC has embarked on the development of an analytical model which studies the profitability of carriers operating in Europe and the way that their profitability is likely to evolve under a number of different scenarios. The first aspect of this work which models airline demand elasticity in terms of Revenue Passenger Miles (RPMs) is now close to completion. This work will result in a model which predicts variations in RPMs arising from changes in a number of “internal and external” parameters such as ticket price, yield, competitor price and yield, unemployment etc.

This work will then be fully integrated into the airline model. The aim of this model is to construct an ‘industry equilibrium’ i.e. to predict the necessary yield increases to achieve a given profitability or to calculate operating margins arising from target yield figures. Changes to any of the demand drivers, airline efficiency parameters or the economic conditions can be incorporated and used to calculate changes to the number of RPMs.
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</table>
Annex : Network Sensitivity

The aim of this Annex is to provide an insight into the variability of the level of ATFM delay to changes in the traffic volume or capacity offered. This analysis has been performed using traffic volume and delay observations from the year 2001 at both the level of individual ACCs but also at the level of the European network.

ECAC level

The European network constitutes a system which exhibits a complex relationship between the observed level of delay, the traffic volume, and the level of capacity offered. It is possible to perform a number of regression analyses to understand the relationship between delay and traffic volume under the assumption that the level of capacity offered remains constant. This complex interaction is further complicated by the notion of delay attribution to the ‘most penalising regulation’ experienced by a flight. This means that within the network, certain delay generating bottlenecks can be ‘protected’ by other more severe bottlenecks but can also serve to induce delay in another ACC due to the ‘smoothing’ effect on the traffic distribution associated with an individual regulation.

Capacity / demand relationships

In order to illustrate the network sensitivity to any capacity shortfall, a series of ATFM simulations were performed for various estimates of capacity provision within each ACC and using an observed traffic sample from one week in Summer 2001. Although performed on a flight by flight basis, the results are expressed in terms of the capacity / demand ratio14. For example, at C/D=1, each ACC is considered to be providing a sustainable capacity equal to the busiest three hour period throughout the entire reference week.

The following curve shows the results of this series of ATFM simulations. As indicated, the level of delay is seen to increase in an exponential fashion (R² = 0.99) with decreasing values of the C/D ratio. Also, at higher capacity / demand ratios, the elasticity of delay is significantly reduced, i.e. any increase in capacity (at constant demand) will have a reduced impact on the observed level of delay.

The reality of the future network is that each ACC will not be operating at the same value of C/D and certain ACCs, as today, will be ‘protecting’ others with a capacity shortfall.

---

14 the level of demand used for each ACC equates to the mean of the busiest three hour period throughout the week
**Delay and Traffic volume relationships**

For the entire period of 2001, the relationship between the observed delays and traffic volume has been studied at both the level of individual ACCs and the network level. The aim is to investigate the relationship between these two parameters and to explore any explanatory relationship between the two. At the level of the entire network, a power function of the following form would appear to best model the relationship between traffic volume and delays:

\[ \text{Delays} = k \times \text{traffic}^{\text{Factor}} \]

By considering the “rate of change” associated with this kind of function, it is possible to define the relationship:

\[ \frac{\Delta\text{Delays}}{D} = \text{Factor} \times \frac{\Delta\text{Traffic}}{T} \]

Therefore, under the assumption that this relationship correctly models the network-wide behaviour, it is to be expected that a 1% increase in traffic demand will result in an increase in delay of “Factor %”.

**Network relationships using weekly data**

The following graph displays the Traffic demand (average number of daily flights) against the average delays (average number of daily minutes) where each observation corresponds to one week of data. Hence one can expect that certain temporal phenomena e.g. variations in performance between weekdays and weekend days, will be smoothed out at this level of granularity.
The red line represents the trend of the distribution and its shape is given by the following power function:

\[ \text{Delays} = 2 \times 10^{-17} \times \text{Traffic}^{4.93} \]  
(Correlation $R^2 = 0.9$)

From this analysis, one can conclude that an increase of 1% of traffic demand will result in an increase of 4.93% in en-route delays (at constant capacity provision).

**Network relationships using differentiated weekday and weekend data**

The following graph presents similar results to those described above with the exception that each observation is derived from a single day of data, and the observations are differentiated according to weekday and weekend periods.

The two sets of observations provide the following results:

<table>
<thead>
<tr>
<th>Period</th>
<th>Traffic → delay elasticity</th>
<th>Confidence ($R^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekday</td>
<td>4.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Weekend</td>
<td>5.3</td>
<td>0.7</td>
</tr>
</tbody>
</table>

The results indicate an increased sensitivity of the European network during weekend periods. It is also important to note that the quality of the implicit correlation function is somewhat lower than using weekly data since a number of effects observed on individual days (strikes, weather, system failure, …) will not have been smoothed out at this level of analysis.
Analysis at the level of individual ACCs

The following section presents the traffic demand and delay relationships throughout 2001 for three ACCs which generated notable levels of ATFM delay during the period of the analysis. When considering the performance of individual ACCs which do not generate delays on all days, there will be a number of observations for which the traffic volume varies but for which (almost) no delay is generated. These observations can be used to yield what can be referred to as the ‘traffic threshold’. This represents the limit of flights under which the centre can handle the traffic with almost no delay. Above the traffic threshold, the delay increases with the traffic (if the capacity remains constant) according to the appropriate elasticity relationship. The variation of delay with traffic volume (above the traffic threshold) was modelled using both a power function relationship (as at the network level) but also using a linear relationship.

The behaviour of the power function is illustrated previously. The linear relationship is assumed to be of the form:

\[
\text{Delays} = k \times \text{traffic} + \text{cst}
\]

Depending on whether the power function or the linear function (i.e. each flight increase the delay by \(k\) minutes) yields the best correlation to the observed data means that an ACC can be effectively modelled as indicated below:

In the following sections, the average daily traffic and average daily delay (on a weekly basis) are studied for three ACCs as a means of understanding their sensitivity in terms of delay to increases in the traffic volume. In addition, the “traffic threshold” is identified for each ACC – essentially the point at which the ACC can be considered as starting to generate delay.

![Example diagram](image-url)
- Geneva ACC
  
  *Traffic threshold*: 1144 flights

  *Power function factor*: 6.7

  *Linear shape*: $k=11.9$

  Some “outliers” in the observed data are evident but even taking these into account, the power function yields a reasonable correlation with a traffic / delay elasticity of 6.7.

- Maastricht ACC
  
  *Traffic threshold*: 2200 flights

  *Power factor*: 6.9

  *Linear shape*: $k=8.7$

  The power function still yields a reasonable description of observed data with a traffic / delay elasticity of 6.9.

- Zurich ACC
  
  *Traffic threshold*: 1637 flights

  *Power factor*: 5.3

  *Linear shape*: $k=8.2$

  A reasonable correlation is obtained for both the linear and power function ($R^2 = 0.7$ in each case) and the traffic / delay elasticity is 5.3.
In each case, the traffic / delay elasticity is typically of the order of 6 i.e. based on the observed data, a 1% increase in traffic volume typically leads to an increase of around 6% in the level of observed delay.

These data do however assume that the provision of capacity is constant throughout the period.

Furthermore, although the effect of the network interaction (delay protection and transfer) is implicit in the data (since the data is derived from observations), this type of approach is not necessarily optimal for considering longer term behaviour of the system due to potential changes in the nature of this network effect.

This section has been included to show that the system as it is operating today is sensitive to variations in the traffic volume. For longer term studies into delay sensitivity of certain scenarios, we have adopted an approach defined below in Section 4.1 - that is to say to perform ATFM simulations, simulating the CFMU slot allocation process for different levels of demand and capacity provision. As described in Section 0, the sensitivity of delay to traffic is closely linked to the level of capacity provision whereas the above analysis has assumed that the capacity remains constant.

Within our modelling analysis of future scenarios, the aim is to capture both a realistic interaction between supply and demand variables (by implicitly including the level of capacity provision) as well as the complications arising from the network effect.