CAPACITY PLANNING AND PERFORMANCE PREDICTIONS: MODELLING THE EUROPEAN NETWORK TO DETERMINE TOMORROW'S NEEDS TODAY

Alan Marsden, Eurocontrol Experimental Centre, Bretigny sur Orge, France

Abstract

Unlike in the United States, the level of delay suffered by airlines in the European ATM network is due primarily to airspace congestion. The long lead time associated with technology development as well as the recruitment and training of controllers has necessitated that EUROCONTROL pioneer an innovative process of capacity planning covering a five year time horizon on behalf of its Member States.

The European ATM network is characterised by a complex web of different service providers with different traffic complexity levels and capacity growth potential. Using fast-time simulation techniques, simulating the behaviour of the entire European network, the Future ATM Profile (FAP) tool-set developed by the EUROCONTROL Experimental Centre (EEC) is in a unique position to quantify the future system capacity requirements.

The extent to which the different service providers will be able to meet their capacity targets will be manifested in the levels of delay which will be observed across the network. A further area of concern is the potential for airports to become constraining nodes of the network - limiting the level of access that carriers are able to obtain to the system due to the process of slot allocation.

The extent to which the "Predict and Provide" approach to capacity enhancement will continue to remain the most appropriate is open to rigorous debate. Indeed, if service providers do not meet their capacity targets then the airlines may take strategic actions in order to ensure continued commercial viability – thereby impacting the shape of the demand pattern. Such actions may include the migration toward larger aircraft, the use of point-to-point services using less congested airports or the operation of flights during less congested periods of the day – as is already being practised in the United States. One of the advantages of the fast-time simulation techniques used in the capacity planning process is that the same tools are ideal for assessing the performance impact of such voluntary actions.

The development of an integrated high speed rail network in Continental Europe provides in certain cases a viable alternative mode of transport for the consumer. This is likely to have an impact on the growth of air services in certain regions. Furthermore, airlines may change their business model and seek a closer collaboration with railway services which may act as "feeder" traffic to the hub operation.

This paper presents the current methods of capacity planning as well as a number of potential future scenarios involving changes to the nature of the demand pattern. The extent to which airports are predicted to emerge as an overall constraint to the growth of air traffic will be described.

Air Transport Growth

In the last ten years the European air transport industry has undergone a process of transition from tight regulation based on bilateral agreements with little competition, towards a single market. This liberalisation and freedom from external control has also resulted in the possibility for air carriers to decide on parameters such as fares, routes and capacities [1].

Since 1993, EU airlines have been able to operate services on intra-EU routes free from the constraints of air service agreements. One of the effects of this is the growth of services operated by carriers on routes previously operated only by the national carriers.

A relatively new phenomenon is the considerable growth in services offered by 'low cost' carriers. Indeed, these carriers represent the market segment which appears the most able to react to the current downturn in air traffic growth.

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Traffic growth in the first 8 months of 2001 was only 1.3%. For 2002, there could be a decline of around -1.5% in traffic levels when compared to 2001 levels. However, the indications are that in the next few years demand will increase and previously predicted growth rates will again become the norm. For this reason, it is considered of paramount importance in Europe to plan to increase capacity in those areas where it is most beneficial.

European Network Analysis

Delay Evolution

Over recent years, the European ATC system has suffered from a lack of available capacity. In many cases, there is not an airspace limitation *per se* but rather an inability of parts of the ATC system to deliver capacity in pace with demand at those times when such capacity is needed. This is a result of the following factors :

- Fragmentation of the European airspace
- Staff shortages amongst some ANSPs
- Inappropriate staff scheduling and choice of airspace configuration at certain time periods – particularly on weekends

Delays in Europe due to Air Traffic Management constraints are managed by the Central Flow Management Unit (CFMU). These delays are referred to as Air Traffic Flow Management (ATFM) delays and are primarily the result of insufficient airspace capacity. Delays are therefore the most significant indicator of a capacity shortfall although other causes such as weather, technical problems or industrial action are observed.

In order to ensure safety and prevent individual ATC sectors from overload, the flow through certain 'regulated' sectors is controlled by the CFMU – the process of control arising from the attribution of a 'take-off slot' to an affected flight. Figure 1 shows the annual evolution in ATFM delay throughout the European network.

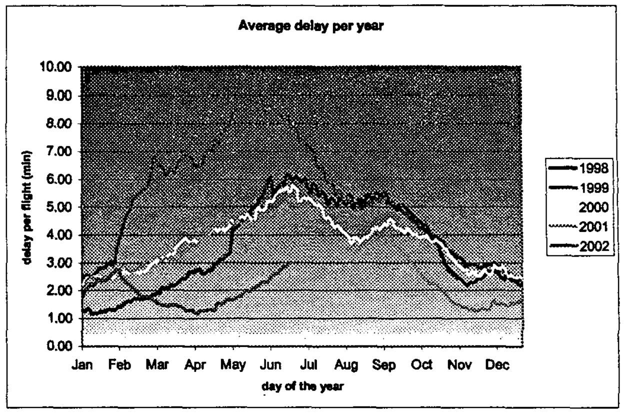

Figure 1. Annual ATFM Delay Evolution

Individual flights may pass through a number of different 'regulated sectors'. The delay incurred by a flight is dictated by the most penalising regulation traversed. The location and cause of the most penalising regulation can therefore be used to attribute the delay to an individual service provider for performance comparison purposes but most notably for the planning of future capacity requirements.

The ATFM delay in 1999 was notorious due to the effects of the Kosovo crisis. Considering the en-route delay generated during Summer 2000, the following diagram indicates how this delay was apportioned to the various Area Control Centres (ACCs) (Figure 2).

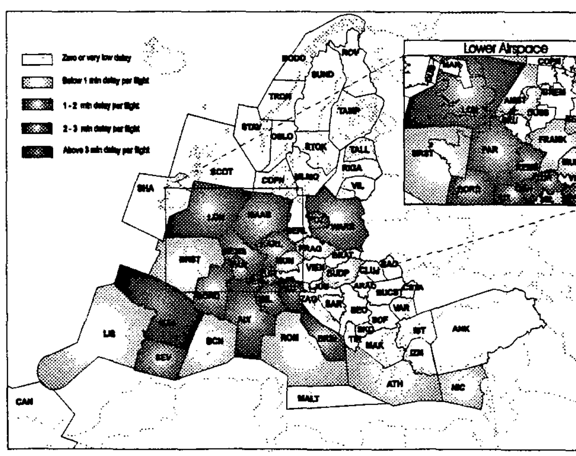

Figure 2. Summer 2000 Delay Locations

In 2002, due to a number of local capacity increases and introduction of the pan-European RVSM programme, the average delay per flight has fallen to a level below the equivalent month in every year since 1997.

Traffic And Delay Relationships

For the entirety 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 being to explore any relationship between the two. The following figure displays the Traffic demand (average number of daily flights) against the average delays (average number of daily minutes) for the entire European network, where each observation corresponds to one week of data.

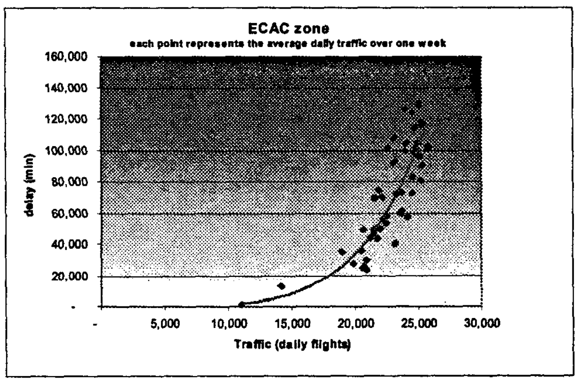

Figure 3. Traffic And Delay Variation (Week)

The best fit trend of the distribution and its shape is given by the following power function:

$$Delays = 2 * 10^{-17} * Traffic^{4.93}$$
(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).

The results of a similar analysis for each day of the year but separated according to weekday and weekend periods indicate an increased sensitivity of the European network during weekend periods – with a traffic / delay elasticity of 5.3 (i.e. a 1% increase in traffic can be expected to cause a 5.3% increase in delay at constant capacity), (Figure 4).

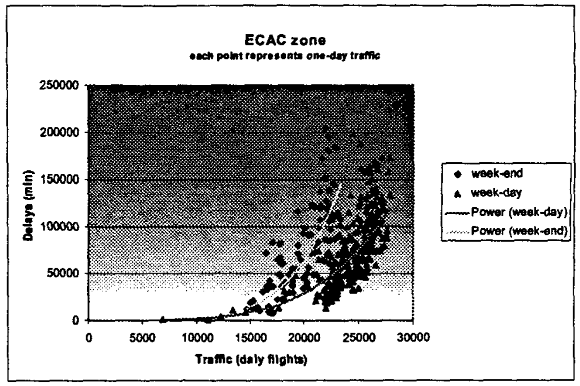

Figure 4. Traffic And Delay Variation (Daily)

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.

Medium Term Capacity Planning

The Challenge

In the late 1990s with ATFM delays on the increase, considerable pressure was placed on the Air Navigation Service Providers to implement a collaborative capacity planning process. The challenge was to generate capacity where most needed in order to cope with increasing demand, whilst at the same time maintaining safety levels and controlling costs.

Generating extra capacity is a complex issue and involves change in a number of different but related fields, namely infrastructure, operational procedures, staffing, rule-making, etc.

In the short term, the potential for modification to the ATM system is usually limited to a better use of already existing human and technological resources, although the availability of such resources can normally be predicted with a high level of confidence. It is worth noting that in some areas of Europe, even traditional capacity-enhancing measures such as airspace reorganisation can take over one year to implement. On the other hand, as the planning time horizon extends to the medium term (typically 5 years), it is possible to consider more radical actions such as revised airspace management, use of improved ATM technology and increased ATC staff growth. In this case, there is more scope for change although the information quality surrounding the potential evolution of the nature of the demand (traffic volume, route utilisation,...) as well as "supply" parameters (staff, technology,...) is necessarily lower.

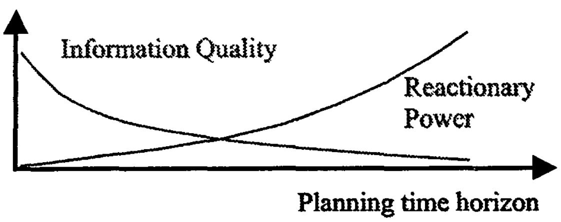

Figure 5. Information Quality And Reactionary Power

In April 2001, the EUROCONTROL Provisional Council (PC), adopted a performance target for the whole European network, namely that by 2006, ATFM delay (due to en-route ATC causes) should be reduced to 1 minute per flight.

Modelling the European Network

The challenge was therefore to develop the appropriate modelling tools to identify where capacity increases should be planned in order for this overall target to be met. Such a modelling environment needs to incorporate at least the following functionality :

- A network flow management simulator able to simulate delay allocation due to lack of capacity
- A traffic generator able to simulate planned traffic growth and construct realistic traffic flows through each node of the network
- The ability to simulate evolutions in the ATC route structure
- An environmental database able to simulate changes to the configuration of individual ACCs.

The Future ATM Profile (FAP) is a methodology and associated tool-set that has been developed around these requirements. FAP is implemented as a set of distributed modelling and analysis tools comprising ATFM simulation facilities as well as Spreadsheet and macro based analysis and reporting tools. The objective within FAP is to provide a set of capacity profiles for each ACC being studied which ensure that the overall PC network performance target is met in the most cost-effective manner.

FAP is the unique tool in Europe able to perform this analysis across the entire network.

Network Flow Management Simulator

The heart of the FAP tool-set is an ATFM simulator which exactly simulates the slot allocation process performed by the CFMU. Individual ACCs are modelled with their effective capacity limits and the simulator is able to analyse both current traffic samples (around 26000 flights per day) as well as simulated future traffic samples. In this way, for a given traffic level (demand) and capacity provision (supply), the location and size of each individual delay can be studied. Of particular interest for this approach is that the "network effect" is also simulated. This is the close inter-relationship between capacity, demand and delay between each of the individual nodes (ACCs and airports) of the ATM system. For example, a characteristic of the European system is that capacity increases in one geographical area can cause the transfer of delay to another – a factor often referred to as "delay protection".

Traffic Growth Scenarios

In collaboration with Member States and other stakeholders including the airlines, traffic growth predictions are developed by the EUROCONTROL STATFOR unit. STATFOR provide a number of growth predictions referred to as "Low", "Medium" and "High". Each of these predictions takes into account various scenarios relating to evolution in Gross Domestic Product, airline productivity, currency value fluctuations etc.

In addition to changes in the demand volume between individual airport pairs, it is also necessary to take into account changes to the ATC route structure. Such changes as well as, for example, changes to the allowable vertical profiles between certain airport pairs ("level capping") will each have an impact on the level of traffic demand at individual ACCs over the time horizon of the study.

Analytical Process

In order to determine capacity targets for the European system it is necessary to :

- Quantify the current capacity performance (baseline) of each ACC
- Build future traffic samples taking into account the current temporal demand profiles and the predicted growth provided by STATFOR
- Simulate the necessary capacity increases at the level of individual ACCs (micro) which ensure convergence to the overall Provisional Council performance target (macro).

Therefore, the overall delay target is translated into individual capacity profiles for each ACC.

The FAP ATFM baseline simulation is based on an analysis of the flow management delays observed for a series of given days in order to determine the "capacity of an ACC". Although regulations are managed by the CFMU at the level of individual sectors, the FAP process works at the level of an ACC[1]. For an ACC, the capacity is defined as the number of aircraft which could pass through the centre whilst generating the same ATFM delay as was actually observed. In flow management terms it is as though the ACC is considered as a single elementary sector.

Future traffic samples are constructed from actual traffic samples but modified according to the predicted growth rates from STATFOR. This ensures that the temporal nature of the demand is preserved. In addition, the hourly airport capacity constraints are taken into account to ensure the level of demand in airspace surrounding the airports (TMAs) remains as realistic as possible.

In the assignment of capacity increases to individual ACCs, FAP uses data provided by both IATA and the EUROCONTROL Central Route Charges Office (CRCO)[2].

[1] Due to the fact that in the medium term an ACC is considered to be a stable entity whereas individual sectors will be changed as part of airspace re-organisation measures.

[2] The en-route European ATM charges in 2001 amounted to some 4.4 billion € .

Based on data from IATA, the assumed cost per flight minute of ground delay is 40€. The marginal cost of capacity provision (C_M) in each ACC is derived from the annual cost of ATC service provision (country cost) and modulated according to the size of the ACC in terms of the number of available sectors and the level of baseline capacity provision.

Clearly there is no "unique solution" to the problem of allocating capacity increases to individual ACCs so as to converge to an overall performance target. In order to ensure maximum overall cost efficiency, FAP capacity increases are based on the 'Return on Investment' (ROI). In general terms, the ROI can be considered as :

ROI = Cost Reduction / Capital outlay

Which in the specific implementation in FAP is translated as :

$$\text{ROI} = (\text{Delay cost reduction} - C_M) / C_M$$

Therefore, the ROI is positive whilst the delay costs are reduced more than the marginal cost of capacity required to achieve the reduction. Firstly, a number of network-wide ATFM simulations are performed whereby the capacity of each ACC is (separately) increased by one flight per hour. This first iteration therefore constitutes N simulations (where N is the number of ACCs being studied[3] and for each simulation a value of ROI is obtained.

For the ACC with the highest value of ROI, the new capacity level is stored as the "current target".

This iterative process continues until the overall network performance target is reached. The convergence to an optimum cost level is indicated in the following figure whereby delay costs are seen to reduce exponentially with increasing capacity and the marginal cost of capacity increases linearly.

[3] Typically around 70 ACCs are studied

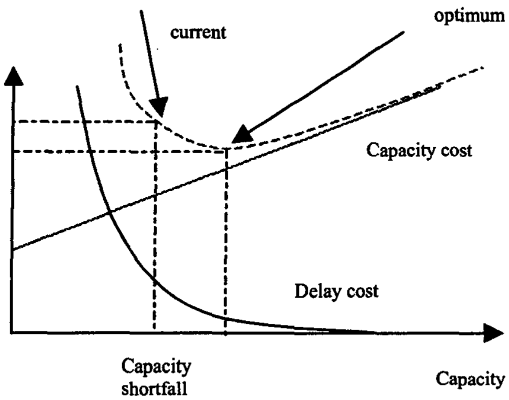

Figure 6. Capacity, Delay And Combined Costs

Once the overall target is obtained then individual capacity profiles for each ACC can be illustrated as follows:

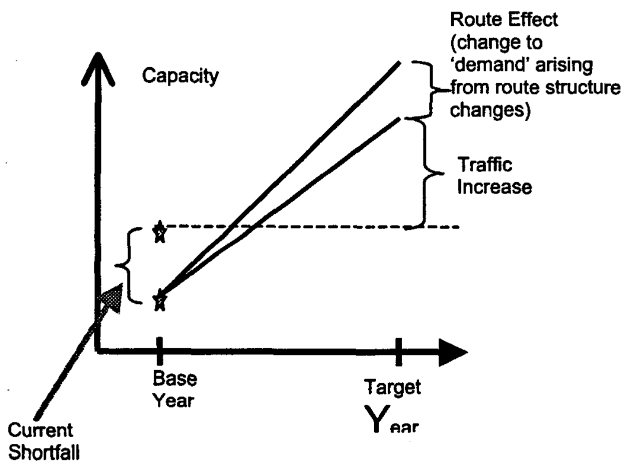

Figure 7. Required ACC Capacity Evolution

Performance Predictions

One of the benefits of the FAP tool-set, particularly the ATFM network simulator, is that it can not only be used for assigning capacity targets as described above but it can also be used for providing performance predictions as a consequence of changes in the level of demand and/or capacity provided both en-route and at airports.

The sixth meeting of the ECAC Ministers of Transport in January 2000 (MATSE/6) included a discussion on the "Constraints to Growth". It was recognised by all parties that the scope for capacity increases in certain parts of Europe is limited and therefore not only should the consequences of increased demand levels be studied but also measures should be taken to promote a better use of existing capacity. Ways of managing or constraining demand could include the increased use of larger aircraft, use of less congested time periods/airports and the promotion of a more integrated air and surface transport infrastructure.

The comprehensive set of simulation tools at the heart of FAP places it in a unique position to provide a greater insight into the effect on ATFM delay associated with future scenarios. The use of ATFM delay is proposed since it is a variable which is directly visible to the airline community and one upon which future strategy and investment decisions may be made.

These performance predictions can address issues such as market access (difficulties of gaining airport slots) as well as delay predictions arising from evolutions in the level of capacity provision or the nature of the demand. Although such performance analysis for future scenarios is interesting in its own right, the quality of the predictions concerning traffic growth and capacity provision necessarily decrease as the prediction horizon increases. It is therefore more interesting and beneficial for the longer term to consider the sensitivity of the network to changes in the demand and capacity profile through comparative analysis.

Market Access

The lack of capacity and therefore slot availability at a number of airports in Europe acts as a barrier to airlines both wishing to enter the market and to those wishing to further develop their services. The number of slots available in a given airport will depend on the most binding constraint and takes into account not only the runway capacity constraints but also constraints comprising apron movements, gate availability and terminal facilities [2].

For slot allocation purposes, airports are classified as either Non co-ordinated (capacity is adequate to meet the demands of users), Co-ordinated (demand is approaching capacity and some voluntary co-operation between the airlines is required at certain time periods) or fully co-ordinated (demand exceeds capacity and formal procedures for the co-ordination of schedules is required).

The following figure indicates the number of slot requests received at Birmingham UK (co-ordinated) airport for the peak week in Summer 2001. Dark areas indicate those time periods where the number of requests exceeded the airport slot capacity:

Cleared time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
500	[illegible]	[illegible]	21	20	[illegible]	13	11
600	30	28	29	[illegible]	31	22	12
700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	18
800	32	32	[illegible]	[illegible]	[illegible]	27	19
900	[illegible]	28	[illegible]	20	[illegible]	20	20
1000	[illegible]	25	24	26	28	25	15
1100	27	28	28	27	28	22	18
1200	[illegible]	[illegible]	28	[illegible]	[illegible]	28	24
1300	22	25	18	25	21	22	23
1400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20	28
1500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22	33
1600	31	30	28	28	25	11	23
1700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	37
1800	28	28	27	27	31	18	30
1900	27	25	27	25	27	12	27
2000	21	18	28	18	21	9	18
2100	7	8	8	4	8	12	4

Figure 8. Market Access Constraints

The FAP tool-set has been used to analyse the extent to which airports will act as constraining parameters in the future system. By considering a baseline traffic sample (typically the actual European traffic over a 14 day period i.e. around 26000 flights per day), the anticipated growth on each traffic flow, and the individual airport hourly capacities, it is possible to identify "capacity busts". These are periods where growth is likely to be constrained by airport capacity if the same temporal nature of the demand is to be retained. In some cases, these flights which constitute the "capacity busts" could potentially be accommodated in less busy periods or at less capacity constrained airports but the first approach is to construct the "do-nothing" scenario (so-called because it reflects the augmented nature of the demand today with no demand management strategies to avoid the constraints). The future traffic sample is constructed through a process of "flight cloning" whereby a real traffic sample is augmented in line with the predictions appropriate to each individual traffic flow.

Those flights which exceed the airport capacity at certain times of the day can be referred to as "unaccommodated demand". The following figure indicates at the overall network level the level of potential demand growth that could not be accommodated at 2006 and 2015.

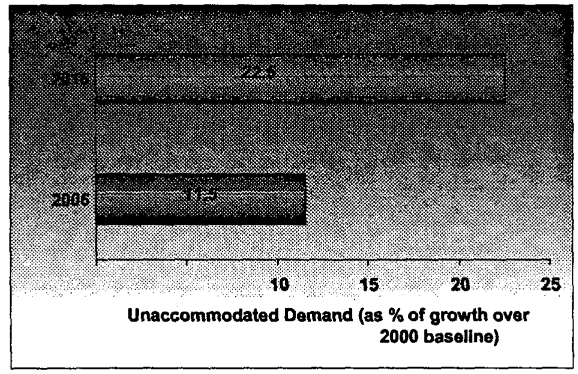

Figure 9. Unaccommodated Demand

This figure indicates that in 2015 some 22.5% of the predicted traffic augmentation beyond 2000 cannot be accommodated by the system as a result of the modelled airport capacity constraints.

Future Delay Evolution ("Do-Nothing")

In order to perform the delay prediction, the individual ACC capacities are assumed to evolve in line with the predictions made by the relevant service providers. For more longer term (15 years) an alternative approach is adopted which takes into account the complexity of the ACC traffic flows and the inherent difficulties of achieving capacity increases through traditional means.

A number of service providers do not predict meeting their medium term (2006) capacity targets as defined by FAP. Through the ATFM network simulator we are able therefore to predict the likely consequences in terms of delay as a result of these capacity shortfalls.

Using the most recent traffic forecasts, the delay in 2006 is predicted to be 2.8 minutes per flight. Unlike the performance in Summer 2000 (Figure 2), the delay is predicted to be centred in a small number of major bottlenecks. This is a consequence of the fact that when capacity is poorly adapted to demand, the level of delay can increase in an exponential fashion, as described earlier). The following figure indicates the network delay distribution for 2006 :

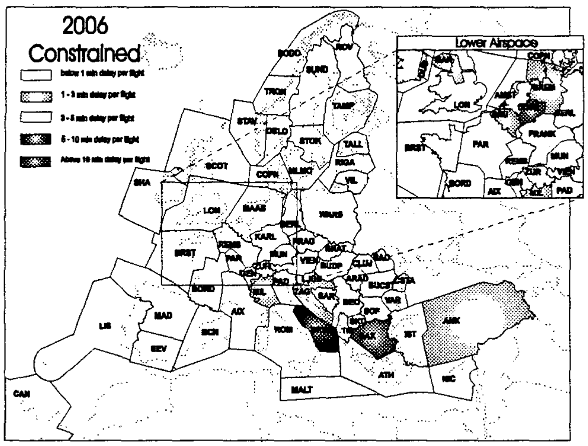

Figure 10. Delay Prediction 2006

Alternative Demand Distribution Scenarios

The aim of the subsequent sections is to explore the effect of constructing demand schedules for future time horizons (e.g. 2006, 2015) but using successively more relaxed parameters than those defined in the definition of the "do-nothing" scenario[4]. A number of such approaches have been tried to some degree in the U.S [3] and are now becoming the centre of vigorous debate in Europe [4].

Schedule Smoothing

The objective 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 thought of 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.

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, alternative traffic samples were constructed, containing the same volume of flights as the "do-nothing" scenario at the 2015 time horizon but each with a modified temporal distribution.

For each scenario, the level of en-route and airport delay was determined through ATFM simulation. 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. Interestingly, the en-route level of delay is relatively constant in each of the scenarios, indicating a reduced sensitivity in en-route airspace to localised peaks in the airport demand profile.

Accommodating Flights In Less Congested Time Periods

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.

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 illustrated in the following figure :

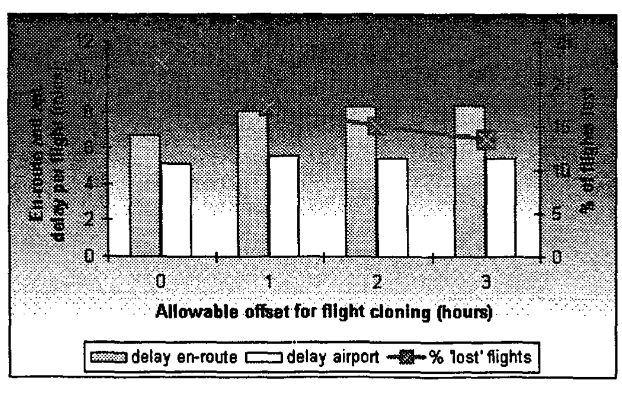

Figure 11. Accommodating Growth In Less Busy Periods

[4] i.e. *inter-alia* to allow flights to be scheduled in less busy periods or to use alternative less congested airports.

Frequency Capping

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.

In the U.S, Continental Airlines 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 [3].

Although some consider such actions to be anti-competitive [5], it is worthy of note that the number of airport pairs which would be impacted by such actions is relatively small. At the 2015 time horizon, 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.

Three simulations were performed in which the number of flights 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. The following figure summarises the results:

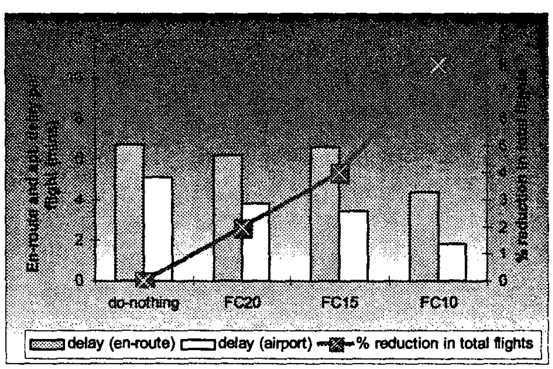

Figure 12. Delay Due To Reduced Frequency Operations

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.

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.

Increased Use Of Secondary Airports

One of the characteristics of European air transport is the high level of market concentration. Indeed, an analysis of the Summer period of 2000 indicates that 50% of the total number of movements were concentrated into the 40 busiest 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. These carriers have provided substantial stimulation of new air traffic due to the establishing of new point to point services from under-utilised or secondary airports which require lower landing fees and provide a better guarantee concerning faster turnaround times - an important factor in the high rotation' nature of the operation of these 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 – under the condition that there was already at least one existing daily flight on this market[5]. Should this

[5] This condition is imposed to ensure that no "unrealistic" airport pair markets are constructed

not be possible then the flight remained as an "unaccommodated" flight.

In this way, a demand forecast was generated which sought to accommodate the desired 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.

The percentage of 'lost' flights (i.e. those for which suitable alternative airports could not be found) reduced from 22.5% (constrained "do-nothing" scenario) to 6.5%. Interestingly, whilst the en-route delay is relatively stable between the two scenarios, there is a notable decrease in the level of airport delay due to the increased level of fragmentation of the market.

Multi-Modal Transport : High Speed Rail

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. 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 categories 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 level of interaction has not been modelled here, but instead, a potential future European rail network has been studied and different "impact thresholds" applied according to the anticipated rail journey time. For short (< 2hours) rail journeys, a reliable rail service could almost completely replace the air service. For longer journeys there will be some level of competition between the modes. At still longer journey times, the rail service ceases to become a viable competitor to the air services and where there is duplication, each mode of transport will attract its own particular "brand" of customer.

The study was based on information from the *UIC-High speed train division* [6] who provide predictions of the likely high speed rail map in Europe at 2010. This data 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 projects.

The applied strategy for substitution and replacement based on the rail journey time 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. However, the predicted en-route and airport delay are observed to reduce significantly as a result of this approach by 24.2% and 68.4% respectively.

Conclusions

This paper has presented an analytical environment which has been developed to address the need to identify capacity increases throughout European airspace so as to converge to a medium term performance target at the overall network level.

The same set of tools can also be used to investigate the network sensitivity to changes in the nature of the demand profile. These changes may in the future become necessary as capacity levels act as a constraining factor to the unfettered growth of civil aviation.

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