EUROCONTROL

Federal Aviation Administration

U.S./Europe Comparison of ATM-related Operational Performance

Produced by the Performance Review Commission
and the Air Traffic Organization Strategy and Performance Business Unit

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BACKGROUND

This document is a joint publication of the Air Traffic Organization Strategy and Performance Business Unit of the FAA and the Performance Review Commission of EUROCONTROL in the interest of the exchange of information.

The objective was to make a factual high-level comparison of operational performance between the US and European air navigation systems. The initial focus was to develop a set of comparable performance measures in order to create a sound basis for factual high-level comparisons between countries and world regions. The specific key performance indicators (KPIs) are based on best practices from both the Air Traffic Organization Strategy and Performance Business Unit and the Performance Review Commission.

U.S./Europe Comparison of ATM-related Operational Performance

Final Report – October 2009

ABSTRACT

Air Navigation Service Providers (ANSPs) are continually seeking to improve operations. Measures derived from operational databases are a key component to assessing performance and recommending improvements. This paper examines several key performance indicators derived from comparable operations databases for both EUROCONTROL and the Federal Aviation Administration (FAA). This research effort developed a comparable population of operations data and harmonized assessment techniques for developing reference conditions for assessing performance. In the end, measures that address efficiency, punctuality and predictability are presented that can compare high level performance between the two systems by phase of flight.

Produced by the Performance Review Commission and
the Air Traffic Organization Strategy and Performance Business Unit

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INTRODUCTION

As in any industry, global comparisons and benchmarking including data analysis can help drive performance and identify best practices in Air Traffic Management (ATM).

Over the years, various groups have sought to estimate the amount of inefficiency that can be addressed by improvements in the ATM system.

Publicly-available data include the 1999 Intergovernmental Panel on Climate Change (IPCC) report which identified a potential 6%-12% inefficiency in the system due to ATM. However, its conclusions drew on analysis that was even then over 10 years old.

Air Navigation Services Providers (ANSP) have also developed methods of examining their operational data in order to identify benefit pools for their system.

In 2003, the FAA presented a paper at the 5th USA/Europe Air Traffic Management Research and Development Seminar. The paper examined flight efficiency by the en-route and terminal phase of flight. It identified the major causal factors that contribute to en-route inefficiency and presented a framework that calculated excess distance outside the terminal environment.

Since then, the FAA has recognised the importance of expanding this work to assess gate-to-gate efficiencies that can be used to assess system performance for comparison with ATM estimates worldwide. This work has led to collaborative efforts between the Air Traffic Organization Strategy and Performance Business Unit of the FAA and the Performance Review Unit (PRU) of EUROCONTROL on the assessment of operational service quality related to ATM described in this report.

The objective of this report, therefore, is to make a factual high-level comparison of operational performance between the US and Europe Air Navigation systems, and to provide updated key system-level figures.

The initial focus has been to develop a set of comparable performance measures in order to create a sound basis for factual high level comparisons between countries and world regions.

Where possible, reasons for differences in system performance were explored in more detail in order to provide an understanding of underlying performance drivers or, where necessary, to stimulate more detailed analyses.

The specific key performance indicators (KPIs) are based on best practices from both the Strategy and Performance Business Unit and PRC. In order to better understand the impact of ATM and differences in traffic management techniques, the analysis is broken down by phase of flight (i.e. pre-departure delay, taxi out, en-route, terminal arrival, taxi-in and arrival delay) as well as aggregate measures. The breakdown by phase of flight supports better measurements of fuel efficiency.

HIGH LEVEL VIEW OF THE ATM SYSTEMS IN EUROPE AND THE US

Table I shows selected high-level figures for the European and the US Air Navigation systems.

TABLE I: US/EUROPE KEY ATM SYSTEM FIGURES (2008)

Calendar Year 2008	Europe	USA	Difference US vs. Europe
Geographic Area (million km²)	11.5	10.4	≈ -10%
Number of en-route Air Navigation Service Providers	38	1	
Number of Air Traffic Controllers (ATCOs in Ops.)	16 800	14 000	≈ -17%
Total staff	56 000	35 000	≈ -40%
Controlled flights (IFR) (million)	10	17	≈ +70%
Share of flights to/ from top 34 airports	68%	64%	≈ -5%
Share of General Aviation Traffic	4%	23%	≈ x 5.5
Flight hours controlled (million)	14	25	≈ +80%
Relative density (flight hours per km²)	1.2	2.4	≈ x 2
Average length of flight (within respective airspace)	541 NM	497 NM	≈ -8%
Nr. of en-route centres	65	20	≈ - 70%
En-route sectors at maximum configuration	679	955	≈ +40%
Nr. of airports with ATC services	≈450	≈263	≈ -42%
Of which are slot controlled	> 73	3	
Source	Eurocontrol	FAA/ATO	

The total surface of continental airspace is similar in Europe and the US. However, the FAA controls approximately 70% more flights and handles significantly more visual Flight Rules (VFR) traffic with some 17% less controllers and fewer en-route facilities. The fragmentation of European ANS with 38 en-route ANSPs is certainly a driver behind such difference.

Figure I shows the traffic density in US and European en-route centres measured in flight hours per square kilometre for all altitudes.

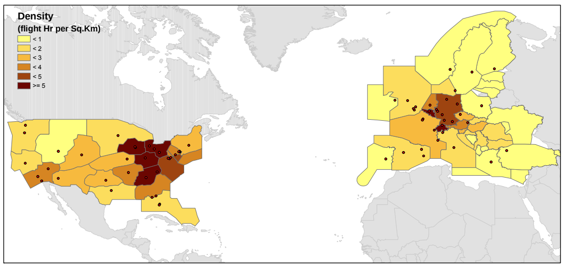


FIGURE I: TRAFFIC DENSITY IN US AND EUROPEAN EN-ROUTE CENTERS

The density in Europe would increase relative to the US if only upper flight levels were considered (the propeller GA aircraft in the US would be excluded). Detailed comparisons on complexities are beyond the scope of this report.

Figure II shows the evolution of IFR traffic in the US and in Europe between 1999 and 2008.

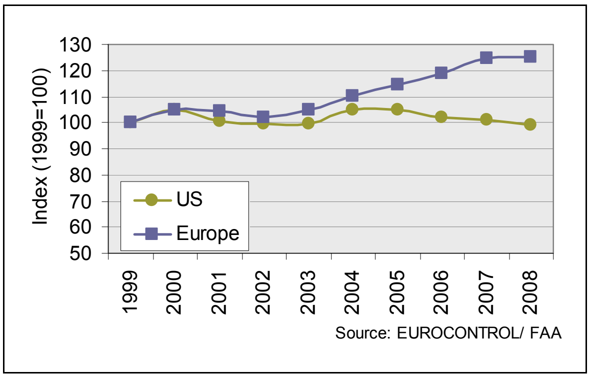


FIGURE II: EVOLUTION OF IFR TRAFFI IN THE US AND IN EUROPE

Over this period, the number of controlled flights did not increase in the US, and increased approximately +25% in Europe (~4% p.a.). However, these average values mask contrasted growth rates within the US and Europe.

In Europe, much of the air traffic growth was driven by strong growth in the emerging markets in the Eastern European States and low cost carriers.

The US is a more homogenous and mature market which shows a different behaviour and less growth. Despite the virtually zero growth rate in the US, a continuous growth of traffic was observed in the high volume airports in the New York area.

An important difference between the US and Europe is the share of general aviation which accounts for 23% and 4% of total traffic in 2008 respectively.

In order to improve comparability of data sets, the more detailed analyses were limited to controlled (IFR) flights from or to the 34 most important airports in the US (OEP34) and Europe.

Traffic to/from the main 34 airports in 2008 represents some 68% of all IFR flights in Europe and 64% in the US.

Table II provides high-level indicators for the main 34 airports in the US and in Europe.

TABLE II: SOME KEY AIPORT DATA

Main 34 airports in 2008	**Europe**	**US**	**Difference US vs. Europe**
Average number of annual movements per airport ('000)	265	421	+59%
Average number of annual passengers per airport (million)	25	32	+29%
Passengers per movement	94	76	-19%
Average number of runways per airport	2.5	4.0	+61%
Annual movements per runway ('000)	106	107	+1%
Annual passengers per runway (million)	10.0	8.1	-19%

The average number of runways (+61%) and the number of movements (+59%) are significantly higher in the US while the number of passengers per movement (-19%) is much lower than in Europe

Average seat size per scheduled flight differs in the two systems, with Europe having a higher percentage of flights using "large" aircraft than the US. Average seat size per scheduled flight over time is shown in Figure III.

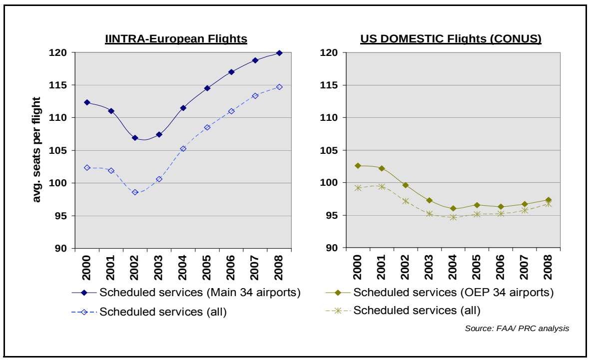


FIGURE III: AVERAGE SEATS PER SCHEDULED FLIGHT

AIR TRAFFIC FLOW MANAGEMENT TECHNIQUES

Both the US and Europe have established system-wide traffic management facilities to ensure that traffic flows do not exceed what can be safely handled by controllers, while trying to optimize the use of available capacity.

However, for a number of operational, geopolitical and even climatic reasons, Air Traffic Flow Management (ATFM) techniques have evolved differently in the US and in Europe:

- While both Air Navigation systems are operated with similar technology and operational concepts, there is only one service provider in the US, all US Centers use the same automation systems and have procedures for cooperation on Inter-Centre flow management.

- In Europe, there are 38 en-route service providers of various geographical areas with little obligation or incentives to cooperate on flow management (e.g. sequencing traffic into major airports of other States) and operating their own systems, which may affect the level of coordination in ATFM and ATC capacity.
- Additionally, in many European States, civil air navigation service providers co-exist with military ANSPs. This can make ATC operations and airspace management more difficult.
- The two systems also differ considerably in terms of scheduling of operations at airports.
- In Europe, traffic at major (coordinated) airports is usually controlled (in terms of volume and concentration) in the strategic phase through the airport capacity declaration process, and the subsequent allocation of airport slots to aircraft operators months before the actual day of operation.
- In the US, airline scheduling is unrestricted at most airports. Demand levels are controlled by airlines and adapted depending on the expected cost of delays and the expected value of operating additional flights (without the risk of losing valuable airport slots as is the case in Europe).
- The airport capacity declaration process at European airports could arguably result in capacities closer to IFR capacity while in the US, where demand levels are controlled by airlines and VFR conditions are more prominent, the airports are scheduled closer to VFR capacity.
- While the unrestricted scheduling at US airports encourages high airport throughputs levels, it also results in higher level of variability when there is a mismatch between scheduled demand and available capacity.
- In the US, convective weather/ thunderstorms are quite severe and widespread in the summer (mostly Eastern half) and may require ground holds and continent wide reroutings of entire traffic flows.

The two ATFM systems differ notably in the timing (when) and the phase of flight (where) ATFM measures are applied.

In Europe, the majority of demand/capacity management measures are applied months in advance through the strategic agreements on airport capacities and slots. In addition, demand is managed in pre-tactical phases (allocation of ATFM take-off slots). The European system operates airport streaming on a local and distributed basis with the CFMU mainly protecting the en-route segments from overload.

In the US, demand management mainly takes place on the day of operation when necessary. The US system appears to have less en route capacity problems and is geared towards maximising airport throughput. With less en-route capacity restrictions, the US has the capability to absorb large amounts of speed control and path stretching in en-route airspace in order to achieve the metering required by TMAs and airports.

Ground based flow management

In Europe when traffic demand is anticipated to exceed the available capacity in en-route control centres or at an airport, ATC units may call for "ATFM regulations". Aircraft subject to ATFM regulations are held at the departure airport according to "ATFM slots" allocated by the Central Flow Management Unit (CFMU).

In the US, ground delay programs are mostly used in case of severe capacity restrictions at airports when less constraining ATFM measures, such as Time Based Metering or Miles in Trail (MIT) are not sufficient. The Air Traffic Command Center (ATCSCC) applies Estimated Departure Clearance Times (EDCT) to delay flights prior to departure. Most of these delays are taken at the gate.

Airborne Flow Management

There is currently no or very limited en-route spacing or metering in Europe. When sequencing tools and procedures are developed locally, their application generally stops at the State boundary.

In the US, in order to ensure maximum use of available capacity in en-route centres and arrival airports, traffic flows are controlled through Miles in Trail (MIT) and Time Based Metering (TBM). Flow restrictions are passed back from the arrival airport to surrounding centres and so on as far as necessary. Ultimately MIT can also affect aircraft on the ground. En Route caused restrictions are small compared to airport driven flow restrictions in the US.

Terminal Management Area

In both the US and the European system, the terminal area around a congested airport is used to absorb delay and keep pressure on the runways. Traffic Management initiatives generally recognize maximizing the airport throughput as paramount.

With TBM systems in US Control Facilities, delay absorption in the terminal area is focused on keeping pressure on the runways without overloading the terminal area. With MIT and TBM, delays can be absorbed further back at more fuel efficient altitudes.

COMPARISON OF OVERALL AIR TRANSPORT PERFORMANCE

This section evaluates operational air transport performance compared to airline schedules in the US and in Europe. It furthermore analyses trends in the evolution of scheduled block times.

On-time performance (Punctuality)

Figure IV compares the industry-standard indicators for punctuality, i.e. arrivals or departures delayed by more than 15 minutes versus schedule.

After a continuous decrease between 2004 and 2007, on-time performance in Europe and in the US shows an improvement in 2008. However, this improvement needs to be seen in a context of lower traffic growth as a result of the global financial and economic crisis, and increased schedule padding in the US (see Figure V).

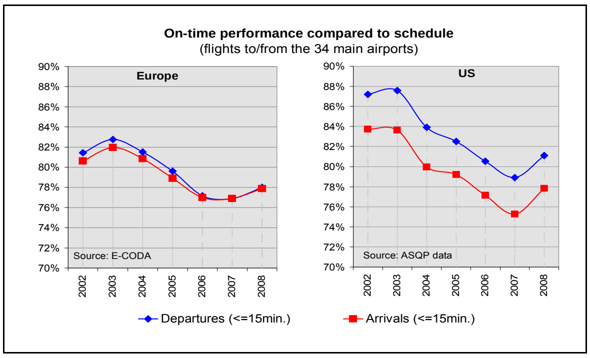


FIGURE IV: ON-TIME PERFORMANCE (2002-2008)

The gap between departure and arrival punctuality is significant in the US and quasi nil in Europe. This can be linked with different flow management and airport capacity allocation policies.

Evolution of scheduled block times

Figure V shows the evolution of airline scheduling times in Europe and the US. The analysis compares the scheduled block times for each flight of a given city pair with the long term average for that city pair over the full period (2000-2008).

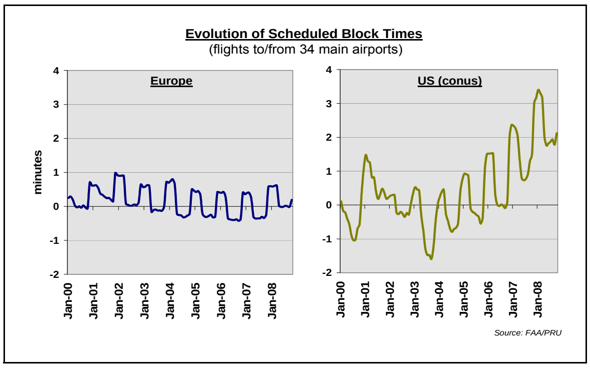


FIGURE V: SCHEDULING OF AIR TRANSPORT OPERATIONS (2000-2008)

Between 2000 and 2008, scheduled block times remained stable in Europe while in the US average block times have increased by some 2 minutes between 2005 and 2008. These increases may result from adding block time to improve on-time performance or could be tied to a tightening of turn-around-times.

Seasonal effects are visible, scheduled block times being on average longer in winter than in summer. US studies by the former Free Flight Office have shown that the majority of increase is explained by stronger winds on average during the winter period.

Predictability of operations

Predictability evaluates the level of variability in each phase of flight as experienced by the airspace users. In order to limit the impact from outliers, variability is measured in 0as the difference between the 80th and the 20th percentile for each flight phase.

Figure VI shows that in both Europe and the US, arrival predictability is mainly driven by departure predictability.

Between 2003 and 2007, departure time variability continuously increased on both sides of the Atlantic. Contrary to Europe, variability increased also in the taxi-out and flight phase in the US, which appears to be driven by the different approaches in both scheduling operations and absorbing necessary delay.

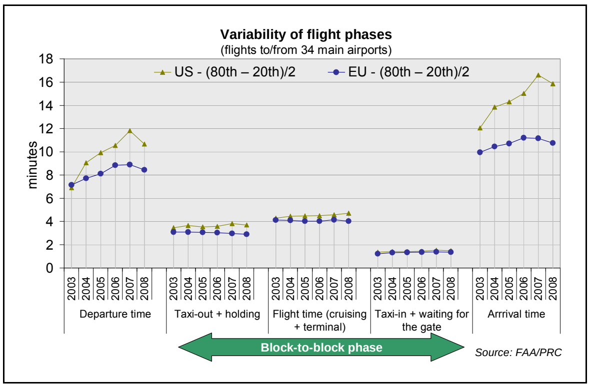


FIGURE VI: VARIABILITY OF FLIGHT PHASES (2003-2008)

As demand increases in congested areas, the variability in times in all flight phases also increases. Over the last 5 years, the US has seen demand increases at congested major airports, driving the variability of the overall ATM system.

EFFICIENCY OF AIR TRANSPORT PERFORMANCE

"Efficiency" generally relates to fuel efficiency or reductions in flight times of a given flight. The analyses in this chapter consequently focus on the difference between the mean travel times and an optimum time.

Figure VII provides a first analysis of how the duration of the individual flight phases has evolved over the years in Europe and the US. The analysis is based on the DLTA Metric and compares actual times for each city pair with the long term average for that city pair over the full period (2003-2008).

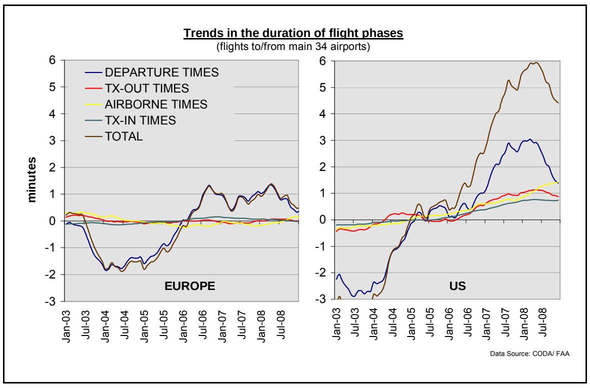


FIGURE VII: TRENDS IN THE DURATION OF FLIGHT PHASES

In Europe, performance is clearly driven by departure delays with only very small changes in the gate-to-gate phase. In the US, the trend is different: in addition to a deterioration of departure times, there is a clear increase in average taxi times and airborne times.

Inefficiencies in the different flight phases have different impacts on aircraft operators and the environment. Whereas ANS-related holdings (ATFM/EDCT delay) result in departure delays mainly experienced at the stands, inefficiencies in the gate-to-gate phase also generate additional fuel burn. The additional fuel burn has an environmental impact through gaseous emissions (mainly CO_2).

This section focuses particularly on the ANS contribution towards overall air transport performance. In order to account for differences in fuel burn, the following section is broken down by phase of flight. The section concludes with an overview of the estimated ANS contribution in individual flight phases.

Before looking at the ANS contribution in more detail, the following points should be borne in mind:

- Not all 'delay' is to be seen as negative. A certain level of 'delay' is necessary and sometimes even desirable if a system is to be run efficiently without under-utilization of available resources.
- Some indicators measure the difference between the actual situation and an ideal (un-congested or unachievable) situation where each aircraft would be alone in the system and not be subject to any constraints. This is for example the case for horizontal flight efficiency which compares actually flown distance to the great circle distance.
- A clear-cut allocation between ATM and non-ATM related causes is often difficult. While ATM is often not the root cause of the problem (weather, etc.) the way the situation is handled can have a significant influence on performance (i.e. distribution of delay between air and ground) and thus on costs to airspace users.
- The approach measures performance from a single airspace user perspective without considering inevitable operational trade-offs, environmental or political restrictions, or other performance affecting factors such as weather conditions.
- ANSP performance is inevitably affected by airline operational trade-offs on each flight. The measures in this report do not attempt to capture airline goals on an individual flight basis. Airspace user preferences to optimize their operations based on time and costs can vary depending on their needs and requirements (fuel price, business model, etc.).

ANS-related departure/gate holdings

This section reviews ANS-related departure delays in the US and in Europe (EDCT vs. ATFM). Aircraft that are expected to arrive during a period of capacity shortfall en-route or at the destination airport are held on the ground at their various origin airports.

ATFM/EDCT departure delays can have various ATM-related (ATC capacity, staffing, etc.) and non-ATM related (weather, accident etc.) reasons.

Table III compares ANS-related departure delays attributable to en-route and airport constraints. For comparability reasons, only EDCT and ATFM delays larger than 15 minutes were included in the calculation.

TABLE III: ANS-RELATED DEPARTURE DELAYS (MAIN 34 AIRPORTS)

Only delays > 15 min. are included.		En-route related delays >15min. (EDCT/ATFM)			Airport related delays >15min. (EDCT/ATFM)		
2008	IFR flights (M)	% of flights delayed >15 min.	delay per flight (min.)	delay per delayed flight (min.)	% of flights delayed >15 min.	delay per flight (min.)	delay per delayed flight (min.)
US	9.2	0.1%	0.1	57	2.6%	1.8	70
Europe	5.6	5.0%	1.4	28	3.0%	0.9	32

The share of flights affected by ATFM/EDCT delays due to en-route constraints differs considerable between the US and Europe. In Europe, flights are as much as 50 times more likely to be held at the gate for en-route constraints.

For airport related delays, the percentage of delayed flights at the gate is similar in the US and in Europe.

In the US, ground delays (mainly due to airport constraints) are applied only after time based metering or miles in trail options are used which consequently leads to a lower share of flights affected by EDCT delays but higher delays per delayed flight than in Europe. More analysis is needed to see how higher delays per delayed flight are related to moderating demand with "airport slots" in Europe.

In Europe, ground delays (ATFM) are used much more frequently for balancing demand with en-route and airport capacity which consequently leads to a higher share of traffic affected but with a lower average delay per delayed flight.

Taxi-out efficiency

The analysis of taxi-out efficiency in the next sections refers to the period between the time when the aircraft leaves the stand (actual off-block time) and the take-off time. The additional time is measured as the average additional time beyond an unimpeded reference time.

The taxi-out phase and hence the performance measure is influenced by a number of factors such as take-off queue size (waiting time at the runway), distance to runway (runway configuration, stand location), downstream restrictions, aircraft type, and remote de-icing to name a few. Of these aforementioned causal factors, the take-off queue size is considered to be the most important one.

In the US, the additional time observed in the taxi-out phase also includes TMS delays due to local en-route departure and MIT restrictions.

Figure VIII shows a significantly higher average additional time in the taxi-out phase in the US (6.2 minutes per departure) than in Europe (4.3 minutes per departure).

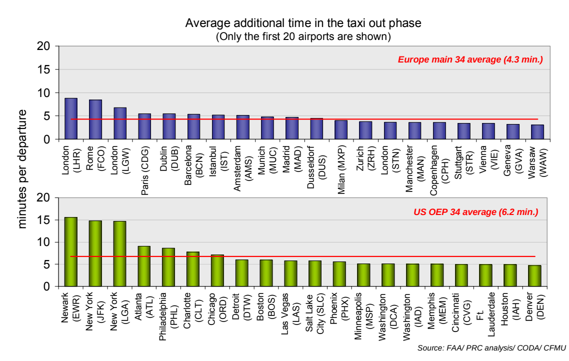


FIGURE VIII: COMPARISON OF ADDITIONAL TIME IN THE TAXI OUT PHASE

The observed differences in inefficiencies between the US and Europe reflect the different flow control policies and the absence of scheduling caps at most US airports. Additionally, the US Department of Transportation collects and publishes data for on-time departures which adds to the focus of getting off-gate on time.

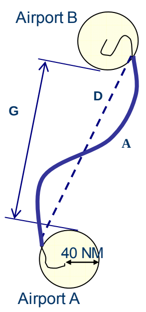
En-route flight efficiency

Deviations from the optimum trajectory generate additional flight time, fuel burn and costs to airspace users. En-route flight efficiency has a horizontal (distance) and a vertical (altitude) component.

The focus of this section is on horizontal en-route flight efficiency, which is of much higher economic and environmental importance than the vertical component. Nevertheless, there is scope for improvement and more work on vertical flight inefficiencies and potential benefits of implementing Continuous Descent Approach (CDA) would form a more complete picture.

The flight efficiency in the terminal manoeuvring areas (TMA) of airports is addressed in the next section. In Europe, en-route flight efficiency is mainly affected by the fragmentation of airspace (airspace design remains under the auspices of the States). For the US the indicator additionally includes some path stretching due to Miles in Trail restrictions.

The Key Performance Indicator (KPI) for horizontal en-route flight efficiency is en-route extension. It is defined as the difference between the length of the actual trajectory (A) and the Great Circle Distance (G) between the departure and arrival terminal areas (radius of 40 NM around the airport).



This difference would be equal to zero in an ideal (and unachievable) situation where each aircraft would be alone in the system and not be subject to any constraints.

While there are economic and environmental benefits in improving flight-efficiency, there are also inherent limitations. Trade-offs and interdependencies with other performance areas such as safety, capacity and environmental sustainability as well as airspace user preferences in route selection due to weather (wind optimum routes) or other reasons (route charges, avoid congestion) need to be considered.

Figure IX depicts the en-route extension for flights to/from the main 34 airports within the respective region (Intra Europe, US-CONUS) and the respective share of flights. "Direct route extension" and corresponding fuel burn are approximately 1% lower in the US for flights of comparable lengths.

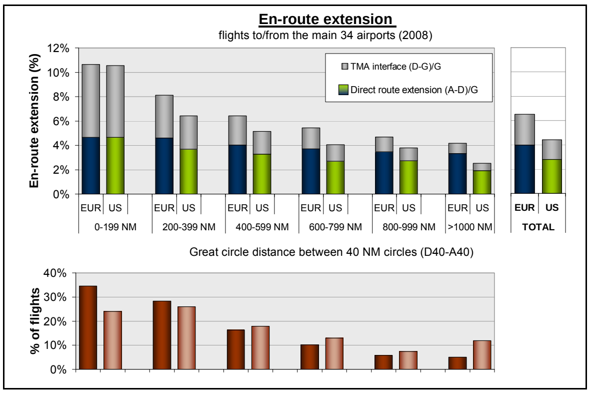


FIGURE IX: COMPARISON OF DIRECT EN-ROUTE EXTENSION

Arrival Sequencing and Metering Area (ASMA) delays

The locally defined TMA is not suitable for comparisons due to considerable variations in shape and size. A standard "Arrival Sequencing and Metering Area" (ASMA) is defined as a ring of 100NM radius around each airport. This is generally adequate to capture tactical arrival control measures (sequencing, flow integration, speed control, spacing, stretching, etc.) irrespective of local ATM strategies.

The figure below shows the additional time within the last 100NM. The "additional" time is used as a proxy for the level of inefficiency within the last 100NM. It is defined as the average additional time beyond the unimpeded transit time for each airport.

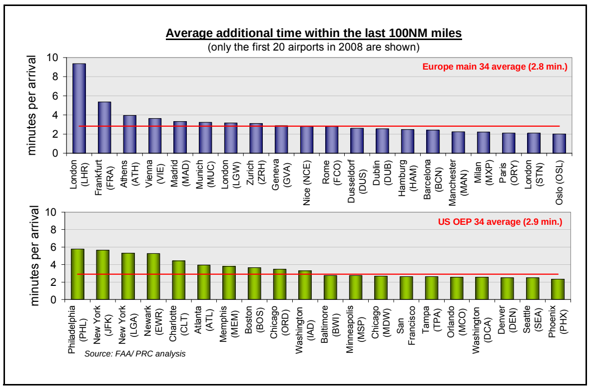


FIGURE X: AVERAGE EXCESS TIME WITHIN THE LAST 100 NM

At system level, the additional time within the last 100NM is similar in the US (2.9 min.) and in Europe (2.8 min.). However the picture is contrasted across airports.

In Europe, London Heathrow (LHR) is a clear outlier, having by far the highest level of additional time within the last 100NM, followed by Frankfurt (FRA) which shows only half the level observed at London Heathrow.

The US shows a less contrasted picture but there is still a notable difference for the airports in the greater New York area which show the highest level of inefficiencies within the last 100NM in 2008.

ESTIMATED BENEFIT POOL ACTIONABLE BY ANS

By combining the analyses for individual phases of flight, an estimate of the improvement pool actionable by ANS can be derived. It is important to stress that this "benefit pool" represents a theoretical optimum which is not achievable at system level due to inherent necessary (safety) or desired (capacity) limitations.

Table IV summarises the estimated level of inefficiency actionable by ANS in the individual flight phases, as analysed in the respective sections.

Although Table IV shows an estimated total to provide an order of magnitude, the interpretation requires a note of caution as inefficiencies in the various flight phases (airborne versus ground) have a very different impact on airspace users in terms of predictability (strategic versus tactical - % of flights affected) and fuel burn (engines on vs. engines off).

TABLE IV: ESTIMATED TOTAL BENEFIT POOL ACTIONABLE BY ANS

Estimated benefit pool actionable by ANS for a typical flight (2008) (flights to/from the main 34 airports)		Estimated additional time (avg. per flight in min.)		Predictability (% of flights affected)	
		EUR	US	EUR	US
Holding at gate per departure (only delays >15min. included)	en-route-related	1.4	0.1	5.0%	0.1%
	airport-related	0.9	1.8	3.0%	2.6%
Taxi-out phase (min. per departure)		4.3	6.2	100%	
Horizontal en-route flight efficiency		3.9	2.6	100%	
Terminal areas (min. per arrival)		2.8	2.9	100%	
Estimated benefit pool actionable by ANS		≈13.3	≈13.6		

Whereas for ANS related holdings at the gate the fuel burn is quasi nil, those delays are not evenly spread among flights (small percentage of flights but high delays) and hence difficult to predict.

The estimated "inefficiencies" in the gate-to-gate phase are generally more predictable for airspace users (more evenly spread but smaller delays) but generate higher fuel burn.

Actual fuel burn depends on the respective aircraft mix and therefore varies for different traffic samples. For comparability reasons, the fuel burn shown in Table IV is based on typical average fuel burn which was equally applied to the US and Europe.

At system level, the total estimated inefficiency pool actionable by ANS and associated fuel burn are of the same order of magnitude in the US and Europe (estimated to be between 6-8% of the total fuel burn) but with notable differences in the distribution along the phases of flight.

While ANS is often not the root cause of delay, the way the delay is managed and distributed along the various phases of flight has an impact on airspace users (predictability, fuel burn), the utilisation of capacity (en-route and airport), and the environment (gaseous emissions).

CONCLUSIONS

The analysis of schedule adherence reveals a similar level of arrival punctuality in the US and Europe, albeit with increasing time buffers in airline schedules and a higher level of variability in the US, part of which is assumed to be result of a combination of airport scheduling closer to VFR capacity and resulting weather effects.

The analysis of actual operations is broken down by phase of flight (i.e. pre-departure delay, taxi-out, en-route, terminal arrival, taxi-in and arrival delay). This reveals strong and weak points on both sides.

- In the US, departure punctuality is better, but taxi-out delays are longer and associated unit fuel burn higher.
- Horizontal en-route flight efficiency is higher in the US, with corresponding fuel burn benefits. The fragmentation of European airspace appears to be an issue which affects overall flight efficiency and which limits the ability of the en-route function to support airport throughput. The development of Functional Airspace Block (FAB) within the Single European Sky Initiative is expected to help improve this.
- On average, the additional time within the last 100 NM is comparable. London and Frankfurt on the European side and the airports in the New York area on the US side show significantly higher arrival transit times on average.

Although safety and capacity constraints limit the practicality of ever fully eliminating these "inefficiencies" there is value in developing a systematic approach to aggregating a benefit pool which is actionable by ANS.

Inefficiencies have a different impact (fuel burn, time) on airspace users, depending on the phase of flight (airborne vs. ground) and the level of predictability (strategic vs. tactical).

While ANS is often not the root cause of a delay, the aim should be to optimize how the delay is taken. The predictability of the different flight phases and the fuel cost will help determine how much and where delay needs to be absorbed. Further work is needed to assess the impact of efficiency and predictability on airspace users, the utilisation of capacity, and the environment.

The estimated inefficiency pool actionable by ANS and associated fuel burn is similar in the US and Europe (estimated to be between 6-8% of the total fuel burn) but with notable differences in the distribution by phase of flight.

These differences possibly originate from different policies in allocation of airport slots and flow management, as well as different weather conditions. The impact on environment, predictability and flexibility in accommodating unforeseen changes may be different. In addition to weather and airport congestion management policy, a more comprehensive comparison of service performance would also need to address Safety, Capacity and other relevant performance affecting factors. A better understanding of trade-offs would be needed to identify best practices and policies.

There is high value in global comparisons and benchmarking in order to optimise performance and identify best practice. Moving forward, the conceptual framework enables operational performance to be measured in a consistent way and ATM best practices to be better understood. Identification and application of today's best practices, with existing technology and operational concepts, could possibly help in raising the level of performance on both sides of the Atlantic in the relatively short term, and may have wider applicability.

1 INTRODUCTION

1.1 Background and Objectives

1.1.1 In 2003, the EUROCONTROL Performance Review Commission (PRC) in collaboration with the US Federal Aviation Administration (FAA) carried out a comparison of economic performance (productivity and cost-effectiveness) in selected US and European en-route centres. Its purpose was to measure economic performance in a homogenous way and to identify systemic differences which would explain the significantly higher level of unit costs observed in Europe [Ref. 1]. The corresponding methodology has now been adopted by the International Civil Aviation Organization (ICAO) [Ref. 2].

1.1.2 As in any industry, global comparisons and benchmarking including data analysis can help optimise performance and identify best practices in Air Traffic Management (ATM). Over the years, various groups have sought to estimate the amount of inefficiency that can be addressed by improvements in the ATM system. Publicly-available data include the 1999 Intergovernmental Panel on Climate Change (IPCC) report which identified a potential 6%-12% inefficiency in the system due to ATM. However, its conclusions drew on analysis that was even then over 10 years old. Air Navigation Services Providers (ANSP) have also developed methods of examining their operational data in order to identify benefit pools for their system.

1.1.3 In 2003, the FAA presented a paper at the 5th USA/Europe Air Traffic Management Research and Development Seminar. The paper examined flight efficiency by the en-route and terminal phase of flight [Ref. 3]. It identified the major causal factors that contribute to en-route inefficiency and presented a framework that calculated excess distance outside the terminal environment.

1.1.4 Since then, FAA has recognised the importance of expanding this work to assess gate-to-gate efficiencies that can be used to assess system performance for comparison with ATM estimates worldwide. This work has led to collaborative efforts between the Air Traffic Organization Strategy and Performance Business Unit of the FAA and the Performance Review Unit (PRU) of EUROCONTROL on the assessment of operational service quality related to ATM described in this report.

1.1.5 Before turning to the objective of the report, it has to be emphasised that, with the exception of on-time performance, there is a lack of commonly agreed and comparable performance indicators world-wide (multiple delay definitions even within ANSPs), at the present time.

1.1.6 The objective of this report, therefore, is to make a high-level comparison of operational performance between the US and Europe Air Navigation systems, and to provide updated key system-level figures. The initial focus has been to develop a set of comparable performance measures in order to create a sound basis for factual high level comparisons between countries and world regions.

1.1.7 In order to better understand the impact of ATM and differences in traffic management techniques, the analysis is broken down by phase of flight (i.e. pre-departure delay, taxi-out, en-route, terminal arrival, taxi-in and arrival delay). The breakdown by flight phase also supports better measurements of fuel efficiency.

1.1.8 Where possible, reasons for differences in system performance were explored in more detail in order to provide an understanding of underlying performance drivers or, where necessary, to stimulate more detailed analyses.

1.1.9 Lastly, this report strives to explain the relationship between existing performance measures including competing goals within airlines and how ATM impacts overall performance.

1.2 Study Scope

1.2.1 There is a strong benefit in global comparisons and benchmarking, which requires common definitions and understanding. Hence the work in this report draws from commonly accepted elements of previous work from ICAO, FAA, EUROCONTROL and CANSO. Hence, the specific key performance indicators (KPIs) used in this report are based on best practices from both the Strategy and Performance Business Unit and PRC.

PERFORMANCE AREAS

1.2.2 Based on expectations of the ATM community, the ICAO Global Performance Manual [Ref. 4] identifies eleven Key Performance Areas (KPAs) and groups them by visibility, as shown in Figure 1.

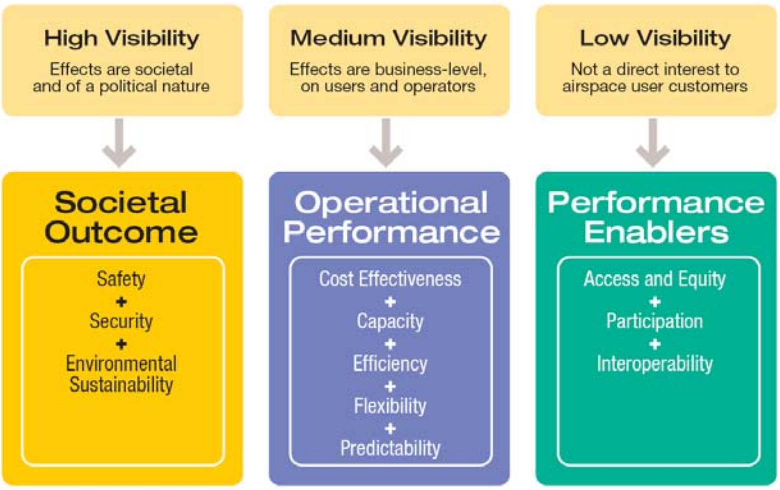


Figure 1: ICAO Key Performance Areas

1.2.3 The scope of this paper is limited to operational service quality. The Key Performance Areas (KPA) addressed are mainly Efficiency and Predictability and, indirectly, Environmental sustainability when evaluating additional fuel burn. To some extent, Capacity is also addressed indirectly as the level of service quality (delays) is generally used as a proxy for the lack of capacity.

1.2.4 Flexibility is currently difficult to measure. It would ultimately measure the ability of airspace users to exploit opportunities in order to optimise their daily operations (i.e.

trade-off speed/time for fuel efficiency or visa versa, prioritize aircraft in arrival sequence, etc.). While this is a worthwhile topic it is outside the scope of this report.

1.2.5 The report also does not directly address other KPAs such as Safety or Cost-effectiveness. It is acknowledged that for a comprehensive comparison of service performance, information about safety, cost and operational performance is needed.

1.2.6 Capacity impacts driving performance are only partially addressed in this report. The relationship between capacity variations/shortages and efficiency problems need further analysis - especially related to weather conditions.

GEOGRAPHICAL SCOPE

1.2.7 In order to ensure comparability of data sets, the scope of the paper was influenced by the need to identify a common set of suitable data sources with a sufficient level of detail and coverage.

1.2.8 Unless stated otherwise, the analyses are limited to controlled commercial (IFR) flights from and to the 34 historically most important airports in terms of commercial/passenger traffic in the US (OEP34[1]) and in Europe. A list of the airports included in this report can be found in Annex I.

1.2.9 For the purpose of this report "Europe" is defined as Air Navigation Services (ANS) provided by the EUROCONTROL States[2] in the EUR region, Estonia and Latvia, excluding Oceanic areas and the Canary Islands.

1.2.10 "US" refers to ANS provided by the Unites States of America in the 48 contiguous States located on the North American continent south of the border with Canada plus the District of Columbia but excluding Alaska, Hawaii and Oceanic areas.

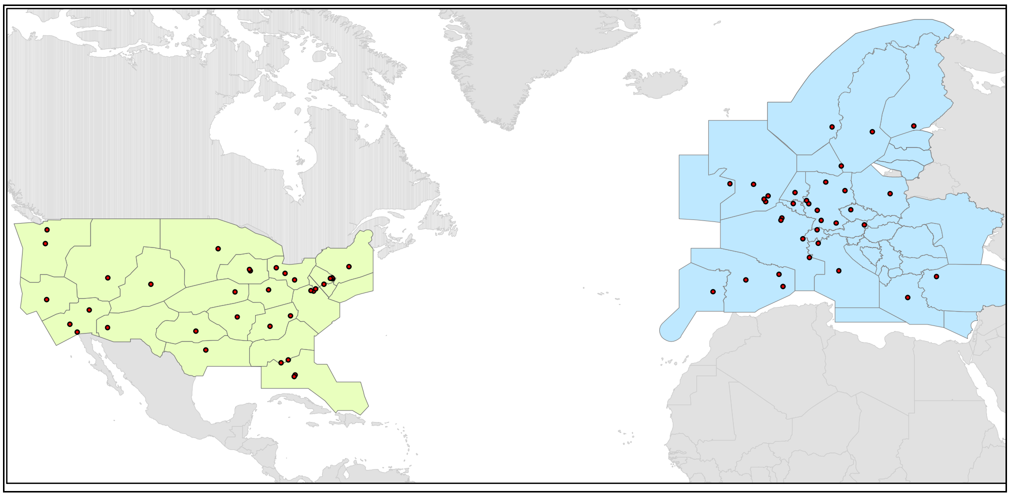


Figure 2: Geographical scope

[1] The list of the Operational Evolution Partnership (OEP) airports - 35 in total - was compiled in 2000, by agreement between the FAA and Congress, drawing on a study that identified the most congested airports in the US. That list has remained unchanged since then. Key FAA performance measures are based on data from this set of airports. For comparison reasons, Honolulu (HNL) was removed from the sample.

[2] The list of EUROCONTROL States can be found in the Glossary.

TEMPORAL SCOPE

1.2.11 The economic crisis which started in the second half of 2008 resulted in a very significant reduction of air traffic in the US and in Europe. Whereas most of the analyses refer to the calendar year 2008, some still refer to the calendar year 2007 in order to avoid a bias from the economic crisis.

1.3 Data sources

1.3.1 There are many different data sources for the analysis of ATM-related operational air transport performance. For consistency reasons, most of the data in this study were drawn from a combination of centralised airline reporting and operational Air Traffic Management systems.

DATA FROM AIRLINES

1.3.2 The US and Europe receive both operational and delay data from airlines for scheduled flights.

1.3.3 In the US, air carriers are required to report performance data if they have at least 1% of total domestic scheduled-service passenger revenues (plus other carriers that report voluntarily). Schedule data does not exist for IFR GA flights, which drives the overall percentage of reporting flights down to approximately 52% of all IFR flights. In the US, there is schedule related data reported for 69% of commercial flights at OEP 34 airports.

1.3.4 The data cover non-stop scheduled-service flights between points within the United States (including territories). Data includes what is referred to as OOOI (Out of the gate, Off the runway, On the runway, and Into the gate). OOOI data along with airline schedules allow for the calculation of gate delay, taxi times, en route times, and gate arrival times delays on a flight by flight basis.

1.3.5 The data also contains causes for arrival delays over 15 minutes on a flight by flight basis. Major cause categories include ATM system, Security, Airline, Extreme Weather, and Late Arrival (from previous leg).

1.3.6 In Europe, the Central Office for Delay Analysis (CODA) collects data from airlines each month. The data collection started in 2002 and the reporting is voluntary.

1.3.7 Currently, the CODA coverage is approximately 60% of scheduled commercial flights and approx. 83% at the 34 main airports. The data reported are similar to the US and include OOOI data, schedule information and causes of delay, according to the IATA delay codes.

1.3.8 A significant difference between the two airline data collections is that the delay causes in the US relate to arrivals, whereas in Europe it relates to the delays experienced at departure.

DATA FROM AIR TRAFFIC MANAGEMENT SYSTEMS

1.3.9 In the US and Europe, key data also come from their respective Traffic Flow Management Systems. For the US, data come from the Enhanced Traffic Management System (ETMS). In Europe, data are derived from the Enhanced Tactical Flow Management System (ETFMS) of the Central Flow Management Unit (CFMU) located in Brussels, Belgium.

1.3.10 Both of these systems have data repositories with detailed data on individual flight plans and track sample points from actual flight trajectories[3]. They also have built-in capabilities for tracking ATM related ground delays[4] by airport and en route reference location.

1.3.11 The data sets also provide information for the calculation of flight efficiency in terms of great circle distance (or wind optimal routes), planned routes and actual flow routing. Initially these data sets focused on the En Route phase of flight but, more recently, they include data in the transition and terminal areas of flight, thus allowing for terminal area benchmarking.

ADDITIONAL DATA ON CONDITIONS

1.3.12 For post operational analyses focused on causes of delay and a better understanding of real constraints. Additional data is needed for airport capacities, runway configurations, sector capacities, winds, visibility and convective weather. The FAA/Air Traffic Organization (ATO) is collecting this data at major airports and uses commercially available data to assess convective weather impacts at a high level. While both EUROCONTROL and the FAA/ATO are in the process of improving these databases, more focus is needed in order to better understand underlying drivers.

1.4 Organisation of this report

1.4.1 The report is organised as follows:

- Chapter 2 provides a high level overview of the two ATM systems providing key figures and a comparison of basic traffic characteristics in order to assess the comparability of the two traffic samples.

- Chapter 3 provides a brief description of basic differences in Air Traffic Management Techniques between Europe and the US and presents the approach used for the assessment of ATM related service performance in the US and in Europe. Lastly, the chapter highlights some important points for the interpretation of the results in this report.

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3 The CFMU updates flight profiles if the position received deviates by more than a given threshold (vertical 007 FL, horizontal 20 NM, temporal 5 min.) from the current estimated trajectory. In the US total distance is calculated by integrating the distance between all recorded data points.

4 Delays are calculated as the difference between the last Estimated take-off time (ETOT) in the flight plan and the Calculated take-off time (CTOT).

- Chapter 4 evaluates air transport on time performance with respect to airline schedules, historic trends in the scheduling of block times, and underlying delay reasons as reported by airlines.

- Chapter 5 addresses the KPA "Predictability" which evaluates the level of variability in the ATM system as experienced by the airspace users.

- Chapter 6 provides an estimate of the level of "Efficiency" of air transport operations compared to an optimum reference time. In order to better understand the impact of ATM and differences in traffic management techniques, the analysis is broken down by phase of flight (i.e. pre-departure delay, taxi out, en-route, terminal arrival, taxi-in and arrival delay).

- The total estimated "benefit pool" which can be influenced by ANS is discussed in Chapter 7 and the main findings are summarised in Chapter 8.

- Chapter 9 presents recommendations for new research that would account for complex interdependencies and would allow for a more complete benchmarking between the two systems.

2 KEY CHARACTERISTICS OF THE TWO ATM SYSTEMS

This chapter provides some key characteristics of the ATM system in the US and in Europe. The purpose is to provide some background information and to ensure comparability of traffic samples for the more detailed analysis of ATM-related service quality by flight phase in Chapters 5 and 6.

2.1 Air traffic characteristics

2.1.1 Table 1 shows selected high-level figures for the European and the US Air Navigation systems.

Table 1: US/Europe ATM System Figures (2008)

Calendar Year 2008	Europe[5]	USA[6]	Difference US vs. Europe
Geographic Area (million km^2)	11.5	10.4	≈ -10%
Number of en-route Air Navigation Service Providers	38	1	
Number of Air Traffic Controllers (ATCOs in Ops.)[7]	16 800 [8]	14 000 [9]	≈ -17%
Total staff	56 000	35 000	≈ -40%
Controlled flights (IFR) (million)	10	17 [10]	≈ +70%
Share of flights to/ from top 34 airports	68%	64%	≈ -5%
Share of General Aviation Traffic	4%	23%	≈ x 5.5
Flight hours controlled (million)	14	25	≈ +80%
Relative density (flight hours per km^2)	1.2	2.4	≈ x 2
Average length of flight (within respective airspace)	541 NM	497 NM	≈ -8%
Nr. of en-route centres	65	20	≈ - 70%
En-route sectors at maximum configuration	679	955	≈ +40%
Nr. of airports with ATC services	≈450	≈263 [11]	≈ -42%
Of which are slot controlled	> 73	3 [12]	
Source	Eurocontrol	FAA/ATO	

2.1.2 The total surface of continental airspace is similar in Europe and the US. However, the FAA controls approximately 70% more flights and handles significantly more visual Flight Rules (VFR) traffic with some 17% less controllers and fewer en-route facilities. The fragmentation of European ANS with 38 en-route ANSPs is certainly a driver behind such difference.

5 EUROCONTROL States plus Estonia and Latvia, excluding Oceanic areas and Canary Islands.

6 Area, flight hours and centre count refers to CONUS only. The term US CONUS refers to the 48 contiguous States located on the North American continent south of the border with Canada, plus the District of Columbia, excluding Alaska, Hawaii and Oceanic areas.

7 Figures include supervisors and towers staffed by the respective ANSPs but exclude contracted towers.

8 Of which 60% are allocated to en-route units and 40% to approach and tower units.

9 FAA has approximately 60% Radar Controller, 25% Tower/TRACON, and 15% Tower. The tower figure includes only FAA managed Towers.

10 The total number of flights controlled within the entire US airspace is approximately 18 million.

11 Total of 503 facilities of which 263 are FAA staffed and 240 contract towers.

12 LGA, JFK, EWR (DCA also considered restricted although not strictly for capacity).

2.1.3 Notwithstanding the large number of airports in the US and European air traffic control systems, only a relatively small number of airports account for the main share of traffic. The main 34 airports account for 68% and 64% of the controlled flights in Europe and the US respectively.

AIR TRAFFIC GROWTH

2.1.4 Figure 3 shows the evolution of IFR traffic in the US and in Europe between 1999 and 2008.

2.1.5 Over this period, the number of controlled flights did not increase in the US, and increased approximately +25% in Europe (~4% p.a.).

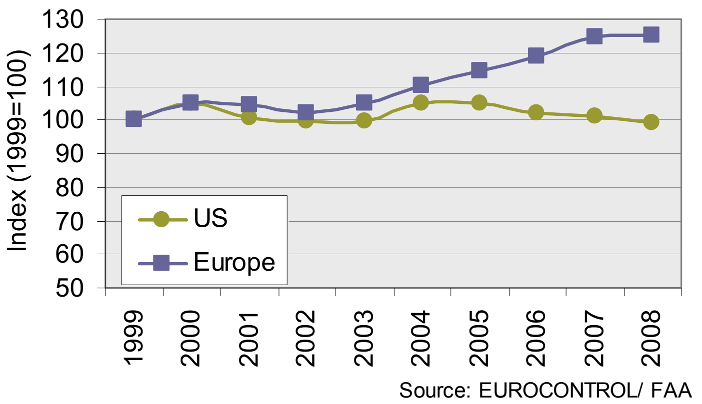


Figure 3: Evolution of IFR traffic in the US and in Europe

2.1.6 These average values in fact mask contrasted growth rates within the US and Europe.

2.1.7 In Europe, much of the air traffic growth was driven by strong growth in the emerging markets in the Eastern European States and low cost carriers.

2.1.8 The US is a more homogenous and mature market which shows a different behaviour and less growth. Despite the virtually zero growth rate in the US, a continuous growth of traffic was observed in the high volume airports in the New York area.

AIR TRAFFIC DENSITY

2.1.9 Figure 4 shows the traffic density in US and European en-route centres measured in flight hours per square kilometre for all altitudes.

2.1.10 The density in Europe would increase relative to the US if only upper flight levels were considered (the propeller GA aircraft in the US would be excluded)[13]. Detailed comparisons on complexities are beyond the scope of this report.

[13] New York Centre shows as less dense due to the inclusion of a portion of coastal/oceanic airspace. If this portion was excluded, NY would be the Centre with the highest density.

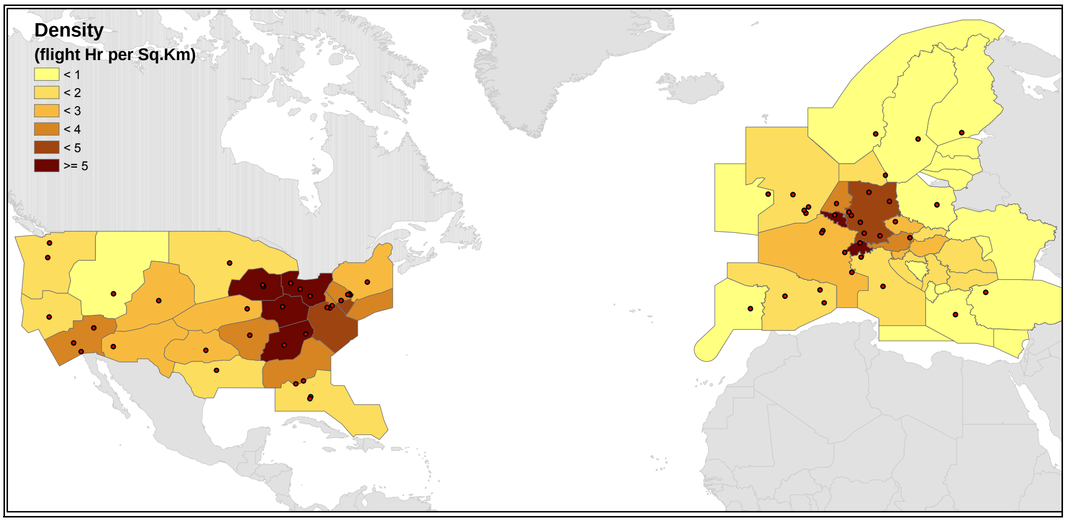


Figure 4: Traffic density in US and European en-route centres (2007)

AVERAGE FLIGHT LENGTH

2.1.11 Table 2 provides a more detailed breakdown of IFR traffic and flight lengths for the US and Europe for the year 2008. The average great circle distances shown in Table 2 refer only to the distances flow within the respective airspace and not the length of the entire flight.

Table 2: Breakdown of IFR traffic (2008)

ALL IFR TRAFFIC 2008	EUROPE N	EUROPE % of total	EUROPE Avg. dist. (NM)	US CONUS N	US CONUS % of total	US CONUS Avg. dist. (NM)
Within region	**7.7 M**	**80.2%**	457 NM	**14.6 M**	**86.2%**	495 NM
Main 34 - Main 34	1.9 M	19.6%	506 NM	3.2 M	19.1%	818 NM
Main 34 - Other	3.7 M	38.2%	454 NM	6.0 M	35.2%	477 NM
Other - Other	2.2 M	22.4%	417 NM	5.4 M	31.9%	322 NM
To/from outside region	**1.8 M**	**18.7%**	885 NM	**2.0 M**	**12.0%**	516 NM
To/from Main 34	1.3 M	13.5%	931 NM	1.6 M	9.5%	534 NM
Other	0.5 M	5.2%	766 NM	0.4 M	2.5%	448 NM
Overflights	**0.1 M**	**1.1%**	853 NM	**0.3 M**	**1.8%**	465 NM
Total IFR traffic	**9.6 M**	**100%**	541 NM	**17.0 M**	**100%**	497 NM

Traffic to/from main 34 airports (2008)	EUROPE N	EUROPE % of total	EUROPE Avg. dist. (NM)	US CONUS N	US CONUS % of total	US CONUS Avg. dist. (NM)
Within region	5.6 M	81.1%	472 NM	9.2 M	85.1%	597 NM
To/from outside region	1.3 M	18.9%	931 NM	1.6 M	14.9%	534 NM
Total	**6.9 M**	**100%**	559 NM	**10.8 M**	**100%**	592 NM

2.1.12 When all flights are taken into account, the average flight length within each respective airspace is slightly longer in Europe (541 NM) compared to the US (497 NM), as shown in Table 2. However, when only flights from and to the main 34 airports are considered, the average flight lengths is longer in the US (592 NM) compared to Europe (559 NM).

2.1.13 Figure 5 shows a continuous increase in average flight length in the US and in Europe between 2005 and 2007. In Europe, the trend continues in 2008 whereas it decreases in the US.

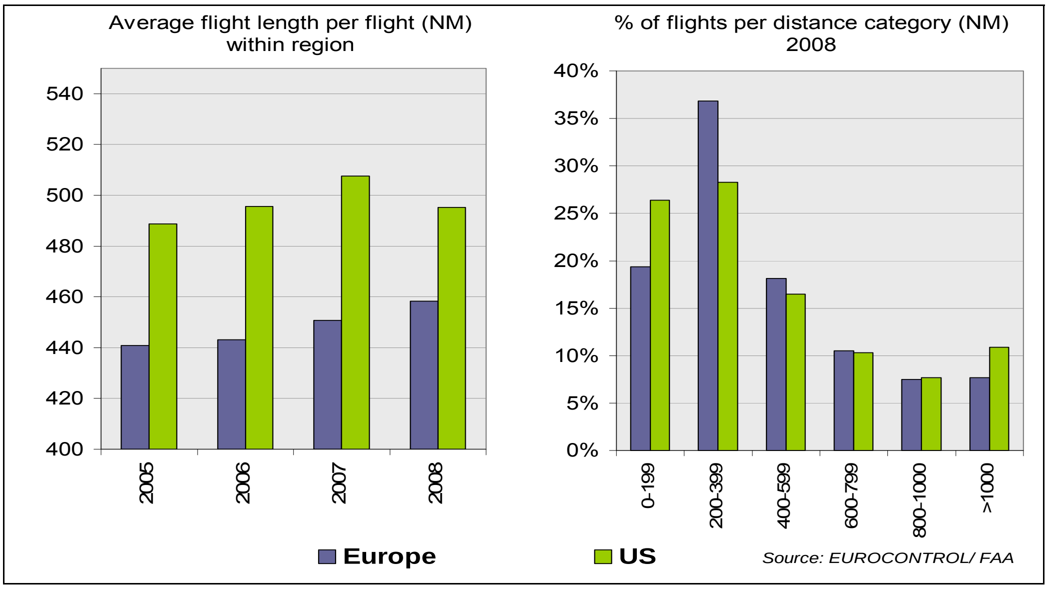


Figure 5: Evolution of average flight lengths (within region)

SEASONALITY

2.1.14 Seasonality and variability of air traffic can be a factor affecting ATM performance. If traffic is highly variable, resources may be underutilised during off-peak times but scarce at peak times. Different types of variability require different types of management practices to ensure that ATM can operate efficiently in the face of variable demand.

2.1.15 In order to avoid a bias from the drop in traffic due to the economic crisis in 2008, analyses in Figure 6 refer to the calendar year 2007.

2.1.16 Figure 6 compares the seasonal variability (relative difference in traffic levels with respect to the respective yearly averages) and the "within week" variability (idem weekly) in the US and Europe.

2.1.17 At system level, seasonality is higher in Europe than in the US. In Europe, traffic is about 20% higher in summer months than in winter months whereas in the US, traffic is only 6% higher in the summer. Weekly traffic profiles are similar in Europe and in the US, with the lowest level of traffic during weekends.

2.1.18 Figure 7 shows the seasonal traffic variability in the US and in Europe at centre level for 2007.

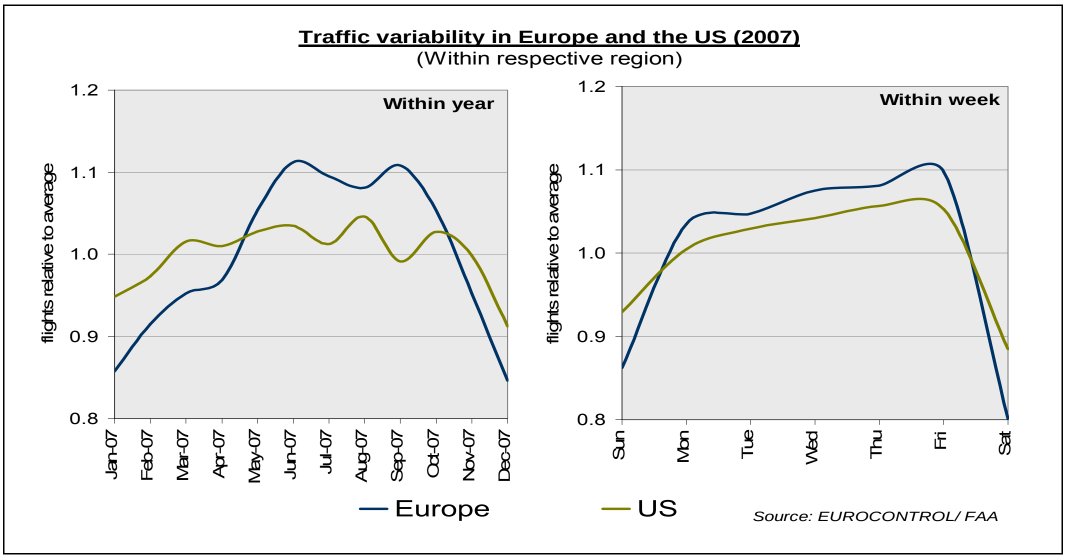


Figure 6: Seasonality/Traffic variability

2.1.19 In Europe, a very high level of seasonality is observed for the holiday destinations in the South. Especially in Greek airspace, the relatively low number of flights in winter contrasts sharply with high demand in summer.

2.1.20 In the US, the overall seasonality is skewed by the high summer traffic in northern en route centres (Boston and Minneapolis) off-setting the high winter traffic of southern centres (Miami and Jacksonville (see Figure 7).

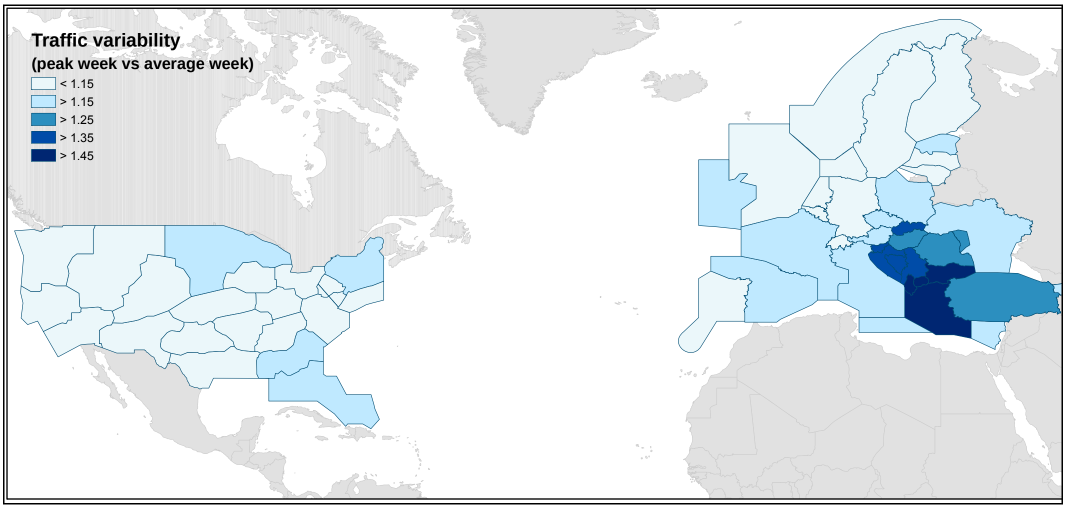


Figure 7: Seasonal traffic variability in US and European en-route centres (2007)

TRAFFIC MIX

2.1.21 Figure 8 shows the distribution of physical aircraft classes for the US and Europe. An important difference between the US and Europe is the share of general aviation which accounts for 23% and 4% of total traffic in 2008 respectively (see Table 1). This is confirmed by the large share of smaller aircraft in the US when analysing all IFR traffic (left side of Figure 8).

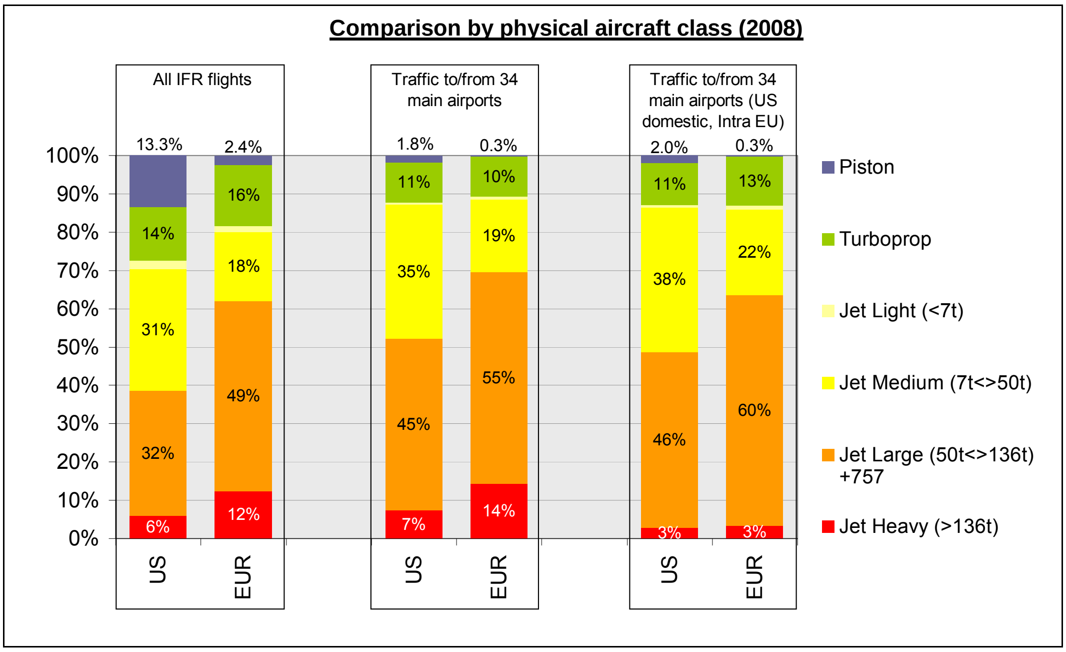


Figure 8: Comparison by physical aircraft class

2.1.22 Figure 8 shows that the samples are more comparable when only flights to and from the 34 main airports are analysed as this removes a large share of the smaller piston and turboprop aircraft (general aviation traffic), particularly in the US.

2.1.23 In order to improve comparability of data sets, the more detailed analyses in Chapters 5 and 6 were limited to controlled (IFR) flights from or to the 34 most important airports in the US (OEP34) and Europe.

2.1.24 Traffic to/from the main 34 airports in 2008 represents some 68% of all IFR flights in Europe and 64% in the US. If only scheduled airlines are considered, IFR traffic to/from the main 34 airports is 80% for Europe and 86% for US.

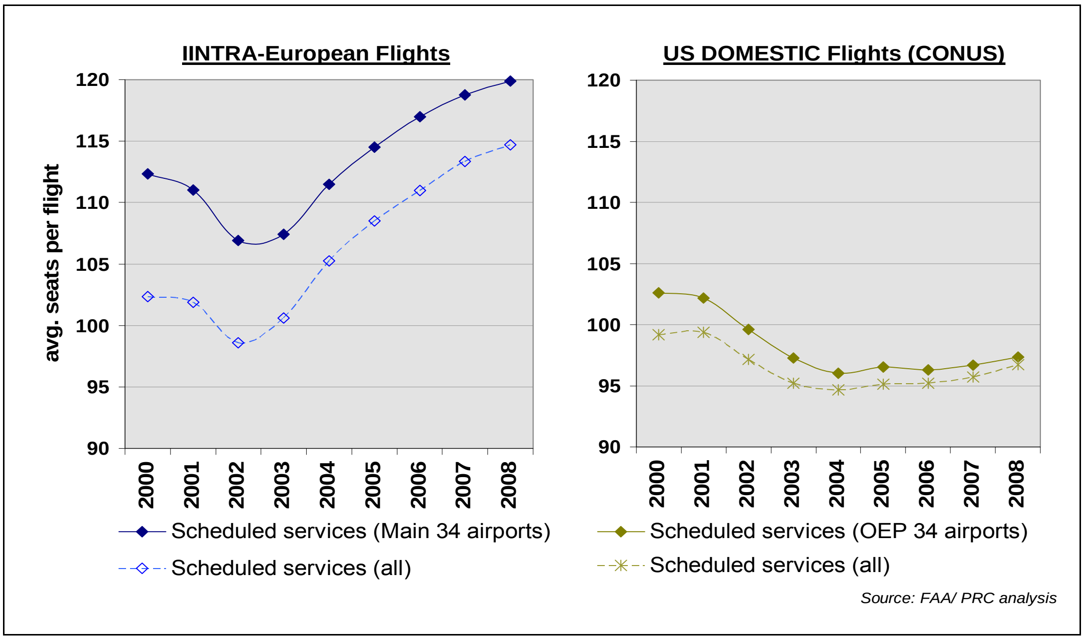


Figure 9: Average seats per scheduled flight

2.1.25 Figure 9 shows the evolution of the number of average seats per scheduled flight in the US and in Europe, based on OAG data for passenger aircraft. Overall, the average number of seats per scheduled flight is higher in Europe which is consistent with the observation in Figure 8 showing a higher share of 'larger' aircraft in Europe.

2.1.26 Whereas in Europe the average number of seats per flight increased continuously between 2002 and 2008, the number of seats per aircraft declined in the US during the same period. More analysis is needed to better understand the factors driving the differing trends in average aircraft size between the US and Europe.

OPERATIONS AT THE MAIN 34 AIRPORTS

2.1.27 Table 3 provides high-level indicators for the main 34 airports in the US and in Europe.

Table 3: Some indicators for the 34 main airports (2008)

Main 34 airports in 2008	Europe	US	Difference US vs. Europe
Average number of annual movements per airport ('000)	265	421	+59%
Average number of annual passengers per airport (million)	25	32	+29%
Passengers per movement	94	76	-19%
Average number of runways per airport	2.5	4.0	+61%
Annual movements per runway ('000)	106	107	+1%
Annual passengers per runway (million)	10.0	8.1	-19%

2.1.28 The average number of runways (+61%) and the number of movements (+59%) are significantly higher in the US while the number of passengers per movement (-19%) is much lower than in Europe, which is consistent with the observations made in Figure 8 and Figure 9.

2.1.29 Annual movements per runway are nearly identical, which may be interesting to note for airport capacity policy purposes.

2.1.30 Figure 10 shows the average daily IFR departures for the 34 main European and US airports included in this study in order to provide an order of magnitude of the operations of the airports.

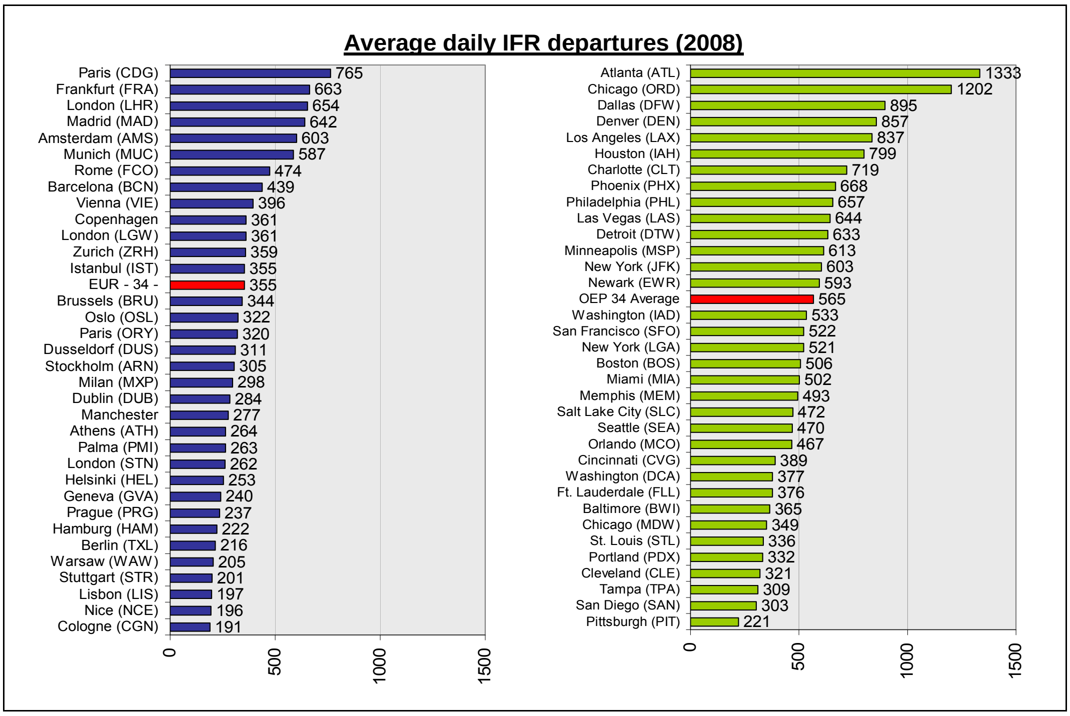


Figure 10: Average daily IFR departures at the main 34 airports (2008)

2.1.31 The average number of IFR departures per airport (565) is considerably higher in the US, compared to 355 average daily departures at the 34 main airports in Europe in 2008[14].

2.2 Organisational and geopolitical characteristics

2.2.1 Both the US and Europe have established system-wide traffic management facilities to ensure that traffic flows do not exceed what can be safely handled by controllers, while trying to optimize the use of available capacity.

2.2.2 However, for a number of operational, geopolitical and even climatic reasons, Air Traffic Flow Management (ATFM) techniques have evolved differently in the US and in Europe.

OPERATIONAL SETUP

2.2.3 While both Air Navigation systems are operated with similar technology and operational concepts, there is only one service provider in the US, all US Centres use the same automation systems and have procedures for cooperation on Inter-Centre flow management.

[14] Figure 10 only shows IFR flights. Some airports - especially in the US - have a significant share of additional VFR traffic. Overall, VFR flights account for an additional 3% at the OEP 34 airports in the US. The top four VFR contributors in the US are Las Vegas (+19%), Salt Lake City (+13%), Ft. Lauderdale (+8%) and Phoenix (+6%). In Europe, the airports with the highest VFR share are medium airports such as Nice, Geneva, Stuttgart.

2.2.4 In Europe, there are 38 en-route service providers of various geographical areas[15], with little obligation or incentives to cooperate on flow management (e.g. sequencing traffic into major airports of other States) and operating their own systems, which may affect the level of coordination in ATFM and ATC capacity. Ground ATFM delays principally originate from en-route capacity shortfalls in Europe, which is not the case in the US.

Figure 11: Fragmentation in Europe

2.2.5 Additionally, in many European States, civil air navigation service providers co-exist with military ANSPs. This can make ATC operations and airspace management more difficult. More study is needed to better understand the impact of ATM civil/ military arrangements on performance. A potential measure for comparison between the US and Europe would be the share of flights that would enter shared civil/military airspace if great circle routes were used.

SCHEDULING OF OPERATIONS

2.2.6 The two systems also differ considerably in terms of scheduling of operations at airports.

2.2.7 In Europe, traffic at major (coordinated) airports is usually controlled (in terms of volume and concentration) in the strategic phase through the airport capacity declaration process, and the subsequent allocation of airport slots to aircraft operators months before the actual day of operation.

2.2.8 In the US, airline scheduling is unrestricted at most airports. Demand levels are controlled by airlines and adapted depending on the expected cost of delays and the expected value of operating additional flights (without the risk of losing valuable airport slots as is the case in Europe).

2.2.9 The few schedule constrained airports in the US are typically served by a wide range of carriers making scheduling processes similar to the ones in Europe a potential necessity. In 2007, schedule constraints existed only at New York LaGuardia, Chicago O'Hare (ORD), and Washington National (DCA). During Fiscal Year 2008, additional scheduled capacity constraints were established at JFK and Newark (EWR) airports while the constraint at Chicago O'Hare was removed with the addition of the new runway.

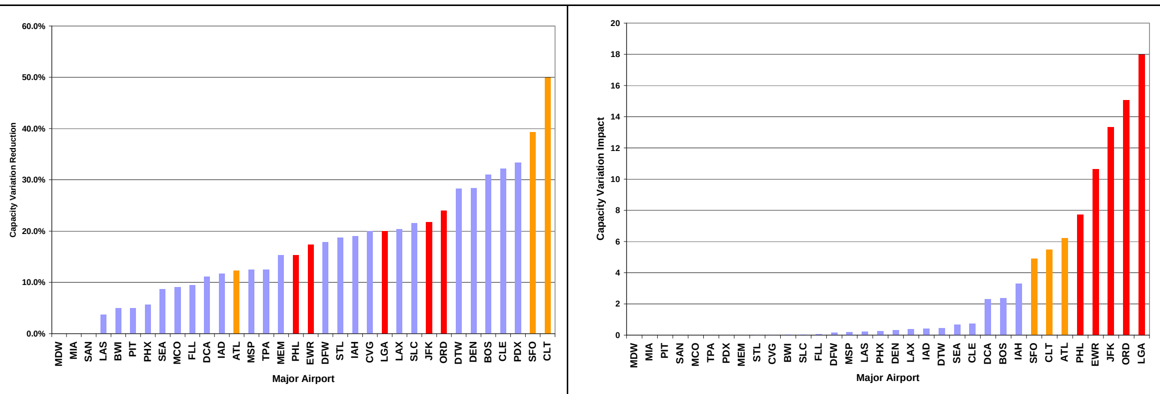
2.2.10 The airport capacity declaration process at European airports could arguably result in capacities closer to IMC capacity while in the US, where demand levels are controlled by airlines and VFR conditions are more prominent, the airports are scheduled closer to VFR capacity [Ref. 5].

15 Air traffic control is historically a national responsibility, which led to a large number of ATC facilities of various sizes.

2.2.11 On average, the US experiences Visual Metrological Conditions (VMC) conditions at the top 34 airports approximately 84% of the time [Ref. 5]. Transition to Instrumental Metrological Conditions (IMC) impact US airports more as traffic is often scheduled to VMC arrival rates. As stated previously, more analysis is needed in capacity variability compared to Europe.

2.2.12 While the unrestricted scheduling at US airports encourages high airport throughputs levels, it also results in higher level of variability when there is a mismatch between scheduled demand and available capacity.

2.2.13 The FAA/ATO collects 15 minute level data on airport capacity changes at major airports through facility reported Airport Arrival Acceptance Rates (AAR) and Airport Departure Rates (ADR). Figure 12 quantifies the capacity variation in two ways. The left side of Figure 12 shows the percent reduction between the 80% and 20% capacity percentiles. The right side of Figure 12 is an index which weights the left side by the number of hours where airport demand exceeds 80% of capacity.



Capacity Variation – Percent Reduction

Capacity Variation – Demand impact

Figure 12: Variability of airport capacity in the US

2.2.14 Figure 12 suggests that capacity variations at Chicago (ORD) and the New York airports (LGA, JFK, EWR) have the most significant impact on demand (red bars on right side of Figure 12). Other airport such as Boston (BOS), Portland (PDX), and Cleveland (CLE) all have the potential for significant delay impact if demand increases.

2.2.15 More work is needed to relate ATM performance to the demand/capacity ratios observed in both Europe and the US. Follow-on research would develop comparable capacity definitions for both systems and would develop a better understanding of the impact of:

- capacity variations;
- scheduling practices;
- air traffic management and peak throughput; and,
- capacity utilisation.

WEATHER CONDITIONS

2.2.16 Convective weather/thunderstorms in the summer are quite severe and widespread in the US (mostly Eastern half) and may require ground holds and continent wide reroutings of entire traffic flows. In the data reported by airlines in the US, delays related to non-extreme weather situations are predominantly attributed to the ATM system (see also Chapter 4.4).

2.2.17 With commercial weather data and ATC data, a Convective Weather Index can be developed which compares traffic demand to convective weather and estimates the impacted traffic flows as a contributor to delays. This calculation can be done hourly, daily, or yearly [Ref. 6]. The index can relate traffic levels and delay to weather conditions and provide more insight into the causal reasons for ATM performance.

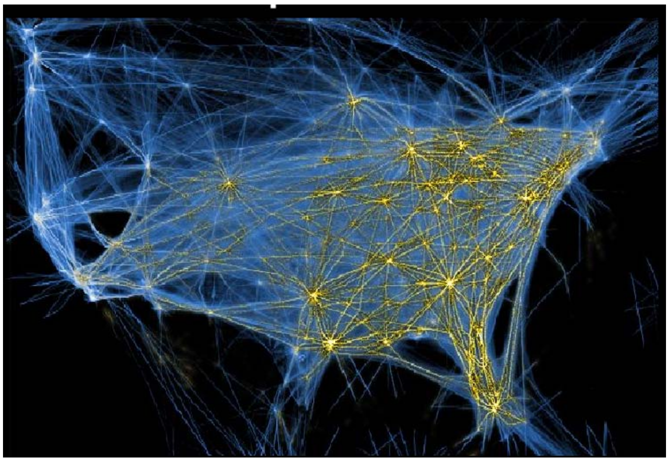


Figure 13: The weather index concept: impacted traffic flows in the US

2.2.18 In Europe, the ability to quantify the impact of weather on air traffic is not as developed as in the US (i.e. WITI[16] Metric, etc) and more work in this direction including supporting data collections would be necessary to identify differences in weather patterns and subsequent air traffic management initiatives.

[16] Weather Impacted Traffic Index (WITI) metric. When the WITI metric is applied to the entire NAS, it is also known as the NAS Weather Index (NWX).

3 APPROACH TO COMPARING ANS SERVICE QUALITY

This chapter provides a brief description of basic differences in Air Traffic Flow Management (ATFM) techniques between the US and Europe and outlines the approach for assessing Air Navigation Services (ANS) related service quality.

3.1 Basic differences in air traffic flow management techniques

3.1.1 The two ATFM systems differ notably in the timing (when) and the phase of flight (where) ATFM measures are applied.

3.1.2 In Europe, the majority of demand/capacity management measures are applied months in advance through the strategic agreements on airport capacities and slots. In addition, demand is managed in pre-tactical phases (allocation of ATFM take-off slots). The European system operates airport streaming on a local and distributed basis with the CFMU mainly protecting the en-route segments from overload.

3.1.3 In the US, demand management mainly takes place on the day of operation when necessary. The US system appears to have less en route capacity problems and is geared towards maximising airport throughput. With less en-route capacity restrictions, the US has the capability to absorb large amounts of speed control and path stretching in en-route airspace in order to achieve the metering required by TMAs and airports.

3.1.4 The comparison of operational performance has the potential to provide interesting insights from a fuel efficiency point of view as Europe applies more delay at the gate. However, as both systems try to optimise the use of available capacity, this needs to be put in context for a complete picture.

GROUND BASED FLOW MANAGEMENT

3.1.5 In Europe when traffic demand is anticipated to exceed the available capacity in en-route control centres or at an airport, ATC units may call for “ATFM regulations”. Aircraft subject to ATFM regulations are held at the departure airport according to “ATFM slots” allocated by the Central Flow Management Unit (CFMU).

3.1.6 The ATFM delay of a given flight is attributed to the most constraining ATC unit, either en-route (en-route ATFM delay) or airport (airport ATFM delay). The CFMU was initially created in the 1990s to manage the lack of en-route capacity of a fragmented ATC system.

3.1.7 In the US, ground delay programs are mostly used in case of severe capacity restrictions at airports when less constraining ATFM measures, such as Time Based Metering or Miles in Trail (MIT) are not sufficient. The Air Traffic Command Center (ATCSCC) applies Estimated Departure Clearance Times (EDCT) to delay flights prior to departure. Most of these delays are taken at the gate.

AIRBORNE FLOW MANAGEMENT

3.1.8 There is currently no or very limited en-route spacing or metering in Europe. When sequencing tools and procedures are developed locally, their application generally stops at the State boundary.

3.1.9 In the US, in order to ensure maximum use of available capacity in en-route centres and arrival airports, traffic flows are controlled through Miles in Trail (MIT) and Time Based Metering (TBM). Flow restrictions are passed back from the arrival airport to surrounding centres and so on as far as necessary. Ultimately MIT can also affect aircraft on the ground. En Route caused restrictions are small compared to airport driven flow restrictions in the US.

3.1.10 If an aircraft is about to take off from an airport to join a traffic flow on which en route spacing or an MIT restriction is active, the aircraft needs a specific clearance for take-off. The aircraft is only released by ATC when it is possible to enter into the sequenced flow. These Traffic Management System (TMS) delays are predominantly taken in the taxi-out phase and to a limited extent at the gate. These delays (when over 15 minutes) are counted in OPSNET–otherwise they are included in excess taxi times. Better data collection and more analysis are needed to understand the real distribution of these delays between the gate and taxi phase.

TERMINAL MANAGEMENT AREA

3.1.11 In both the US and the European system, the terminal area around a congested airport is used to absorb delay and keep pressure on the runways. Traffic Management initiatives generally recognize maximizing the airport throughput as paramount. With TBM systems in US Control Facilities, delay absorption in the terminal area is focused on keeping pressure on the runways without overloading the terminal area. With MIT and TBM, delays can be absorbed further back at more fuel efficient altitudes.

3.2 Conceptual framework for assessing ANS related service quality

3.2.1 The FAA/ATO and EUROCONTROL have been sharing approaches to performance measurement informally over the past 5+ years. Both have developed similar sets of Key Performance Areas and Indicators. The specific key performance indicators (KPIs) used in this paper are based on best practices from both the FAA/ATO and EUROCONTROL.

3.2.2 The objective of the report is the high-level evaluation of the ATM-related service quality in the US and in Europe. Quality of service can be expressed in terms of:

- Performance compared to airline schedule (actual compared to plan); and,
- Predictability (variability) and Efficiency (fuel, time) of actual operations.

3.2.3 Figure 14 outlines the conceptual framework for assessing ANS related service quality.

3.2.4 As a first step, Chapter 4 analyses the performance compared to scheduled airline block times including some of the underlying delay reasons as reported by airlines through airline data collections (see also Chapter 1.3).

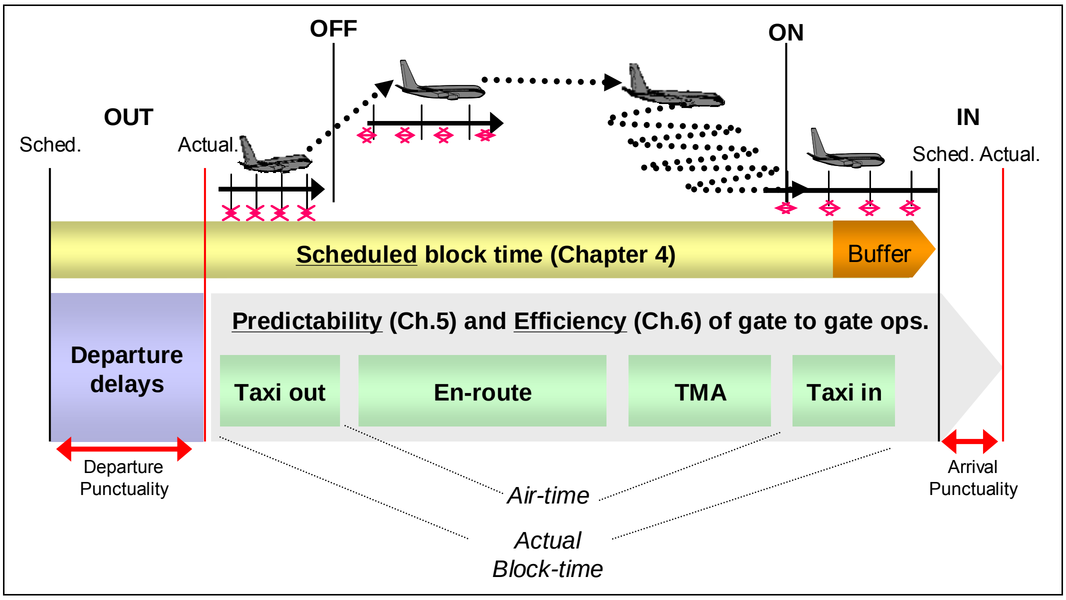


Figure 14: Conceptual framework to measuring ATM related service quality

3.2.5 Although the analysis of performance compared to airline schedules is valid from a passenger point of view and provides first valuable insights, the "masking" of expected travel time variations through the inclusion of strategic time buffers in scheduled block times makes a more detailed analysis of actual operations necessary.

3.2.6 Chapters 5 and 6 focus on the "predictability" and "efficiency" of the actual operations by phase of flight (departure, taxi-out, en-route, terminal area, taxi-in, arrival) in order to better understand the ATM contribution and differences in traffic management techniques.

3.2.7 In this context, it is important to clearly illustrate the interrelation between the delay compared to the scheduled times as reported by airlines (on-time performance/ punctuality), and the predictability and efficiency of actual operations as outlined in Figure 15.

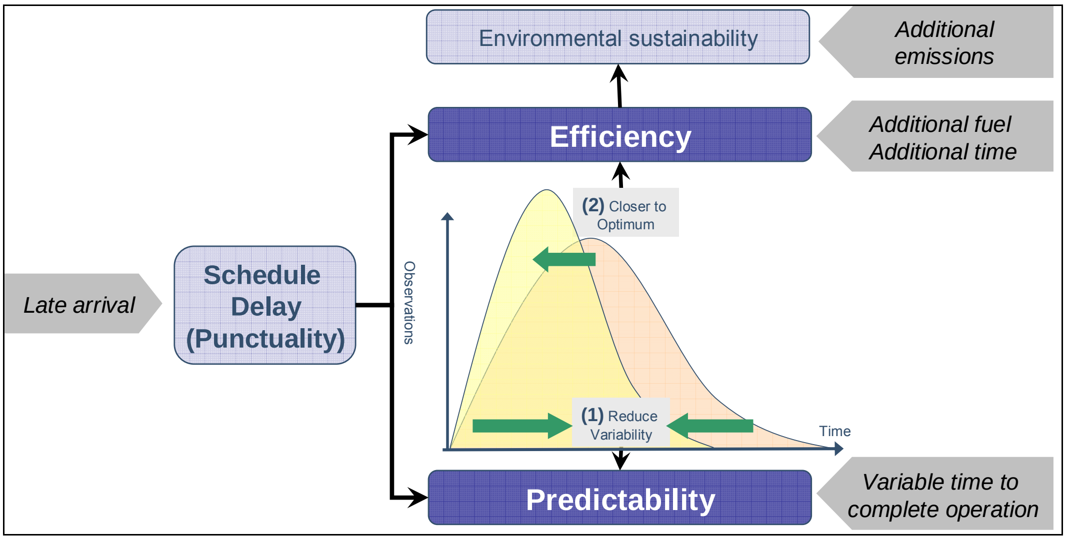


Figure 15: Schedule delay, predictability and efficiency

3.2.8 From a scheduling/planning point of view, the predictability of operations months before the day of operations has a major impact to which extent the use of available resources (aircraft, crew, etc.) can be maximised. The lower the predictability of operations in the scheduling phase, the more time buffer is required to maintain a satisfactory level of punctuality[17] and hence the higher the 'strategic' costs to airspace users.

3.2.9 "Predictability" measures the variation in air transport operations as experienced by the airspace users. It consequently focuses on the variance (distribution widths) associated with the individual phases of flight (see (1) in Figure 15). Reducing the variability of actual block times can potentially reduce the amount of excess fuel that needs to be carried for each flight in order to allow for uncertainties.

3.2.10 For the airborne phase of flight, it is important to note that wind can have a large impact on day to day predictability compared to a planned flight time for scheduling purposes. Understanding the ATM, airline, and weather influences on predictability is a key element of base lining system performance. The US strong Jet Stream winds in the winter and convective weather in the summer impact overall predictability statistics.

3.2.11 In addition to "Predictability", the efficiency of operations is of major importance to airspace users. "Efficiency" generally relates to fuel efficiency or reductions in flight times of a given flight and can be expressed in terms of fuel and/or time. It consequently focuses on the difference between mean travel times from a pre-defined (schedule) or unimpeded optimum time (see (2) in Figure 15).

3.2.12 Additional fuel burn has also an environmental impact through gaseous emissions (mainly CO_2) which is illustrated by the link between "Efficiency" and "Environmental sustainability" in Figure 15.

3.2.13 The goal is to minimise overall direct (fuel, etc.) and strategic (schedule buffer, etc.) costs whilst maximising the utilisation of available capacity.

3.2.14 While this report does not directly address capacity, measures focused directly on capacity improvements as opposed to the resulting delay are extremely valuable in assessing ATM progress.

3.3 Interpretation of the results

3.3.1 For the interpretation of the results in the next chapters, the following points should be borne in mind:

a) Not all 'delay' is to be seen as negative. A certain level of 'delay' is necessary and sometimes even desirable if a system is to be run efficiently without under utilisation of available resources.

b) Due to the stochastic nature of air transport (winds, weather) and the way both systems are operated today (airport slots, traffic flow management), different levels of

[17] The level of "schedule padding" is subject to airline policy and depends on the targeted level of on-time performance.

delay may be required to maximize the use of scarce capacity in the US and Europe. There are lessons however to be learned from both sides.

c) A clear-cut allocation between ATM and non-ATM related causes is often difficult. While ATM is often not the root cause of the problem (weather, etc.) the way the situation is handled can have a significant influence on performance (i.e. distribution of delay between air and ground) and thus on costs to airspace users.

d) The approach measures performance from a single airspace user perspective without considering inevitable operational trade-offs, environmental or political restrictions, or other performance affecting factors such as weather conditions.

e) ANSP performance is inevitably affected by airline operational trade-offs on each flight. The measures in this report do not attempt to capture airline goals on an individual flight basis. Airspace user preferences to optimise their operations based on time and costs can vary depending on their needs and requirements (fuel price, business model, etc.).

f) Some indicators measure the difference between the actual situation and an ideal (un-congested or unachievable) situation where each aircraft would be alone in the system and not be subject to any constraints. This is for example the case for horizontal flight efficiency which compares actually flown distance to the great circle distance. Other measures compare actual performance to an ideal that is based on the best performance of flights in the system today. More analysis is needed to better understand what is and will be achievable in the future.

4 PUNCTUALITY OF OF AIR TRANSPORT OPERATIONS

From a passenger viewpoint, safety, price, convenience of schedule, and on-time performance are among the most important selection criteria when choosing an airline.

4.1 On time performance

4.1.1 This chapter evaluates operational air transport performance compared to airline schedules in the US and in Europe. It furthermore analyses trends in the evolution of scheduled block times. The last section aims at identifying the main delay drivers by analysing the delay information reported by airlines (see Chapter 1.3) in order to get a first estimate of the ATM contribution towards overall air transport performance.

4.1.2 There are many factors contributing to the on-time performance of a flight.

4.1.3 On-time performance is the "end product" of complex interactions between airlines, airport operators and Air Navigation Service Providers (ANSPs), from the planning and scheduling phases up to the day of operation. Strong network effects are expected in air transport performance.

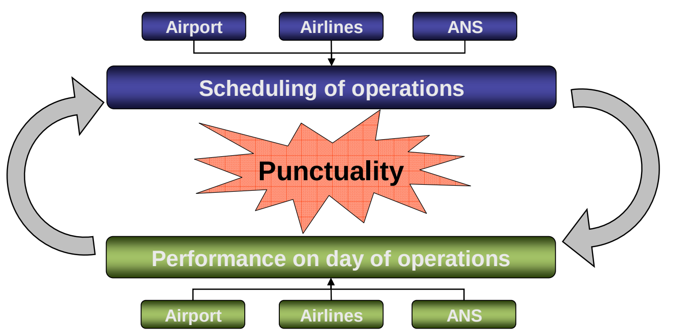


Figure 16: Punctuality of Operations

4.2 Evolution of on time performance

4.2.1 Figure 17 compares the industry-standard indicators for punctuality, i.e. arrivals or departures delayed by more than 15 minutes versus schedule.

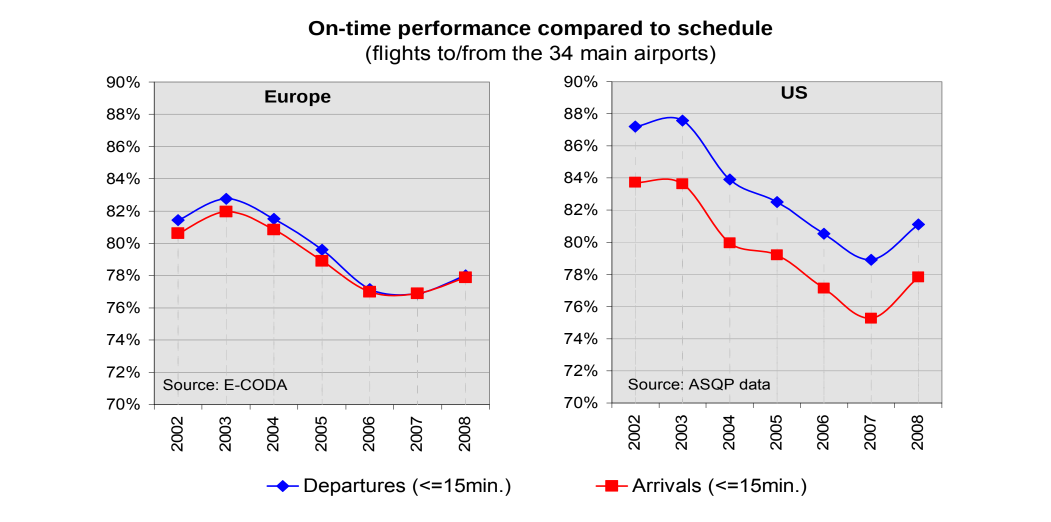


Figure 17: On-time performance (2002-2008)

4.2.2 After a continuous decrease between 2004 and 2007, on-time performance in Europe and in the US shows an improvement in 2008, as shown in Figure 17. However, this improvement needs to be seen in a context of lower traffic growth (and in the case of the US lower overall traffic) as a result of the global financial and economic crisis, and increased schedule padding in the US (see Figure 20).

4.2.3 Overall, the level of arrival punctuality is similar in the US and in Europe but the gap between departure and arrival punctuality is significant in the US and quasi nil in Europe. This is most likely due to differences in flow management techniques as outlined in Chapter 3.1. In Europe, flights are usually delayed at the departure gate according to "ATFM slots" while in the US flow management techniques focus more on the gate-to-gate phase. Additionally, the slot coordination in Europe may play a role in smoothing departure and arrival punctuality.

4.2.4 The system wide on-time performance is the result of contrasted situations among airports. Figure 18 shows the share of arrivals delayed by more than 15 minutes compared to schedule for the 20 most penalising airports in Europe and the US in 2008.

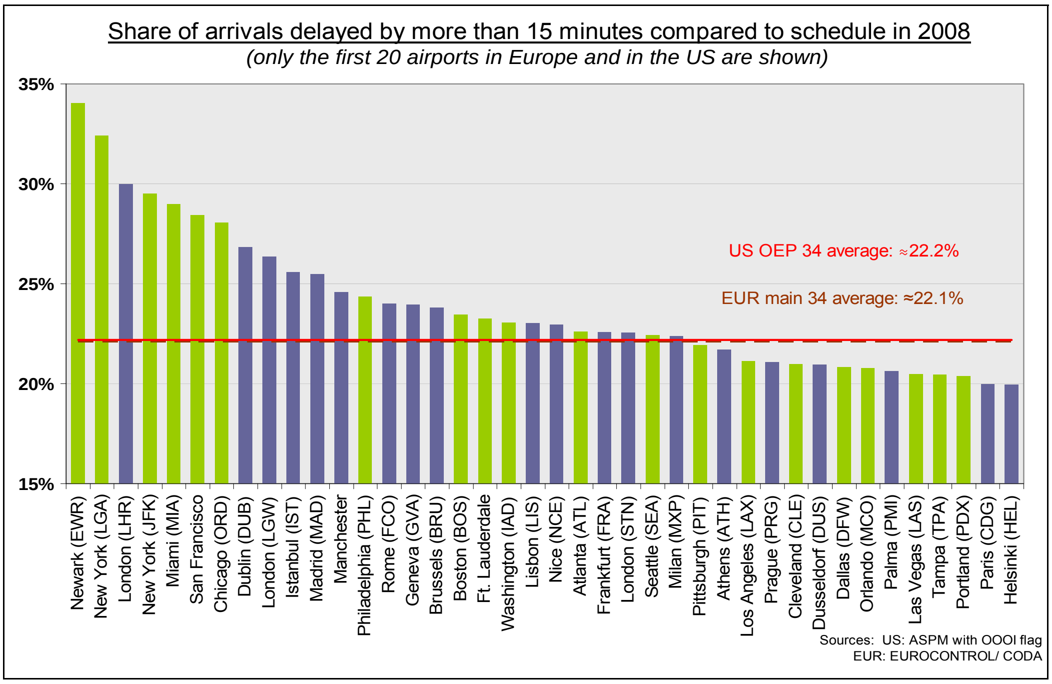


Figure 18: Arrival punctuality (airport level)

4.2.5 In the US, the airports in the New York area showed the highest share of flights delayed by more than 15 minutes compared to schedule in 2008. In Europe, London Heathrow was the most penalising airport in 2008.

4.2.6 The impact and the importance of performance at individual airports on the air traffic management network and vice versa needs to be better understood. On time performance at each airport is influenced by performance at departure airports and previous flight legs. A US Study showed that for Miami Airport in 2000, when traffic dropped considerably, on time performance decreases were clearly a function of the performance at the linked airports in the OEP 35 [Ref. 7].

4.3 Evolution of scheduled block times

4.3.1 Airlines often include ‘strategic’ time buffers in their schedules to account for a certain level of variation in travel times on the day of operations and to provide a sufficient level of punctuality to their customers. The level of “schedule padding” is subject to airline policy and depends on the targeted level of on-time performance.

4.3.2 Airlines build their schedules for the next season by applying a quality of service/ punctuality target to the distribution of previously observed block-to-block times (usually by applying a percentile target to the distribution of previously flown block times). The wider the distribution (and hence the higher the level of variation) of historic block-to-block times, the more difficult it is to build reliable schedules resulting in higher utilisation of resources (e.g. aircraft, crews) and higher overall costs.

4.3.3 The impact of a shift in block times variability is outlined in the right graph of Figure 19.

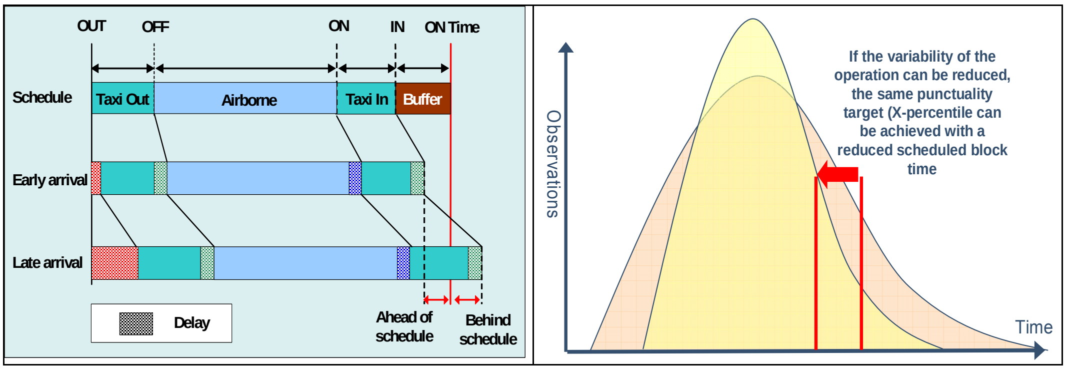


Figure 19: Scheduling of airline operations

4.3.4 Nevertheless, it should be pointed out that improvements in block time distributions does not automatically result in higher punctuality levels, as the scheduled times for the new season will be reduced automatically by applying the punctuality target to the set of improved block times (block times are cut to improve utilisation of aircraft and crews).

4.3.5 Figure 20 shows the evolution of airline scheduling times in Europe and the US. The analysis compares the scheduled block times for each flight of a given city pair with the long term average for that city pair over the full period (DLTA Metric[18)].

4.3.6 Between 2000 and 2008, scheduled block times remained stable in Europe while in the US average block times have increased by some 2 minutes between 2005 and 2008. These increases may result from adding block time to improve on-time performance or could be tied to a tightening of turn-around-times. The US has seen a redistribution of demand in already congested airports (e.g. JFK) which is believed to be responsible for growth of actual and scheduled block times.

18 The Difference from Long-Term Average (DLTA) metric is designed to measure changes in time-based (e.g. flight time) performance normalised by selected criteria (origin, destination, aircraft type, etc.) for which sufficient data are available. It provides a relative change in performance without underlying performance driver.

4.3.7 Seasonal effects are visible, scheduled block times being on average longer in winter than in summer. US studies by the former Free Flight Office have shown that the majority of increase is explained by stronger winds on average during the winter period [Ref. 8].

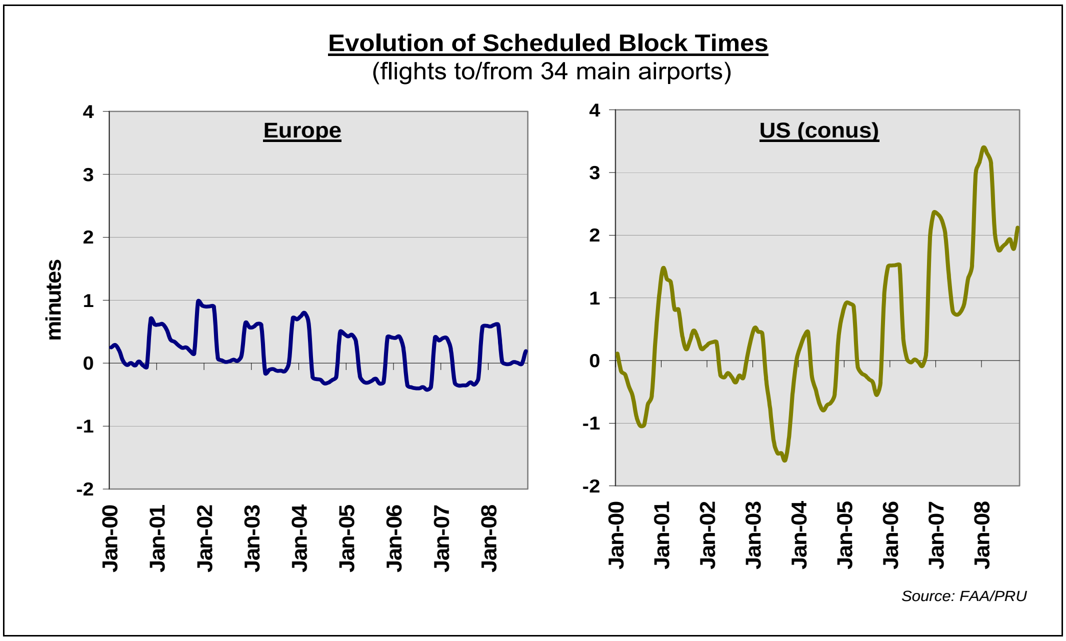


Figure 20: Scheduling of air transport operations (2000-2008)

4.3.8 Figure 20 should be seen in combination with Figure 17. From 2004 to 2008 not only has on-time performance decreased but scheduled flight times have also increased in the US due to congestion, meaning that delay costs are understated because airlines are padding schedules. Schedule padding can cost an airline more than $50 per minute and costs airlines even when flights are early (under most airline labour agreements, pilots and crew are paid the maximum of actual or scheduled time) [Ref. 9].

4.4 Drivers of air transport performance – as reported by Airlines

4.4.1 This section aims at identifying underlying delay drivers as reported by airlines[19] in the US and in Europe (see also Chapter 1.3). The reported delays relate to the schedules published by the airlines.

4.4.2 A significant difference between the two airline data collections is that the delay causes in the US relate to the scheduled arrival times whereas in Europe they relate to the delays experienced at departure.

4.4.3 Hence, for the US the reported data also includes further delays or improvements in the en-route and taxi phase which is not the case in Europe.

4.4.4 Broadly, the delays in the US and in Europe can be grouped into the following main categories: Airline + Local turnaround, Extreme Weather, Late arriving aircraft (= reactionary delay), Security, and ATM system (ATFM/ NAS delays).

19 The analysis of predictability and efficiency in Chapters 5 and 6 is based on ANSP data.

- Air Carrier + Local turnaround: The cause of the delay is due to circumstances within local control. This includes airlines, or other parties such as ground handlers involved in the turn around process (e.g. maintenance or crew problems, aircraft cleaning, baggage loading, fuelling, etc.). As the focus of the paper is on ATM contribution, a more detailed breakdown of air carrier + local turnaround delays is beyond the scope of the paper.
- Extreme Weather: Significant meteorological conditions (actual or forecast) that, in the judgment of the carrier, delays or prevents the operation of a flight such as icing, tornado, blizzard or hurricane. In the US, this category is used by airlines for very rare events like Hurricanes and is not useful for understanding the day to day impacts of weather. Delays due to non-extreme weather conditions are attributed to the ATM System.
- Late-arriving aircraft/reactionary delay: Delays on earlier legs of the aircraft that cannot be recuperated during the turn-around phases at the airport. Due to the interconnected nature of the air transport system, long primary delays can propagate throughout the network until the end of the same operational day.
- Security: Delays caused by evacuation of a terminal or concourse, re-boarding of aircraft because of security breach, inoperative screening equipment and/or other security related causes.
- ATM System (NAS)/ATFM: Delays attributable to the national aviation system that refer to a broad set of conditions, such as non-extreme weather conditions[20], airport operations, heavy traffic volume, and air traffic control. In Europe, aircraft are held at their origin through "ATFM slots" which may cause delays to the concerned flights. The ATFM delay of a given flight is attributed to the most constraining ATC unit, either en-route (en-route ATFM delay) or departure/arrival airport (airport ATFM delay).

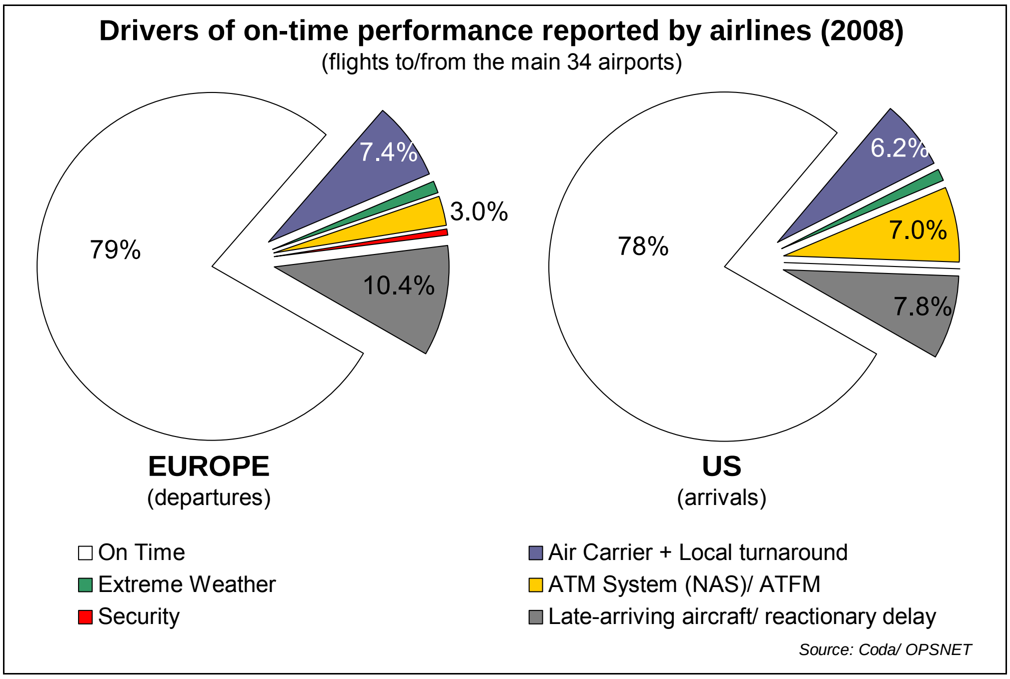


Figure 21: Drivers of on-time performance in Europe and the US

20 According to a more detailed study of the FAA, weather conditions are the main driver of delays attributed to the NAS system.

4.4.5 Figure 21 provides a breakdown of primary delay drivers in the US and Europe. Only delays larger than 15 minutes compared to schedule are included in the analysis.

4.4.6 In Europe, according to airline reporting much of the primary delay at departure is not attributable to the ANS system but more to local turnaround delays caused by airlines, airports and ground handlers.

4.4.7 In the US, the distribution relates to the scheduled arrival times and the higher share of ANS related delay at arrival is partly due to the fact that only ATM delays are accrued after departure.

4.4.8 The share of delay due to reactionary delay is considerably higher in Europe which might be due to the fact that the delays refer to scheduled departure times and therefore do not consider possible improvements in the gate-to-gate phase. More work to better understand the propagation of primary delay through the respective air transport networks would be required.

4.4.9 It should be noted that the ANS system related delays in Figure 21 result from not only en-route and airport capacity shortfalls but to weather effects which ATM and aircraft systems are not currently able to mitigate (IMC approaches, convective weather). According to FAA analysis, by far the largest share of ATM system related delay is driven by weather in the US [Ref.. 10].

4.4.10 Figure 22 and Figure 23 show time series analyses of the delays reported by airlines for Europe and the US. In order to ensure comparability, only the share of flights with an arrival delay (all possible delay causes) of more than 15 minutes compared to schedule are shown for the US and for Europe.

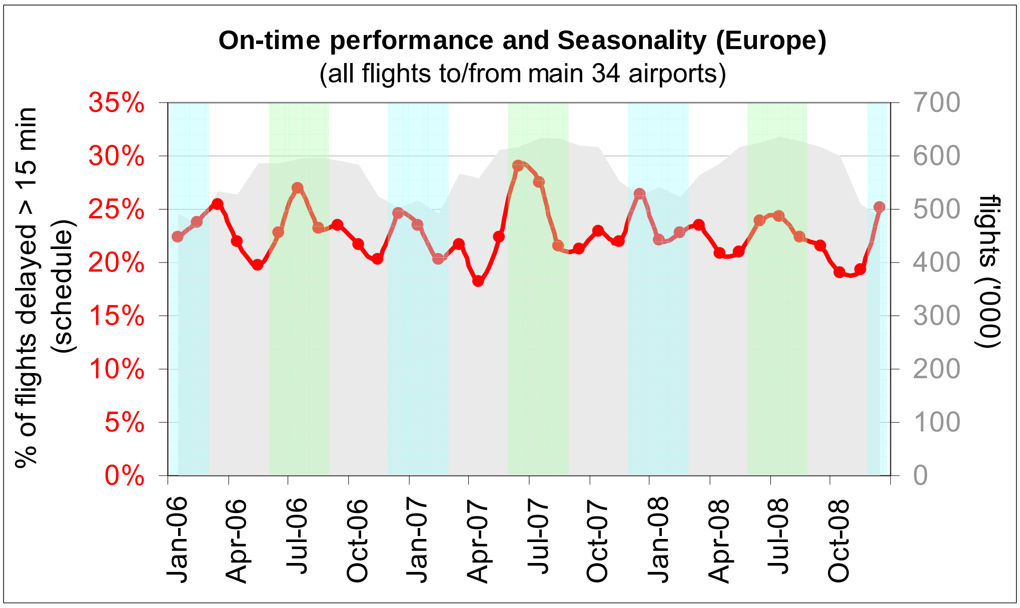


Figure 22: Seasonality of delays (Europe)

4.4.11 Figure 23 shows the seasonality of delay for flights between the top 34 airports in the US.

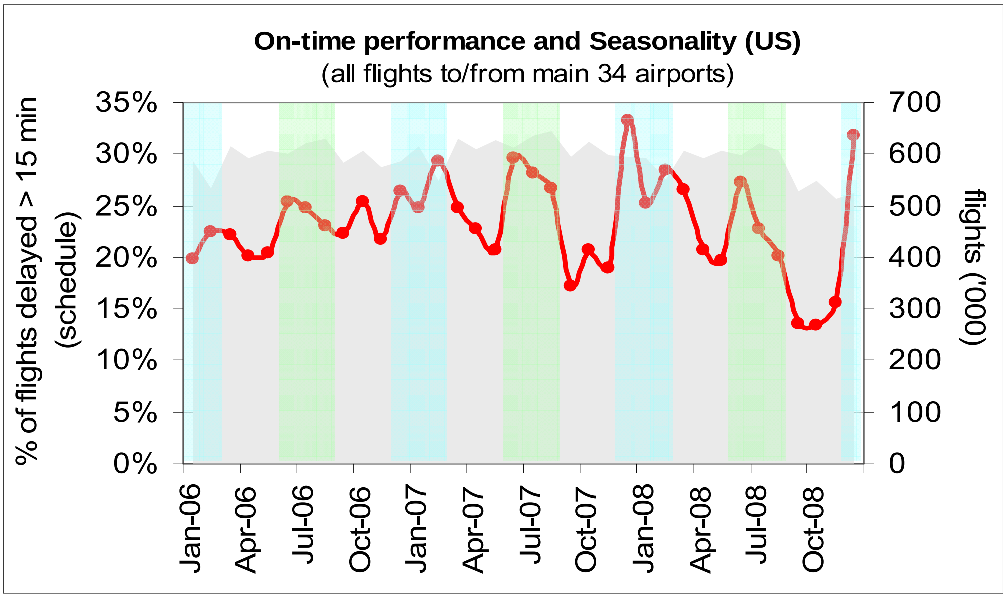


Figure 23: Seasonality of delays (US)

4.4.12 In Europe and the US a clear pattern of summer and winter peaks is visible.

4.4.13 Whereas the winter peaks are more the result of weather related delays at airports, the summer peaks are driven by the higher level of demand and resulting congestion but also by convective weather in the en-route airspace in the US and a lack of en-route capacity in Europe.

4.4.14 In contrast to this chapter which evaluates performance compared to the airline schedules, the following two chapters are based on the statistical analysis of actual travel times and segregated by phase of flight. They provide a first order of magnitude in terms of air transport "*Predictability*" (Chapter 5) and "*Efficiency*" (Chapter 6). Both Chapters break performance down to a flight segment level to give more visibility into causal factors.

5 PREDICTABILITY OF AIR TRANSPORT OPERATIONS

This chapter looks at predictability by phase of flight using airline provided data for gate "out", wheels "off", wheels "on", and gate "in" data. This out, off, on, in data is often referred to as OOOI data and is almost entirely collected automatically using a basic airline Datalink system.

5.1 Predictability by phase of flight

5.1.1 Due to the multitude of variables involved, a certain level of variability is natural. Depending on the magnitude and frequency of the variations, those variations can become a serious issue for airline scheduling departments as they have to balance the utilisation of their resources and the targeted service quality.

5.1.2 Predictability evaluates the level of variability in each phase of flight as experienced by the airspace users[21]. In order to limit the impact from outliers, variability is measured as the difference between the 80th and the 20th percentile for each flight phase.

5.1.3 ANS contributes though the application of various flow management measures as described in Chapter 3.1.

5.1.4 In the departure phase, ANS contributes to the departure time variability through ANS related departure holdings and subsequent reactionary delays on the next flight legs. The ANS related departure delays are analysed in more detail in Chapter 6.3.

5.1.5 The gate-to-gate phase is affected by a multitude of variables including congestion (queuing at take off and in TMA) wind and flow management measures applied by ANS (see Chapter 3.1).

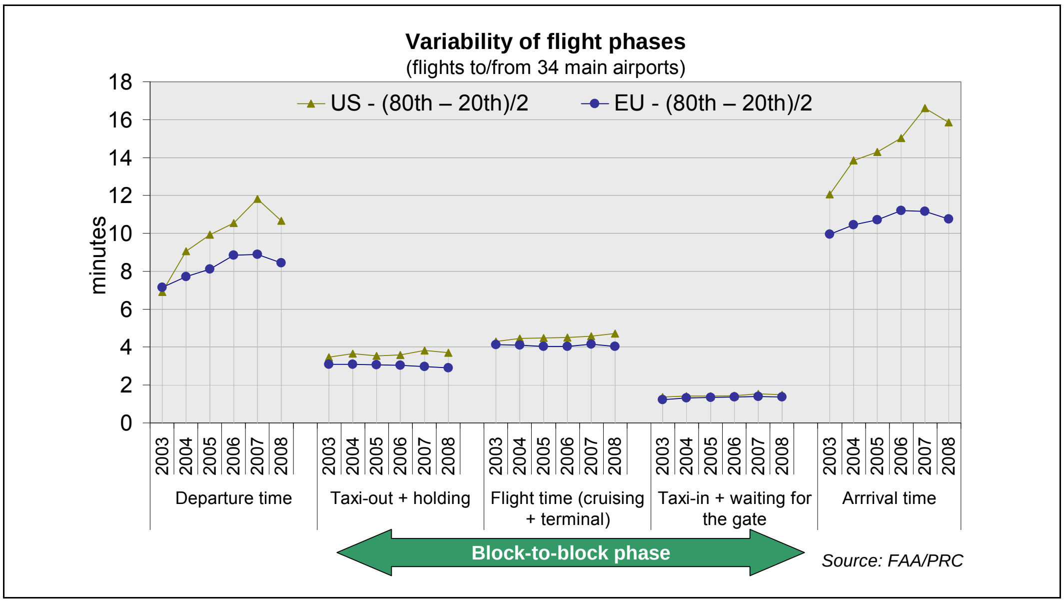


Figure 24: Variability of flight phases (2003-2008)

21 Intra flight variability (i.e. monthly variability of flight XYZ123 from A to B). Flights scheduled less than 20 times per month are excluded.

5.1.6 Figure 24 shows that in both Europe and the US, arrival predictability is mainly driven by departure predictability. Despite the lower level of variability in the gate-to-gate phase, it is understood that the reduction of variability – especially in the taxi out and terminal airborne phase – can warrant substantial savings in direct operational and indirect strategic costs for the airlines.

5.1.7 With the exception of taxi-in times, variability in all flight phases is higher in the US.

5.1.8 Between 2003 and 2007, departure time variability continuously increased on both sides of the Atlantic. Contrary to Europe, variability increased also in the taxi-out and flight phase in the US, which appears to be driven by the different approaches in both scheduling operations and absorbing necessary delay (see Chapter 3.1).

5.1.9 As demand increases in congested areas, the variability in times in all flight phases also increases. Over the last 5 years, the US has seen demand increases at congested major airports, driving the variability of the overall ATM system [Ref. 11].

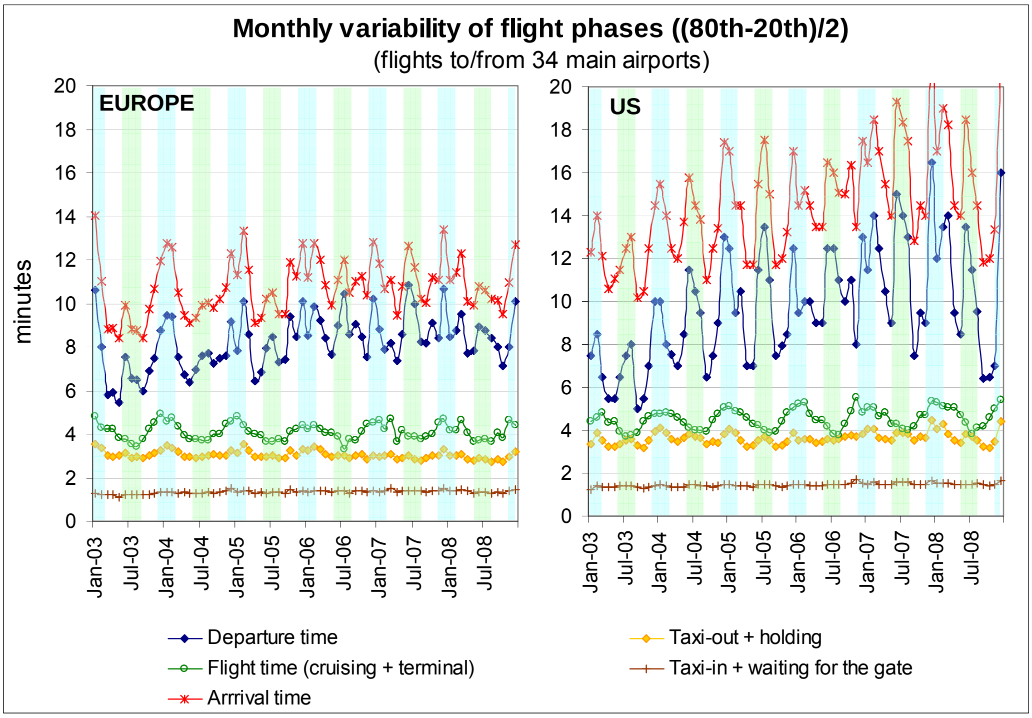


Figure 25: Monthly variability of flight phases

5.1.10 At US airports, winter delays are believed to be driven by higher frequency of instrument meteorological conditions (IMC) combined with scheduling closer to visual metrological conditions (VMC) - (see paragraph 2.2.10). Summer delays result from convective weather blocking en route airspace. The high variability may be related to scheduling and the seasonal differences in weather.

5.1.11 In Europe where the declared airport capacity is assumed to be closer to IMC capacity, the overall effects of weather on operational variability are expected to be generally less severe.

5.1.12 Figure 25 shows a clear link between the various seasons and the level of variability in the US and in Europe. The higher variability in the winter is mainly due to weather effects. The higher airborne flight time variability in the winter in the US and in Europe is caused by wind effects and also partly captured in airline scheduling (see Figure 20).

5.1.13 More detailed analysis is needed to evaluate the impact of the respective air traffic management system, weather, and airline scheduling on the level of variability in the individual flight phases.

6 EFFICIENCY OF AIR TRANSPORT OPERATIONS

"Efficiency" generally relates to fuel efficiency or reductions in flight times of a given flight. The analyses in this chapter consequently focus on the difference between the mean travel times and an optimum time (see also Figure 15 on page 20).

6.1 High level trend analysis

6.1.1 Figure 26 provides a first analysis of how the duration of the individual flight phases (departure, taxi-out, airborne, taxi-in, total) has evolved over the years in Europe and the US. The analysis is based on the DLTA Metric (see footnote 18 on page 25) and compares actual times for each city pair with the long term average for that city pair over the full period (2003-2008).

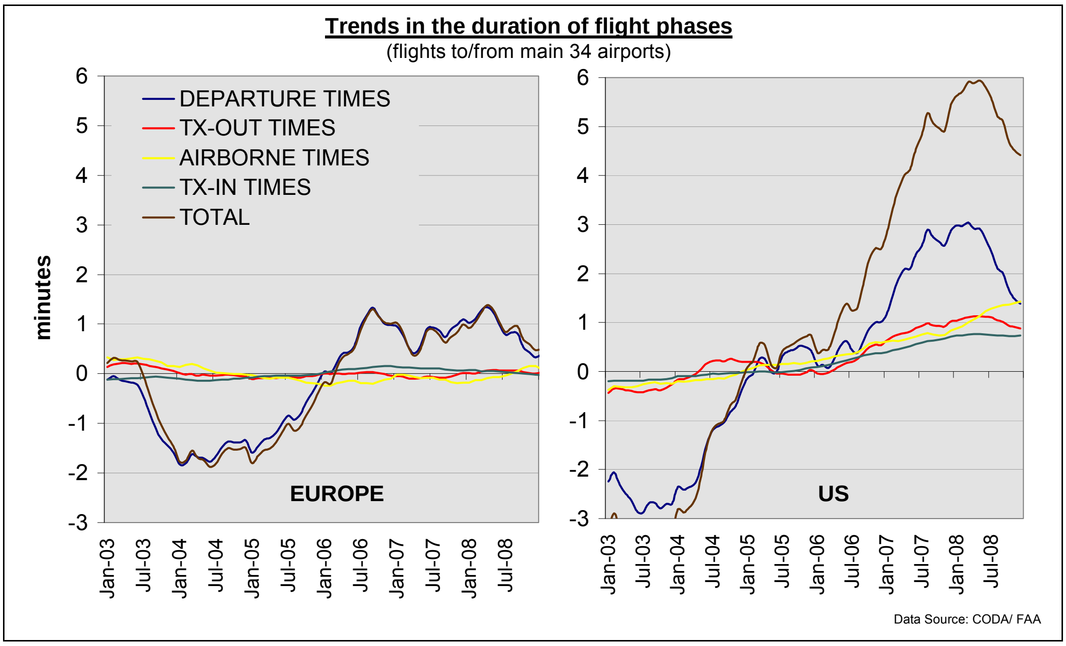


Figure 26: Trends in the duration of flight phases (2003-2008)

6.1.2 In Europe, performance is clearly driven by departure delays with only very small changes in the gate-to-gate phase. In the US, the trend is different: in addition to a deterioration of departure times, there is a clear increase in average taxi times and airborne times.

6.1.3 The trends shown in Figure 26 are consistent with the analysis of the level of variability in the individual phases of flight in Figure 24 in Chapter 5. The block time trends in Figure 20 are also similar.

6.1.4 The differences above are striking given the decreases in overall traffic in the US post 2005. Much of the delay increase can be explained by the transfer of some traffic to already congested areas. Figure 27 shows how traffic increases in the New York and Philadelphia areas are driving much of the delay though 2007.

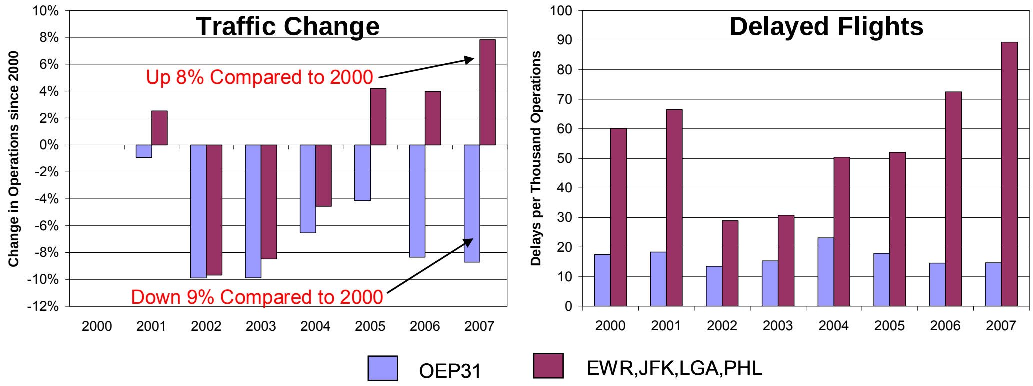


Figure 27: Growth in congested airports drives delay in the US

6.1.5 As can be seen in Figure 27, demand has decreased in areas not experiencing high levels of congestion and additional delays result from peaking of airport schedules.

6.1.6 The next sections in this chapter provide a more detailed analysis of "Efficiency" indicators by phase of flight (Figure 28). In order to better understand the impact of ATM and differences in traffic management techniques, the analysis is broken down by phase of flight (i.e. pre-departure delay, taxi out, en-route, terminal arrival, taxi-in and arrival delay).

6.2 Conceptual framework for the more detailed analysis of efficiency

6.2.1 Inefficiencies in the different flight phases have different impacts on aircraft operators and the environment. Whereas ANS-related holdings (ATFM/ EDCT delay) result in departure delays mainly experienced at the stands, inefficiencies in the gate-to-gate phase also generate additional fuel burn. The additional fuel burn has an environmental impact through gaseous emissions (mainly CO2), which generates a link to the "Environmental sustainability" KPA as shown in Figure 15 on page 20.

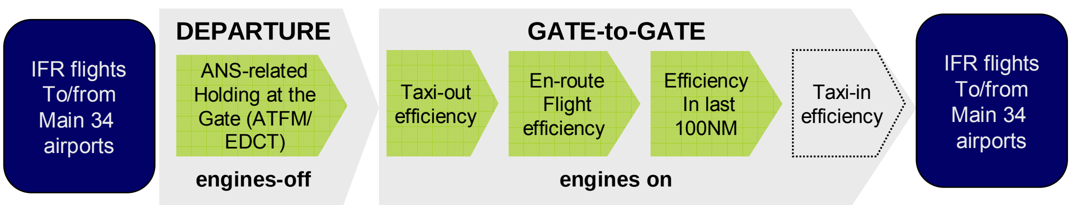


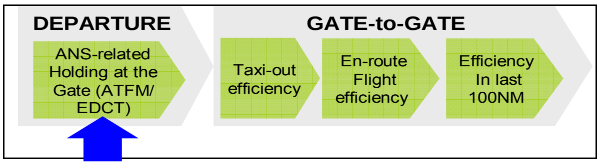
Figure 28: Measurement of efficiency by phase of flight

6.2.2 Clearly, keeping an aircraft at the gate saves fuel but, if it is held and capacity goes unused, the cost to the airline of the extra delay may exceed the fuel cost by far. Since weather uncertainty will continue to impact ATM capacities in the foreseeable future, ATM and airlines need a better understanding of the interrelations between variability, efficiency and capacity utilisation.

6.2.3 The taxi-in and the TMA departure phase (40NM ring around departure airport) were not analysed in more detail as they are generally not considered to be large contributors to ANS related inefficiencies. However, it is acknowledged that at some selected airports, the efficiency of the taxi in phase can be an issue due to apron and stand limitations. Other restrictions at individual airports may also need further study to quantify improvement opportunities.

6.3 ANS-related departure holdings

6.3.1 This section reviews ANS-related departure delays in the US and in Europe (EDCT vs. ATFM).



6.3.2 Aircraft that are expected to arrive during a period of capacity shortfall en-route or at the destination airport are held on the ground at their various origin airports (see also Chapter 3.1).

6.3.3 The delays are calculated with reference to the times in the last submitted flight plan (not the published departure times in airline schedules). Most of these delays are taken at the gate but some occur also during the taxi phase.

6.3.4 ATFM/EDCT departure delays can have various ATM-related (ATC capacity, staffing, etc.) and non-ATM related (weather, accident etc.) reasons.

6.3.5 While ATM is not always the root cause of the ATFM/EDCT departure holdings, the way the situation is handled can have a considerable impact on costs to airspace users and the utilisation of scarce capacity.

6.3.6 Reducing gate/surface delays (by releasing too many aircraft) at the origin airport when the destination airport's capacities are constrained potentially increases airborne delay (i.e. holding or extended final approaches). Applying excessive gate/surface delays, risks under utilisation of capacity and thus increase overall delay.

6.3.7 The US and Europe currently use different strategies for absorbing necessary delay in the various flight phases. More study is needed to understand the real costs of each strategy.

6.3.8 Flights to and from the main 34 airports account for 68% (Europe) and 64% (US) of the controlled flights but experience 80% and 95% of total ATFM/EDCT delay respectively.

6.3.9 Table 4 compares ANS-related departure delays attributable to en-route and airport constraints. For comparability reasons, only EDCT and ATFM delays larger than 15 minutes were included in the calculation.

6.3.10 For the US, TMS delays (see 3.1.10) due to local en-route departure and MIT restrictions are considered in the taxi time efficiency section (see Chapter 6.4).

6.3.11 The share of flights affected by ATFM/EDCT delays due to en-route constraints differs considerable between the US and Europe. In Europe, flights are as much as 50 times more likely to be held at the gate for en-route constraints (see Table 4).

6.3.12 For airport related delays, the percentage of delayed flights at the gate is similar in the US and in Europe.

Table 4: ANS related departure delays (flights to/from main 34 airports within region)

Only delays > 15 min. are included.		En-route related delays >15min. (EDCT/ATFM)			Airport related delays >15min. (EDCT/ATFM)		
2008	***IFR flights (M)***	***% of flights delayed >15 min.***	***delay per flight (min.)***	***delay per delayed flight (min.)***	***% of flights delayed >15 min.***	***delay per flight (min.)***	***delay per delayed flight (min.)***
US	9.2	0.1%	0.1	57	2.6%	1.8	70
Europe	5.6	5.0%	1.4	28	3.0%	0.9	32

6.3.13 In the US, ground delays (mainly due to airport constraints) are applied only after time based metering or miles in trail options are used which consequently leads to a lower share of flights affected by EDCT delays but higher delays per delayed flight than in Europe. More analysis is needed to see how higher delays per delayed flight are related to moderating demand with "airport slots" in Europe.

6.3.14 In Europe, ground delays (ATFM) are used much more frequently for balancing demand with en-route and airport capacity which consequently leads to a higher share of traffic affected but with a lower average delay per delayed flight (see Table 4). The results in Table 4 are consistent with the differences in the application of flow management techniques described in Chapter 3.1.

6.3.15 Figure 29 shows the share of flights with ANS related departure holdings for airport and en route constraints (ATFM/ EDCT) larger than 15 minutes by month and cause for the US and Europe.

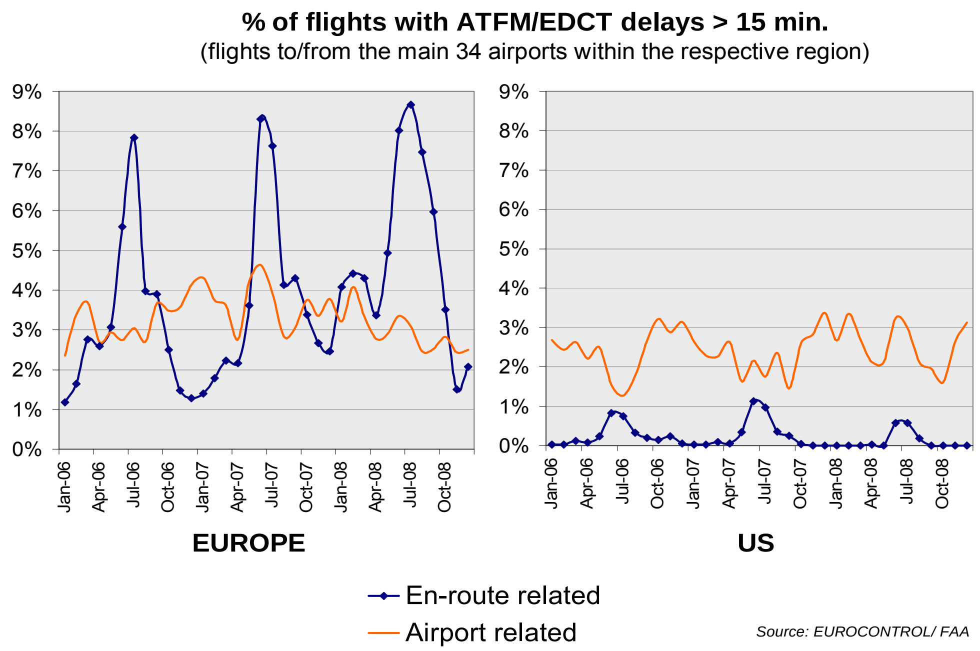


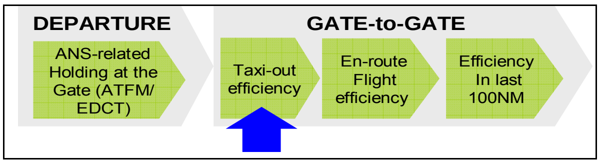
Figure 29: Evolution of EDCT/ATFM delays

6.3.16 Similar to the arrival punctuality (see also Figure 22 and Figure 23), a pattern of summer and winter peaks is visible for ANS related departure holdings in the US and in Europe.

6.3.17 The en-route related delays are much lower in the US but show similar summer peaks on both sides of the Atlantic, but for completely different reasons. While in the US, en-route delays are mostly driven by convective weather, in Europe they are mainly the result of capacity and staffing constraints driven by variations in peak demand (large differences between summer and winter). More analysis of en route delay and capacities in the US and Europe is needed.

6.4 Taxi-out efficiency

6.4.1 This section aims at evaluating the level of inefficiencies in the taxi out phase.



6.4.2 Neither FAA nor EUROCONTROL have developed a perfect methodology for the measurement of taxi-out efficiency but the magnitude of excess time and trends are clear. As surface data improves, the methodologies and accuracy will improve.

6.4.3 The analysis of taxi-out efficiency in the next sections refers to the period between the time when the aircraft leaves the stand (actual off-block time) and the take-off time. The additional time is measured as the average additional time beyond an unimpeded reference time.

6.4.4 The taxi-out phase and hence the performance measure is influenced by a number of factors such as take-off queue size (waiting time at the runway), distance to runway (runway configuration, stand location), downstream restrictions, aircraft type, and remote de-icing to name a few. Of these aforementioned causal factors, the take-off queue size[22] is considered to be the most important one [Ref. 12].

6.4.5 In the US, the additional time observed in the taxi-out phase also includes TMS delays (see 3.1.10) due to local en-route departure and MIT restrictions. In Europe, the additional time might also include a small share of ATFM delay which is not taken at the departure gate or some delays imposed by local restriction such as Minimum Departure Interval (MDI).

6.4.6 In order to get a better understanding, two different methodologies were applied. While the first method is simpler, it allows for application of a consistent methodology. The method uses the 20th percentile of each service (same operator, airport, etc.) as reference for the "unimpeded" time and compares it to the actual times. This can be easily computed with US and European data.

22 The queue size that an aircraft experienced was measured as the number of take-offs that took place between its pushback and take-off time.

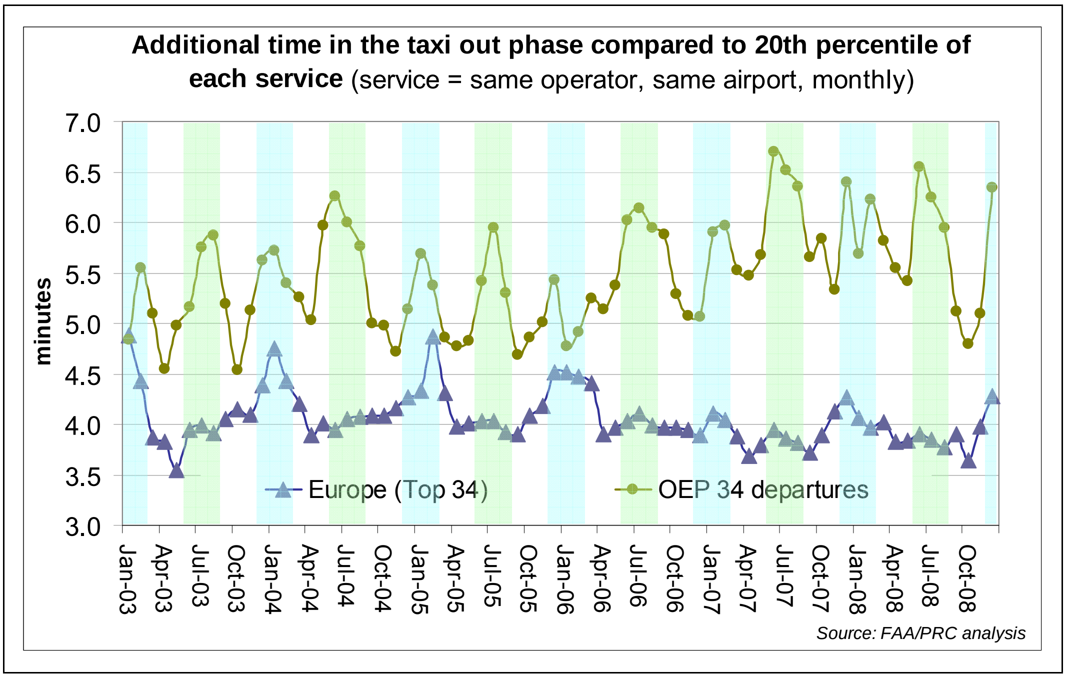


Figure 30: Additional times in the taxi out phase (system level)

6.4.7 Two interesting points can be drawn from Figure 30:

- On average, additional times in the taxi out phase appear to be higher in the US (approx. 2 minutes more per departure in 2007 and 2008).
- Seasonal patterns emerge but with different cycles in the US and in Europe. Whereas in Europe the additional times peak during the winter months most likely due to weather conditions, in the US the peak is in the summer which is most likely linked to congestion.

6.4.8 The high level result in Figure 30 is driven by contrasted situations among airports. Figure 31 shows a more detailed comparison of additional time in the taxi out phase at the major airports in Europe and the US.

6.4.9 The comparison of additional times by airport in Figure 31 is based on the respective official methodologies for the evaluation of inefficiencies in the taxi out phase as described in Annexes III and IV.

6.4.10 Although some care should be taken when comparing the 2 indicators, due to differing methodologies, Figure 31 tends to confirm the higher average additional time in the taxi-out phase in the US (6.2 minutes per departure in US compared to 4.3 minutes per departure in Europe). For reasons of clarity, only the 20 most penalising airports of the 34 main airports are shown.

6.4.11 The observed differences in inefficiencies between the US and Europe reflect the different flow control policies and the absence of scheduling caps at most US airports. Additionally, the US Department of Transportation collects and publishes data for on-time departures which adds to the focus of getting off-gate on time.

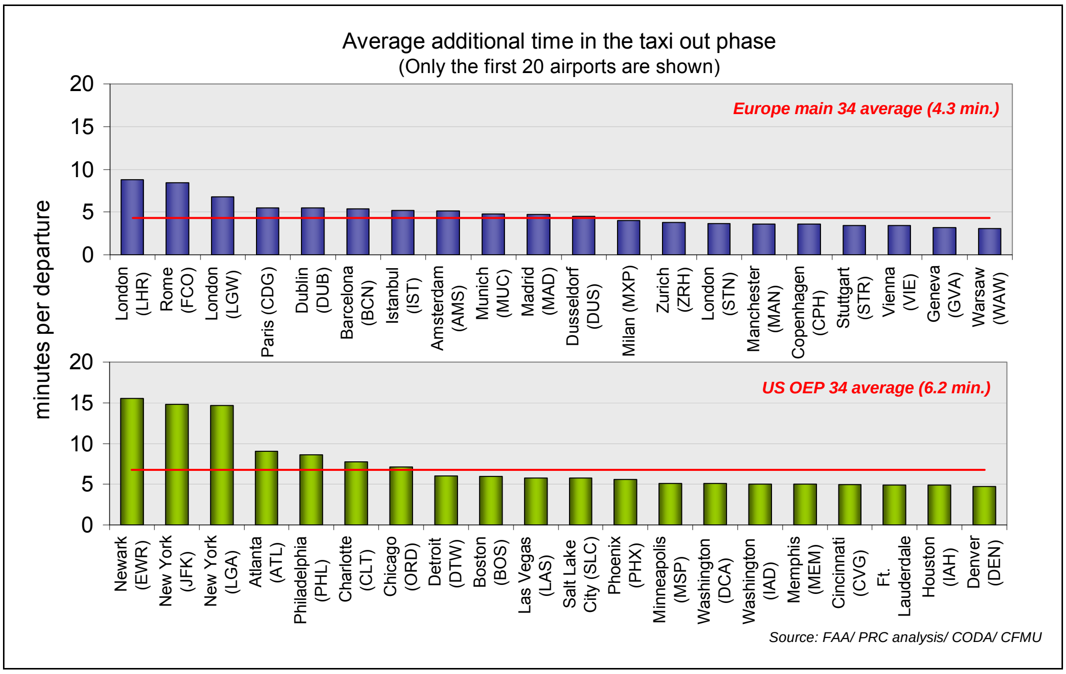


Figure 31: Comparison of additional time in the taxi out phase

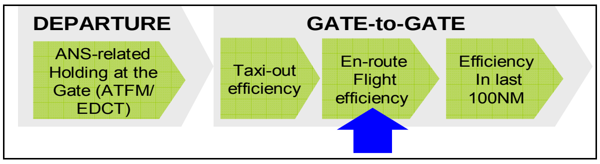
6.4.12 The impact of ANSPs on taxi times is marginal when runway capacities are constraining departures. The data on taxi delays is useful, however, in developing policies and procedures geared towards keeping aircraft at the gate longer: in the same way as Europe does with Airport Collaborative Decision Making (A-CDM).

6.4.13 A-CDM initiatives in Europe try to optimise the departure queue while minimising costs to aircraft operators. Departing aircraft are sequenced by managing the pushback times and the taxi out phase to provide minimal queues and improved sequencing at the runway.

6.4.14 The aim is to keep aircraft at the gate in order to minimise fuel burn due to departure holdings at the runway. These departure delays at the gate are reflected in the departure punctuality measures (see Chapter 4) however the ANS part due to congestion in the taxiway system is presently difficult to isolate with the available data set.

6.5 En-route flight efficiency

6.5.1 This section aims at approximating the level of ANS related inefficiencies in the en-route phase.



6.5.2 Deviations from the optimum trajectory generate additional flight time, fuel burn and costs to airspace users. En-route flight efficiency has a horizontal (distance) and a vertical (altitude) component.

6.5.3 The focus of this section is on horizontal en-route flight efficiency, which is of much higher economic and environmental importance than the vertical component [Ref. 13]. Nevertheless there is scope for improvement and more work on vertical flight inefficiencies and potential benefits of implementing Continuous Descent Approach CDA would form a more complete picture.

6.5.4 The flight efficiency in the terminal manoeuvring areas (TMA) of airports is addressed in Chapter 6.6.

6.5.5 The Key Performance Indicator (KPI) for horizontal en-route flight efficiency is en-route extension[23]. It is defined as the difference between the length of the actual trajectory[24] (A) and the Great Circle Distance (G) between the departure and arrival terminal areas (radius of 40 NM around the airport). This difference would be equal to zero in an ideal (and unachievable) situation where each aircraft would be alone in the system and not be subject to any constraints.

6.5.6 Where a flight departs or arrives outside the respective airspace, only that part inside the airspace is considered. Flights with a great circle distance (G) shorter than 60NM between terminal areas were excluded from the analysis.

6.5.7 As illustrated in Figure 32, "En-route extension" can be further broken down into "Direct route extension", which is the difference between the actual flown route (A) and the most direct course (D) and the "TMA interface" which is the difference between the most direct course between the two terminal entry points (D) and the Great Circle Distance (G).

6.5.8 Whereas the "TMA interface" is more concerned with the location of the TMA entry points, the "*Direct route extension*" relates more to the actual flight path.

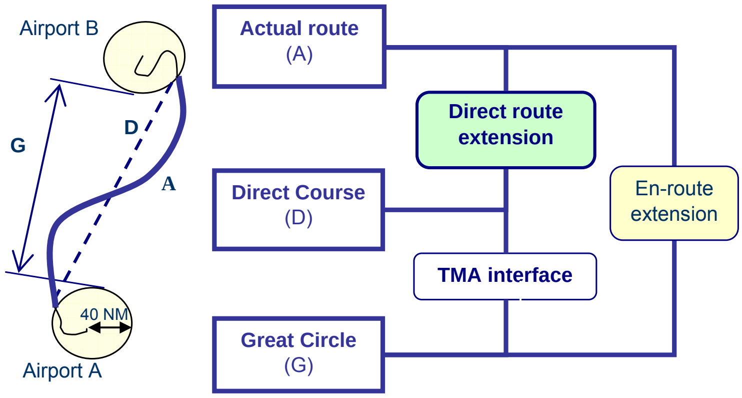


Figure 32: Conceptual framework for horizontal flight efficiency

6.5.9 Figure 33 depicts the en-route extension for flights to/from the main 34 airports within the respective region (Intra Europe, US-CONUS) and the respective share of flights (bottom of Figure 33).

23 As the indicator is distance based, it does not evaluate possible effects of speed reductions imposed on airspace users.

24 Differences in ground distances (irrespective of wind), not air distances (including wind effect). The actual route distance is computed for all IFR flights based on ETFMS data, i.e. quasi radar data.

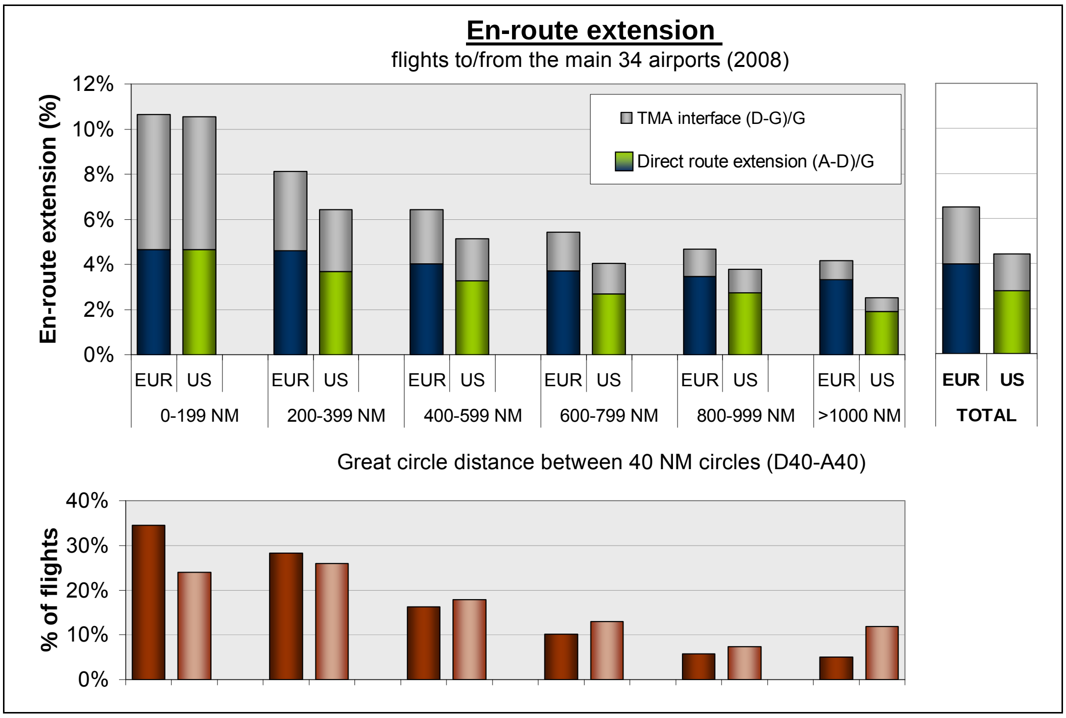


Figure 33: Comparison of en-route extension

6.5.10 "*Direct route extension*" is predominantly driven by ATC routing (flow measures such as MIT but also more direct routing), route utilisation (route selection by airspace users) and en-route design (prevailing route network). Overall, it is approximately 1% lower in the US for flights of comparable length.

6.5.11 In Europe, en-route flight efficiency is mainly affected by the fragmentation of airspace (airspace design remains under the auspices of the States) [Ref. 14]. For the US the indicator additionally includes some path stretching due to MIT restrictions.

LIMITATIONS TO IMPROVING HORIZONTAL FLIGHT-EFFICIENCY

6.5.12 While there are economic and environmental benefits in improving flight-efficiency, there are also inherent limitations. Trade-offs and interdependencies with other performance areas such as safety, capacity and environmental sustainability as well as airspace user preferences in route selection due to weather (wind optimum routes) or other reasons (differences in route charges[25], avoid congested areas) need to be considered.

6.5.13 The horizontal flight efficiency measure takes a single flight perspective as it relates actual performance to the great circle distance, which is an ideal (and unachievable) situation where each aircraft would be alone in the system and not be subject to any constraints.

6.5.14 From a system point of view, flow separation is essential for safety and capacity reasons with a consequent negative impact on flight efficiency. Consequently, the aim is not the unachievable target of direct routing for all flights at any time but to achieve an acceptable level of flight efficiency, which balances safety and capacity requirements.

[25] In Europe, the route charges differ from State to State.

6.5.15 A certain level of inefficiency is inevitable and the following limiting factors should be borne in mind for the interpretation of the horizontal flight efficiency results:

- Basic rules of sectorisation and route design. For safety reasons, a minimum separation has to be applied between routes;
- Systematisation of traffic flows to reduce complexity and to generate more capacity;

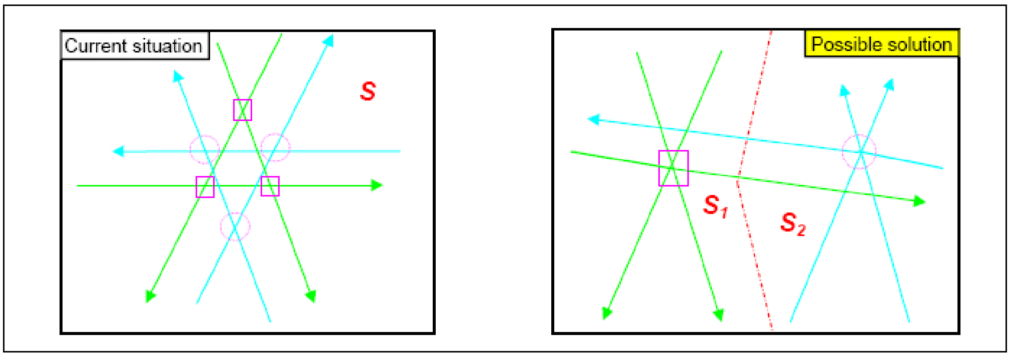


Figure 34: Systematisation of traffic flows to reduce structural complexity

6.5.16 Strategic constraints on route/ airspace utilisation (rules that govern the utilisation of the network, restricted areas, shared civil/military airspace). Figure 35 shows path stretching to avoid NY area airspace. Over time, flight paths have moved further away from the New York area. The excess distance is needed to manage workload and maintain safety.

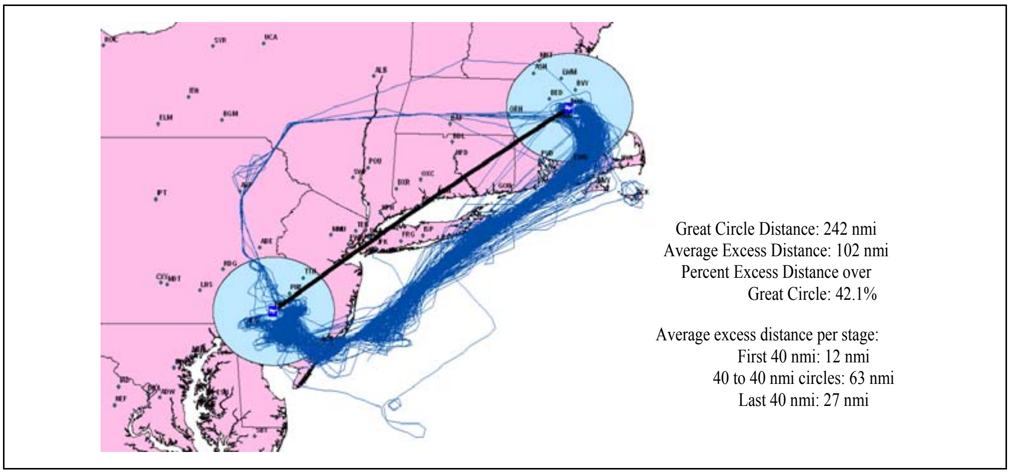


Figure 35: Drivers of inefficiencies on short haul flights (BOS-PHL July 2007)

6.5.17 Figure 36 shows the impact of shared civil/military airspace in France and Germany with the highlighted airspace representing the Ramstein area, which is primarily used by the US Military for training missions. Below is French shared civil/military airspace. The combination of the two negatively affects flight efficiency on some major routes. The Functional Airspace Block European Central (FABEC) is looking at potential solutions to improve this airspace.

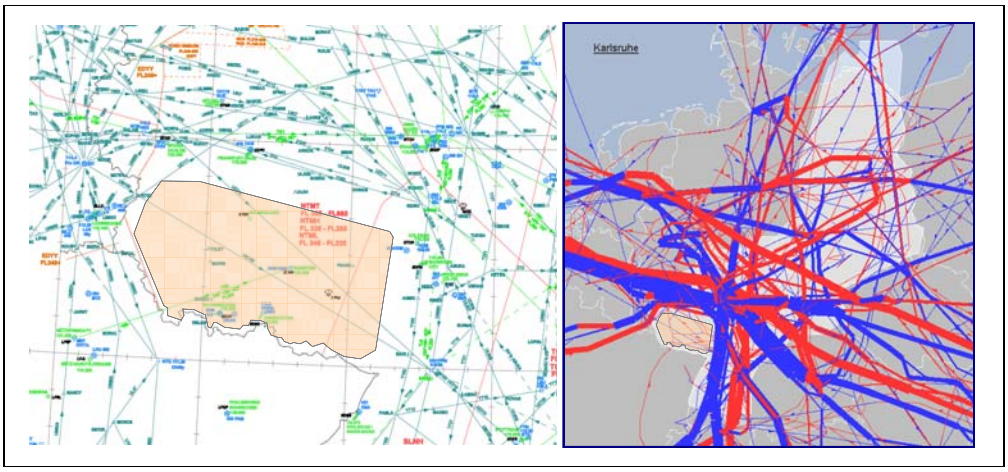


Figure 36: Use of military airspace as driver of inefficiencies southeast of Frankfurt

- Interactions with major airports. Major terminal areas tend to be more and more structured. As traffic grows, departure traffic and arrival traffic are segregated and managed by different sectors. This TMA organisation affects en-route structures as over-flying traffic has to be kept far away, or needs to be aligned with the TMA arrival and departure structures.

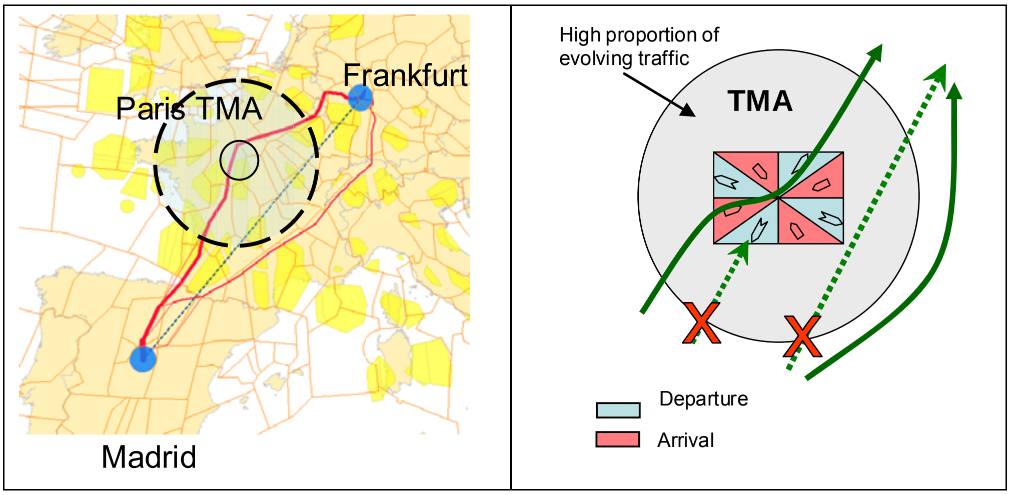


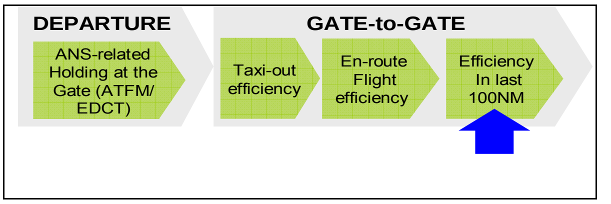
Figure 37: Impact of TMA on traffic flows

- Lastly, great circle routes do not address altitude optimizations. In Germany, most flights departing and arriving within DFS control are held to flight levels under 245. The GCD measure will, of course, not measure this constraint.

6.5.18 While new technologies and procedures have helped to further optimise safety, added some capacity, and increased efficiency (e.g. Reduced Vertical Separation Minima, RNAV), it will remain challenging to maintain the same level of efficiency while absorbing projected demand increases over the next 20 years.

6.6 Flight efficiency within the last 100 NM

6.6.1 This section aims at estimating the level of inefficiencies due to airborne holding, metering and sequencing of arrivals.



6.6.2 For this exercise, the locally defined terminal manoeuvring area (TMA) is not suitable for comparisons due to considerable variations in shape and size and ATM strategies.

6.6.3 Figure 38 illustrates how local ATM strategies affect arrival flows at three major European airports on a day in February 2008. Whereas at London Heathrow the majority of the approach operations take place in close proximity to the airport, at Frankfurt and Paris CDG, the sequencing of arrival traffic starts already much further out.

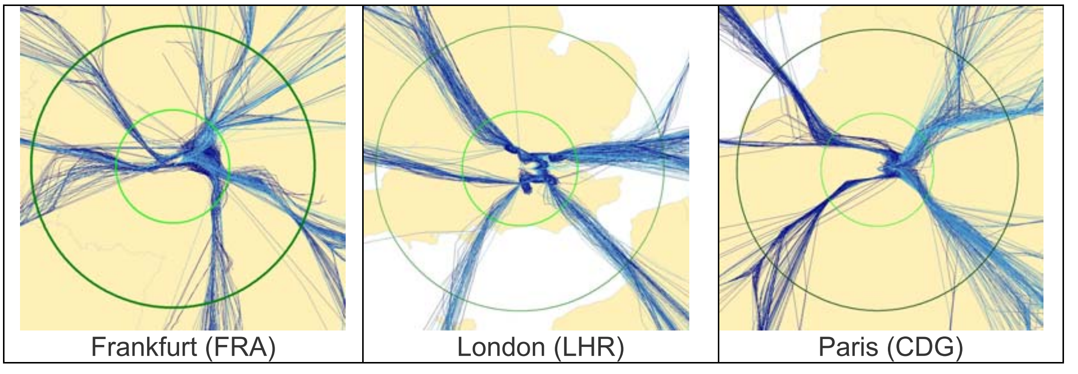


Figure 38: Impact of local ATM strategies on arrival flows

6.6.4 In order to capture tactical arrival control measures (sequencing, flow integration, speed control, spacing, stretching, etc.), irrespective of local ATM strategies a standard "Arrival Sequencing and Metering Area" (ASMA) is defined as two consecutive rings with a radius of 40 NM and 100NM around each airport.

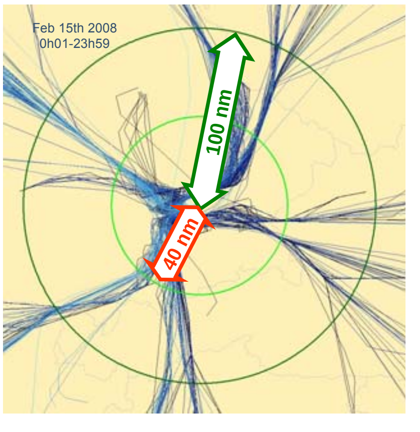


Figure 39: Arrival Sequencing and Metering Area

6.6.5 This incremental approach is sufficiently wide to capture effects related to approach operations. It also enables a distinction to be made between delays in the outer ring (40-100 NM) and the inner ring (40 NM-landing) which have a different impact on fuel burn and hence on environmental performance.

6.6.6 The actual transit times within the 100 NM ring are affected by a number of ANS and non-ANS related parameters including flow management measures (holdings, etc.), airspace design, airports configuration, aircraft type, pilot performance, environmental restrictions, and in Europe, to some extent the objectives agreed by the airport scheduling committee when declaring the airport capacity.

6.6.7 The "*additional*" time is used as a proxy for the level of inefficiency within the last 100NM. It is defined as the average additional time beyond the unimpeded transit time for each airport.

6.6.8 Although the methodologies are expected to produce rather similar results, due to data issues the calculation of the unimpeded times in Europe and the US is based on the respective "standard" methodologies (Annex II and IV) and the results should be interpreted with a note of caution.

6.6.9 Figure 40 shows the average additional time within the last 100 NM for the US and Europe in 2008. For clarity reasons only the 20 most penalising airports of the 34 main airports are shown.

6.6.10 At system level, the additional time within the last 100 NM is similar in the US (2.9 min.) and in Europe (2.8 min.). However the picture is contrasted across airports.

6.6.11 In Europe, London Heathrow (LHR) is a clear outlier, having by far the highest level of additional time within the last 100 NM, followed by Frankfurt (FRA) which shows only half the level observed at London Heathrow.

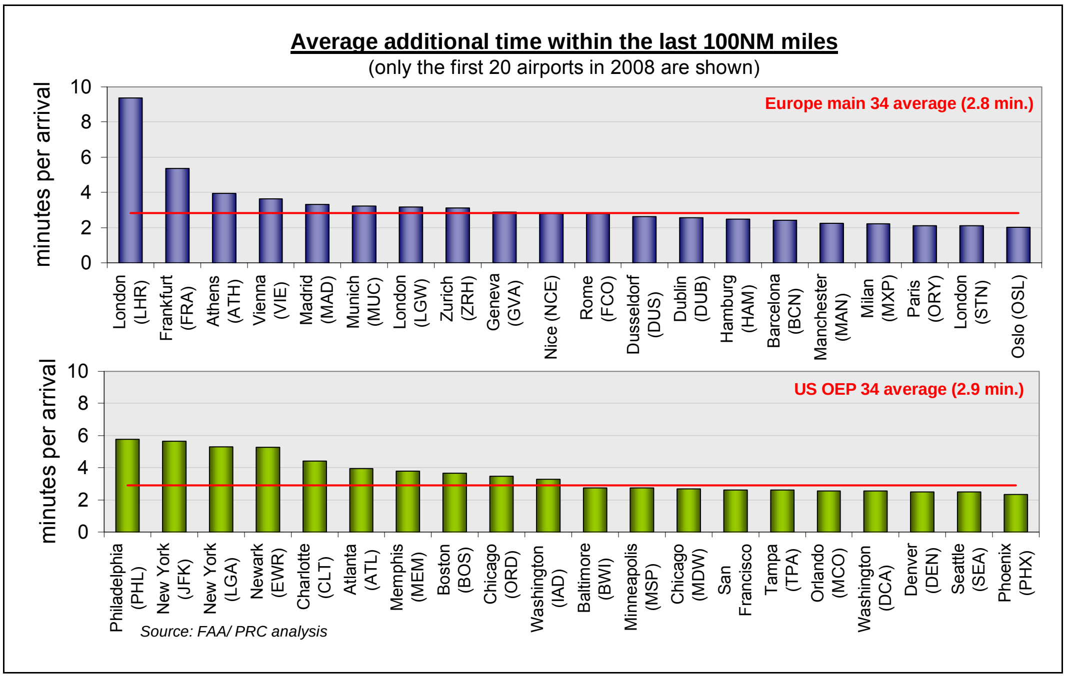


Figure 40: Estimated average additional time within the last 100 NM

6.6.12 It should be noted that the performance at London Heathrow (LHR) is consistent with the 10 minute average delay criterion agreed by the airport scheduling committee.

6.6.13 The US shows a less contrasted picture but there is still a notable difference for the airports in the greater New York area which show the highest level of inefficiencies within the last 100 NM in 2008.

6.6.14 Due to the large number of variables involved (see also paragraph 6.6.6), the direct ANS contribution towards the additional time within the last 100 NM is difficult to determine. One of the main differences of the US air traffic management system is the ability to maximise airport capacity with the en-route function supporting this in form of path stretching in order to achieve the in-trail spacing required.

6.6.15 In Europe, the support of the en-route function is limited and rarely extends beyond the national boundaries (see also paragraph 3.1.8). Hence most of the sequencing is done at lower altitudes around the airport. Additional delays beyond what can be absorbed around the airport are taken on the ground at the departure airports.

6.6.16 On both sides of the Atlantic, the operations at those airports operating close to VMC capacity are vulnerable to adverse weather conditions and cause high levels of delay to airspace users.

6.6.17 The impact of the respective air traffic management systems on airport capacity utilisation in the US and in Europe is not quantified in this report but would be a worthwhile subject for further study. The US quantifies capacity utilisation formally through its Terminal Arrival Efficiency Rating (TAER) measure. However, benchmarking the two systems would require a common understanding of how capacity is declared for comparable airports.

7 ESTIMATED BENEFIT POOL ACTIONABLE BY ANS

7.1.1 There is value in developing a systematic approach to aggregating ANS related inefficiencies. Since there are opportunities for many trade-offs between flight phases, an overall measure allows for high-level comparability across systems.

7.1.2 This chapter provides a summary of the estimated benefit pool for a typical flight, based on the analysis of traffic from and to the 34 main airports in Europe and the US.

7.1.3 By combining the analyses for individual phases of flight, an estimate of the improvement pool actionable by ANS can be derived. It is important to stress that this "benefit pool" represents a theoretical optimum (averages compared to unimpeded times) which is not achievable at system level due to inherent necessary (safety) or desired (capacity) limitations[26], as described in Chapters 3.3 and 6.5.

7.1.4 Table 5 summarises the estimated level of inefficiency actionable by ANS in the individual flight phases, as analysed in the respective chapters.

Table 5: Estimated benefit pool actionable by ANS (2008)

Estimated benefit pool actionable by ANS for a typical flight (2008) (flights to/from the main 34 airports)		Estimated additional time (avg. per flight in min.)		Predictability (% of flights affected)		Fuel burn	Est. excess fuel burn (kg)[27]	
		EUR	US	EUR	US	engines	EUR	US
Holding at gate per departure (only delays >15min. included)	en-route-related	1.4	0.1	5.0%	0.1%	OFF	≈0	≈0
	airport-related	0.9	1.8	3.0%	2.6%	OFF	≈0	≈0
Taxi-out phase (min. per departure)[28]		4.3	6.2	100%		ON	65 kg	93kg
Horizontal en-route flight efficiency[29]		2.1-3.9	1.4-2.6	100%		ON	180kg	118kg
Terminal areas (min. per arrival) [30]		2.8	2.9	100%		ON	115kg	119kg
Estimated benefit pool actionable by ANS		≈11.5-13.3	≈12.4-13.6				360kg	330kg

26 The CANSO report on "ATM Global Environmental Efficiency Goals for 2050" also discusses interdependencies in the ATM system that limit the recovery of calculated "inefficiencies". These interdependencies include capacity, safety, weather, noise, military operations, and institutional practices requiring political will to change.

27 Fuel burn calculations are based on averages representing a "typical" aircraft in the system [Ref. 15]. (Taxi ≈ 15kg/min., Cruise.≈ 46kg/min., TMA holding 41kg/min.).

28 The estimated inefficiencies in the taxi out phase refer only to departures from the main 34 airports. If all flights to/from the main 34 airports were considered, the "inefficiency' per flight would be lower because departures from less congested airports to the main 34 airports were included.

29 The horizontal flight efficiency figures relate to the distance between the 40 NM radius at the departure and the 100 NM radius at the arrival airport. The range in horizontal en-route flight efficiency relates to direct route extension (A-D)/G which assumes the need to maintain a route structure in the TMA area and the en-route extension (A-G)/G which assumes that all the route structure including TMA can be improved (see also Figure 32). Europe/US differences in the average distance would lead to different results, as the "inefficiency" is measured as a percentage of the great circle distance. For comparability reasons, the estimated additional time calculation was based on an average great circle distance of 450 NM for the US and Europe.

30 The estimated inefficiencies in the last 100 NM refer only to arrivals at the main 34 airports. If all flights to/from the main 34 airports were considered, the "inefficiency" per flight would be lower because arrivals at less congested airports from the main 34 airports were included.

7.1.5 Although Table 5 shows an estimated total to provide an order of magnitude, the interpretation requires a note of caution as inefficiencies in the various flight phases (airborne versus ground) have a very different impact on airspace users in terms of predictability (strategic versus tactical - % of flights affected) and fuel burn (engines on vs. engines off).

7.1.6 Whereas for ANS related holdings at the gate (see Chapter 6.3) the fuel burn is quasi nil, those delays are not evenly spread among flights (small percentage of flights but high delays) and hence difficult to predict.

7.1.7 The estimated "inefficiencies" in the gate-to-gate phase are generally more predictable for airspace users (more evenly spread but smaller delays) but generate higher fuel burn.

7.1.8 Actual fuel burn depends on the respective aircraft mix and therefore varies for different traffic samples. For comparability reasons, the fuel burn shown in Table 5 is based on typical average fuel burn which was equally applied to the US and Europe figures (main 34 airports).

7.1.9 At system level, the total estimated inefficiency pool actionable by ANS and associated fuel burn are of the same order of magnitude in the US and Europe (estimated to be between 6-8% of the total fuel burn) but with notable differences in the distribution along the phases of flight [Ref. 14].

7.1.10 Inefficiencies in the vertical flight profile and in the taxi-in phase are assumed to be of lower magnitude [Ref. 13] and were therefore not included in Table 5. The magnitude can change by region or airport and it is acknowledged that there is also scope for improvement in those areas and that there is a need to include them in future benefit pool estimations in order to get an even more complete picture.

8 CONCLUSIONS

8.1.1 The paper provides a high-level comparison of operational performance between the US and Europe Air Navigation systems, based on a set of commonly agreed indicators from the FAA/ATO and EUROCONTROL.

8.1.2 The initial focus has been to develop a set of comparable performance measures in order to create a sound basis for high level comparisons between countries and world regions.

8.1.3 Overall, the FAA controls approximately 70% more flights and handles significantly more visual Flight Rules (VFR) traffic with some 17% less controllers and fewer en-route facilities.

8.1.4 In order to ensure comparability of data sets, the analyses were limited to controlled (IFR) flights to or from the 34 most important airports in the US and in Europe.

8.1.5 The analysis of schedule adherence reveals a similar level of arrival punctuality in the US and Europe, albeit with increasing time buffers in airline schedules and a higher level of variability in the US, part of which is assumed to be result of a combination of airport scheduling closer to VFR capacity and resulting weather effects.

8.1.6 Although the analysis of performance compared to airline schedules is valid from a passenger point of view and provides first valuable insights, the "masking" of expected travel time variations through the inclusion of strategic time buffers in scheduled block times makes a more detailed analysis of actual operations necessary to better understand the impact of ATM and differences in traffic management techniques.

8.1.7 The analysis of actual operations is broken down by phase of flight (i.e. pre-departure delay, taxi-out, en-route, terminal arrival, taxi-in and arrival delay). This reveals strong and weak points on both sides.

- In the US, departure punctuality is better, but taxi-out delays are longer and associated unit fuel burn higher.
- Horizontal en-route flight efficiency is higher in the US, with corresponding fuel burn benefits. The fragmentation of European airspace appears to be an issue which affects overall flight efficiency and which limits the ability of the en-route function to support airport throughput. The development of Functional Airspace Block (FAB) within the Single European Sky Initiative is expected to help improve this.
- On average, the additional time within the last 100 NM is comparable. London and Frankfurt on the European side and the airports in the New York area on the US side show significantly higher arrival transit times on average.

8.1.8 Although safety and capacity constraints limit the practicality of ever fully eliminating these "inefficiencies" there is value in developing a systematic approach to aggregating a benefit pool which is actionable by ANS.

8.1.9 Inefficiencies have a different impact (fuel burn, time) on airspace users, depending on the phase of flight (airborne vs. ground) and the level of predictability (strategic vs. tactical).

8.1.10 While ANS is often not the root cause of a delay, the aim should be to optimize how the delay is taken. The predictability of the different flight phases and the fuel cost will help determine how much and where delay needs to be absorbed. Further work is needed to assess the impact of ATM performance on airspace users, the utilisation of capacity, and the environment.

8.1.11 The estimated inefficiency pool actionable by ANS and associated fuel burn is similar in the US and Europe (estimated to be between 6-8% of the total fuel burn) but with notable differences in the distribution by phase of flight.

8.1.12 These differences possibly originate from different policies in allocation of airport slots and flow management, as well as different weather conditions. The impact on environment, predictability and flexibility in accommodating unforeseen changes may be different. In addition to weather and airport congestion management policy, a more comprehensive comparison of service performance would also need to address Safety, Capacity and other relevant performance affecting factors. A better understanding of trade-offs would be needed to identify best practices and policies.

8.1.13 There is high value in global comparisons and benchmarking in order to drive performance and identify best practice. Moving forward, the conceptual framework enables operational performance to be measured in a consistent way and ATM best practices to be better understood. Identification and application of today's best practices, with existing technology and operational concepts, could possibly help in raising the level of performance on both sides of the Atlantic in the relatively short term, and may have wider applicability.

9 EMERGING THEMES AND NEXT STEPS

9.1.1 The report provides a high-level comparison of operational performance between the US and Europe. The findings raise many questions to what extent performance differences are driven by scheduling policies, ATM operating strategies, and/or differences in weather conditions.

9.1.2 The main questions revolve around the ATM application of delay along the various flight phases, the subsequent environmental and economic impact, and the ability to maximise the use of scarce capacity.

9.1.3 For the US, the application of policies similar to those in Europe could improve delay statistics but at what economic cost? How much are US scheduling and ATM policies driven by the predominant weather conditions in the US? (High percentage of VMC days, convective weather in summer).

9.1.4 For Europe, the questions revolve around the use of capacities. Are capacities too low and over-constraining demand and efficient scheduling? Is the number of ANSPs impacting en route throughput and how does IMC weather and wind impact airport throughput?

9.1.5 While this high level study raises questions, more in-depth study is needed to better understand what procedural changes could be made now and in the future. There may be good reason for different focuses in the future ATM systems in Europe and the US.

9.1.6 Below are several specific research topics for further joint study with a view to identifying best practices (taking weather and other appropriate constraints into account) to further improve ATM performance on both sides of the Atlantic and possibly world wide.

1) <u>Refinement of benefit pool actionable by ANS:</u> In order to establish a more complete understanding of the benefit pool actionable by ANS, it will be necessary to include vertical flight efficiency and inefficiencies in the taxi in phase in future benefit pool estimations (see 7.1.10).

2) <u>ATM Performance, environmental impact and fuel burn:</u> While ANS is often not the root cause of delay, the way the delay is managed and distributed along the various phases of flight has an impact on airspace users (predictability, fuel burn), the utilisation of capacity (en-route and airport), and the environment (gaseous emissions).

   The high level results in this report reveal considerable differences between the US and Europe in this context. Two interesting questions to be addressed and also relevant for NextGen and SESAR are:

   - What level of "delay" is necessary to maximise the use of capacity?
   - How should delay be distributed along the various phases of flight in order to minimise impact on airspace users and the environment?

   More research is required to determine the relation of optimised trajectories to the performance indicators. This would require more detailed aircraft performance modelling that could establish benchmark times according to weather, aircraft weight and user preferences.

Although not in the scope of the report, the potential benefit pool for intercontinental flights on Oceanic routes should be explored in order to identify scope for improvement.

3) ATM and airport capacity utilisation: More work is needed to better understand the impact of differences in airport scheduling practices and air traffic flow management on peak airport throughput in the US and in Europe (see 2.2.15).

4) Provision of en-route capacity in Europe: Compared to the US, a large share of the delay in Europe is due to en-route constraints. More work to better understand the drivers of en-route constraints in Europe (i.e. traffic growths, staffing, seasonality, fragmentation, complexity etc.) and differences compared to the US could help reducing en-route related constraints in the European ATM system.

5) ATM and weather: In Europe, the ability to quantify the impact of weather on air traffic is not as developed as in the US (i.e. WITI[31] Metric, etc) and more work in this direction including supporting data collections would be necessary to identify differences in weather patterns and subsequent air traffic management initiatives between the US and Europe (see 2.2.18).

   Additional work on how to improve the predictability of flight times for a given weather condition and demand level on the day of operations and on how to minimise the capacity gap between IMC and VMC at airports in the longer term will further help to improve overall system performance.

   Develop a better understanding of how weather may be impacting the application of coordinated "airport slot" policies in the US and Europe.

6) Specific Study on taxi delay and the impact of Airline schedules as well as opportunities for virtual taxi queues in the US versus Europe.

7) Aircraft sizes: considerable differences in average aircraft size between the US and Europe were observed (see 2.1.25). Are policy difference regarding pre-coordinated airport slots impacting aircraft size or is it more a factor of priority on frequency of flights and the hub and spoke model in the US? A more detailed analysis would help to better understand the factors driving the differing trends in average aircraft size.

8) Impact of shared airspace on ATM: In Europe there is a high density of civil and military activity in the core area. More study is needed to evaluate the impact of ATM civil/ military arrangements on flight efficiency in the US and Europe (see 2.2.5 and 6.5.17).

9) Consistent approach to ANS performance measurement: In addition to operational performance measure, there would be value in extending the scope to other performance areas such as Safety or Cost-effectiveness in order to develop a consistent and systematic approach for high level comparisons between countries and world regions.

[31] Weather Impacted Traffic Index (WITI) metric. When the WITI metric is applied to the entire NAS, it is also known as the NAS Weather Index (NWX).

ANNEX I - LIST OF AIRPORTS INCLUDED IN THIS STUDY

Table 6: Top 34 European airports included in the study

	EUROPE	ICAO	IATA	COUNTRY	Avg. daily IFR departures in 2008
1	Amsterdam (AMS)	EHAM	AMS	NETHERLANDS	603
2	Athens (ATH)	LGAV	ATH	GREECE	264
3	Barcelona (BCN)	LEBL	BCN	SPAIN	439
4	Berlin (TXL)	EDDT	TXL	GERMANY	216
5	Brussels (BRU)	EBBR	BRU	BELGIUM	344
6	Cologne (CGN)	EDDK	CGN	GERMANY	191
7	Copenhagen (CPH)	EKCH	CPH	DENMARK	361
8	Dublin (DUB)	EIDW	DUB	IRELAND	284
9	Dusseldorf (DUS)	EDDL	DUS	GERMANY	311
10	Frankfurt (FRA)	EDDF	FRA	GERMANY	663
11	Geneva (GVA)	LSGG	GVA	SWITZERLAND	240
12	Hamburg (HAM)	EDDH	HAM	GERMANY	222
13	Helsinki (HEL)	EFHK	HEL	FINLAND	253
14	Istanbul (IST)	LTBA	IST	TURKEY	355
15	Lisbon (LIS)	LPPT	LIS	PORTUGAL	197
16	London (LGW)	EGKK	LGW	UNITED KINGDOM	361
17	London (LHR)	EGLL	LHR	UNITED KINGDOM	654
18	London (STN)	EGSS	STN	UNITED KINGDOM	262
19	Madrid (MAD)	LEMD	MAD	SPAIN	642
20	Manchester (MAN)	EGCC	MAN	UNITED KINGDOM	277
21	Milan (MXP)	LIMC	MXP	ITALY	298
22	Munich (MUC)	EDDM	MUC	GERMANY	587
23	Nice (NCE)	LFMN	NCE	FRANCE	196
24	Oslo (OSL)	ENGM	OSL	NORWAY	322
25	Palma (PMI)	LEPA	PMI	SPAIN	263
26	Paris (CDG)	LFPG	CDG	FRANCE	765
27	Paris (ORY)	LFPO	ORY	FRANCE	320
28	Prague (PRG)	LKPR	PRG	CZECH REPUBLIC	237
29	Rome (FCO)	LIRF	FCO	ITALY	474
30	Stockholm (ARN)	ESSA	ARN	SWEDEN	305
31	Stuttgart (STR)	EDDS	STR	GERMANY	201
32	Vienna (VIE)	LOWW	VIE	AUSTRIA	396
33	Warsaw (WAW)	EPWA	WAW	POLAND	205
34	Zurich (ZRH)	LSZH	ZRH	SWITZERLAND	359
					355

Table 7: US OEP 34 airports included in the study

	USA	ICAO	IATA	COUNTRY	Avg. daily IFR departures in 2008
1	Atlanta (ATL)	KATL	ATL	United States	1333
2	Baltimore (BWI)	KBWI	BWI	United States	365
3	Boston (BOS)	KBOS	BOS	United States	506
4	Charlotte (CLT)	KCLT	CLT	United States	719
5	Chicago (MDW)	KMDW	MDW	United States	349
6	Chicago (ORD)	KORD	ORD	United States	1202
7	Cincinnati (CVG)	KCVG	CVG	United States	389
8	Cleveland (CLE)	KCLE	CLE	United States	321
9	Dallas (DFW)	KDFW	DFW	United States	895
10	Denver (DEN)	KDEN	DEN	United States	857
11	Detroit (DTW)	KDTW	DTW	United States	633
12	Ft. Lauderdale (FLL)	KFLL	FLL	United States	376
13	Houston (IAH)	KIAH	IAH	United States	799
14	Las Vegas (LAS)	KLAS	LAS	United States	644
15	Los Angeles (LAX)	KLAX	LAX	United States	837
16	Memphis (MEM)	KMEM	MEM	United States	493
17	Miami (MIA)	KMIA	MIA	United States	502
18	Minneapolis (MSP)	KMSP	MSP	United States	613
19	New York (JFK)	KJFK	JFK	United States	603
20	New York (LGA)	KLGA	LGA	United States	521
21	Newark (EWR)	KEWR	EWR	United States	593
22	Orlando (MCO)	KMCO	MCO	United States	467
23	Philadelphia (PHL)	KPHL	PHL	United States	657
24	Phoenix (PHX)	KPHX	PHX	United States	668
25	Pittsburgh (PIT)	KPIT	PIT	United States	221
26	Portland (PDX)	KPDX	PDX	United States	332
27	Salt Lake City (SLC)	KSLC	SLC	United States	472
28	San Diego (SAN)	KSAN	SAN	United States	303
29	San Francisco (SFO)	KSFO	SFO	United States	522
30	Seattle (SEA)	KSEA	SEA	United States	470
31	St. Louis (STL)	KSTL	STL	United States	336
32	Tampa (TPA)	KTPA	TPA	United States	309
33	Washington (DCA)	KDCA	DCA	United States	377
34	Washington (IAD)	KIAD	IAD	United States	533
					565

ANNEX II - US methodology for Terminal Arrival Efficiency

This Annex describes the methodology for calculating the efficiency of individual flights in a defined terminal area. The efficiency is based on flight time inside of a 100NM arc around the airport. The baseline or unimpeded time that actual flight times are compared to come from an existing FAA measure called the Terminal Arrival Efficiency Rating (TAER). The TAER is an official FAA performance metric used to assess throughput and the ETA used in its calculation serves as a benchmark of unimpeded time and indicator of flight efficiency. The benchmark times used in the subject terminal arrival efficiency measure are developed for unique combinations of:

(1) Approach Path
(2) Arrival Configuration - *From National Traffic Management Log (NTML) Database*
(3) Meteorological Condition - *Determined by ASPM*
(4) Aircraft Class - *Physical Class & Weight Class*

The sections below describe how RADAR based databases are processed to determine a representative approach path and aircraft class for each runway used at an airport.

Data Requirements: The following table describes data extracted from RADAR sources in combination with data from ASPM that reports the runway used. For each flight that crosses the 40 NMI circle from the arrival airport, the following data fields are needed to generate unimpeded benchmark ETAs:

Field	Description
ARR_APRT	Arrival airport
ARR_RUNWAY_CONFIGURATION	Runway configuration in use for arrivals
ARR_MC	Meteorological conditions at the airport at time of arrival
PHYSICAL_CLASS	Physical class: *Jet, Turboprop, Piston, Other*
WEIGHT_CLASS	Weight class: *Heavy, 757, Large Jet, Commuter, Medium and Light*
CROSS_100	Boolean value whether or not the flight crossed the 100 NMI circle from the airport (flight may be less than 100 NMI in Great Circle Distance)
TIME_CROSS_100	Time at the 100 NMI crossing (if crossed)
TIME_CROSS_40	Time at the 40 NMI crossing
TIME_ON	The On Time for the flight
BEARING_CROSS_100	The bearing from the airport (0 is due North, 90 is due East) of the 100 NMI crossing point (if crossed)
BEARING_CROSS_40	The bearing from the airport of the 40 NMI crossing point
DISTANCE_FLOWN_100_40	The distance flown (NMI) between the 100 NMI circle and the 40 NMI circle (if the 100 NMI circle is crossed)
DISTANCE_FLOWN_40_ON	The distance flown (NMI) between the 40 NMI circle and the airport

Process 1: Assigning Approach Paths (Creation of Fix Regions)
When generating the TAER ETAs, one of the grouping variables that used is an "assigned fix" based on the direction that the flight is approaching the airport. The process does not use the specific arrival fixes according to the airspace configuration data. Instead, it examines the data to see where flights actually cross the 40 NMI circle from the airport and applies a peak finding algorithm to approximate locations for arrival fixes. Benchmark times are then developed for this clustered group of flight paths depending on their eventual arrival runway and their specific aircraft class.

For each airport, we count how many flights crossed the 40 NMI circle in each degree bin:

SELECT ARR_APRT, ROUND(BEARING_CROSS_40,0), COUNT(*) FROM ASPM_TAER_DATA GROUP BY ARR_APRT, ROUND(BEARING_CROSS_40);

This creates an airport by airport histogram of the flight counts binned by the degree from which the flight approached the airport. This is the process for creating the fix regions for a specific airport:

1. Create a rolling five degree centred count of flights at each degree bin. That is, the rolling count $r(n) = \sum_{n-2}^{n+2} c(n)$ where $c(n)$ is the original histogram count and the bins are assumed to go through 0/360 degrees (that is, for example, $r(0) = c(358) + c(359) + c(0) + c(1) + c(2)$)
2. Find the maximum $r(n)$ that is at least 2% of the total number of flights at that airport and not within 20 degrees (inclusive) of another previously determined fix. If such a value exists, add it to the fix list and repeat step 2, else go on to step 3.
3. Sort the fix list and assign cut off values for the fix regions as the average value between two adjacent fixes (including the last fix and the first fix).

This creates the list of fixes and the ranges for which to assign flights to a clustered set of approach paths.

Process 2: Calculate Benchmark Times by Group

For each flight, read in all of the required data. Using the BEARING_CROSS_100 if the CROSS_100 value is true, or the BEARING_CROSS_40 if the CROSS_100 is false, find the assigned fix value by using the fix bin ranges calculated in Process 1. Then group the flights which crossed the 100 NMI circle (where CROSS_100 is true) by the following category data:

1. Arrival Airport
2. Assigned Approach Path (Fix Region)
3. Arrival Configuration
4. Meteorological Condition
5. Physical Class
6. Weight Class

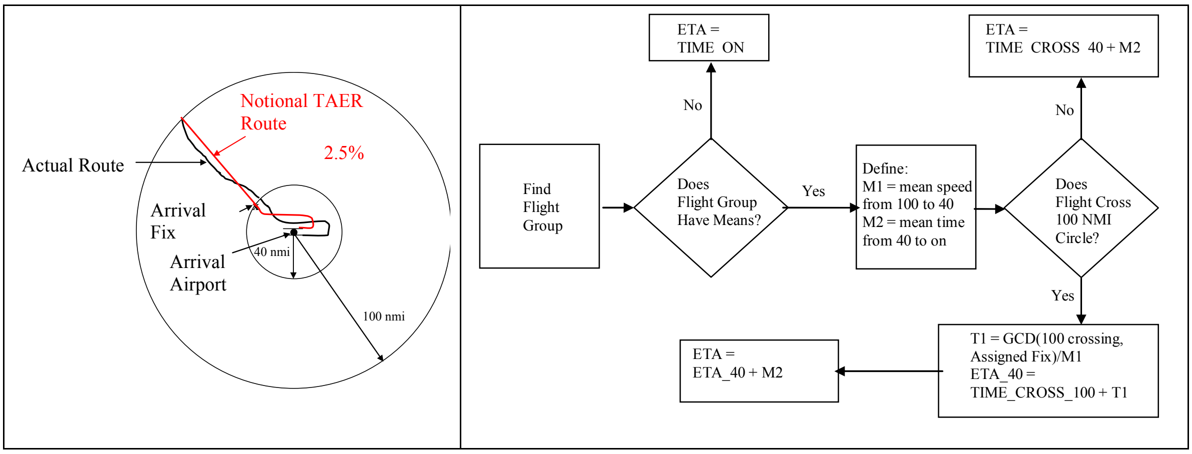
For each group that had at least 50 flights during the year, we sort the flights by the total distance flown from the 100 NMI circle crossing to the arrival airport, DISTANCE_FLOWN_100_40 + DISTANCE_FLOWN_40_ON. From that, we take the flights between the 5^{th} and 15^{th} percentiles… those flights that are short, but not the extreme shortest flights. We then use those flights (the 5^{th} to 15^{th} percentile flights by distance) to calculate an average ground speed flown between the 100 NMI circle and the 40 NMI circle (DISTANCE_FLOWN_100_40/(TIME_CROSS_40-TIME_CROSS_100), and the average time from the 40 NMI circle to the airport (TIME_ON-TIME_CROSS_40).

To reiterate, for each group of flights, we now have an average speed from the 100 to 40 NMI circles and an average time from the 40 NMI circle to the runway. These averages are based on the flights that are relatively short in distance flown and thus are more likely to be unimpeded.

Process 3: Find Flight by Flight ETAs

Now that we have the grouped means, we can calculate the flight by flight ETAs. For each flight:

1. Find the grouping for the flight as in Process 2 above. Do this even if the flight did not cross the 100 NMI circle.
2. Find the two means calculated in Process 2 above. If the grouping for the flight did not have enough flights to use to calculate the means in Process 2, assign the ETA to be the TIME_ON and finish. If there were enough flights and the means exist for this grouping, proceed to Step 3.
3. If the flight did not cross the 100 NMI circle, that is CROSS_100 is false, assign the ETA to be the TIME_CROSS_40 + mean time from 40 NMI to the airport and finish. Else, proceed to Step 4.
4. If the flight did cross the 100 NMI circle, use the BEARING_CROSS_100 and the Assigned Fix Bearing to find the great circle distance from the 100 NMI crossing position to the assigned fix. Calculate the estimated time from the 100 NMI circle to the 40 NMI circle by dividing the great circle distance by the mean speed from 100 to 40 calculated in Process 2. Add that time to the TIME_CROSS_100 to find an estimated time of crossing at the 40 NMI assigned fix. To that 40 NMI estimated time, add the mean time from 40 NMI to the airport to generate the ETA.


Notional TAER
Route
2.5%
Actual Route
Arrival
Fix
Arrival
Airport
40 nmi
100 nmi
ETA =
TIME ON
ETA =
TIME CROSS 40 + M2
No
No
Find
Flight
Group
Does
Flight Group
Have Means?
Yes
Define:
M1 = mean speed
from 100 to 40
M2 = mean time
from 40 to on
Does
Flight Cross
100 NMI
Circle?
Yes
ETA =
ETA_40 + M2
T1 = GCD(100 crossing,
Assigned Fix)/M1
ETA_40 =
TIME_CROSS_100 + T1

ANNEX III - US methodology for unimpeded taxi-out times

1. Start with a city pair flight with the data items: date (year, month, and day), departure and arrival airport, departure and arrival times (both scheduled and actual), OOOI times (out, off, on, and in). The season parameter is defined as follows: winter in (12, 01, 02), spring in (03, 04, 05), summer in (06, 07, 08), and fall in (09, 10, 11). At least, the above is the way I think how the seasons go in the East in the United States.
2. Split a flight into two parts: departure and arrival.
3. The departure part contains: Airport, Carrier, Season, Actual gate-out time (entry time into a departure queue), and Actual wheels-off time (exit time out of the departure queue).
4. The arrival part contains: Airport, Carrier, Season, Actual wheels-off time (entry time into an arrival queue), and Actual gate-in time (exit time out of the arrival queue).
5. Set up a bin for each minute of a single day and count how many aircraft (both departing and arriving) ahead of the flight at the queue entry time for the departure and arrival queues separately.
6. Compute for each group an upper quartile (75th percentile) and exclude the upper 25% from the estimation computation. This is done to prevent extremely large values from exerting excessive effects on the estimates. After all, we are estimating an optimal taxi times, assuming there is no obstruction in the taxiways.
7. Run a regression for each subgroup determined by the airport, air carrier, and season, again, separately for the departure and arrival queues.

   $y_o = ax_o + bx_i + c$, where y_o is a taxi-out time and x_o and x_i are the number of aircraft taxing out and taxing in, respectively. a and b are regression coefficients with $a \geq 0$ and $b \geq 0$.

8. Adopt only results for which both regression coefficients are positive (the more air craft, the longer taxi times).
9. For the subgroups with non-positive regression coefficients, do other things with boundary conditions set for the resulting coefficients to be positive. (SAS used has some regression or non-linear model fitting procedures in which I can specify the boundary conditions.)
10. Finally, to obtain the unimpeded taxi-out times, set the number of departing air craft to be 1 and arriving air craft to be 0 in the regression equation for the departure queue, meaning that my aircraft is only one moving. For the unimpeded taxi-in times, set the number of arriving aircraft to be 1 and departing air craft to be 0 in the equation for the arrival queue.
11. The other statistics are for information only as a reference to see if the unimpeded times are reasonable.

ANNEX IV - European methodology for unimpeded time

This Annex describes the Methodology used for the calculation of the additional time in the taxi out phase and within the last 100NM for Europe.

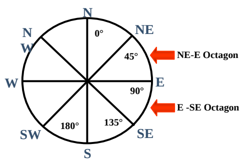
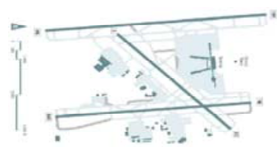
Data Requirements

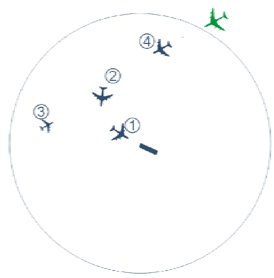
For each flight, the following data fields were used for the calculation of the unimpeded times. Presently, the runway and stand information is not available in the central data collections accessible to EUROCONTROL. When this data was not available, the unimpeded times were calculated at a lower level of detail (i.e. without stand runway combination).

Field	Last 100 NM	Taxi out	Description	Source
DEP_APRT		X	Departure airport	CFMU
ARR_APRT	X		Arrival airport	CFMU
DEP_RUNWAY		X	Departure Runway	Airport
ARR_RUNWAY	X		Arrival Runway	Airport
AIRCRAFT_CLASS	X	X	Physical class: Jet, Turboprop, Piston	CFMU
BEARING_CROSS_100	X		The bearing from the airport (0 is due North, 90 is due East) of the 100 NMI crossing point (if crossed)	CFMU
TIME_CROSS_100	X		Time at the 100 NMI crossing (if crossed)	CFMU
BEARING_CROSS_40	X		The bearing from the airport of the 40 NMI crossing point	CFMU
TIME_CROSS_40	X		Time at the 40 NMI crossing	CFMU
ALDT	X		Actual Landing Time	CFMU
AOBT		X	Actual Off-block Time	CODA
DEPARTURE GATE		X	Departure gate/ stand	
ATOT		X	Actual Take-off Time	

Process 1: Grouping of flights

Each flight is categorised according to some key factors (as far as available) relevant for performance measurement:

• Aircraft class: grouping of aircraft type into Heavy, Medium, Small Jet or Turbo Prop in order to account for speed differences.	Physical class: Jet, Turboprop, Piston	Last 100NM / Taxi out
• ASMA entry sector: The ASMA (circle around airport with a radius of 100Nm) is divided into 8 sectors of 45° in order to capture the direction from which the flight entered into the ASMA.		Last 100NM
• Runway use: The inclusion of the arrival/ departure runway provides useful additional information for airport performance analyses.		Last 100NM / Taxi out

• <u>Congestion index:</u> The allocation of a congestion level to each flight is important to remove congestion effects in the calculation of the unimpeded transit times. • For the last 100NM, it considers the number of landings by other aircraft between the analysed flight enters the 40NM radius and its actual landing. • For taxi out, it considers the number of take-offs and landings by other aircraft between the analysed flight goes off block and its take off.		Last 100NM / Taxi out

Process 2: Calculation of unimpeded reference time

For each group with the same characteristics (aircraft class, entry sector, runway, stand, if available or applicable), an unimpeded reference time is calculated.

The unimpeded reference time is the truncated average (10^{th}-90^{th} percentile) of all flights equal to or below a predefined congestion index. The aim is not to capture the fastest times but to reference the average behaviour when no congestion is present.

In order to take the difference in airport throughput into account, the threshold for the congestion index to be used for the calculation of the unimpeded time is defined as 50% (or alternatively 25%) of the maximum airport throughput using the following formula (max = 25% * max. throughput *12/60). This assumes that the unimpeded transit time is around 12 min. For example, for an airport with a maximum throughput of 40, only the flights with a congestion index of 4 or less would be included in the calculation of the unimpeded transit time.

Process 3: Additional time calculation

For each group (same aircraft class, entry sector, runway, stand, if available and applicable), the additional time is calculated as the difference between the average transit time (of all flights in this group) and the unimpeded reference time for this group determined in the previous step.

In order to get high level results, the weighted average of all the individual groups (aircraft class, entry sector and runway, if available) is calculated in a final step.

The sensitivity analysis showed that the methodology appears to be robust for high-level performance measurement. Subject to data availability, the methodology can also be adjusted the level of detail (runway-entry point combination).

ANNEX V - GLOSSARY

AAR	Airport Arrival Acceptance Rates
ACC	Area Control Centre. That part of ATC that is concerned with en-route traffic coming from or going to adjacent centres or APP. It is a unit established to provide air traffic control service to controlled flights in control areas under its jurisdiction.
ACI	Airports Council International (http://www.aci-europe.org/)
ADR	Airport Departure Rates (ADR)
AIG	Accident and Incident Investigation (ICAO)
Airside	The aircraft movement area (stands, apron, taxiway system, runways etc.) to which access is controlled.
AIS	Aeronautical Information Service
ANS	Air Navigation Service. A generic term describing the totality of services provided in order to ensure the safety, regularity and efficiency of air navigation and the appropriate functioning of the air navigation system.
ANSP	Air Navigation Services Provider
APP	Approach Control Unit
ARTCC	Air Route Traffic Control Center (ARTCC) is the equivalent of an ACC in Europe.
ASM	Airspace Management
ASMA	Arrival Sequencing and Metering Area
ASPM	FAA Aviation System Performance Metrics (ASPM)
ATC	Air Traffic Control. A service operated by the appropriate authority to promote the safe, orderly and expeditious flow of air traffic.
ATCO	Air Traffic Control Officer
ATFCM	Air Traffic Flow and Capacity Management.
ATFM	Air Traffic Flow Management. ATFM is established to support ATC in ensuring an optimum flow of traffic to, from, through or within defined areas during times when demand exceeds, or is expected to exceed, the available capacity of the ATC system, including relevant aerodromes.
ATFM delay (CFMU)	The duration between the last Take-Off time requested by the aircraft operator and the Take-Off slot given by the CFMU.
ATFM Regulation	When traffic demand is anticipated to exceed the declared capacity in en-route control centres or at the departure/arrival airport, ATC units may call for “ATFM regulations”.
ATM	Air Traffic Management. A system consisting of a ground part and an air part, both of which are needed to ensure the safe and efficient movement of aircraft during all phases of operation. The airborne part of ATM consists of the functional capability which interacts with the ground part to attain the general objectives of ATM. The ground part of ATM comprises the functions of Air Traffic Services (ATS), Airspace Management (ASM) and Air Traffic Flow Management (ATFM). Air traffic services are the primary components of ATM.
ATS	Air Traffic Service. A generic term meaning variously, flight information service, alerting service, air traffic advisory service, air traffic control service.
Bad weather	For the purpose of this report, “bad weather” is defined as any weather condition (e.g. strong wind, low visibility, snow) which causes a significant drop in the available airport capacity.
CAA	Civil Aviation Authority
CANSO	Civil Air Navigation Services Organisation (http://www.canso.org)
CDA	Continuous Descent Approach
CDM	Collaborative Decision Making
CDR	Conditional Routes
CFMU	EUROCONTROL Central Flow Management Unit
CO_2	Carbon dioxide
CODA	EUROCONTROL Central Office for Delay Analysis
CTOT	Calculated Take-Off Time

EC	European Commission
ECAC	European Civil Aviation Conference.
E-CODA	Enhanced Central Office for Delay Analysis (EUROCONTROL)
EDCT	Estimate Departure Clearance Time. EDCT is a long term Ground Delay Program (GDP), in which the command centre (ATCSCC) selects certain flights heading to a capacity limited destination airport and assigns an EDCT to each flight, with a 15 minute time window.
EU	European Union [Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany , Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom]
EUROCONTROL	The European Organisation for the Safety of Air Navigation. It comprises Member States and the Agency.
EUROCONTROL Member States	Thirty-eight Member States (31.12.2008): Albania, Armenia, Austria, Belgium, Bosnia & Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Malta, Moldova, Monaco, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, The former Yugoslav Republic of Macedonia; Turkey, Ukraine and United Kingdom.
FAB	Functional Airspace Blocks
FIR	Flight Information Region. An airspace of defined dimensions within which flight information service and alerting service are provided.
FL	Flight Level. Altitude above sea level in 100 feet units measured according to a standard atmosphere. Strictly speaking a flight level is an indication of pressure, not of altitude. Only above the transition level (which depends on the local QNH but is typically 4000 feet above sea level) flight levels are used to indicate altitude, below the transition level feet are used.
FMP	Flow Management Position
FUA **Level 1** **Level 2** **Level 3**	Flexible Use of Airspace Strategic Airspace Management Pre-tactical Airspace Management Tactical Airspace Management
GAT	General Air Traffic. Encompasses all flights conducted in accordance with the rules and procedures of ICAO. The report uses the same classification of GAT IFR traffic as STATFOR: 1. Business aviation: All IFR movements by aircraft types in the list of business aircraft types (see STATFOR Business Aviation Report, May 2006, for the list); 2. Military IFR: ICAO Flight type= 'M', plus all flights by operators or aircraft types for which 70%+ of 2003 flights were 'M'; 3. Cargo: All movements by operators with fleets consisting of 65% or more all-freight airframes ; 4. Low-cost: See STATFOR Document 150 for list. 5. Traditional Scheduled : ICAO Flight Type = 'S', e.g. flag carriers. 6. Charter: ICAO Flight Type = 'N', e.g. charter plus air taxi not included in (1)
General Aviation	All civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire.
IATA	International Air Transport Association (www.iata.org)
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules. Properly equipped aircraft are allowed to fly under bad-weather conditions following instrument flight rules.
IMC	Instrument Meteorological Conditions
KPA	Key Performance Area
KPI	Key Performance Indicator
M	Million
MET	Meteorological Services for Air Navigation
MIL	Military flights
MIT	Miles in Trail
MTOW	Maximum Take-off Weight
NAS	

NM	Nautical mile (1.852 km)
OEP	Operational Evolution Partnership (a list of 35 US airports that was compiled in 2000, based on lists from the FAA and Congress and a study that identified the most congested airports in the US).
OPS	Operational Services
Opsnet	The Operations Network (OPSNET) is the official source of NAS air traffic operations and delay data. The data collected through OPSNET is used to analyze the performance of the FAA's air traffic control facilities.
PRC	Performance Review Commission
Primary Delay	A delay other than reactionary
PRU	Performance Review Unit
Punctuality	On-time performance with respect to published departure and arrival times
RAD	Route availability document
Reactionary delay	Delay caused by late arrival of aircraft or crew from previous journeys
Separation minima	Separation Minima is the minimum required distance between aircraft. Vertically usually 1000 ft below flight level 290, 2000 ft above flight level 290. Horizontally, depending on the radar, 3 NM or more. In the absence of radar, horizontal separation is achieved through time-separation (e.g. 15 minutes between passing a certain navigation point).
SES	Single European Sky (EU) http://europa.eu.int/comm/transport/air/single_sky/index_en.htm
SESAR	The Single European Sky implementation programme
Slot (ATFM)	A take-off time window assigned to an IFR flight for ATFM purposes
STATFOR	EUROCONTROL Statistics & Forecasts Service
Summer period	May to October inclusive
Taxi- in	The time from touch-down to arrival block time.
Taxi- out	The time from off-block to take-off, including eventual holding before take-off.
TBM	Time Based Metering
TMA	Terminal manoeuvring area
TMS	Traffic Management System
TRACON	Terminal Radar Approach Control
UAC	Upper Airspace Area Control Centre
US	United States of America
US CONUS	The 48 contiguous States located on the North American continent south of the border with Canada, plus the District of Columbia, excluding Alaska, Hawaii and oceanic areas
VFR	Visual Flight Rules
VMC	Visual metrological conditions

ANNEX VI - REFERENCES

1 A comparison of performance in selected US and European En-route Centres, Performance Review Commission, (May 2003).

2 ICAO Manual on Air Navigation Services Economics, Document 9161 – Fourth Edition 2007.

3 D. Howell, M Bennett, J. Bonn, D. Knorr, Paper 23, "Estimating the en route efficiency benefits pool", 5th USA-Europe ATM Seminar, Budapest Hungary, June 2003.

4 ICAO Manual on Global Performance of the Air Navigation System (ICAO Document 9883)

5 Amedeo Odoni and Thomas Morisset, "The declared capacity: A critical decision for major airports", May 2009.

6 Post, J., J. Bonn, M. Bennett, D. Howell, and D. Knorr, 2002, The use of Flight Track and Convective Weather Densities for National Airspace System Efficiency Analysis, IEEE/AIAA Digital Aviation Systems Conference (DASC).

7 Timothy Ayanla and Dave Knorr, FAA Brief: Analysis of Delays at Miami and Fort Lauderdale.

8 FAA Free Flight Performance Metrics Reports 1999-2001.

9 http://www.airlines.org/economics/cost+of+delays

10 http://www.transtats.bts.gov/OT_Delay/ot_delaycause1.asp?type=4&pn=1.

11 http://earthobservatory.nasa.gov/IOTD/view.php?id=6679.

12 Husni Idris, John-Paul Clarke, Rani Bhuva and Laura Kang, Massachusetts Institute of Technology, "Queuing Model for Taxi-Out Time Estimation", ATC Quarterly 2001.

13 Performance Review Commission "Evaluation of Vertical Flight-efficiency" (March 2008)

(http://www.EUROCONTROL.int/prc/gallery/content/public/Vertical_Flight_Efficiency_MAR_2008.pdf)

14 Performance Review Commission, Performance Review Report 2008 (PRR 2008). An Assessment of Air Traffic Management in Europe during the Calendar Year 2008 (May 2009).

15 CANSO, "ATM Global Environmental Efficiency Goals for 2050", December 2008.