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2015 | Comparison of Air Traffic Management-Related Operational Performance: U.S./Europe

Produced by:
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This document is a joint publication of the Air Traffic Organization System Operations Services of the FAA and EUROCONTROL on behalf of the European Union in the interest of the exchange of information.

It is prepared in application of Annex 2 of the Memorandum of Cooperation NAT-I-9406 signed between the United States of America and the European Union on 12 February 2013 and managed by a joint European Commission-FAA Performance Analysis Review Committee (PARC). The report builds on the body of work developed since 2009 between the FAA and EUROCONTROL.

The objective is to make a factual high-level comparison of Air Traffic Management performance between the US and Europe. It is based on a set of comparable performance indicators, developed jointly and reviewed year after year, creating a sound basis for factual comparisons between countries and world regions. The specific key performance indicators (KPIs) are based on best practices from both the Air Traffic Organization System Operations Services and the performance scheme of the Single European Sky initiative.

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2015 Comparison of ATM-related performance: U.S. – Europe

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ABSTRACT

This report is the 5th in a series of joint ATM operational performance comparisons between the US and Europe. It represents the 2nd edition under the Memorandum of Cooperation between the United States and the European Union. Building on established operational key performance indicators, the goal of the joint study conducted by the Federal Aviation Administration (FAA) and EUROCONTROL on behalf of the European Union is to understand differences between the two ATM systems in order to further optimise ATM performance and to identify best practices for the benefit of the overall air transport system. The analysis is based on a comparable set of data and harmonised assessment techniques for developing reference conditions for assessing ATM performance.

Produced by EUROCONTROL on behalf of the European Union and the Federal Aviation Administration Air Traffic Organization System Operations Services

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EXECUTIVE SUMMARY

This report is the 5th in a series of joint ATM operational performance comparisons between the US and Europe. It represents the 2nd edition under the Memorandum of Cooperation between the United States and the European Union. The report provides a comparative operational performance assessment between Europe and the US using Key Performance Indicators (KPIs) that have been harmonized by both groups. The report provides demonstrated examples of the KPIs listed in the 2016 ICAO Global Air Navigation Plan (GANP) which can be used to assess the benefits of the global implementation of Aviation System Block Upgrades (ASBUs).

The indicators used are those proven to meet key ANSP objectives of identifying system constraints through delay/capacity measures and improving flight efficiency by measuring actual trajectories against an ideal. The report also includes punctuality and block time indicators that relate performance more directly to the airline/passenger perspective. Complementary to the well-established indicators already used in previous versions of the comparison reports, this edition also features two supporting studies on 1) Air Traffic Flow and Capacity Management (ATFCM) and 2) Vertical Flight Efficiency in the arrival phase.

The first part of this report examines commonalities and differences in terms of air traffic management and performance influencing factors, such as air traffic demand characteristics and weather, which can have a large influence on the observed performance.

Overall, air navigation service provision is more fragmented in Europe with more ANSPs and physical facilities than in the US. The European area comprises 37 Air Navigation Service Providers (ANSPs) with 62 en-route centres and 16 stand-alone Approach Control (APP) units (total: 78 facilities). The US CONUS has 20 en-route centres supplemented by 26 stand-alone Terminal Radar Approach Control (TRACON) units (total: 46 facilities), operated by one ANSP.

Although the US CONUS airspace is 10% smaller than the European airspace, the US controlled approximately 57% more flights operating under Instrument Flight Rules (IFR) with 24% fewer full time Air Traffic Controllers (ATCOs) than in Europe in 2015. US airspace density is, on average, higher and airports tend to be notably larger than in Europe.

In terms of traffic evolution, there was a notable decoupling between the US and Europe in 2004 when the traffic in Europe continued to grow while US traffic started to decline. The effect of the economic crisis starting in 2008 impacted traffic growth on both sides of the Atlantic. While traffic in Europe decreased by 3.3%, air traffic in the US decreased by 9.9% between 2008 and 2015.

The second part of this report analyses operational performance in both systems from an airline and from an ANSP point of view. The airline perspective evaluates efficiency and predictability compared to published schedules whereas the ANSP perspective provides a more in-depth analysis of ATM-related performance by phase of flight compared to an ideal benchmark distance or time. For the majority of indicators, trends are provided from 2008 to 2015 with a focus on the change in performance from 2013 to 2015.

Punctuality is generally considered to be the industry standard indicator for air transport service quality. The trend in punctuality was similar in the US and Europe between 2005 and 2009 when both systems reached a comparable level of around 82% of arrivals delayed by 15 minutes or less in 2009. Whereas in the US performance remained stable in 2010, punctuality in Europe degraded to the worst level on record mainly due to weather-related delays (snow, freezing conditions) and strikes. From 2010 to 2012, punctuality in Europe improved again and continued to improve in the US. However in 2013 and 2014, whereas punctuality in Europe remained largely unchanged, punctuality in the US saw a sharp decline. In 2015 both systems reached again a similar performance level due to notable improvements in the US and performance degradation in Europe.

While the evaluation of air transport performance compared to airline schedules provides valuable first insights, the involvement of many different stakeholders and the inclusion of time buffers in airline schedules limit the analysis from an air traffic management point of view. Hence, the evaluation of ATM-related performance in this comparison aims to better understand and quantify constraints imposed on airspace users through the application of air traffic flow measures and therefore focuses more on the efficiency of operations by phase of flight compared to an unconstrained benchmark distance or time.

After the bad performance due to weather and strikes in 2010, average ATM-related departure delay in Europe decreased again until 2013. Between 2013 and 2015, total ATM-related ground delays increased in Europe by 43.4% whereas traffic grew by 4.1% during the same time. The US has also shown an improvement since 2008, some of which can be attributed to improving weather and declining traffic levels. Between 2013 and 2015, total ATM-related ground delay in the US decreased by 12.7% (mainly due to less weather-related delays) with system-wide CONUS traffic levels increasing by 1.6% during the same time. In Europe, the notable performance deterioration between 2013 and 2015 was due to a significant increase in capacity/volume related delays and to a lesser extent due to weather.

ATM-related ground delay per flight in Europe (en-route and airport) was lower than in the US in 2015 (1.3 vs. 1.6 minutes per flight) however a larger percentage of flights is affected in Europe (4.3% vs 3.3%). The underlying reasons and the application of ATM-related departure restrictions among facilities differ notably between the two systems. Europe ascribes a greater percentage of delay to en-route facilities (43% of total delay in 2015) while in the US the large majority is ascribed to constraints at the airport (82.1% of total delay in 2015).

The share of flights affected by ATM-related departure restrictions at origin airports differs considerably between the US and Europe. Despite a reduction from 5.0% of all flights in 2008 to 2.0% in 2015, flights in Europe are still over twice more likely to be held at the gate or on the ground for en-route constraints than in the US where the share of flights affected by ATM-related departure restrictions was 0.8% in 2015.

For airport-related ground delays, the percentage of delayed flights at the gate or on the surface is slightly lower in Europe than in the US (2.3% vs. 2.5% in 2015). However, with 51 minutes, the delay per delayed flight in the US is notably higher than in Europe in 2015 (33 mins). In the US, the airports which make up a large percentage of those delays are airports like New York (LGA), Chicago (ORD), Newark (EWR), San Francisco (SFO), New York (JFK), and Philadelphia (PHL) which report a large number of hours with demand near or over capacity and have lower predictability of capacity.

Taxi-out efficiency improved continuously between 2007 and 2012 in the US but deteriorated again by 0.5 minutes per departure between 2012 and 2015. During the same period, with the exception of 2010 where taxi-out efficiency decreased due to the strong winter, performance in Europe improved continuously at a moderate rate but also showed a slight deterioration in 2015.

After a notable closure of the gap between the US and Europe until 2012, the performance gap is widening again and in 2015 average additional taxi-out time in the US is, on average, some 1.5 minutes higher per departure than in Europe. This is largely driven by different flow control policies and the absence of scheduling caps at most US airports. Whereas in Europe the inefficiency levels in the taxi-out phase are more evenly spread among airports, the observed taxi-out performance in the US is predominantly driven by the New York airports, Philadelphia (PHL), and Chicago (ORD).

Horizontal en-route flight efficiency (between a 40NM radius around the departure airport and a 100NM radius around the arrival airport) in filed flight plans and in actual trajectories is still better in the US than in Europe in 2015. Overall, horizontal en-route efficiency on flights to or from the main 34 airports in the US is approximately 0.1% better than in Europe in 2015.

Similar to en-route flight efficiency, the US also continued to show a higher level of efficiency in the last 100NM before landing. Overall, the average additional time within the last 100 NM (Arrival Sequencing and Maneuvering Area (ASMA)) was similar in the two regions in 2008 but decreased in the US between 2008 and 2010 after which it has remained almost constant at 2.5 minutes across the main airports. At the same time, flight efficiency within the last 100 NM deteriorated in Europe. Although at different levels, performance in the US and in Europe remained relatively stable between 2013 and 2015.

At system level, average additional ASMA time was 2.5 minutes per arrival in the US in 2015 which was 0.4 minutes lower than in Europe. The result in Europe was significantly affected by London Heathrow (LHR) which had an additional time of 9.5 minutes per arrival - almost twice the level of London Gatwick (LGW) with 4.9 minutes per arrival in 2015. In the US, efficiency levels in the terminal area are more homogenous.

As there are many trade-offs between flight phases, the aggregation of the observed results enables a high-level comparison of the "benefit pool" actionable by ATM in both systems. For the interpretation of the observed results, it is important to stress that the determined "benefit pool" is based on a theoretical optimum (averages compared to unimpeded times), which is, due to inherent necessary (safety) or desired (capacity) limitations, clearly not achievable at system level.

Although in a context of declining traffic, system-wide ATM performance improved notably in the US and in Europe between 2010 and 2015. The resulting savings in terms of time and fuel in both ATM systems had a positive effect for airspace users and the environment.

The improvement in Europe over the past five years was mainly driven by a notable reduction of ATM-related departure delay, improvements in taxi-out efficiency, and better en-route flight efficiency. In this context it is however important to point out that 2010 was a year with comparatively high delays in Europe due to adverse weather and ATC strikes. The performance improvement in the US was mainly due to a substantial improvement of taxi-out efficiency, although average additional time in the taxi-out phase in the US increased again slightly in 2015.

Overall, the relative distribution of the ATM-related inefficiencies associated with the different phases of flight is consistent with the differences in flow management strategies described throughout the report. In Europe ATM-related departure delays are much more frequently used for balancing demand with en-route and airport capacity than in the US, which leads to a notably higher share of traffic affected but with a lower average delay per delayed flight. Moreover the share of en-route related Traffic Management Initiatives (TMIs) in Europe is close to 50% while in the US more than 80% of TMIs are airport-related during 2015.

Consequently, in Europe flights are over twice more likely to be held at the gate or on the ground for en-route constraints than in the US. For TMIs related to arrival airport constraints the situation is different. The percentage of delayed flights at the departure gate or on the surface is slightly higher in the US than in Europe and the delay per delayed flight in the US is almost twice as high as in Europe. Most of this delay in the US is generally linked to weather-related constraints at a number of high density airports including, New York (LGA), Chicago (ORD), Newark (EWR), San Francisco (SFO), New York (JFK), and Philadelphia (PHL).

1. INTRODUCTION

1.1 Background and objectives

The US-Europe Comparison Report is jointly developed under Annex 2 of the Memorandum of Cooperation between the United States of America and the European Union signed in 2013 and managed by a joint European Commission-FAA Performance Analysis Review Committee (PARC).

The EUROCONTROL Performance Review Unit (PRU) and the US Air Traffic Organization[1] (FAA-ATO) have produced a series of joint performance studies using commonly agreed metrics and definitions to compare, understand, and improve air traffic management (ATM) performance.

The initial benchmark report comparing operational performance through 2008 was completed in 2009 [Ref.1]. Subsequent benchmark reports comparing ATM performance in the US and Europe have since been published in 2010, 2012, and 2014 [Ref.2]. This report is the 5th in the series of joint ATM operational performance comparisons between the US and Europe.

1.2 Report Scope

Figure 1-1 shows the geographical scope of this report with the US CONUS subdivided into 20 Air Route Traffic Control Centers (ARTCCs) and the European area subdivided into 62 en-route centres[2].

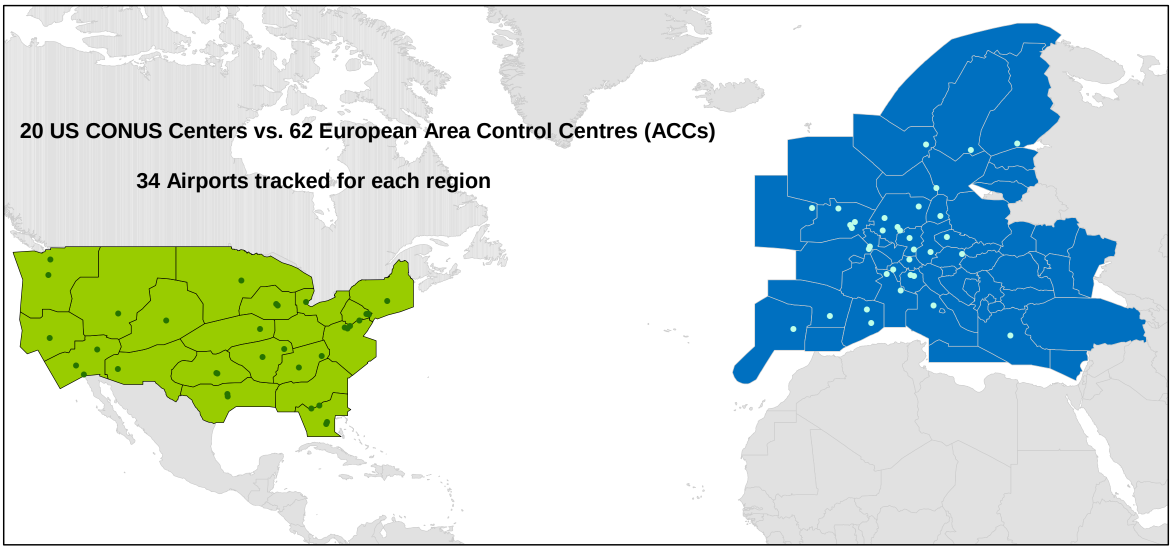

Figure 1-1: Geographical scope of the comparison in the report

Unless stated otherwise, for the purpose of this report, "Europe" is defined as the geographical area where the Air Navigation Services (ANS) are provided by the European Union Member

[1] The US Air Traffic Organization (ATO) was created as the operations arm of the Federal Aviation Administration (FAA) in December 2000, to apply business-like practices to the delivery of air traffic services.

[2] The map shows European airspace at Flight Level 300. Therefore not all the en-route facilities are visible as some control lower airspace only.

States plus those States outside the EU that are members of EUROCONTROL[3], excluding Oceanic areas, Georgia and the Canary Islands.

Unless otherwise indicated, "US" refers to ANS provided by the United 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 (US CONUS).

In order to ensure the comparability of operational ATM performance, the analysis scope of this report was influenced by the need to identify a common set of data sources with a sufficient level of detail and coverage. Therefore - unless stated otherwise - the detailed analyses of ATM-related operational performance by phase of flight in Chapter 5 are limited to flights to or from the main 34 airports for IFR traffic in both the US and in Europe. A detailed list of the airports included in this report can be found in Annex I.

Although they are within the top 34 airports in terms of traffic in Europe in 2015, Istanbul Ataturk (IST), Istanbul (SAW), Antalya (AYT), and Warsaw (WAW) airports were not included in the analysis due to data availability issues.

The 34 main airports used for more detailed performance tracking are also shown in Figure 1-1. Although these airports remain consistent for the most part, there have been minor changes since the last comparison report in 2013. In the US, Dallas Love (DAL) and Nashville (BNA) have replaced Cleveland (CLE) and Raleigh-Durham (RDU).

For the US, many of these high volume airports are located on the coasts or edges of the study region creating a greater percentage of longer haul flights in the US, especially when only flights within the study region are considered. The airborne trajectory on these transcontinental flights may be more affected by the influences of wind and convective weather.

TEMPORAL SCOPE

The operational analyses in this report were carried out for the calendar year 2015 and, where applicable, comparisons to previous years were made to track changes over time. In particular, this report contrasts the performance of 2015 versus the performance observed (and reported) in the 2013 edition of this report.

1.3 Data Sources

Various data sources have been used for the analysis of operational ATM performance. These data sources include, inter alia, trajectory position data, ATFM imposed delay, key event times and scheduled data from airlines, and METAR information for weather.

DATA FROM AIR TRAFFIC MANAGEMENT SYSTEMS

Both the US and Europe obtain key data from their respective air traffic flow management (ATFM) systems. There are two principal sources within ATM. These include trajectory/flight plan databases used for flight efficiency indicators, and delay databases that record ATFM delay and often include causal reasons for the delay.

For the US, flight data come from the Traffic Flow Management System (TFMS). In Europe, data

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

are derived from the Enhanced Tactical Flow Management System (ETFMS) of the European Network Manager. These data sources provide the total IFR traffic picture and are used to determine the “main” airports in terms of IFR traffic and the flight hour counts used to determine traffic density.

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

The data sets also provide flight trajectories which are used for the calculation of flight efficiency in terms of planned routes and actual flown routing. The data sets which include data in the en-route transitional phase and in the terminal areas allow for performance comparison throughout various phases of flight. This report features an initial assessment of vertical flight efficiency for a subset of airports based on the aforementioned trajectory data.

DATA FROM AIRLINES

The US and Europe receive operational and delay data from airlines for scheduled flights. This represents a more detailed subset of the traffic flow data described above and is used for punctuality or phase of flight indicators where more precise times are required.

These data include what is referred to as OOOI (Gate Out, Wheels Off, Wheels On, and Gate In) times which are recorded to 1 minute resolution. OOOI data along with airline schedules allow for the calculation of gate delay, taxi times, en-route times, and gate arrival time delay on a flight by flight basis. The data also contains cause codes for delays on a flight-by-flight basis.

In the US, most performance indicators are derived from the Aviation System Performance Metrics (ASPM) database which fuses detailed airline data with data from the traffic flow management system (TFMS). Air carriers are required to report performance data if they have at least 1% of total domestic scheduled-service passenger revenues. In addition there are other carriers that report voluntarily. ASPM coverage in 2015 was approximately 94% of the IFR traffic at the main 34 airports with 87% of the total IFR traffic reported as scheduled operations. Airline-reported performance data for traffic at the main 34 airports represent 71% of all IFR flights at these airports. This percentage as well as the specific carriers that report does not stay constant from reporting period to reporting period and this has some effect on the performance indicators based on OOOI data. For the US, this effect was most pronounced for airports with high use by American Airline (AAL) in which OOOI coverage increased (CLT, ORD). There was also some effect for airports such as Detroit (DTW) with high use of certain regional carriers such as Endeavor Air (FLG) which moved from reporting to non-reporting from 2013-2015.

In Europe, the Central Office for Delay Analysis (CODA) collects data from airlines each month. The data collection started in 2002 and the reporting was voluntary until the end of 2010. As of January 2011, airlines which operate more than 35 000 flights per year[4] within the European Union (EU) airspace are required to submit the data on a monthly basis according to EU Regulations [Ref.3]. In 2015, the CODA coverage was approximately 62% of total IFR flights and approximately 74% of flights at the 34 main airports.

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

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[4] Calculated as the average over the previous three years.

ANS PERFORMANCE DATA

This comparison study builds on the data describing the ANS operations within the aforementioned scope of the US and European region. Within the field of air transport statistics a variety of sources report on air traffic. Care has to be taken when comparing the data from different sources, as data collection and reporting requirements entail different conventions concerning the breakdown of the data in terms of flight operations, type of flights, etc.

Within the US, the Bureau of Transportation Statistics (BTS) establishes air traffic related data and statistics for the purpose of analysing the US air transportation market. The underlying statistical data collection process accounts for flights of US carriers with an annual revenue of 20M USD or more and flights of foreign carriers with more than 10 000 passengers per month (to/from the US).

Across Europe, different sources report on air traffic statistics also for the purpose of market analysis. For example, Eurostat reports on air traffic observed at EU-28 level, while different States (typically the national civil aviation authorities or associated statistics agencies) report traffic at the national level with varying granularity levels or breakdowns.

The data sets used in this study are derived from the aforementioned systems and ensure comparability of the data with respect to the provision of air navigation services and operational ANS performance.

ADDITIONAL DATA ON CONDITIONS

Post-operational analysis should identify the causes of delay and a better understanding of real constraints. In identifying causal factors, additional data is needed for airport capacities, runway configurations, sector capacities, winds, visibility, and convective weather. For this report, airport capacities and meteorological data have been used (see Chapter 3).

1.4 European and FAA Performance Reporting

Both FAA and European ANSPs have their own reporting requirements. Some Key Performance Indicators (KPIs) such as ATM attributable delay are common to both groups using calculations and underlying databases that are very similar. There are other indicators that are common but have different priorities in terms of reporting status and/or regulation. For example, European indicators use horizontal trajectory efficiency and ATFM delay for official target setting whereas FAA management focuses on Capacity and Capacity Efficiency for official targets. FAA, under RTCA and the NextGen Advisory Committee (NAC) also report Block Time, Track Distance, Throughput, Taxi-out Time and Gate Departure Delay [Ref. 4]. These metrics, using definitions that have been harmonized for joint EU/US benchmarking are part of later chapters of this report.

The report examines several operational key performance indicators derived from comparable databases for both EUROCONTROL and the Federal Aviation Administration (FAA).

KEY PERFORMANCE AREAS (KPAS) AND KEY PERFORMANCE INDICATORS (KPIS)

Comparisons and benchmarking require common definitions and understanding. Hence the work in this report draws from commonly accepted elements of previous work from ICAO, the FAA, EUROCONTROL and CANSO. An outcome of these performance evaluations is the development of harmonized key performance indicators (KPIs) that can be used for international benchmarking. The KPIs used in this report are associated with ICAO's Key Performance Areas (KPAs) and are developed using the best available data from both the FAA-ATO and the EUROCONTROL Performance Review Unit (PRU).

In its Manual on Global Performance of the Air Navigation System [Ref. 5], ICAO identified eleven Key Performance Areas (KPAs) of interest in understanding overall ATM system performance: Access and Equity, Capacity, Cost Effectiveness, Efficiency, Environmental Sustainability, Flexibility, Global Interoperability, Predictability, Participation, Safety, and Security.

At the time of writing this report, ICAO is in the process of updating the Global Air Navigation Plan (GANP, ICAO Doc 9750 [Ref. 6]). As part of this update, the 2016 ICAO assembly will endorse the recognition of ATM performance monitoring. The 2016 update to the GANP includes documentation for 16 potential KPIs that are recommended for tracking performance improvements and identifying performance shortfalls. The US/Europe comparison reports provide demonstrated application for many of these indicators. The reports also show how common indicators can be used to benchmark performance across facilities and across ICAO regions.

This report addresses the Key Performance Areas that relate to the operational efficiency of the ATM system. These are the KPAs of Capacity, Efficiency, Predictability, and Environmental Sustainability as it is linked to Efficiency when evaluating additional fuel burn.

Table 1-1 provides an overview of the harmonized KPIs used in this report that are associated with the ICAO KPAs. Many of these indicators are linked. All flight efficiency indicators have a degree of variability which may be reported as a KPI for Predictability.

Table 1-1: US/Europe Harmonized Key Performance Indicators

Key Performance Area	Key Performance Indicator
Capacity	Declared Airport Capacity
	Maximum Airport Throughput
Efficiency	Airline-Reported Delay Against Schedule
	Airline-Reported Attributable Delay
	En-route and Airport ATM-Reported Attributable Delay
	Taxi-Out Additional Time
	Horizontal En-Route Flight Efficiency (flight plan and actual)
	Additional Time in Terminal Airspace
	Taxi-In Additional Time
Predictability	Airline-Reported Arrival and Departure Punctuality
	Capacity Variability
	Phase of Flight Time Variability

In addition to the KPIs listed in Table 1-1, this report also provides a series of related indicators that help to explain why a KPI improved or became worse over time. These related indicators do not fit the standard ICAO KPA framework. However they are typical indicators that would be monitored by an ANSP to help explain how external factors may influence the core KPIs. These Related Indicators principally address operator demand and weather. Table 1-2 below shows the main related indicators reported.

Table 1-2: US/Europe - related indicators

Related Area	Related Indicator
Traffic/Schedules	System IFR Flight Counts
	System IFR Flight Distance
	Facility IFR Flight Counts
	Traffic Density
	Traffic Variability
	Schedule Block Time
	Seat capacity on scheduled flights
Weather	Operations by Met Condition
	Delay by Met Condition
System Characteristics	System size & structure

1.5 Organisation of this report

The report is organised into seven chapters:

- Chapter 1 contains the introduction and provides some background on report objectives, scope and data sources used for the analyses for ATM performance in this report. It also lists the Key Performance Indicators and related indicators that are studied in this report.

- Chapter 2 provides background information on the two ATM systems that may also be used to explain differences in the core KPIs. These include differences in air traffic flow management techniques as well as external factors such as weather and capacity restrictions which can be shown to have a large influence on performance.

- Chapter 3 provides a quantitative overview of the indicators that may externally influence the KPIs related to ATM performance. These are principally related to changes in traffic levels, traffic peaks, capacity at the aerodrome, and meteorological conditions.

- Chapter 4 provides a comparison of airline-related KPIs. These indicators assess delay and operational service quality as it relates to the airline schedule. It includes the causal reasons for delay as provided by the airlines.

- Chapter 5 provides a detailed comparison of the ATM-related KPIs focusing on ATFM delay and the efficiency of actual operations by phase of flight. It includes causal reasons for delay as provided by the ANSP.

- Chapter 6 introduces two supporting studies aimed at further expanding the scope and the level of analysis of the U.S. / Europe comparison of operational performance. The first study analyses air traffic flow and capacity management in more detail and the second study addresses vertical flight efficiency in the arrival phase.

- Chapter 7 concludes with a summary of findings.

2. COMPARISON OF AIR TRAFFIC MANAGEMENT (ATM) IN THE US AND EUROPE

This section provides background information on both the US and European ATM systems that may be used to explain similarities and differences in the KPIs used throughout this report. This section starts with a comparison in terms of physical geographic airspace and organisation of ATM.

2.1 Organisation of ATM

While the US and the European system are operated with similar technology and operational concepts, there is a key difference. The US system is operated by one single service provider using the same tools and equipment, communication processes and a common set of rules and procedures. Although ATFM and ASM in Europe are provided/coordinated centrally by the Network Manager, at the ATC level the European system is much more fragmented and the provision of air navigation services is still largely organised by State boundaries.

In total, there are 37 different en-route ANSPs of various geographical areas. Historically, they have been operating different systems under slightly different sets of rules and procedures. Since 2004, the Single European Sky (SES) initiative of the European Union aims at reducing this fragmentation. It provides the framework for the creation of additional capacity and for improved efficiency and interoperability of the ATM system in Europe.

2.2 Airspace management (ASM) and design

In the US the Federal Aviation Administration (FAA) is responsible for airspace management and route design, whereas in the amalgamated European ATM system, airspace management was traditionally the prerogative of the individual States.

In the current system, the design of airspace and related procedures is no longer carried out or implemented in isolation in Europe. Inefficiencies in the design and use of the air route network are considered to be a contributing factor towards flight inefficiencies in Europe, therefore the development of an integrated European Route Network Design is one of the tasks given to the Network Manager[5]. This is done through a CDM process involving all stakeholders.

A further challenge is the integration of military objectives and requirements which need to be fully coordinated within the respective ATM system. To meet their national security and training requirements while ensuring the safety of other airspace users, it is occasionally necessary to restrict or segregate airspace for exclusive use which may conflict with civilian objectives to improve flight efficiency as flights must then detour around these areas. To accommodate the increasing needs of both sets of stakeholders, in terms of volume and time, close civil/military cooperation and coordination across all ATM-related activities is a key requirement.

In terms of the organisation of the civil/military cooperation, the US and Europe both apply a similar model:

[5] EU Regulation 677/2011 defines the tasks of the Network Manager. The main ones are: the provision of ATFCM services, the development of an integrated European Route Network Design, providing the central function of radio frequency allocation, coordinating improvements to SSR code allocation, and providing support for network crisis management.

- In the US, the DoD Policy Board on Federal Aviation (PBFA) is the single voice of the military services in communicating the DoD position on airspace policy and air traffic management as both a global air navigation service provider and user; at the operational level the FAA headquarters is the final approval authority[6] for all permanent and temporary Special Use Airspace (SUA)[7], and operations are organised according to a common set of rules.

- In Europe, the European Defence Agency (EDA) represents the interests of military aviation in the development of the Single European Sky; at the operational level, through the implementation of the Flexible Use of Airspace (FUA) concept – which is included in EU legislation since 2005 [Ref. 7] – the Network Manager coordinates civil and military requirements through a dynamic CDM process which culminates in the publication of the daily European Airspace Use Plan (AUP) on D-1 and Updated Airspace Use Plans (UUP) on the day of operations. The AUP and UUP activate Conditional Routes and allocate Temporary Segregated Areas and Cross-Border Areas for specific periods of time.

Looking at the map, the comparison of SUA between the US and Europe (in Europe generally referred to as segregated airspace) in Figure 2-1 illustrates a significant difference in the number and location of the special use airspace within the respective ATM systems[8]. It is to be emphasised that these airspace volumes are not all active at the same time, because they are managed flexibly.

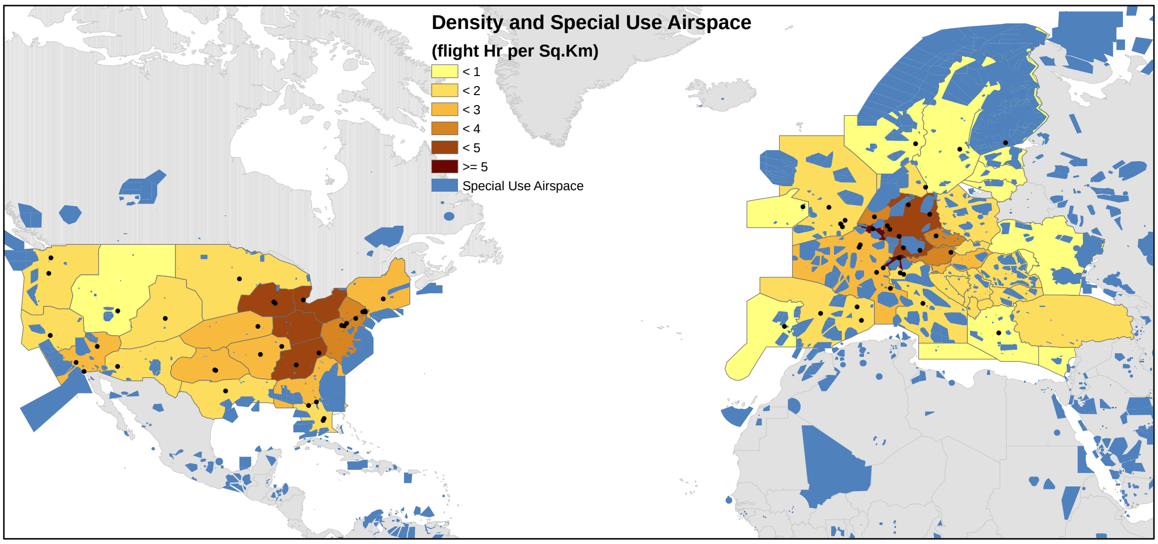

Figure 2-1: Comparison of Special Use Airspace (SUA)

Europe clearly shows a larger number of SUA than the US with quite a number being located directly in the core area of Europe and potentially affecting the flow of civil air traffic. In the US, SUA tends to be more located along the coastlines allowing for less constrained transcontinental connections.

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6 FAA Order JO 7400.2J – Part 5 Chapter 21

7 Airspace of defined dimensions identified by an area on the surface of the earth wherein activities must be confined because of their nature and/or wherein limitations may be imposed upon aircraft operations that are not a part of those activities. Often these operations are of a military nature.

8 Based on Aeronautical Information Publication (AIP) data available from the European AIS Database (EAD).

2.3 Air traffic flow management (ATFM) and air traffic control (ATC)

ATFM is a function of air traffic management (ATM) established with the objective of contributing to a safe, orderly, and expeditious flow of traffic while minimizing delays. The purpose of ATFM is to avoid safety risks associated with overloaded ATC sectors by regulating traffic demand according to available capacity. When ATFM also includes a capacity management function, it is called ATFCM. At the tactical level, ATC also plays a role in flow management.

This section compares the similarities and differences between the US and Europe in terms of facility organization and the strategies for balancing demand and capacity.

2.3.1 ATFM and ATC Facility organization

Both the US and Europe have established system-wide, centralised traffic management facilities to ensure that traffic flows do not exceed what can be safely handled by ATC units, while trying to optimise the use of available capacity. Table 2-1 provides an overview of the key players involved and the most common ATFM techniques applied [Ref.8].

Table 2-1: Organisation of ATFM (Overview)

	Flight phase	Local ATC units	US	Europe	ATFM measures	Network (ATFM) US	Network (ATFM) Europe
Strategic	Origin Airport				Airport scheduling (departure slot)		
	Taxi-out	Ground control	*Airports with ATC services: 517*	*Airports with ATC services: 415*	Dep. restrictions (ground holding)	Air traffic Control System Command Center (ATCSCC) located in Warrenton, Virginia.	Eurocontrol Network Operations Centre (NMOC), located in Brussels, Belgium (formerly - CFMU).
	Take-off	Tower control					
	En route	En route Area control	*Air Route Traffic Control Center (ARTCC): 20 US CONUS*	*Area Control Centre (ACC): 62*	Routing, sequencing, speed control, holding		
	Approach	Terminal control	*Terminal Radar Approach Control (TRACONs): Stand-alone: 26 (US CONUS) Collocated: 134*	*Approach Control units (APPs): Stand-alone: 16 Collocated: 262*	Airborne holding (circular, linear), vectoring		
	Landing	Tower					
	Taxi-in	Ground					
Strategic	Destination Airport				Airport scheduling (Arrival slot)		

The key difference is that the European ATM system is an amalgamation of a large number of individual ANSPs whereas the US system is operated by a single ANSP.

There are 20 Air Route Traffic Control Centres (ARTCC) in the US CONUS compared to 62 ACCs in Europe[9]. Figure 2-2 depicts the size of the 20 US ARTCCs compared to the 20 largest ACCs in Europe, in terms of average daily IFR flights.

9 For Europe, a 63rd en-route center is located in the Canaries, outside of the geographical scope of the study. In the US, 3 additional en-route centers are operated by the FAA, outside of the US CONUS.

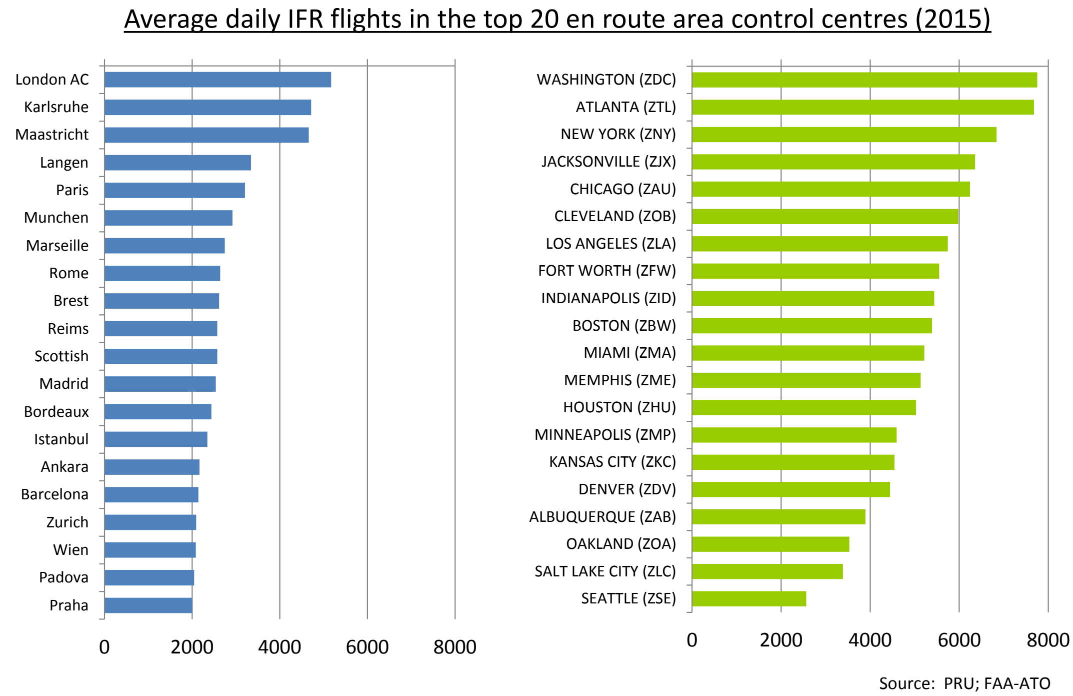

Figure 2-2: Comparison of en-route area control centres (2015)

A further key difference between the two systems is the role of the network ATFM function. The fact that the ATM system in the US is operated by a single provider puts the Air Traffic Control System Command Center (ATCSCC) in a much stronger position with more active involvement of tactically managing traffic on the day of operations than is the case in Europe.

As far as traffic management issues are concerned, there is a clear hierarchy in the US. Terminal Radar Approach Control (TRACON) units work through the overlying ARTCC which coordinate directly with the ATCSCC in Virginia. The ATCSCC has final approval authority for all national traffic management initiatives in the US and is also responsible for resolving inter-facility issues.

In Europe, the Network Manager Operations Centre (NMOC) in Brussels monitors the traffic situation and proposes flow measures which are coordinated through a CDM process with the local authority. Usually the local Flow Management Positions (FMP), embedded in ACCs to coordinate the air traffic flow management in the area of its responsibility, requests the NMOC to implement flow measures.

In 2009, the role of the network function in Europe was strengthened by the second package of Single European Sky (SES) legislation[10]. This evolution foresees a more proactive role in Air Traffic Flow Management, ATC capacity enhancement, airspace structure development and the support to the deployment of technological improvements across the ATM network for the European Network Manager.

[10] The SES I legislation adopted in 2004 was revised and extended by the SES II package in 2009 aimed at increasing the overall performance of the air traffic management system in Europe, shifting the focus from capacity to performance in general. The SES II package also introduced the comprehensive performance scheme with target-setting at EU-level.

2.3.2 Demand Capacity balancing (DCB)

In order to minimize the effects of ATM system constraints, the US and Europe use a comparable methodology to balance demand and capacity[11]. This is accomplished through the application of an "ATFM planning and management" process, which is a collaborative, interactive capacity and airspace planning process, where airport operators, ANSPs, Airspace Users (AUs), military authorities, and other stakeholders work together to improve the performance of the ATM system (see Figure 2-3).

This CDM process allows AUs to optimize their participation in the ATM system while mitigating the impact of constraints on airspace and airport capacity. It also allows for the full realization of the benefits of improved integration of airspace design, ASM and ATFM. The process contains a number of equally important phases:

- ATM planning
- ATFM execution
  - Strategic ATFM
  - Pre-tactical ATFM
  - Tactical ATFM
  - Fine-tuning of traffic flows by ATC (shown in Figure 2-3 as Optimized operations)
    - Traffic Management Initiatives (TMIs) that have an impact on traffic prior to take-off
    - TMIs acting on airborne traffic
- Post-operations analysis.

A detailed description and comparison of the different phases – including an overview of the various TMIs used on both sides of the Atlantic can be found in Annex II.

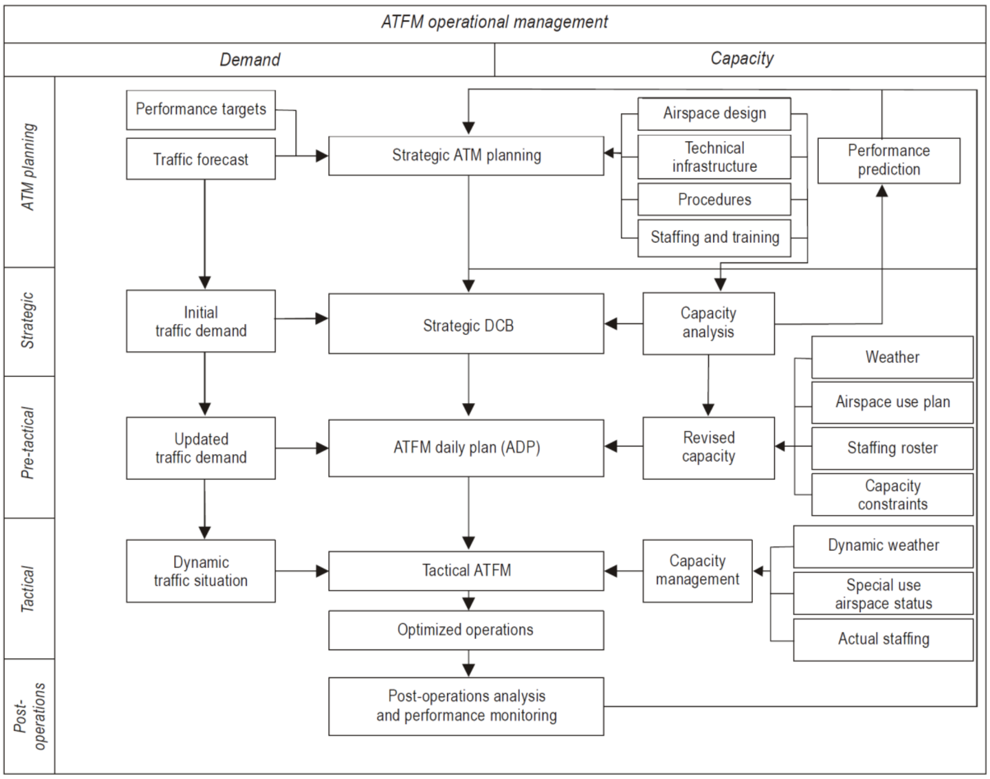

Figure 2-3: Generic ATFM process (ICAO Doc 9971)

11 In line with the guidance in ICAO Doc 9971 (Manual on Collaborative Air Traffic Flow Management).

3. EXTERNAL FACTORS AFFECTING KEY PERFORMANCE INDICATORS

This chapter describes and quantifies the effects of some of the key external factors that impact the primary Key Performance Indicators. These related indicators focus on changing traffic levels, airport capacity, and weather in the US and Europe. In addition to external factors, the way the ATM system is managed with the US having a single provider compared to the European system of multiple ANSPs can also influence the resulting KPIs. These differences in the ATM systems are addressed in more detail in Chapter 2.

3.1 Traffic characteristics in the US and in Europe

This section provides some key air traffic characteristics of the ATM system in the US and in Europe to provide some background information and to ensure comparability of traffic samples.

Table 3-1: US/Europe ATM key system figures at a glance (2015)

Calendar Year 2015	Europe[12]	USA[13]	US vs. Europe
Geographic Area (million km^2)	11.5	10.4	≈ -10%
Nr. of civil en-route Air Navigation Service Providers	37	1	
Number of Air Traffic Controllers (ATCOs in Ops.)	17 370	13 138[14]	≈ -24%
Number of OJT/developmental ATCOs	960	1 959	≈ +104%
Total ATCOs in OPS plus OJT/developmental	18 330	15 097	≈ -18%
Total staff	56 300	31 501	≈ -44%
Controlled flights (IFR) (million)	9.8	15.3	≈ +57%
Flight hours controlled (million)	14.8	23.1	≈ +56%
Relative density (flight hours per km^2)	1.3	2.2	≈ x1.7
Share of flights to or from top 34 airports	64%	62%	
Share of General Aviation	3.7%	22%	
Average length of flight (within respective airspace)	575 NM	524 NM	≈ -9%
Number of en-route facilities	62	23[15]	-39
Number of stand-alone APP/TRACON units	16	27[16]	+11
Number of APP units collocated with en-route or TWR fac.	262	134	-128
Number of airports with ATC services	415	517[17]	+102
Of which are slot controlled	> 100 [18]	4 [19]	
Number of FMPs (Europe) / TMUs (US) [20]	51	≈65	≈ +14
Source	EUROCONTROL	FAA/ATO	

12 EUROCONTROL States, excluding Oceanic areas, Georgia and Canary Islands. European staff numbers and facility count refer to 2014 which is the latest year available.

13 Area and flight hours refer to CONUS only. Centre count refers to the NAS.

14 This value reflects the CANSO reporting definition of a fully trained ATCO in OPS and includes supervisors. It is different than the total controller count from the FAA controller workforce plan which does not include supervisors. The number of ATCOs in OPS does not include 1 292 controllers reported for contract towers.

15 20 en-route centers (ARTCCs) are in the US CONUS, 3 are outside.

16 26 stand-alone TRACONs are in the US CONUS, 1 is outside (Alaska).

17 Total of 517 facilities of which 264 are FAA staffed and 253 Federal contract towers.

18 IATA Level 2: ±70. IATA Level 3: ±100.

19 IATA Level 2: ORD, LAX, MCO, SFO. IATA Level 3: JFK, EWR (EWR will become Level 2 as of winter 2016). In addition restrictions exist at DCA and LGA based on Federal and local rules.

20 FMPs and TMUs are the local ATFCM partners for the collaborative process with the NMOC and ATCSCC respectively.

As shown in Table 3-1, the total surface of continental airspace analysed in the report is similar for Europe and the US. However, the US controls approximately 57% more flights operating under Instrument Flight Rules (IFR)[21] with less Air Traffic Controllers (ATCOs)[22] and fewer en-route and terminal facilities.

Using the definition employed by the ACE and CANSO benchmarking reports which excludes those designated as "on-the-job training" in Europe or as a "developmental" at the FAA, the US operated with some 24% less full time ATCOs than Europe in 2014/2015.

For the ATM system, Europe is more fragmented and operates with more physical facilities than the US. Currently the European study region comprises 37 ANSPs (and a similar number of different regulators), 62 Area Control Centres (ACC) and 16 stand-alone Approach Control (APP) units (total: 78 facilities). The US has one ANSP and the US CONUS is served by 20 Air Route Traffic Control Centres (ARTCC) supplemented by 26 stand-alone TRACONs providing services to multiple airports (total: 46 facilities). In addition the US has 134 Approach Control Facilities combined with Tower services; Europe has 262 collocated APP units.

A notable difference illustrated in Table 3-1 is the low number of airports with schedule or slot limitations in the US compared to Europe, where most of the airports are slot-coordinated.

Notwithstanding the large number of airports in the US and Europe, only a relatively small number of airports account for the main share of traffic. The main 34 airports account for approximately 64% of the controlled flights in Europe and the US.

3.1.1 AIR TRAFFIC GROWTH

Figure 3-1 depicts the evolution of IFR traffic in the US and in Europe between 2000 and 2015.

There was a notable decoupling in 2004 when the traffic in Europe continued to grow while US traffic started to decline. Whereas traffic in Europe grew by 15.5% between 2000 and 2015, the traffic in the US declined by -13.8% during the same period.

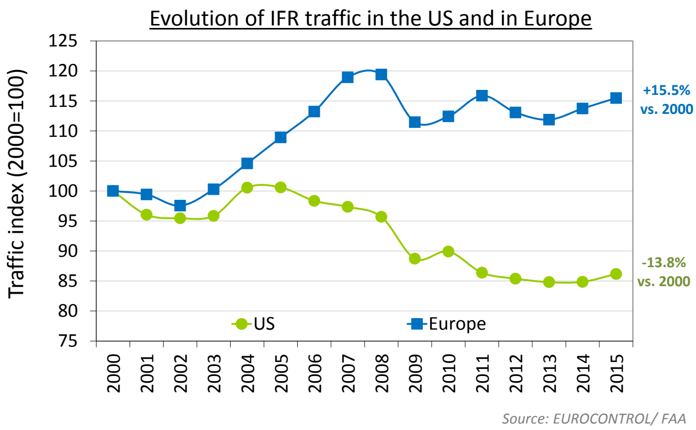

Figure 3-1: Evolution of IFR traffic in the US and in Europe

Although traffic in the US CONUS grew by 1.6% from 2013-2015, the traffic at the main 34 airports was unchanged over this time period (Figure 3-9 below). The effect of the economic crisis starting in 2008 is clearly visible on both sides of the Atlantic.

The system level averages mask contrasted growth rates within the US and Europe as illustrated in the map in Figure 3-2. Traffic growth in Europe shows a contrasted picture between the more

21 Although not included in this study, the US also handles significantly more Visual Flight Rules (VFR) traffic.

22 ATCO's refer to civil ATCOs – military ATCOs with a civil license were not considered in the report.

mature markets in Western Europe and the emerging markets in Central & Eastern Europe which shows a substantial growth. Also the notable shift of traffic following the tragic loss of MH17 in Ukrainian airspace in July 2014 and the resulting airspace closure contributed to some of the observed high growth rates in States affected by changed traffic flows.

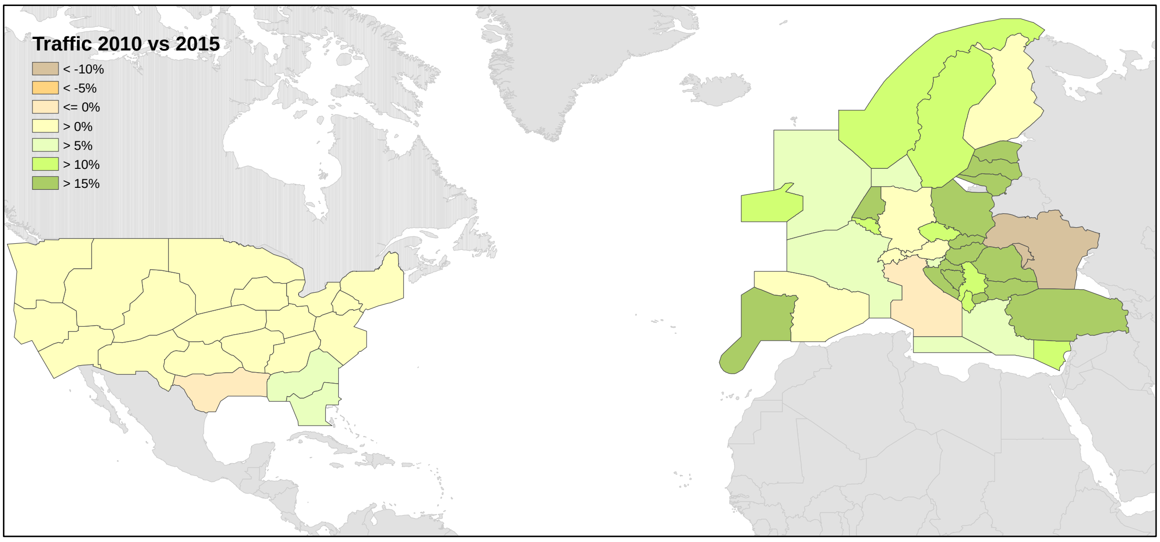

Figure 3-2: Evolution of IFR traffic in the US and in Europe (2015 vs. 2010)

The US is a more homogenous and mature market which shows a different behaviour. Compared to 2010, traffic levels stayed relatively constant, aside from the Florida centers, which experienced a stronger growth. The traffic growth at the main airports in the US and Europe is shown in Figure 3-8 and Figure 3-9 on page 29 respectively.

3.1.2 Air traffic density

Figure 3-3 shows the traffic density in US and European en-route centres measured in annual flight hours per square kilometre for all altitudes in 2015. For Europe, the map is shown at the State level because the display by en-route centre would hide the centres in lower airspace.

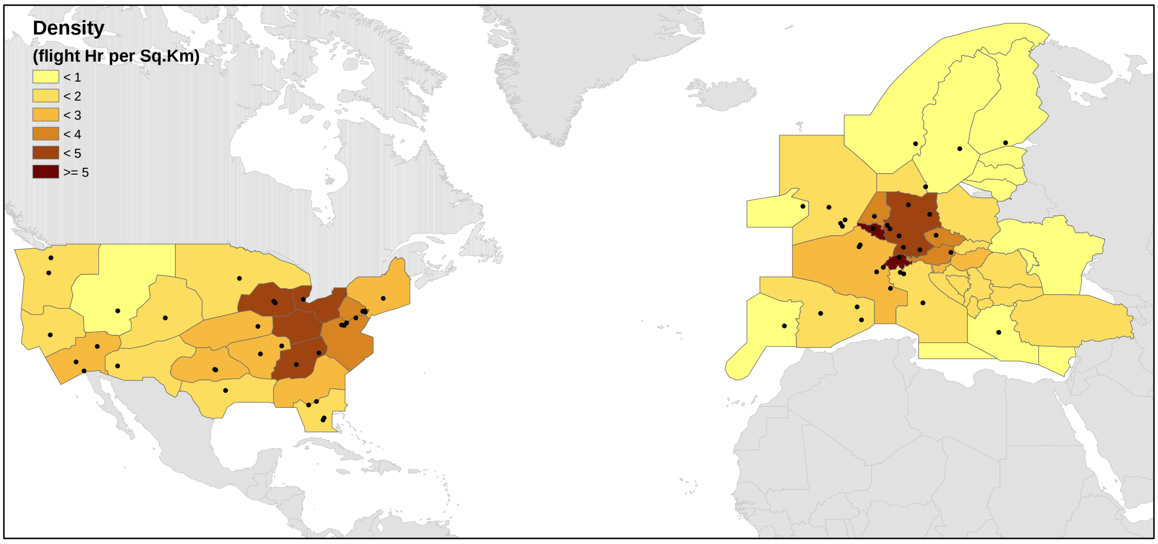

Figure 3-3: Traffic density in the US and in Europe (2015)

In Europe, the "core area" comprising of the Benelux States, Northeast France, Germany, and Switzerland is the densest and most complex airspace.

Similarly in the US, the centrally located centres of Cleveland (ZOB), Chicago (ZAU), Indianapolis (ZID), and Atlanta (ZTL) have flight hour densities of more than twice the CONUS-wide average. The New York Centre (ZNY) appears less dense due to the inclusion of a portion of coastal/oceanic airspace. If this portion was excluded, ZNY would be the centre with the highest density in the US.

3.1.3 AVERAGE FLIGHT LENGTH

Table 3-2 provides a more detailed breakdown of IFR traffic for the US and Europe in 2015. The average great circle distances shown in Table 3-2 refer only to the distances flown within the respective airspace and not the length of the entire flight.

Table 3-2: Breakdown of IFR traffic

ALL IFR TRAFFIC	EUROPE (2015)			US CONUS (2015)		
	N	% of total	Avg. dist. (NM)	N	% of total	Avg. dist. (NM)
Within region	7.8 M	78.4%	506 NM	12.8 M	83.9%	524 NM
To/from outside region	1.9 M	19.5%	801 NM	2.1 M	14.0%	530 NM
Overflights	0.2 M	2.2%	809 NM	0.3 M	2.1%	489 NM
Total IFR traffic	9.9 M	100%	575 NM	15.3 M	100.0%	524 NM

Traffic to/from main 34 airports	EUROPE (2015)			US CONUS (2015)		
	N	% of total	Avg. dist. (NM)	N	% of total	Avg. dist. (NM)
Within region	5.1 M	80.5%	504 NM	8.2 M	82.9%	639 NM
To/from outside region	1.2 M	19.5%	878 NM	1.7 M	17.1%	558 NM
Total	6.3 M	100%	581 NM	9.9 M	100.0%	625 NM

The table is broken into two parts which both show similar trends. The top portion shows all flights while the lower focuses on traffic to or from the main 34 airports. The population of flights in the lower part of the table (traffic to or from the main 34 airports) is the basis for many of the metrics in this report.

By far the largest share of total IFR traffic in both systems is due to traffic within the respective region. In the US this share is 83.9% compared to 78.4% in Europe. When all IFR flights including overflights are taken into account, the average flight length in Europe is 575 NM compared to 524 NM in the US.

However, this changes when only "domestic" flights within the respective regions are considered. For example, en-route efficiency indicators shown later in Section 5.2.3 use "within region" traffic to or from the main 34 airports (lower part of Table 3-2). For this population, the average flight length in the US is 625 NM compared to 581 NM in Europe. This is due mainly to the large amount of transcontinental traffic in the US system.

For the US, a significant amount of "Outside Region" traffic have a coastal airport as a final destination or traverse a significant distance through Canada before entering US airspace. For Europe, the "Outside Region" traffic is less concentrated at coastal entry airports but more scattered with direct long haul flights to worldwide destinations from almost every capital city airport. For instance, a flight from London Heathrow (LHR) to the Middle East would traverse almost the entire European airspace before exiting the airspace. As a consequence, the average distance of those flights is considerably higher in Europe than in the US.

3.1.4 SEASONALITY

Seasonality and variability of air traffic demand 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. Figure 3-4 compares the seasonal variability (relative difference in traffic levels with respect to the yearly averages) and the "within week" variability.

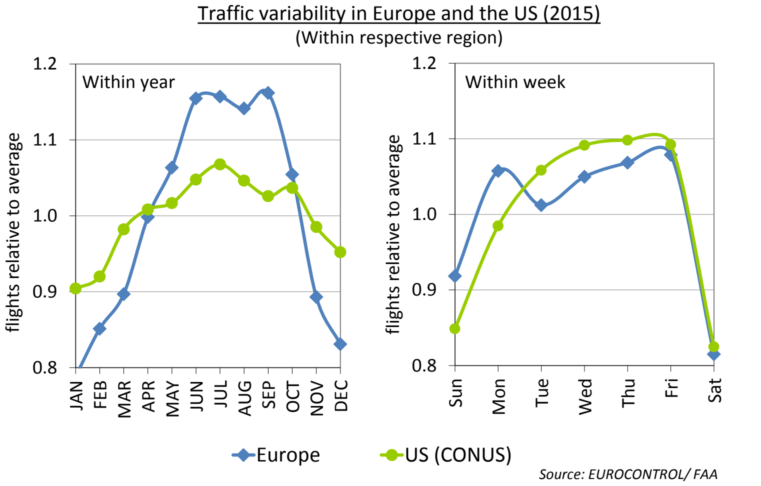

Figure 3-4: Seasonal traffic variability in the US and Europe (system level)

Whereas weekly traffic profiles in Europe and the US are similar (lowest level of traffic during weekends), the seasonal variation is higher in Europe. European traffic shows a clear peak during the summer months. Compared to average, traffic in Europe is in summer about 15% higher whereas in the US the seasonal variation is more moderate.

Figure 3-5 shows the seasonal traffic variability in the US and in Europe for 2015. In Europe, a very high level of seasonal variation is observed for the holiday destinations in South Eastern Europe where a comparatively low number of flights in winter contrast sharply with high demand in summer.

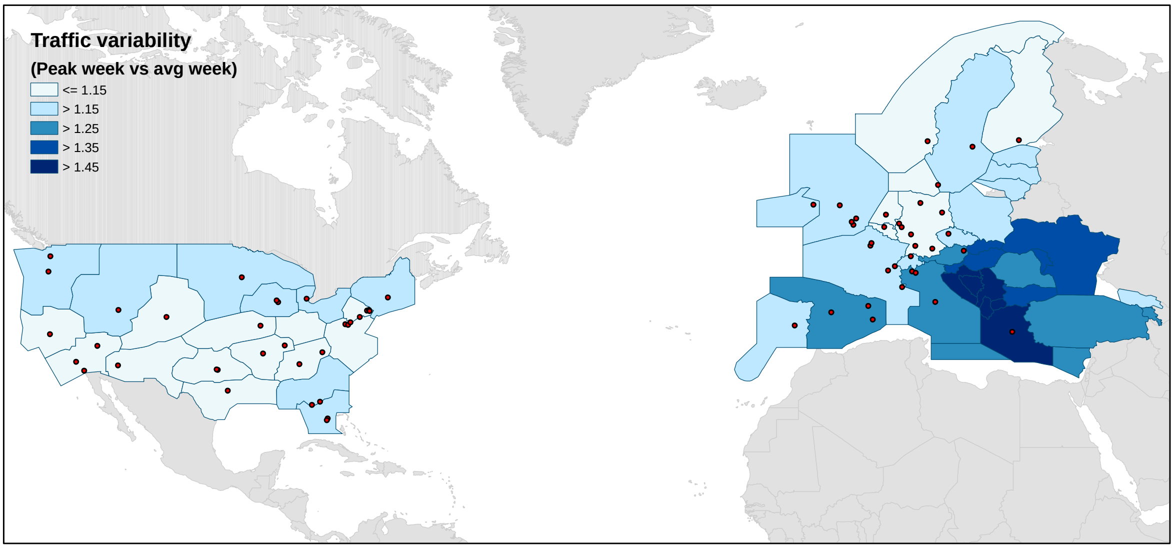

Figure 3-5: Seasonal traffic variability in the US and in Europe (2015)

In the US, the overall seasonality is skewed by the high summer traffic in northern en-route centres (Boston, Chicago, and Minneapolis) offsetting the high winter/spring traffic of southern centres (Miami and Jacksonville) (see Figure 3-5).

3.1.5 TRAFFIC MIX

A notable difference between the US and Europe is the share of general aviation which accounts for 22% and 3.7% of total traffic in 2015, respectively (see Table 3-1 on page 21). This is confirmed by the distribution of physical aircraft classes in Figure 3-6 which shows a large share of smaller aircraft in the US for all IFR traffic (left side of Figure 3-6).

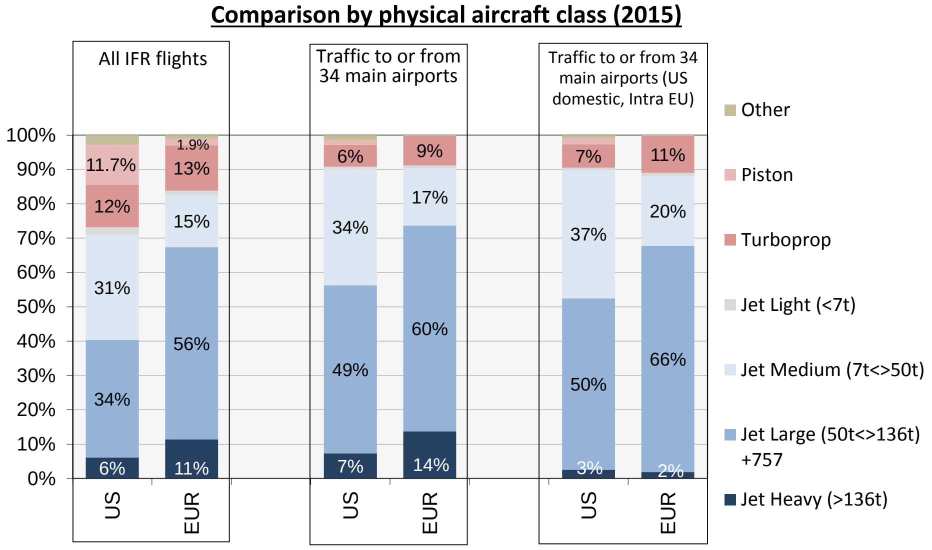

Figure 3-6: Comparison by physical aircraft class (2015)

In order to improve comparability of data sets, the more detailed analyses in Chapters 4 and 5 are limited to controlled IFR flights either originating from or arriving to the main 34 US and European airports (see Annex I). 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. Traffic to or from the main 34 airports in 2015 represents some 64% of all IFR flights in Europe and in the US.

Figure 3-7 shows the evolution of the number of average seats per scheduled flight in the US and in Europe, based on data for passenger aircraft.

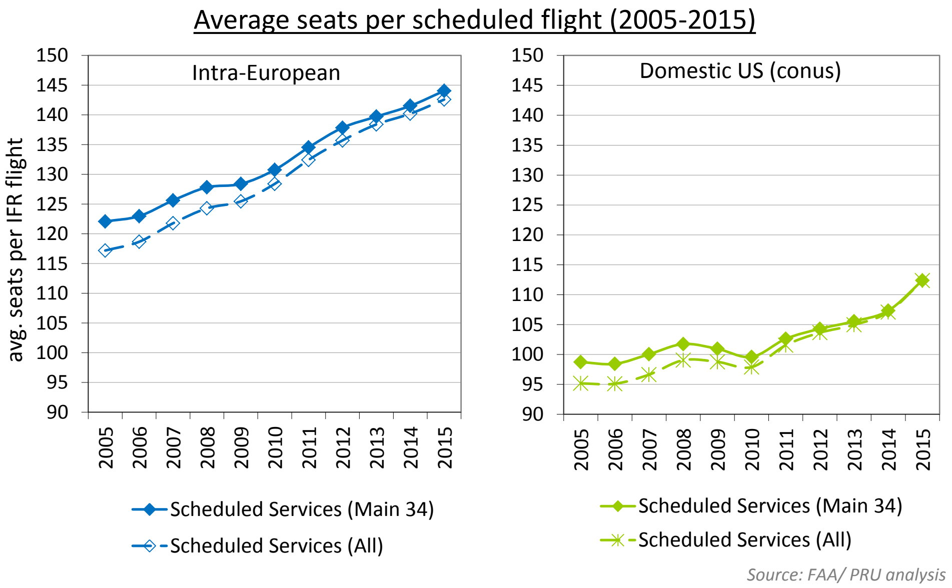

Figure 3-7: Average seats per scheduled flight (2005-2015)

For 2015, the average number of seats per scheduled flight is 28% higher in Europe for traffic to or from the main 34 airports. This is consistent with the observation in Figure 3-6 showing a higher share of larger aircraft in Europe.

Whereas in Europe the average number of seats per flight increased continuously between 2005 and 2015, the number of seats per aircraft declined in the US between 2008 and 2010. However, recent US trends since 2010 point to an increase in aircraft gauge. Figure 3-7 indicates the potential for growing the number of US passengers with relatively flat or modest growth in operations.

The notable difference observed in aircraft gauge in the two regions is tied to the different practices of airlines, which are linked to demand, market competition, and other factors [Ref. 9]. An increasing number of European low cost carriers are utilising a high density one-class seat layout compared to a standard two-class configuration preferred by US carriers. Additionally, since only a few US airports are slot restricted, this enables airlines to increase the frequency of service (with smaller aircraft) to win market share and to attract high yield business travellers.

The notable increase in the US since 2013 is assumed to be the result of consolidation that resulted, on average, in fewer frequencies but with larger aircraft.

3.2 Airport operations and changes in airport capacity

The system wide and facility level performance indicators shown in Chapters 4 and 5 are driven by airport operations (demand), airport capacity and the imbalance that can occur between demand and capacity. Facilities with a) high levels of operations; b) demand that is near capacity, or; c) having capacity that is highly variable, i.e. unpredictable, will tend to form the dominant contributors to system performance. Understanding changes in these factors can also help in understanding year over year changes. This section, along with Section 3.3 on weather, provides a quantification of these related factors influencing the reported KPIs.

Airport operations depend upon a number of factors as well as on interactions between them which all affect runway capacity to some degree. In addition to physical constraints, such as airport layout, there are “strategic” factors such as airport scheduling and “tactical” factors which include, inter alia, the sequencing of aircraft and the sustainability of throughput during specific weather conditions.

Safe operation of aircraft on the runway and in surrounding airspace is the dominant constraint of runway throughput. Airport layout and runway configuration, traffic mix, runway occupancy time of aircraft during take-off and landing, separation minima, wake vortex, ATC procedures, weather conditions and environmental restrictions - all affect the throughput at an airport.

The runway throughput is directly related to the time needed to accommodate each flight safely. The separation requirements in segregated mode[23] depend on the most constraining of any one of the three parameters: (1) wake vortex separation, (2) radar separation, or (3) runway occupancy time. The challenge is to optimise final approach spacing in line with wake vortex and radar separation requirements so that the spacing is close to runway occupancy time. For mixed mode runway operations[24], throughput is driven by inter arrival spacings into which departures are interleaved.

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[23] Applies to dual runway systems where runways are used exclusively for landing or departing traffic.

[24] Landing and departing aircraft are mixed on the same runway.

ENVIRONMENTAL CONSTRAINTS

One of the major challenges of airport communities is the need to balance airport capacity requirements with the need to manage aircraft noise and negative effects on the population in the airport vicinity. Quite a number of airports in Europe operate under some environmental constraints which invariably affect runway throughput, the level of complexity and therefore, ATM performance.

The main affecting factors are (1) Noise Preferential Routes and Standard Instrument Departure, (2) Restrictions on runway mode of operations and configurations, and (3) night noise regulations. In the early morning, night noise curfews might even result in considerable arrival holding with a negative impact on fuel burn and thence CO_2 emissions.

More work is required to better understand the differences in the impact of environmental constraints on ATM performance in Europe and the US (i.e. how noise and emissions are handled in the two systems and the potential impact on performance).

3.2.1 AIRPORT LAYOUT AND OPERATIONS AT THE MAIN 34 AIRPORTS

The number of operations which can be safely accommodated at an airport not only depends on the number of runways but also to a large extent on runway layout and available configurations (many runways may not be operated independently). The choice of the configuration depends on a number of factors including weather conditions and wind direction, type of operation (arrival/ departure peak) and environmental considerations such as noise constraints. The configuration, combined with environmental restrictions, as well as apron and terminal airspace limitations affect the overall capacity of the airport.

Some of the key factors determining runway throughput are the distance between runways (dependent or independent[25]), the mode of operation (mixed[26] or segregated[27]), and geographical layout (intersecting runways, crossing taxiways).

Although some airports technically have a large number of runways, operational data shows that the applied configurations restrict the type of operations and runways to be used at any one time.

For this reason, the number of runways used for the comparison of operations at the 34 main airports in the US and in Europe in Table 3-3 was based on statistical analysis (see grey box) rather than the physical runway count. The passenger numbers are based on Airport Council International (ACI) data and refer to all operations.

<u>Use of runways at the airports</u>

In previous versions (2008 and 2010) of the report the number of existing physical runways was used for the computation of the indicators in Table 3-3.

Acknowledging that not all physical runways are available for use at any one time, a different methodology was used to determine the number of runways in use at each of the airports.

In a first step, the number of simultaneously active runways was determined for each 15 minute interval. A runway (e.g. 09R/27L) was considered as being active if used in any of the directions.

In a second step, the upper 10th percentile of the distribution was used as the number of simultaneously active runways at the respective airport. The number of physical runways might be higher.

---

25 Independent operations ensure flexibility and usually allow a higher throughput whereas dependent operations may mean that only one runway can be used at a time. In order to operate independently, ICAO safety rules require the runways to be far enough apart and/or configured so that aircraft operation on one runway does not affect the other.

26 Landing and departing traffic are mixed on the same runway.

27 Applies to dual runway systems where runways are used for either landing or departing traffic only.

Table 3-3: Comparison of operations at the 34 main airports in the US and Europe

Main 34 airports	Europe 2015	Europe vs. 2013	US 2015	US vs. 2013	US vs. Europe (2015)
Avg. number of annual IFR movements per airport ('000)	236	3.6%	380	-0.1%	61%
Avg. number of annual passengers per airport (million)	28.0	10.1%	36.3	9.6%	30%
Passengers per IFR movement	118	6.3%	96	9.8%	-19%
Average number of active runways per airport	2.0	-1.5%	3.4	0.9%	73%
Annual IFR movements per runway ('000)	120	5.2%	112	-1.0%	-7%
Annual passengers per runway (million)	14.2	11.8%	10.7	8.7%	-25%

There were several airport development projects in the US since 2008, including new runways at Chicago O'Hare (ORD), Charlotte (CLT), Seattle (SEA), and Dulles (IAD). A runway extension was also completed for Philadelphia (PHL) that resulted in improved capacity for the airport. In Europe, a fourth runway went into operation at Frankfurt (FRA) airport in October 2011.

Table 3-3 shows that the average number of IFR movements (+61%) and the number of annual passengers per airport (+30%) are significantly higher in the US than in Europe. Consistent with Figure 3-6 and Figure 3-7, the number of passengers per movement is much lower (-19%) in the US due to the US on average utilizing a larger share of smaller aircraft and offering fewer seats per scheduled flight.

Figure 3-8 shows the average number of daily IFR departures at the 34 main European and US airports.

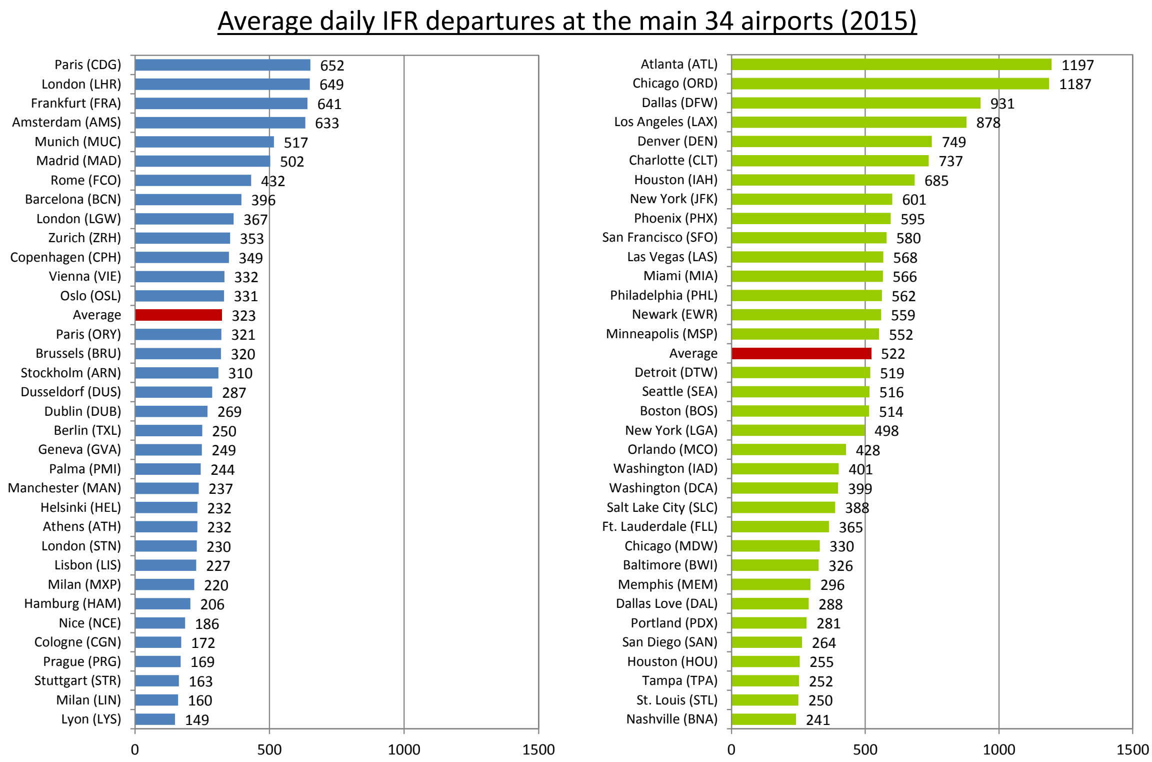

Figure 3-8: Operations at the main 34 airports (2015)

The IFR flights are the basis for the majority of the trends and analysis presented in this report. The average number of IFR departures per airport (522) is considerably higher (62%) in the US, compared to 323 average daily departures at the 34 main airports in Europe in 2015[28].

Figure 3-9 shows the change in IFR departures by airport compared to 2013. In the US, the airports with the highest decrease in departures between 2013 and 2015 are Detroit (-64), Denver (-55), and Washington (-50), and the airports showing a growth in departures compared to 2013 include Seattle (+87), Dallas Love (DAL) (+55) and New York JFK (+44). Although overall traffic in the US increased by 1.6%, the average traffic level for the main 34 population was virtually unchanged.

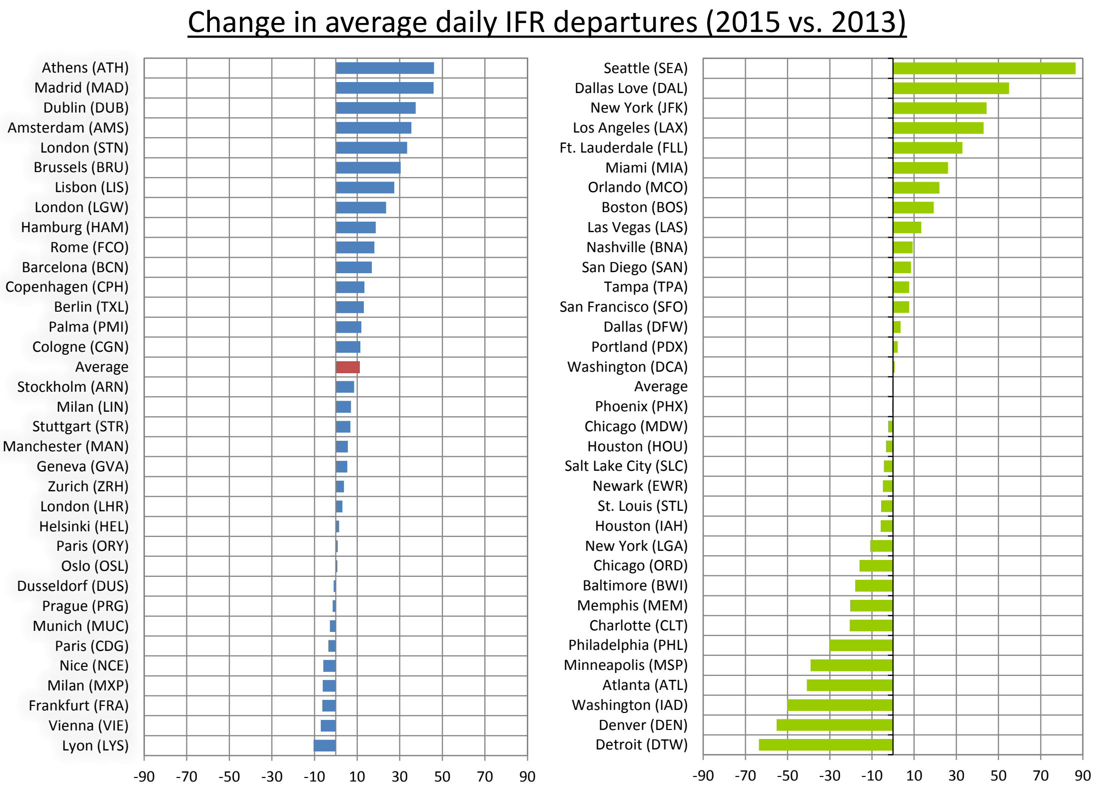

Figure 3-9: Change in operations at the main 34 airports (2015 vs. 2013)

In Europe, the airports with the highest decrease in terms of departures were Lyon (-10), Vienna (VIE) (-7), and Frankfurt (-6). The airports showing an increase in departures compared to 2013 include Athens (+46), Madrid (+46), and Dublin (+37).

[28] The analysis relates only to IFR flights. Some airports - especially in the US - have a significant share of additional VFR traffic which has not been considered in the analysis.

3.2.2 Declared capacity and peak throughput

In Europe, the declared airport capacity is a limit typically set as early as six months before the day of operations through a coordination process involving the airport managing body, the airlines, and local ATC.

In the US, the FAA called arrival rates reflect tactical, real time values based on the number of operations scheduled, available runway configuration, and weather, among other considerations.

> **95th percentile airport peak arrival throughput**
>
> The peak arrival throughput is an approximation of the operational airport capacity in ideal conditions. It is the 95th percentile of the number of aircraft in the "rolling" hours sorted from the least busy to the busiest hour.
>
> The indicator has, however, limitations when the peak throughput is lower than the peak declared capacity, in which case it is necessary to determine whether a variation in peak arrival throughput is driven by a change in demand or by a change in operational airport capacity.

Figure 3-10 provides a comparison of the two types of capacities and throughput described above. Although they are developed and used for different purposes, the values may provide some insights into the role of capacity on operational performance.

Actual airport throughput vs. declared capacity (2015)

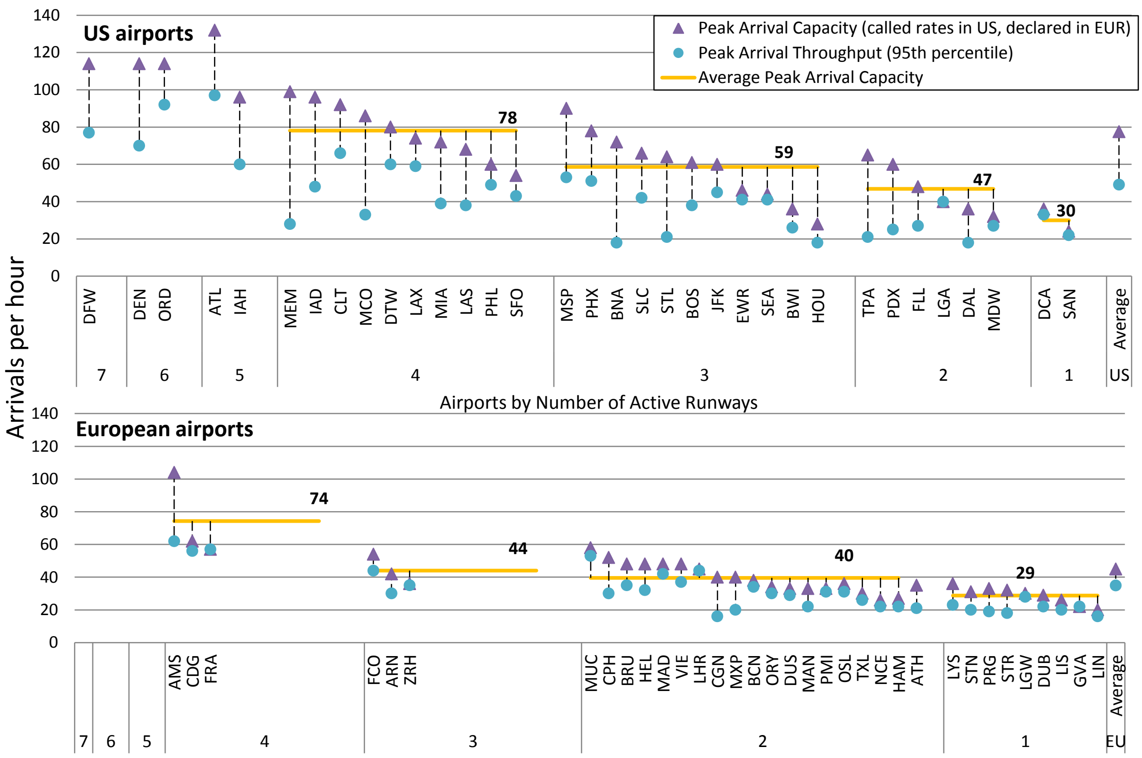

Figure 3-10: Actual airport throughput vs. declared capacity (2015)

The figure depicts the peak arrival capacity (peak called arrival rates for US airports and peak declared arrival capacities for European airports) together with the airports' 95th percentile peak arrival throughput (see grey box). The airports are furthermore categorised by the number of active runways (see Section 3.2.1 for the computation of the number of active runways).

This grouping allows for a first order comparison among different airports. It is however recognised that this simplified analysis should be viewed with a note of caution as there are significant differences in runway layout among airports in the same class that can explain the variation.

In the US and Europe, airports with one and even two active runways are more comparable in terms of peak arrival capacity for the two regions. For the US, the two active runway case average value (47) is influenced by the ability to operate in mixed mode with independent runways for Tampa (TPA) and Portland (PDX). Otherwise the grouping is more comparable.

For airports with three or more active runways, the peak arrival capacity at US airports is on average notably higher than at European airports. The majority of US airports have three or more active runways whereas in Europe, most of the airports have one or two active runways.

Despite normalising the comparison by grouping airports by number of active runways, airport capacities within the same active runway grouping can be starkly different due to differing runway layouts, runway dependencies and aircraft fleet mix. In general, the US airports with high value arrival capacity rates in the same class indicate the use of runways in mixed mode where arrivals are possible among all active runways. As such, Munich (MUC), Minneapolis (MSP), Tampa (TPA), and Portland (PDX) have a considerably higher peak arrival capacity than the other airports in their runway group.

Peak arrival throughput levels also vary in the two regions. Whereas in Europe peak arrival throughput is usually close to the peak declared capacity, in the US peak arrival throughput tends to be substantially lower than the peak capacity arrival rates, with the exception of a few high impact airports (i.e, New York airports, Philadelphia) where demand and, therefore, throughput is closer to the peak capacity level. As schedule limitations dictate a close adherence of scheduled operations to pre-allocated airport slots (a surrogate for capacity), the slot-controlled airports in the US and Europe tend to show a peak throughput closer to peak capacity.

There are a number of key challenges in providing a true like-with-like comparison of airport capacities and throughput for the two regions. One difficulty in this exercise is that airports within each active runway group may not be directly comparable due to differences in runway layout. Munich (MUC), having two parallel independent runways and the highest throughput in its two-runway class, is not directly comparable to LaGuardia (LGA), which also has two active runways, but in a dependent crossed configuration. The throughput values for the two airports are, therefore, very different.

More analysis is needed to better group and compare European and US airports based on runway layout, runway dependency, and mixed and single mode operations. Another difficulty is that throughput is highly sensitive to demand. High demand drives high throughput and vice-versa. It is difficult to properly assess throughput as demand levels are lower on both sides of the Atlantic with some airports having larger demand drops than others. Lastly, measuring throughput is dependent on the time interval used for the assessment. In this analysis, peak throughput was measured every five minute rolling hour. Results using a different approach may reveal a difference not seen at the five minute rolling hour level.

3.2.3 CAPACITY VARIATION AT US AIRPORTS

Many of the differences in performance appear to be attributable to the effects of capacity variation between most favourable and least favourable conditions. Also, many of the improvements at the system level observed over time track with an overall decrease in demand.

The analysis in this section seeks to quantify capacity changes using the performance sources described in Section 1.3. Changes in capacity can in part be tied to changes in demand, weather, and airport infrastructure. In Figure 3-11, the average hourly arrival ATC acceptance rates for the 34 main US airports between 6AM-10PM local time are shown with the percent change in arrival capacity compared to 2013 (top of Figure 3-11).

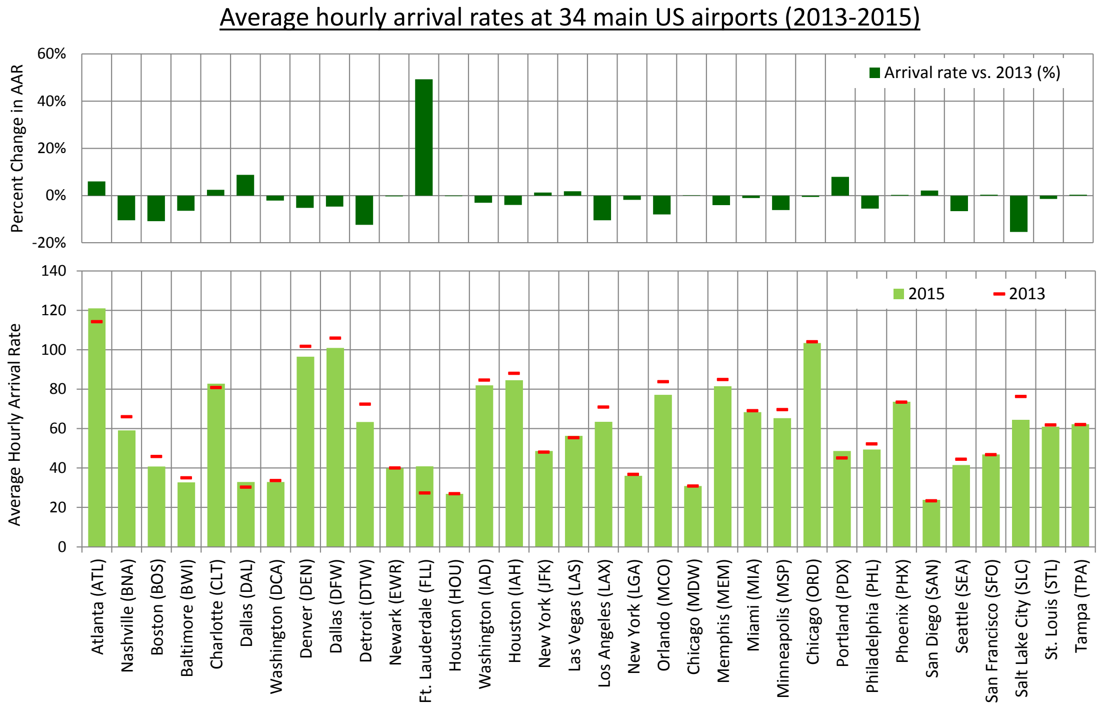

Figure 3-11: Average hourly arrival rates at 34 main US airports (2013-2015)

Ft. Lauderdale (FLL) had the largest percent change from 2013 to 2015. Its increase was due to a runway coming back into service in November of 2014. Salt Lake City (SLC) saw a decrease due to a change in strategy for calling a balanced rate.

Capacity at airports can be tied to demand at the facility and also be impacted by external factors, such as weather conditions. It is also the case that not all capacity variation and performance changes can be explained by meteorological conditions as facilities may operate at low capacity rates during good weather due to other events such as temporary runway maintenance or dependencies with traffic flow of nearby airports.

For this reason, it is more straightforward to assess capacity variation using a percentile method that does not depend on a link to all the causal reasons described above.

Figure 3-12 combines the various elements (volume, capacity reduction, and frequency) which drive performance at US airports using percentiles. In the previous section, peak capacity and throughput values were presented. In the following section, the focus is on how much capacity varies from low to high values and how often this variation becomes a strain on airports due to demand levels close to or exceeding capacity. Note that capacity and demand do not have to be at a peak level for an airport to be impacted or strained. In general, it only takes a mismatch of the two entities and not necessarily high levels of each.

Figure 3-12 combines various elements of capacity and demand, calculated using filed times from day of operation, as one means of measuring the congestion at airports as well as the predictability of capacity. The top chart in Figure 3-12 shows airport capacity and demand for both 2013 and 2015 by reporting the average number of hours the demand is greater than 80% of the called rate capacity for the airport. For example, LGA experienced a demand greater than the 80th percentile capacity for 12.4 hours per day on average during 2015. This means for the majority of the operating day, LGA's demand exceeded the 80th percentile capacity. In relation to Figure 3-9, the operations at Seattle have not only increased but by this indicator, are becoming more comparable to the busier US airports. While Fort Lauderdale traffic has grown, its congestion by this measure is less due to one of its runways coming back into service.

To capture this effect, a percent capacity reduction metric can be used by calculating the (85th-15th)/85th. This metric in the lower part of Figure 3-12, shows the percent capacity variability by calculating the percent decrease in capacity from the 85th to 15th percentile. This metric produces similar results for LGA (low variability, low capacity) and CLT (high variability, high capacity). Philadelphia (PHL), Boston (BOS), Detroit (DTW), and Nashville (BNA) report the largest percent capacity reductions of the Main 34 airports.

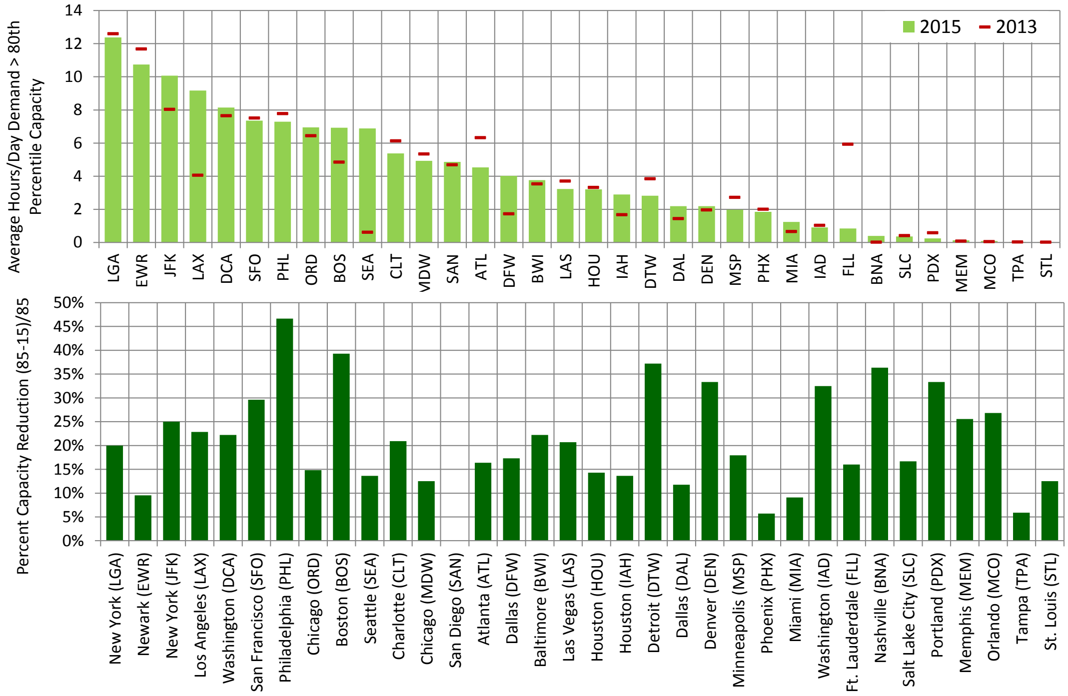

Figure 3-12: Capacity variation and impact on operations at US airports

Although a percentile method was used to characterise airport capacity variation, it is still important for performance analysis groups to link these changes to causal factors. At this time, it is difficult to apply a practical automated process that can explain capacity variation across all facilities. For example, it is known that for San Francisco (SFO), variation can be tied to precipitation, haze, fog and other METAR cloud cover conditions which are not captured by ceiling/visibility alone. For Philadelphia (PHL), the capacity variation can be linked to wind effects [Ref. 10]. Additional performance data development and automated procedures are needed to assess these effects across airports.

A key challenge for ATM is to ensure safe operations while sustaining a high runway throughput in the various weather conditions. Even small improvements at high density airports will yield a considerable benefit for airspace users and the entire network. This will encompass the use of new and enhanced technology as foreseen in NextGen and SESAR.

3.3 Impact of Weather Conditions on airport operations

Runway throughput at airports is usually impacted by meteorological conditions. As weather conditions deteriorate, separation requirements generally increase and runway throughput is reduced. The impact of weather (visibility, wind, convective weather, etc.) on operations at an airport and hence on ATM performance can vary significantly by airport and depends on a number of factors such as, inter alia, ATM and airport equipment (instrument approach system, radar, etc.), runway configurations (wind conditions), and approved rules and procedures.

As illustrated in Figure 3-13, movement rates depend on visibility conditions. Runway throughput can drop significantly when Low Visibility Procedures (LVP)[29] need to be applied.

LVPs require increased spacing between aircraft to maintain the signal integrity of the Instrument Landing System (ILS) which in turn reduces throughput.

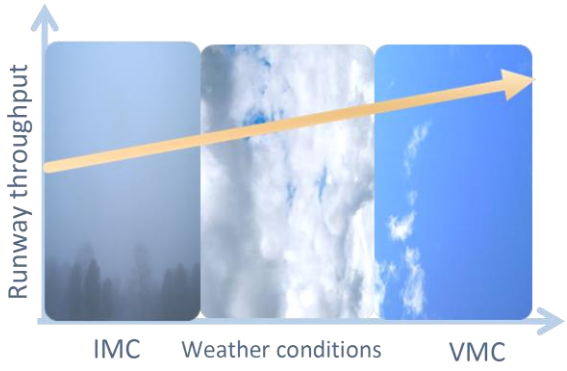

Figure 3-13: Impact of visibility conditions on runway throughput

Wind conditions also impact runway throughput. With the separations based on distance, wind with a high headwind component lowers the ground speed of aircraft and consequently reduces the rate at which aircraft make their final approach.

The analysis of performance by meteorological condition provides an indication of how weather affects system performance and which airports are most impacted by changes in weather condition.

Section 3.3.1 provides an assessment of weather in the two regions using general criteria for ceiling and visibility. Section 3.3.2 compares ATFM delay attributed to weather causes at US and European arrival airports.

3.3.1 Measuring weather conditions

Both US and European performance groups use detailed weather observation reports known as METAR[30] and both groups have developed procedures for assessing weather's impact on aviation performance [Ref. 11 and 12]. A typical METAR contains data on temperature, dew point, wind speed and direction, precipitation, cloud cover and heights, visibility, and barometric pressure.

Historically, many of the performance analysis indicators and modelling processes at the FAA segregate time periods into visual or instrument meteorological conditions (VMC/IMC). This provides a simple first-order examination of the effects of weather on performance using ceiling

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29 Low visibility procedures have been devised to allow aircraft to operate safely from and into aerodromes when the weather conditions do not permit normal operations.

30 METAR is also known as Meteorological Terminal Aviation Routine Weather Report or Meteorological Aerodrome Report.

and visibility as the primary criteria for defining weather. Performance by VMC/IMC was also examined in the previous benchmark reports as a practical way of comparing weather changes over time and weather differences between facilities.

Precise definitions differ between the US and Europe but for the analysis in the next section, a cloud ceiling of less than 1 000 feet or visibility of less than 3 miles (5 km) was used for the demarcation of IMC. Conditions better than IMC are termed visual meteorological conditions (VMC). In addition, there are airport specific thresholds where visual approaches (and typically visual separations) may be used. Conditions below such thresholds, but still better than IMC, are referred to as Marginal VMC. For simplicity, the following thresholds were used for *all airports* to provide a basic assessment of the frequency of various weather conditions.

Table 3-4: Ceiling and visibility criteria

		Visibility (miles)		
		< 3	**[3, 5)**	**≥ 5**
Ceiling (feet)	**≥ 3,000**	Instrument	Marginal	Visual
	[1000, 3000)	Instrument	Marginal	Marginal
	< 1,000	Instrument	Instrument	Instrument

It is important to note that VMC does not necessarily equate to favourable or perfect weather although it is often the case. METAR data contains records with weather events, such as rain showers, thunderstorms and strong winds occurring during periods with high visibility and clear skies. These weather events are currently not assessed as part of these related indicators and more work is needed in the future to develop a more comprehensive definition for weather.

Figure 3-14 shows the percent of time spent in visual, marginal, and instrument conditions in Europe and the US at system level in 2013 and in 2015 between 6AM-10PM local time.

In general, weather in Europe at system level is less favourable than the US.

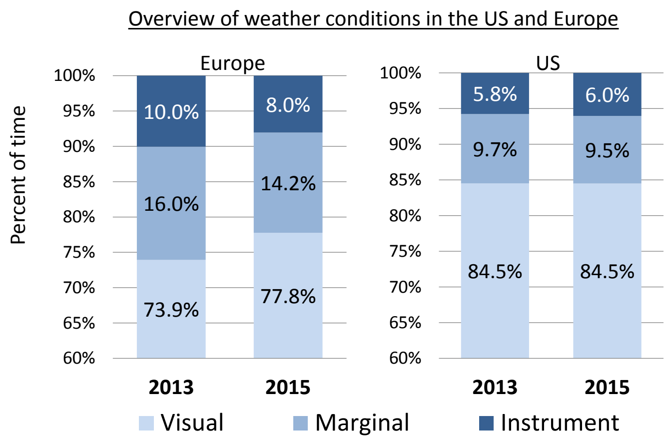


Figure 3-14: Overview of weather conditions in the US and Europe

In 2015, 84.5% of the year at the main 34 US airports was spent in VMC with 9.5% occurring in marginal and 6% in instrument conditions. Overall, the weather in the US appears to be similar as in 2013 with a slightly higher frequency of IMC in 2015 (+0.2%). The main 34 European airports spend on average 77.8% of the time in VMC, 14.2% in marginal, and 8% in instrument. At system level, weather conditions in Europe improved in 2015 compared to 2013 with a -2.0% reduction in IMC and a -1.8% reduction in marginal conditions.

At the airport level, the share of time spent in VMC, MMC, and IMC vary based on differing susceptibility to weather events which is largely based on geographic location (Figure 3-15). The European airports located in the subtropical Mediterranean region including Nice (NCE), Palma (PMI), Madrid (MAD), Rome (FCO), Athens (ATH), and Barcelona (BCN) are the airports with the highest percentage of the VMC.

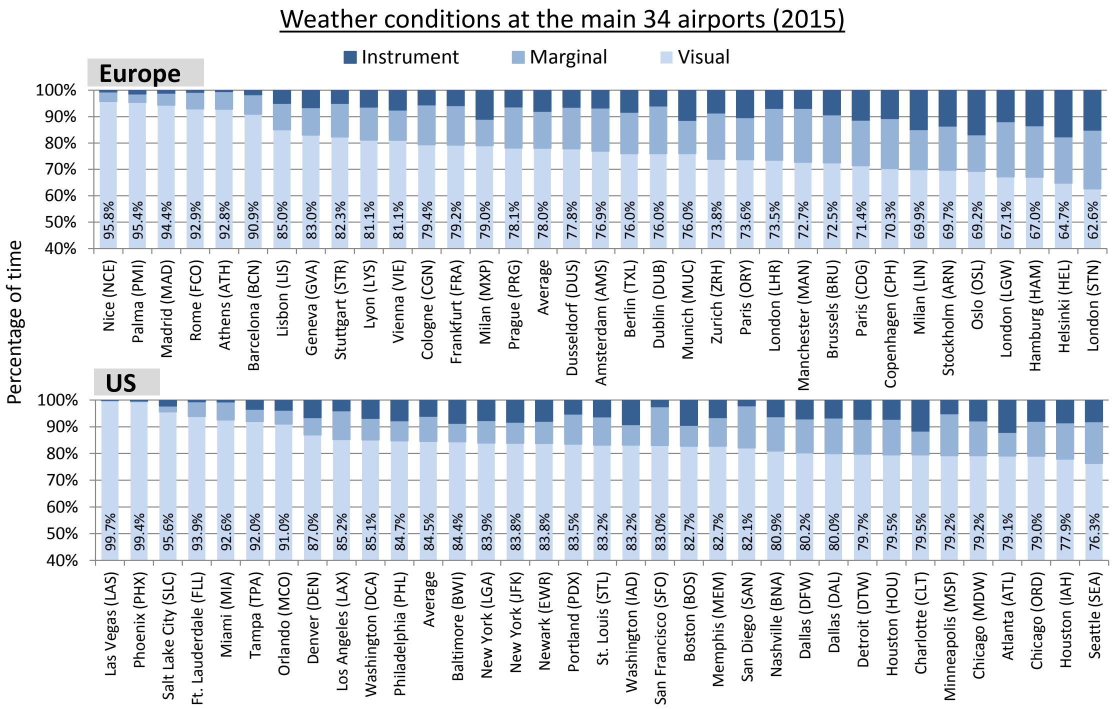


Figure 3-15: Percent of time by meteorological condition at the main 34 airports (2015)

In the US, Las Vegas (LAS) and Phoenix (PHX) rarely experience anything other than VMC with their dry desert climate. Similarly, the Florida airports (FLL, MCO, TPA, and MIA) also spend a high percentage of time in VMC.

Figure 3-16 shows how the change in instrument conditions is broken down by airport in Europe (-2%) and the US (+0.2%) in 2015. In terms of performance, the observed capacity gap, traffic volume, and frequency of IMC drive overall system performance.

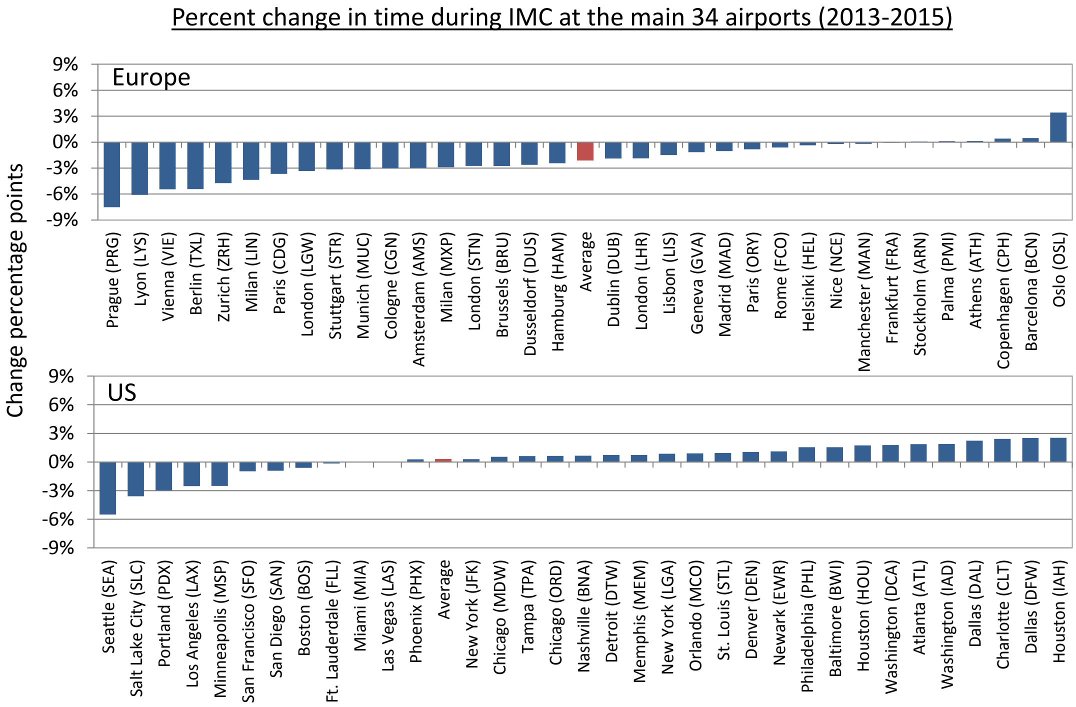


Figure 3-16: Percent change in time during IMC at the main 34 airports (2013-2015)

The airports with considerably more time spent in marginal and instrument conditions and less time in VMC may call lower called rates more often, but performance at these airports will only be impacted if demand levels rise above the available capacity. As mentioned previously in this section, ceiling and visibility provide only a preliminary step towards measuring weather conditions. More work is needed to relate the impact of weather conditions on airport and air traffic performance.

3.3.2 Weather-related airport ATFM delays at the main 34 airports

As weather is a major factor influencing runway throughput and airport capacity, airports typically issue ATFM restrictions to address capacity to demand imbalances when adverse weather occurs. Using comparable data sources in the US and Europe, this section provides a preliminary analysis of the specific types of weather-related causes for ATFM delays at the arrival airport. A more detailed analysis of ATFM delay for all causal factors is provided in Section 5.2.1.

Figure 3-17 shows the average airport arrival ATFM delay[31] by causal factor at system level for the main 34 airports between 2008 and 2015.

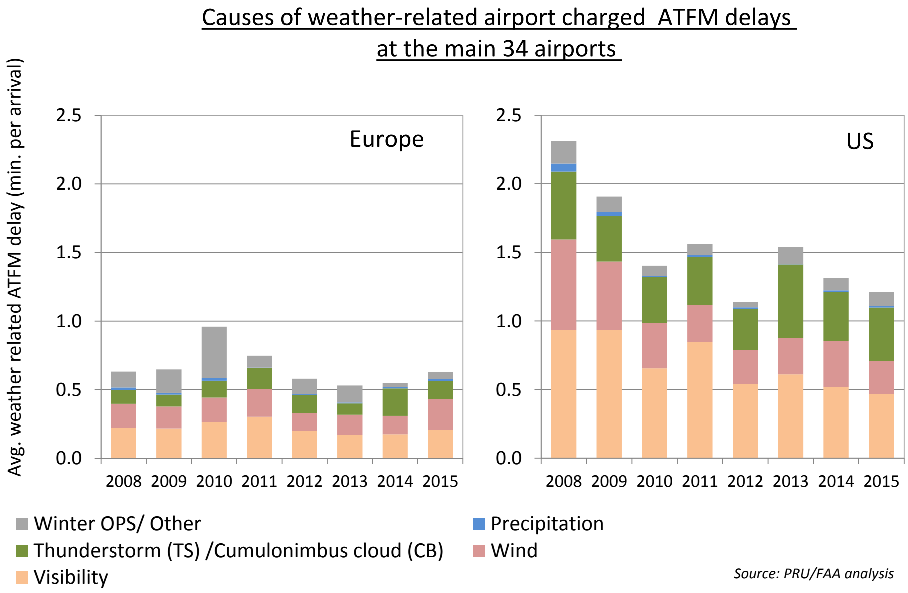


Figure 3-17: Causes of weather-related airport ATFM delays (2008-2015)

Overall, relatively higher ATFM delays per arrival are observed in the US compared to Europe when weather-related restrictions are present. This may be due to European capacities being set more conservatively to allow for unforeseeable events whereas the US operates by calling a higher capacity by presuming ideal operating conditions. Major contributors to the US values include airports with high demand and highly variable capacity.

In Europe, ATFM airport regulations due to visibility are the main driver of delay, followed by wind, winter operations and thunderstorms. A notable exception is observed for 2010 where

[31] Please note that for Europe all ATFM delays are included whereas for the US only delays equal or greater than 15 minutes are included.

winter operations were the main cause for weather related airport ATFM regulations. As can be seen in Figure 3-17, average weather related ATFM arrival delays increased in Europe between 2013 and 2015.

Similarly in the US, the primary driver for ATFM delays is visibility, however, the impact of thunderstorms and severe weather are also very prominent. Different than in Europe, weather related airport ATFM delays continuously decreased in the US between 2013 and 2015.

Figure 3-18 provides a breakdown of weather-related ATFM delay by arrival airport and by cause in 2015. A high average weather-related airport arrival delay is usually the result of a notable capacity reduction in bad weather combined with a high level of demand (i.e. peak throughput close to or higher than the declared capacity).

Airport charged weather-related ATFM delays by destination airport (2015)

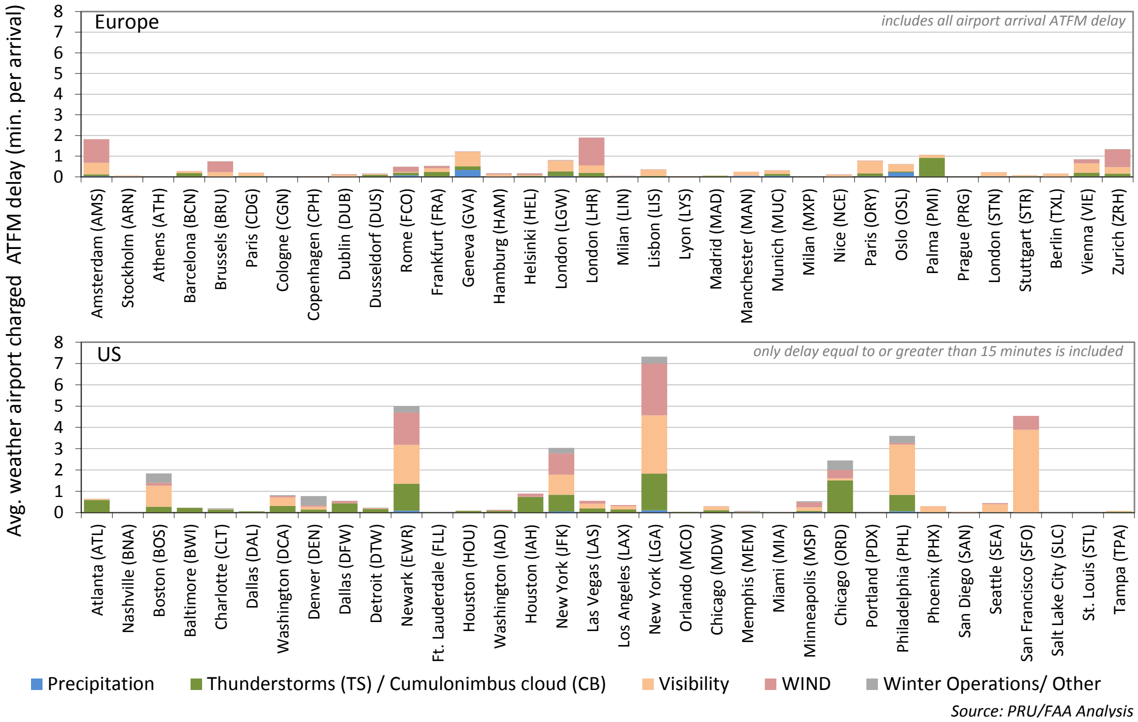


Figure 3-18: Airport charged weather-related ATFM delays by destination airport (2015)

As can be seen from the figure, a few notable US airports experience delay levels that are magnitudes higher than other airports in the country or in Europe. The New York area airports (EWR, LGA, and JFK) experience very high average ATFM weather-related delays. For this reason, the New York area has implemented a severe weather avoidance plan (SWAP) to handle aircraft reroutes and departure clearances during thunderstorm events. On the west coast, fog and low visibility are the most impactful weather cause for ATFM delays at San Francisco (SFO).

In Europe, London Heathrow (LHR) shows the highest impact of weather on operations in 2015, followed by Amsterdam (AMS), Zurich (ZRH), and Geneva (GVA). The average weather-related airport arrival ATFM delays at London (LHR) were mainly related to wind and visibility.

4. COMPARISON OF AIRLINE-RELATED OPERATIONAL SERVICE QUALITY

This chapter compares US and European performance using data provided by airlines. Specific KPIs provided in this section include airline-reported punctuality, airline-reported delay against the schedule, airline-reported attributable delay, and phase of flight time variability.

The section starts with a high level evaluation of the share of delayed flights compared to airline schedules, which is often used as a proxy for "service quality". There are many factors contributing to the "service quality" of air transport. In fact, it can be seen as the "end product" of complex interactions between airlines, ground handlers, airport operators, and ANSPs, from the planning and scheduling phases up to the day of operation.

The KPI is reported by the US Department of Transportation [Ref.13] and in Europe by the Central Office for Delay Analysis (CODA) [Ref. 14]. The chapter furthermore assesses trends in the evolution of scheduled block times as changes in this scheduled time can have a first order effect on punctuality KPIs. The main delay drivers are also identified by analysing the information reported by airlines in order to get a first estimate of the ATM-related[32] contribution towards overall air transport performance.

4.1 On-time performance

Figure 4-1 compares the industry-standard indicators for on-time performance, i.e. arrivals or departures delayed by less than or equal to 15 minutes versus schedule. The results need to be seen together with the time buffers included in airline schedules in order to achieve a certain level of on-time performance. A more detailed discussion on how increasing block time can lead to an apparent improvement in performance is included in the next section (see Section 4.2).

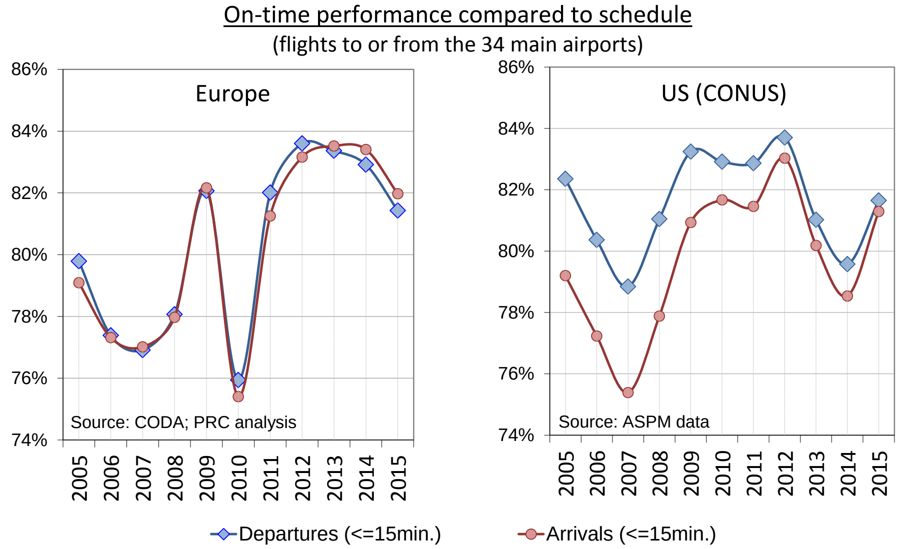


Figure 4-1: On-time performance (2005-2015)

A notable difference was the gap between departure and arrival punctuality that occurred prior to 2010 in the US, and which was not observed for Europe. The reasons for this gap are not fully understood but may involve policy, differences in flow management techniques as well as other incentives to have high on-time departures. While in the US, flow management strategies focus

32 In this report, "ATM-related" means that ATM has a significant influence on the operations.

more on the gate-to-gate phase, in Europe flights are usually held at the gates with only comparatively few constraints once an aircraft has left the gate. However from 2010 this gap has largely disappeared with a trend similar to Europe.

Historically, between 2005 and 2007, on-time performance degraded in the US and in Europe and improved notably between 2007 and 2009. It is interesting to note that, at system level, traffic in Europe increased by 2.3% while traffic in the US declined by 11.8% between 2005 and 2009 (compare Figure 3-1).

Whereas in the US performance remained stable in 2010, punctuality in Europe degraded to the worst level on record mainly due to weather-related delays (snow, freezing conditions) and strikes[33]. From 2010 to 2012, punctuality in Europe improved again and continued to improve in the US. However in 2013 and 2014, whereas punctuality in Europe remained largely unchanged and then degraded from 2014-2015, punctuality in the US saw a sharp decline from 2012-2014 followed by a rebound from 2014-2015. Figure 4-2 and Figure 4-3 show the facilities that most influence system wide on-time performance as well as contributed to the change from 2013-2015 (US 80.2% vs 81.3%).

The system-wide on-time performance is the result of contrasted situations among airports. Figure 4-2 shows the arrival punctuality at the 34 main European and US airports in 2015. The changes in arrival punctuality compared to 2013 are shown in Figure 4-3

In the US, the New York airports (LGA, EWR, JFK) had the lowest on-time performance (arrivals), followed by San Francisco (SFO) and Los Angeles (LAX). Compared to 2013, only a few airports showed degradation in arrival punctuality (see Figure 4-3).

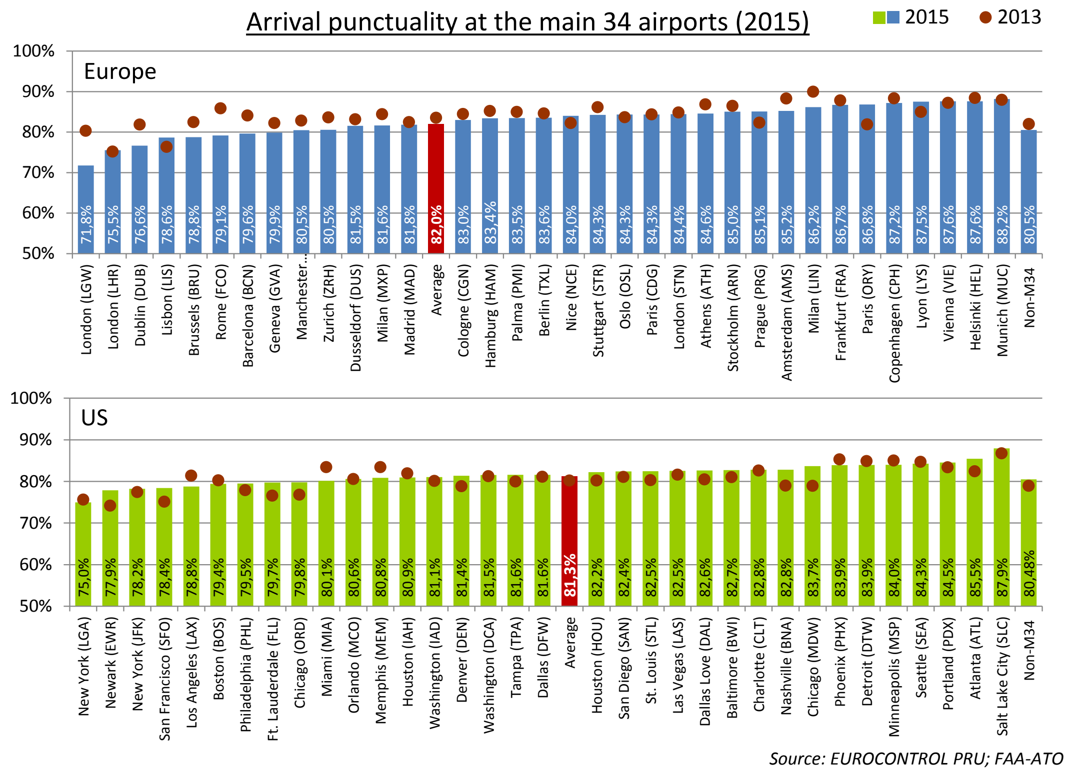


Figure 4-2: Arrival punctuality at the main 34 airports (2015)

[33] The volcanic ash cloud in April and May 2010 had only a limited impact on punctuality, as the majority of the flights were cancelled and are, thus, excluded from the calculation of on-time performance indicators.

In Europe, the two London airports (LHR, LGW) and Dublin (DUB) had the lowest level of arrival punctuality in 2015 (top chart in Figure 4-2). Compared to 2013, Paris (ORY) (+4.9% pt.) showed the highest improvement and a notable deterioration can be observed for London (LGW), Rome (FCO) and Dublin (DUB).

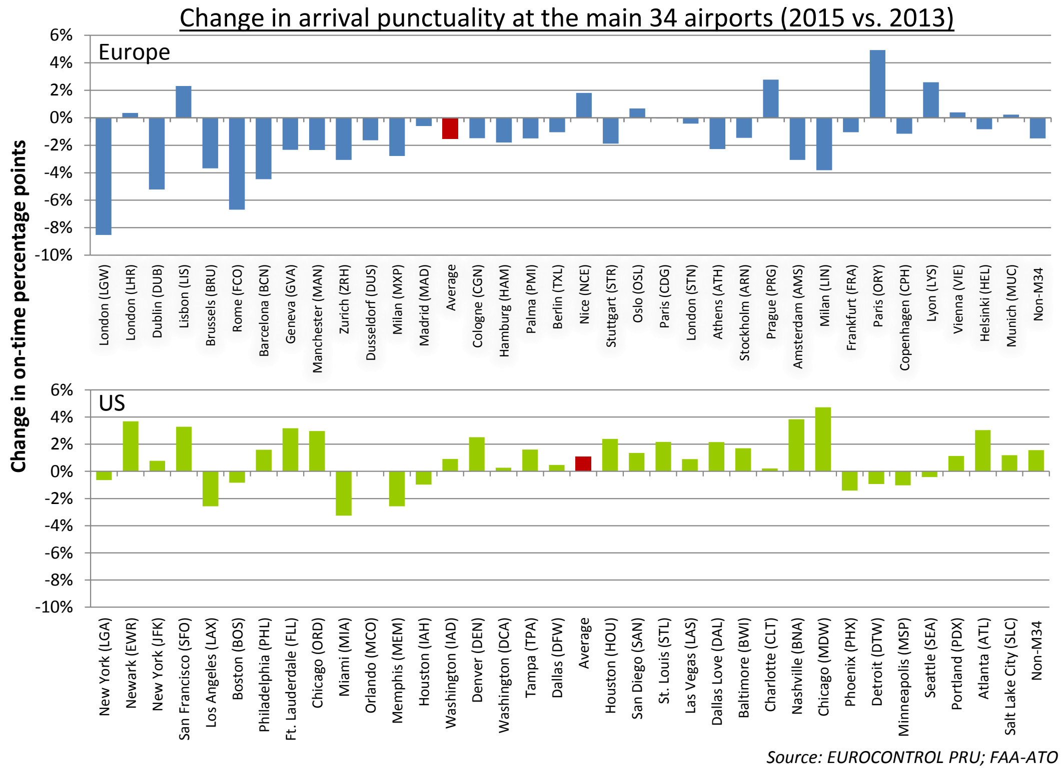


Figure 4-3: Change in arrival punctuality at the main 34 airports (2015 vs. 2013)

Figure 4-4 shows monthly arrival punctuality levels (red line) together with traffic levels (brown line) for flights to or from the top 34 airports in the US and Europe between 2010 and 2015.

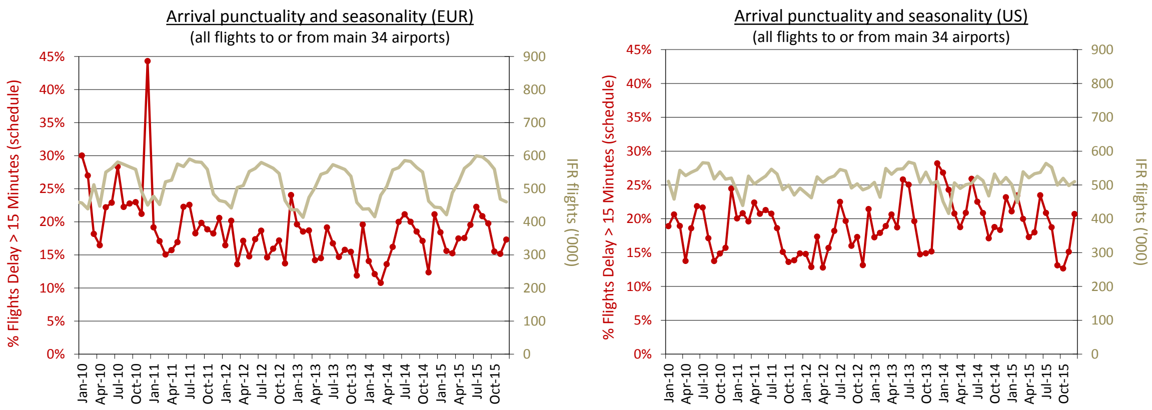


Figure 4-4: Arrival punctuality by month (2010-2015)

In Europe and the US, a clear pattern of summer and winter peaks is visible. 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. The strong increase in Europe in December 2010 is due to exceptional weather conditions (ice & snow).

As already mentioned at the beginning of this chapter, it is important to understand that on-time performance is the 'end product' of complex interactions involving many stakeholders, including ATM. Arrival punctuality is influenced by departure punctuality at the origin airport and often by delays which already occurred on previous flight legs (see also Section 4.3). Depending on the type of operation at airports (hub & spoke versus point to point) and airline route itinerary, local performance can have an impact on the entire network through ripple effects but also on the airport's own operation.

Hence, there are interdependencies between ATM performance and the performance of other stakeholders and/or events outside the control of ATM which require a high level of cooperation and coordination between all parties involved. This may include competing goals within airlines, weather, or changes to airport infrastructure that affect capacity.

4.2 Airline scheduling

On-time performance can be linked to a number of different factors including traffic levels, weather, airport capacity, and airline scheduling preferences, such as schedule peaks and scheduled block times. Frequently, airlines may pad their schedules to achieve a higher level of on-time punctuality. The inclusion of "time buffers" in airline schedules to account for a certain level of anticipated travel time variation on the day of operations and to provide a sufficient level of on-time performance may therefore mask changes in actual performance (see grey box).

Generally speaking, the wider the distribution of historic block-to-block times (and hence the higher the level of variation), the more difficult it is for airlines to build reliable schedules resulting in higher utilisation of resources (e.g. aircraft, crews) and higher overall costs.

Additionally, a number of airlines operate hub and spoke systems that interconnect flights to and from spoke airports to the carriers' hubs. Therefore disturbances at one hub airport can quickly propagate through the entire airline schedule. Operating an aircraft servicing several airports can further amplify and increase the delay propagation.

Airline scheduling

Airlines build their schedules for the next season on airport slot allocation (mainly Europe), crew activity limits, airport connecting times, and by applying a quality of service 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 level of "schedule padding" is subject to airline strategy and depends on the targeted level of on-time performance.

Nevertheless, it should be pointed out that efficiency improvements in actual flight time distributions do not automatically result in improved on-time performance, as the airline schedules for the new season are likely to be reduced by applying the punctuality target to the set of improved flight times (block times are cut to improve utilisation of aircraft and crews).

Figure 4-5 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[34]). Generally speaking, the scheduled

[34] 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. The analysis evaluates a relative change in performance over time but does not provide an indication of the underlying performance drivers.

block times follow the pattern of the actual block times of the previous season.

At system level, scheduled block times remained largely stable in Europe with only a slight increase between 2008 and 2010 and again as of 2012. In the US, average block times increased continuously between 2005 and 2010 but decreased again between 2010 and 2015. In 2015 average block times increased again notably in the US which could be due to the degraded punctuality observed in 2014 (see Figure 4-1). These observed increases in schedule padding in the US may result from adding block time to improve on-time performance or could be tied to a tightening of turnaround times. More work is needed on a city pair level to accurately and more specifically identify the numerous factors influencing the changes in on-time performance.

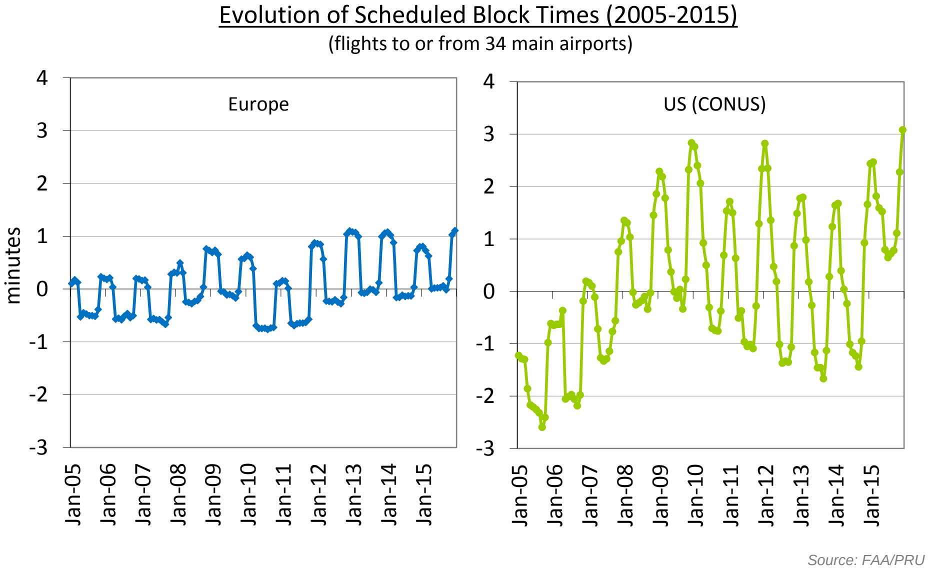


Figure 4-5: Scheduling of air transport operations (2005-2015)

Seasonal effects are visible in Figure 4-5 with scheduled block times being on average longer in winter than in summer. US studies have shown that the majority of the increase is explained by stronger winds on average during the winter period [Ref. 15].

4.3 Drivers of air transport performance – as reported by airlines

This section aims at identifying underlying delay drivers as reported by airlines in the US and in Europe. The reported delays relate to the schedules published by the airlines.

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

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 (or reactionary delay), Security, and ATM system (ATFM/NAS delays):

- Airline + Local turnaround: Delay due to circumstances within local control including airlines or other parties, such as ground handlers involved in the turnaround 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 in the US.
- Late-arriving aircraft/reactionary delay: Delays on earlier legs of the aircraft that cannot be recuperated during the turnaround 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: Delays attributable to ATM refer to a broad set of conditions, such as non-extreme weather conditions, airport operations, heavy traffic volume, ATC.

Figure 4-6 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. Clearly, US airlines attribute a larger fraction of causal delay to US ATM than what is seen in Europe.

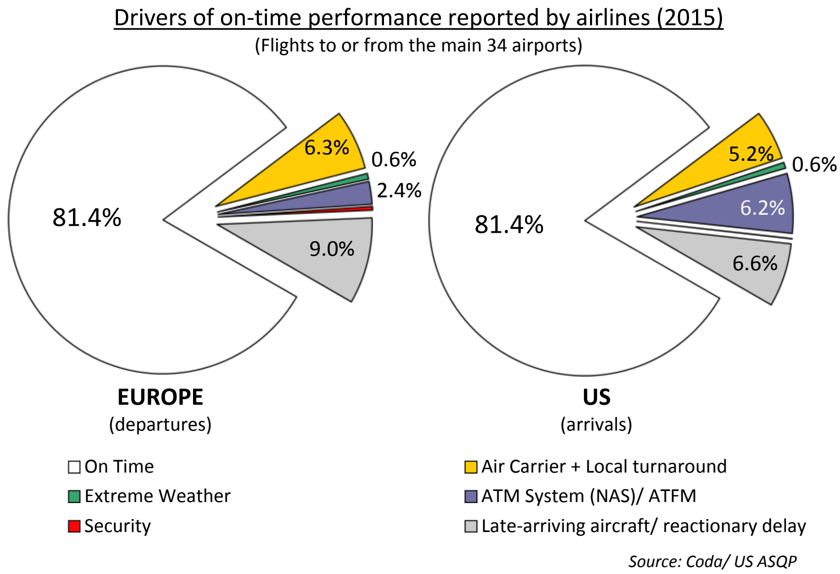


Figure 4-6: Drivers of on-time performance in Europe and the US (2015)

In the US, ATM system delay is largely due to weather which is attributed to the ATM system and equipment problems. In Europe, according to airline reporting, much of the primary delay at departure is not attributable to ATM but more to local turnaround delays caused by airlines, airports, and ground handlers.

As already mentioned, the US distribution relates to the scheduled arrival times and the higher share of ATM-related delay at arrival is partly due to the fact that this figure is impacted by ATM delays accrued after departure (i.e taxi-out, en-route, terminal).

It should be noted that the ATM system related delays in Figure 4-6 result from not only en-route and airport capacity shortfalls but also include weather effects which negatively influence ATM and aircraft operations (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. 16].

Figure 4-7 provides an analysis of how the duration of the individual flight phases (gate departure delay[35], taxi-out, airborne, taxi-in, total) have evolved over the years in Europe and the US. It is based on the DLTA Metric (see footnote 34) and compares actual times for each city pair with the long-term average for that city pair over the full period (2005-2015). For example, in the US at the peak of the curve at the end of 2008, total average actual flight time among city pairs had increased over 5 minutes since 2005 and was 4 minutes above the long-term average.

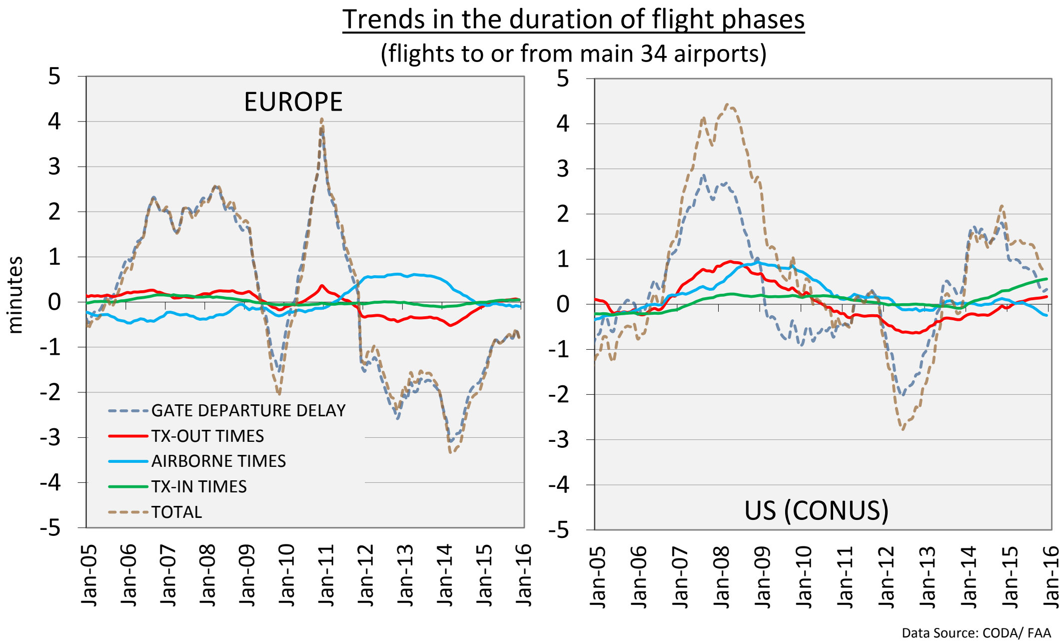


Figure 4-7: Trends in the duration of flight phases (2005-2015)

In Europe, performance is clearly driven by gate departure delays with only very small changes in the gate-to-gate phase (i.e. there is only a very small gap between departure time and total). The drop in gate departure delay in 2009 when traffic levels fell as a result of the economic crisis is significant. In 2010, despite a traffic level still below 2008, gate departure delays increased again significantly mainly due to exceptional events (industrial actions, extreme weather, technical upgrades). Since 2010, performance in almost all phases of flight improved again substantially.

In the US, the trailing 12-month average began to decline at the beginning of 2008. Similar to Europe, departure delay was the largest component associated with the change in average flight time. Between 2008 and 2010, most flight components went back to their long-term average and improved even further between 2010 and 2012 before they decreased again in 2014-2015. A substantial improvement is also visible for taxi-out times as a result of the initiatives to improve performance in this area.

[35] Gate departure delay is defined as the difference between the actual gate out time and the schedule departure time published by the operators.

4.4 Variability by phase of flight

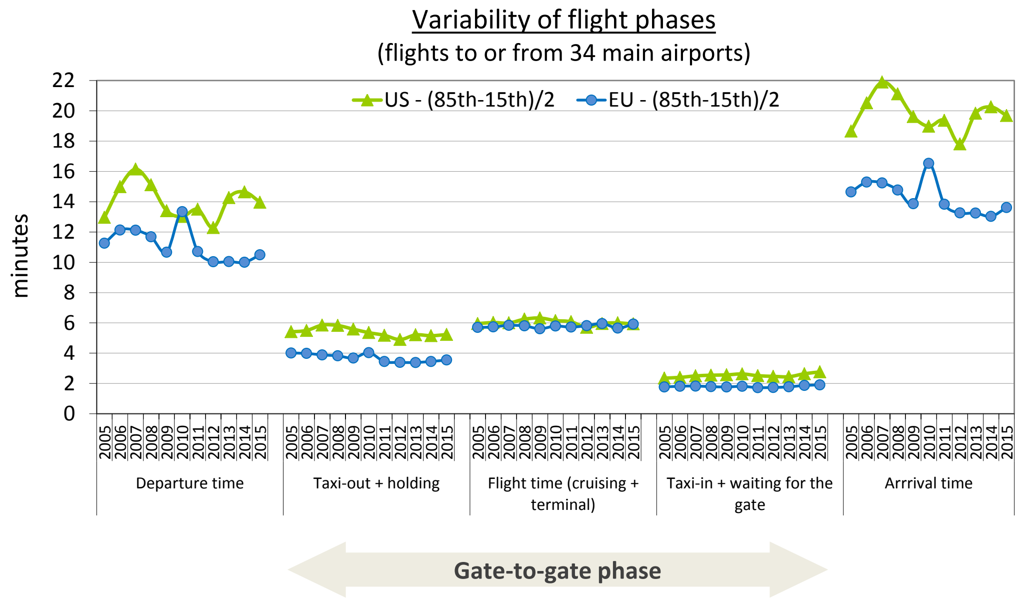
This section looks at the Key Performance Area of Predictability or variability by phase of flight using airline-provided data for gate "out," wheels "off," wheels "on," and gate "in" data. This out, off, on, in data is often referred to as OOOI data and is almost entirely collected automatically using a basic airline data-link system (see Section 1.3 for more information on data sources).

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

> **Variability**
>
> The "variability" of operations determines the level of predictability for airspace users and hence has an impact on airline scheduling. It focuses on the variance (distribution widths) associated with the individual phases of flight as experienced by airspace users.
>
> The higher the variability, the wider the distribution of actual travel times and the more costly time buffer is required in airline schedules to maintain a satisfactory level of punctuality. 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.

Predictability evaluates the level of variability in each phase of flight as experienced by the airspace users[36]. In order to limit the impact from outliers, variability is measured as the difference between the 85th and the 15th percentile for each flight phase. This captures 70% of flights and would be representative of one standard deviation if in fact travel times were normally distributed and not skewed due to delay. In targeting high levels of punctuality, airlines may in fact require "certainty" around a broader population of flights than 70% and therefore view the system as more "variable" and less predictable than what is shown below. However, the focus on this report is to compare the US and Europe using a common methodology.

Figure 4-8 shows that in both Europe and the US, arrival predictability is mainly driven by gate departure predictability. Variability in all flight phases is higher in the US than Europe.



Source: FAA/PRC

Figure 4-8: Variability of flight phases (2005-2015)

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

Between 2005 and 2007, gate departure time variability continuously increased on both sides of the Atlantic. Contrary to Europe, variability increased also in the taxi-out phase in the US, which appears to be driven by the different approaches in both scheduling operations and absorbing necessary delay.

Historically, the differences between the US and Europe have been largest on the ground both at the gate and in taxi-out. Despite the lower level of variability, improvement in the gate-to-gate phase – especially in the taxi-out and terminal airborne phase – can warrant substantial savings in direct operational and indirect strategic costs for the airlines.

Figure 4-9 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 4-5).

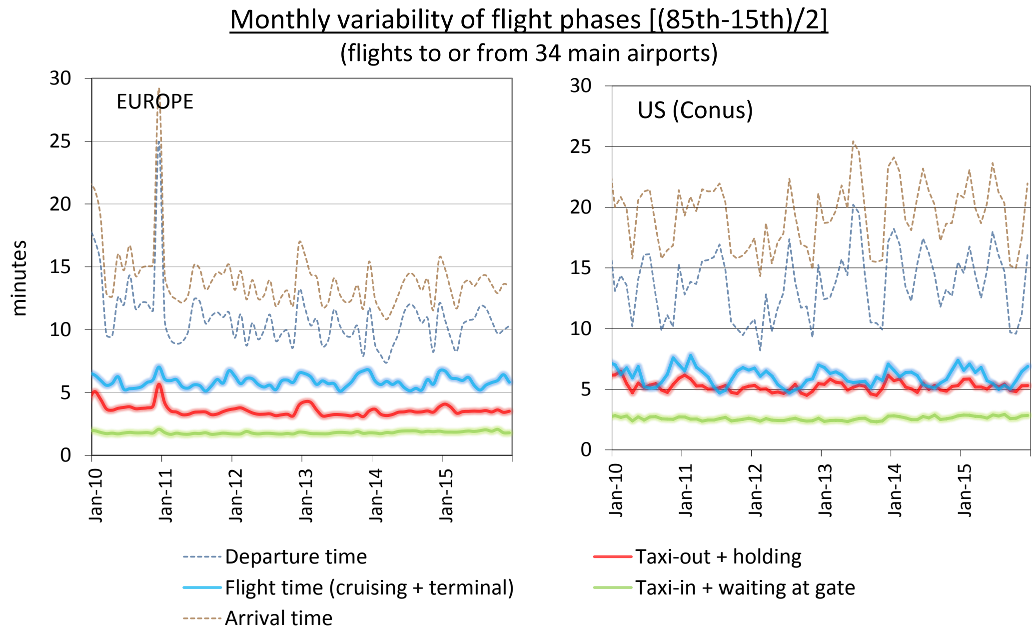


Figure 4-9: Monthly variability of flight phases (2010-2015)

In the departure phase, ATM can contribute to the variability through ATM-related departure holdings and subsequent reactionary delays on the next flight legs. The ATM-related departure delays are analysed in more detail in Section 5.2.1. Due to the interconnected nature of the aviation system, variability originating at constrained airports can propagate throughout the entire network.

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 ATM.

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 baselining system performance. The strong jet stream winds in the winter and convective weather in the summer impact overall predictability statistics.

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

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.

After a high level analysis of operational performance from the airline point of view, the next chapter provides an assessment of performance evaluated from the ATM perspective. The following analysis of ATM-related service quality is indicative of what can be influenced by improvements or actions taken by the ANSP.

5. COMPARISON OF ATM-RELATED OPERATIONAL SERVICE QUALITY

Although the analysis of performance compared to airline schedules (on-time performance) in Section 4.1 is valid from a passenger point of view and provides valuable first insights, the involvement of many different stakeholders and the inclusion of time buffers in airline schedules require a more detailed analysis for the assessment of ATM performance.

This section compares US and European performance using Key Performance Indicators calculated using data available to the ANSP. Specific KPIs include ATM-reported attributable delay, flight plan additional distance, and additional time in the various phases of flight including taxi-out, en-route, descent and arrival, and taxi-in.

The evaluation of ATM-related operational service quality will focus on the Key Performance Areas of efficiency of actual operations by phase of flight in order to better understand the ATM contribution and differences in traffic management techniques between the US and Europe. The KPA of environmental sustainability is addressed as it relates to efficiency when evaluating additional fuel burn.

The FAA-ATO and EUROCONTROL have been sharing approaches to performance measurement over the past years. Both have developed similar sets of operational key performance areas and indicators. The specific key performance indicators (KPIs) used in this report were developed using common procedures on comparable data from both the FAA-ATO and EUROCONTROL (see Section 1.3).

5.1 Approach to comparing ATM-related service quality

Figure 5-1 shows the conceptual framework for the analysis of ATM-related service quality by phase of flight applied in the next sections of this report. The high level passenger perspective (on-time performance) is shown at the top together with the airline scheduling. The various elements of ANS performance analysed in more detail in the following sections are highlighted in blue in Figure 5-1.

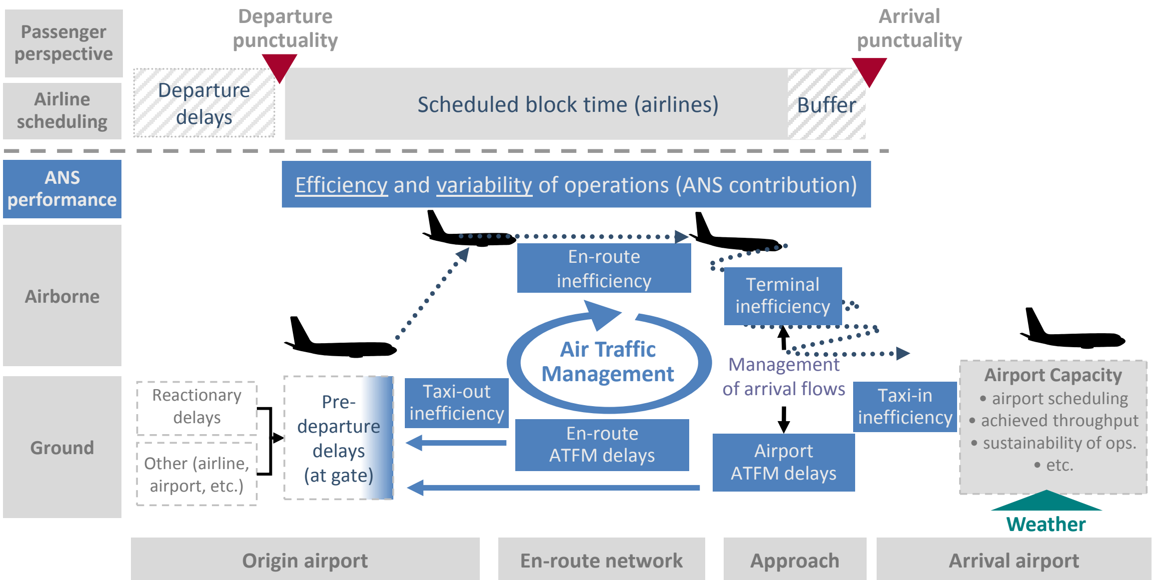


Figure 5-1: Conceptual framework to measuring ATM-related service quality

The evaluation of ATM-related service quality in the remainder of this report focuses on the Efficiency (time, fuel) of actual operations by phase of flight (see information box).

ATM may not always be the root cause for an imbalance between capacity and demand (which may also be caused by other stakeholders, weather, military training and operations, noise and environmental constraints, etc.).

However, depending on the way traffic is managed and distributed along the various phases of flight (airborne vs. ground), ATM has a different impact on airspace users (time, fuel burn, costs), the utilisation of capacity (en-route and airport), and the environment (emissions).

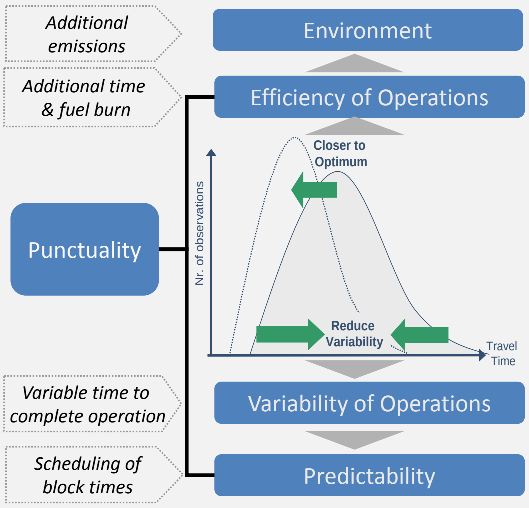
The overarching goal is to minimise overall direct (fuel, etc.) and strategic (schedule buffer in the form of added block time, etc.) costs whilst maximising the utilisation of available en-route and airport capacity.

While maximising the use of scarce capacity, there are trade-offs[37] to be considered when managing the departure flow at airports (holding at gate vs. queuing at the runway with engines running).

Efficiency

'Efficiency' in this report measures the difference between actual time/distance and an unimpeded reference time/distance. "Inefficiencies" can be expressed in terms of time and fuel and also have an environmental impact.

Due to inherent necessary (safety) or desired (noise, capacity, cost) limitations the reference values are not necessarily achievable at system level and therefore ATM-related 'inefficiencies" cannot be reduced to zero.



Similarly, the management of arrival flows needs to find a balance between the application of ground holding, terminal airborne holdings and en-route sequencing and speed control [Ref. 17].

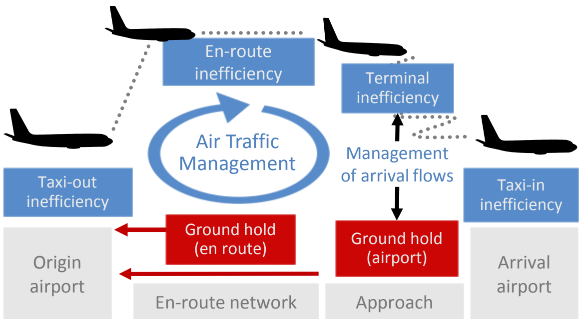
[37] It should be noted that there may be trade-offs and interdependencies between and within Key Performance Areas (i.e. Capacity vs. Cost-efficiency) which need to be considered in an overall assessment.

5.2 ATM-related efficiency by phase of flight

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 actual travel times and an optimum time of the various phases of flight illustrated in Figure 5-1. For the airborne phase of flight, this "optimum" may be a user-preferred trajectory which would include both the vertical and horizontal profile.

5.2.1 ATM-RELATED DEPARTURE RESTRICTIONS (GROUND HOLDING)

Both the US and Europe report delay imposed on flights[38] by the ANSP in order to achieve required levels of safety as well as to most effectively balance demand and capacity.



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

The categories of delay cause codes differ in the US and Europe; however, five general categories were developed to encompass the varying causal factors (see grey box). Both systems track the constraining facility which allows delay to be reported as either due to terminal/airport or en-route constraints.

Figure 5-2 shows average total ATFM ground delay (en-route and terminal) per flight between 2008 and 2015. More detailed analyses of causal reasons for changes between 2013 and 2015 are provided in later figures for both US and Europe.

For comparability reasons, only flights with ATFM ground delays equal or greater 15 minutes were included in the analyses.

Mapping of ATFM delay causes

The table shows how the differing delay codes for EU and US were mapped to produce the analysis in this section.

EUR Code	ATFM reason code (CFMU)	Example	US CODE
C	C-ATC Capacity	Demand exceeds capacity	VOLUME
S	S-ATC Staffing	Illness; Traffic delays on highway	VOLUME
G	G-Aerodrome Capacity	Demand exceeds the declared apt. capacity	VOLUME
V	V-Environmental Issues	Noise restrictions	RUNWAY
I	I-Industrial Action (ATC)	Controllers' strike	OTHER
R	R-ATC Routeing	Phasing in new procedures	OTHER
T	T-Equipment (ATC)	Radar failure; RTF failure	EQUIPMENT
W	W-Weather	Low Visibility; crosswinds	WX
D	D-De-icing	De-icing	WX
A	A-Accident/Incident	RWY23 closed due to accident	RUNWAY
E	E-Equipment (non-ATC)	Runway or taxiway lighting failure	EQUIPMENT
M	M-Military activity	Brilliant Invader; ODAX	OTHER
N	N-Industrial Action (non-ATC)	Firemen's strike	OTHER
O	O-Other	Security alert	OTHER
P	P-Special Event	European Cup Football	OTHER

The delays are calculated with reference to the estimated take-off time in the last submitted flight plan (not the published departure times in airline schedules).

38 In the US, ATM delay by Causal Factor is recorded in the FAA OPSNET database. FAA requires facilities to report all delay equal or greater than 15 minutes.

In Europe, average ATFM delay continuously decreased until 2013, following the historically bad performance due to weather and strikes in 2010.

Between 2013 and 2015, total ATFM ground delays equal or greater 15 minutes increased in Europe by 43.4% whereas traffic only increased by 4.1% during the same time.

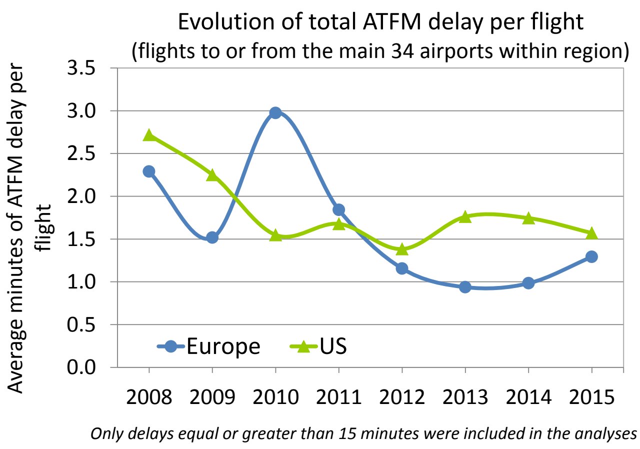


Figure 5-2: Evolution of total ATFM delay per flight (2008-2015)

The US has also shown a decline since 2008. Some of this improvement can be attributed to improving local weather at SFO and declining traffic levels at key facilities such as ORD and PHL as shown in Chapter 3. Between 2013 and 2015, total ATFM delay decreased by 12.7% with overall traffic levels at the main 34 held constant.

Figure 5-3 shows this change from 2013 to 2015 by causal factor. In the US, the decrease between 2013 and 2015 was largely due to weather including en-route convective weather not quantified in Chapter 3.

In Europe, the notable performance deterioration was due to a significant increase in capacity related delays and to a lesser extent due to weather.

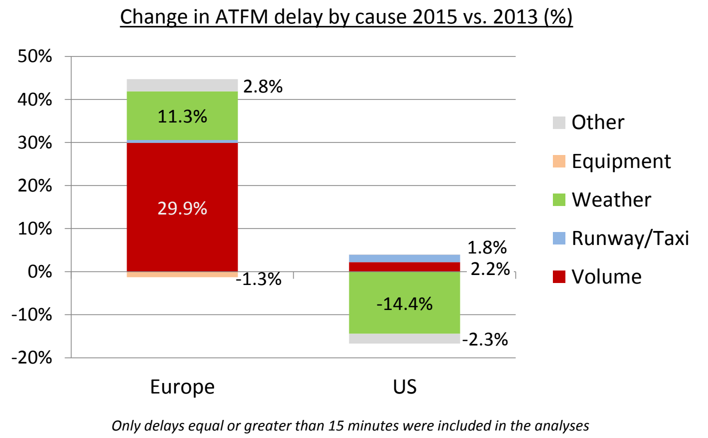


Figure 5-3: Percent change in ATFM delay by cause (2015 vs. 2013)

Table 5-1 compares ATM-related departure restrictions imposed in the two ATM systems due to en-route and airport constraints. As can be expected, the share of flights affected by departure ground restrictions at origin airports differs considerably between the US and Europe. Despite a reduction from 5.0% in 2008 to 2.0% in 2015, flights in Europe are still over twice more likely to be held at the gate or on the ground for en-route constraints than in the US where the share of flights was 0.8% in 2015.

Table 5-1: ATFM departure delays (flights to or from main 34 airports within region)

Only delays > = 15 min. are included.		EUROPE			US (CONUS)		
		2008	2013	2015	2008	2013	2015
	IFR flights (M)	5,5	4,8	4,8	9,3	8,4	8,2
En route related delays >=15min. (EDCT/ATFM)	% of flights delayed >=15 min.	5,0%	1,3%	2,0%	1,1%	0,8%	0,8%
	delay per flight (min.)	1,4	0,4	0,6	0,4	0,3	0,3
	delay per delayed flight (min.)	28	31	28	38	36	35
Airport related delays >=15min. (EDCT/ATFM)	% of flights delayed >=15 min.	2,8%	1,6%	2,3%	4,1%	2,6%	2,5%
	delay per flight (min.)	0,9	0,5	0,7	2,3	1,5	1,3
	delay per delayed flight (min.)	32	33	33	56	57	51

For airport related delays, the percentage of delayed flights at the gate or on the surface is slightly higher in the US than in Europe. However, the delay per delayed flight in the US is 55% higher (51 vs. 33).

Whereas in the US, en-route delays are mostly driven by convective weather, in Europe they are mainly the result of capacity and staffing constraints (including ATC industrial actions) driven by variations in peak demand (see large differences between summer and winter in Europe in Figure 3-4 and Figure 3-5).

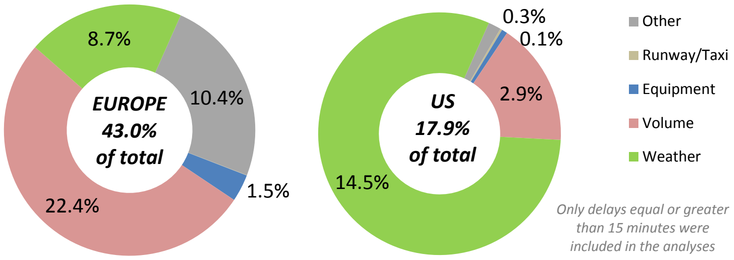


Figure 5-4: Breakdown of en-route ATFM delay by cause (2015)

At system level, the causes for airport-related ATFM delays are similar in both the US and Europe. Weather is the predominant driver of ATFM delays in both Europe and the US (Figure 5-5).

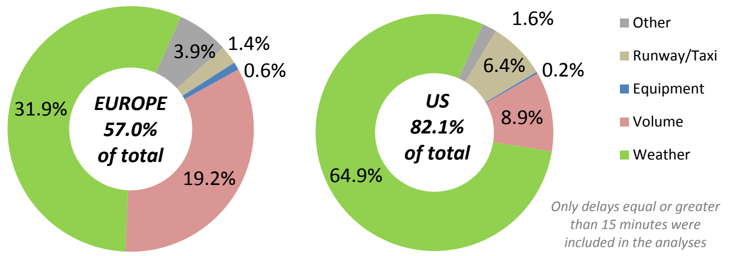
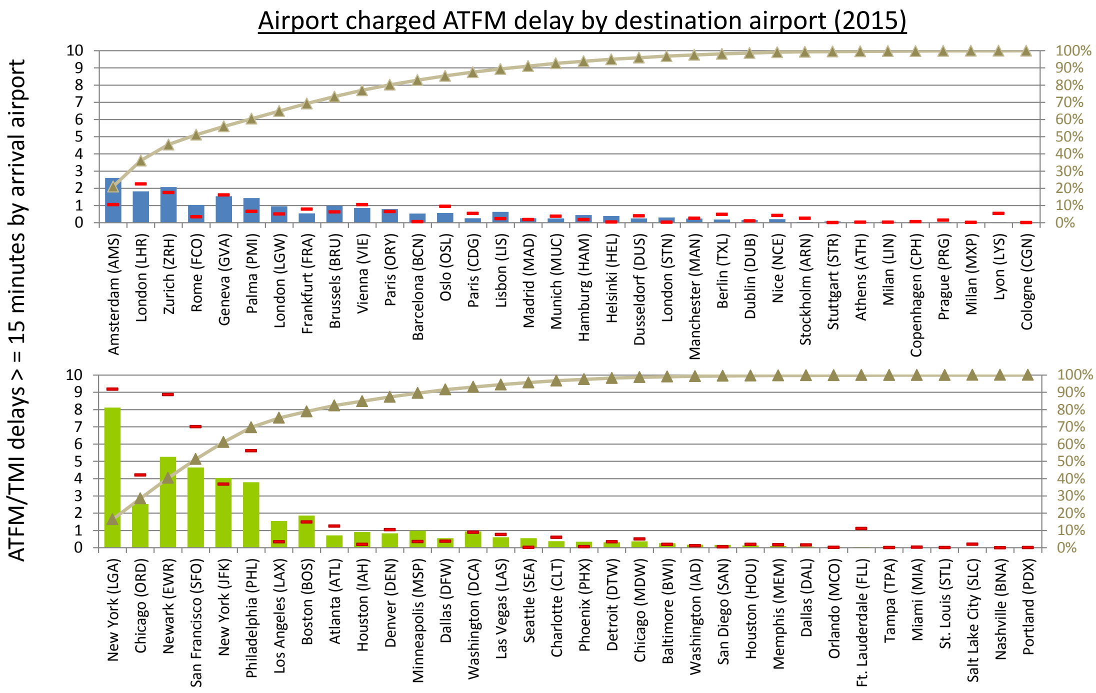


Figure 5-5: Breakdown of airport arrival ATFM delay by cause (2015)

Figure 5-6 compares the average minutes of airport-related ATFM departure delays attributed to the constraining destination airport. The airports are sorted in descending order by number of ATFM delay minutes; however, airports with a high number of flights will show lower average ATFM delays.



Source: EUROCONTROL PRU/ FAA-ATO

Figure 5-6: Airport charged ATFM delay by destination airport (2015)

In Europe, delays are more evenly spread across airports with Amsterdam (AMS), London (LHR), and Zurich (ZRH) generating the highest amounts of airport ATFM delay in 2015 in absolute terms.

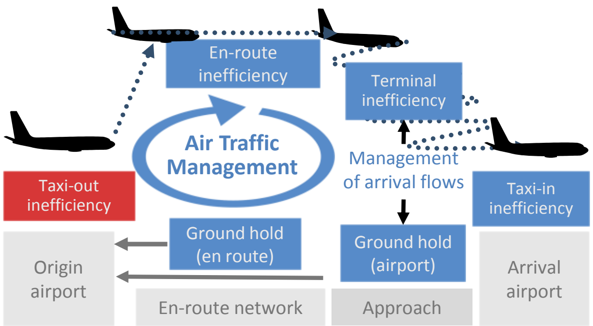
For the US, approximately 70% of the total delay minutes are concentrated at six airports in the US: New York (LGA), Chicago (ORD), Newark (EWR), San Francisco (SFO), New York (JFK), and Philadelphia (PHL). From Figure 5-6, it can be seen that flights to New York-LaGuardia (LGA) have an average ATFM delay which is four times higher than London Heathrow (LHR). Figure 5-6 also shows the facilities the drove the overall 2013-2015 reduction with ORD and EWR contributing the most followed by SFO and PHL. During this time, SFO gained an improved ability to run reduced separation under converging operations and lower minimums. Los Angeles (LAX), which experienced increased traffic, contributed the most to increasing system wide ATFM delay.

The difference in ATFM strategy between the US and Europe is clearly visible. In the absence of en-route sequencing in Europe, reducing ATFM delays (by releasing too many aircraft) at the origin airport when the destination airport's capacity is constrained potentially increases airborne delay (i.e. holding or extended final approaches). On the other hand, applying excessive ATFM delays risks underutilisation of capacity and thus, increases overall delay.

More analysis is needed to see how higher delays per delayed flight are related to moderating demand with "airport slots" in Europe.

5.2.2 ATM-RELATED TAXI-OUT EFFICIENCY

This section aims at evaluating the level of inefficiencies in the taxi-out phase. The analysis of taxi-out efficiency 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.



In the US, the additional time observed in the taxi-out phase also includes some delays 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).

The taxi-out phase and hence the performance indicator 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 departure flow restrictions, aircraft type, and remote de-icing, to name a few. Of these aforementioned causal factors, the take-off queue size[39] is considered to be the most important one for taxi-out efficiency [Ref. 18].

[39] 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.

Although the impact of ANSPs on total additional time is limited when runway capacities are constraining departures, in Europe, Airport Collaborative Decision Making (A-CDM) initiatives try to optimise the departure queue by managing the pushback times.

The aim is to keep aircraft at the stand to reduce additional time and fuel burn in the taxi-out phase to a minimum by providing only minimal queues and improved sequencing at the threshold to maximise runway throughput. These departure delays at the gate are reflected in the departure punctuality indicators. However, the ATM part due to congestion in the taxiway system is presently difficult to isolate with the available data set.

Two different methodologies were applied for the analysis of inefficiencies in the taxi-out time.

While the first method used for Figure 5-7 is simpler, it allows for the application of a consistent methodology. The method uses the 20th percentile of each service (same operator, airport, etc.) as a reference for the "unimpeded" time and compares it to the actual times. This can be easily computed with US and European data.

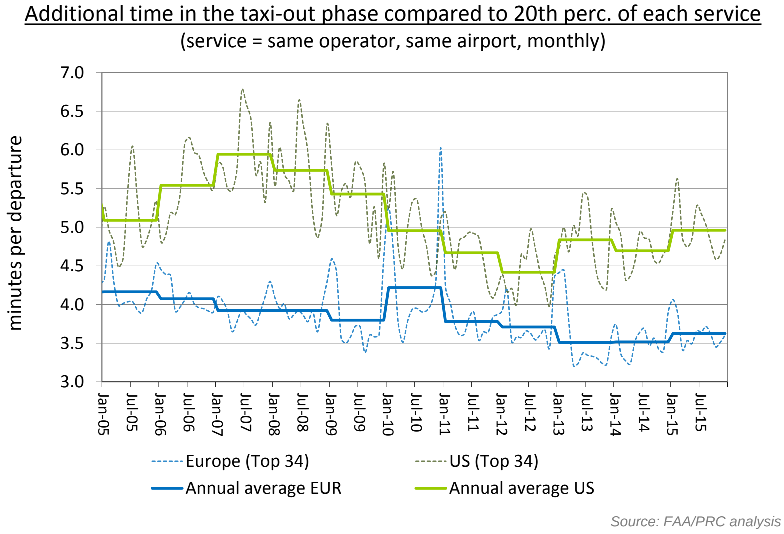


Figure 5-7: Additional times in the taxi-out phase (system level)

On average, additional times in the taxi-out phase appear to be higher in the US with a maximum difference of approximately 2 minutes more per departure in 2007. Between 2008 and 2012, US performance improved continuously while European performance only improved gradually which narrowed the gap between the US and Europe.

Although the gap notably reduced since 2008, the observed differences in inefficiencies between the US and Europe are largely driven by 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 could add to the focus of getting off-gate on time.

In 2015, both European and US performance deteriorated. The increase in additional taxi-out times in the US may be linked to worsening weather conditions for specific areas of the country or as a result of ATFM delay taken on the ground.

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.

The analysis by airport in Figure 5-8 and Figure 5-9 as well as the overview in Figure 5-10 is based on the more sophisticated methodologies by each of the performance groups in the US and Europe[40].

[40] A description of the respective methodologies can be found in the Annex of the 2010 comparison report.

Figure 5-8 shows a more detailed comparison of additional time in the taxi-out phase at the major airports in Europe and the US which illustrates the contrasted situations among airports.

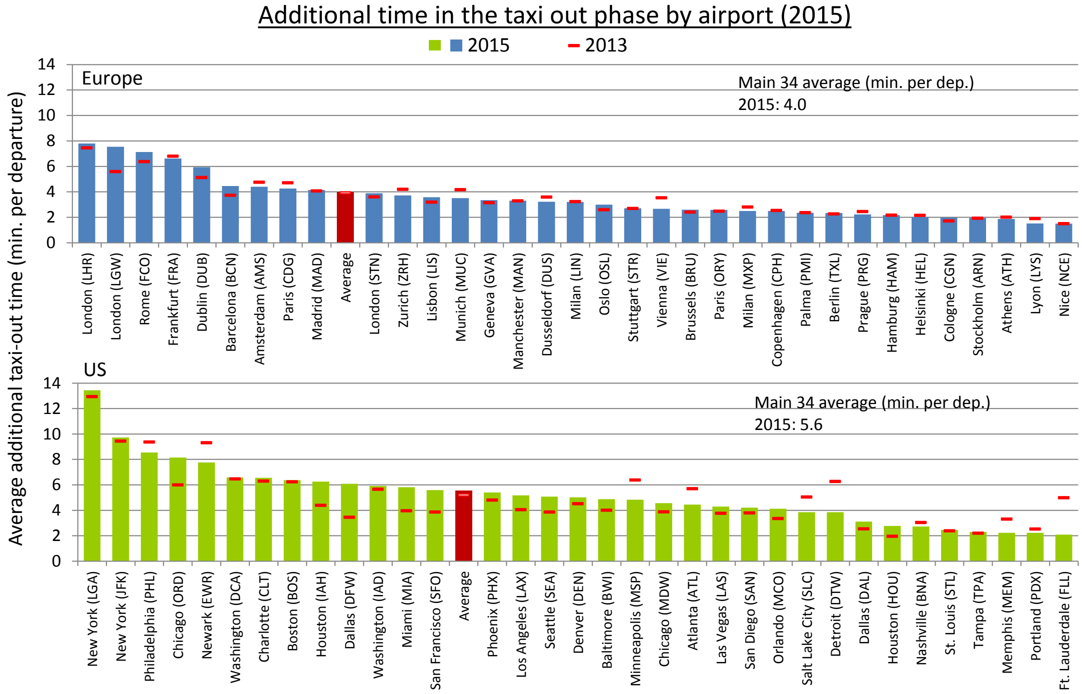


Figure 5-8: Additional time in the taxi-out phase by airport (2015)

In Europe, the two London airports (LHR, LGW), and Rome (FCO) showed the highest average additional taxi out time in 2015. On average, London Gatwick (LGW) showed an increase in additional taxi-out time of almost 2 minutes between 2013 and 2015.

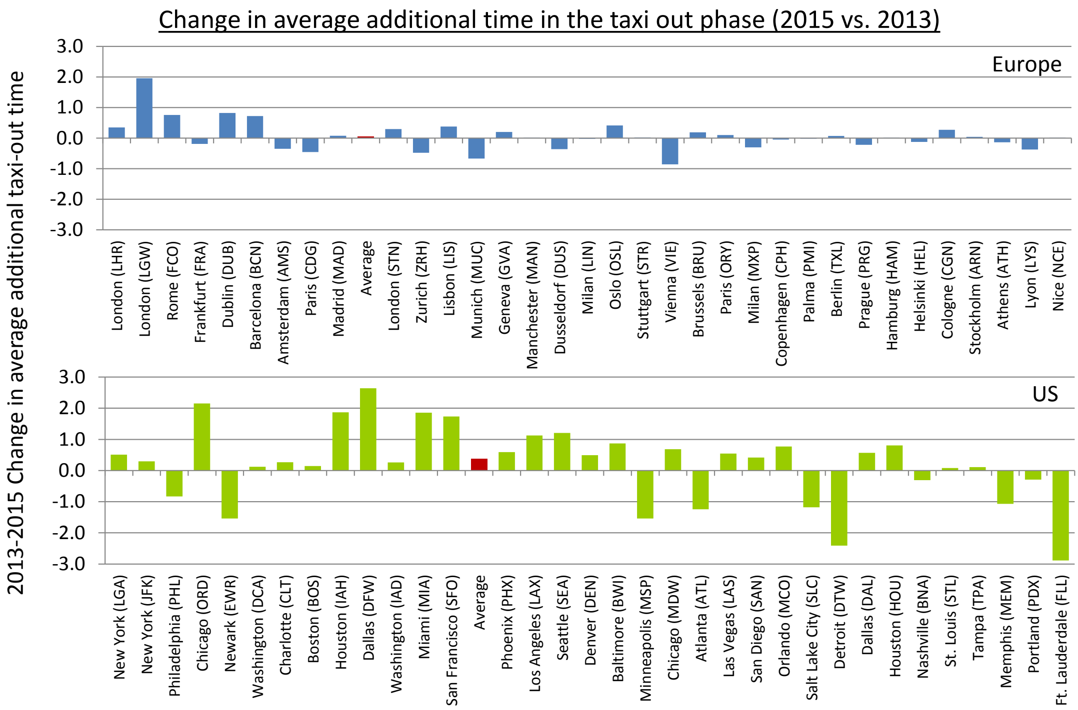


Figure 5-9: Difference in additional time in the taxi-out phase by airport (2015 vs. 2013)

In the US, the New York airports, Philadelphia (PHL), and Chicago (ORD) showed the highest average additional time in 2015. In contrast to flights destined for ORD and San Francisco (SFO) (Figure 5-6), flights departing these airports experienced an increase of delay on departure in the taxi-out phase. In addition, the Texas airports of Dallas (DFW) and Houston (IAH) contributed to the increase in system wide taxi-out delay however these airports also had decreases in airline reported data (OOOI) flights. Atlanta (ATL) contributed the most to improvement on the system-wide measure. Unlike ORD and SFO, Newark (EWR) showed significant improvement for both taxi-out delay and for flights destined to EWR (Figure 5-6). Although DTW showed the largest decrease in traffic from 2013-2015, the improvement shown should be caveated due to significant changes in the reporting carriers for OOOI data. The most notable performance improvement for an airport was observed for Fort Lauderdale (FLL). This is attributed to the increase in declared capacity that occurred with the completed expansion of a runway.

Although some care should be taken when comparing the two indicators due to slightly differing methodologies, Figure 5-10 tends to confirm the trends seen in Figure 5-7.

Overall, additional times in the taxi-out phase appear to be higher in the US but the gap closed between 2008 and 2011. As of 2012, the US performance started to deteriorate again whereas the performance in Europe remained largely stable during the same period.

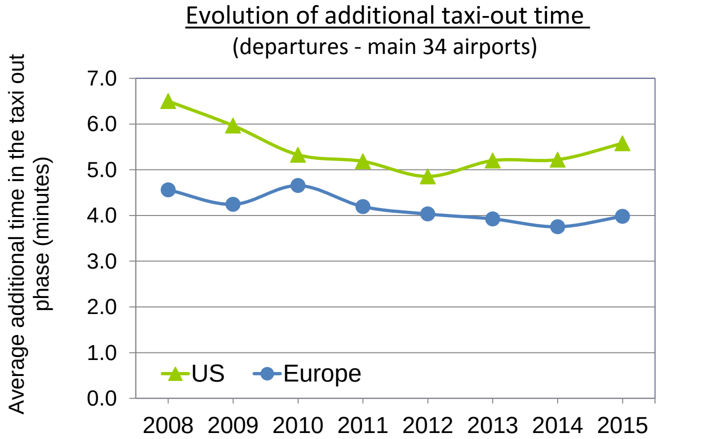
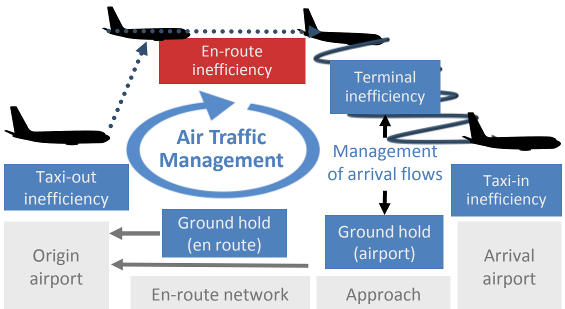


Figure 5-10 Evolution of average additional minutes in the taxi out phase (2008-2015)

5.2.3 En-route flight efficiency

This section evaluates en-route flight efficiency in the US and Europe. En-route flight efficiency indicators assess actual flight trajectories or filed flight plans against an ideal or benchmark condition.

From an operator's perspective, this ideal trajectory would be a User-Preferred Trajectory that would have a horizontal (distance) and a vertical (altitude) component.



Ideal altitudes are highly affected by external factors such as aircraft specific weight and performance as well as turbulence and other weather factors. For this reason, much more detailed data from airlines and tactical responses to weather would be needed to establish an efficiency criterion for altitude. Furthermore, the horizontal component is, in general, of higher economic and environmental importance than the vertical component across Europe as a whole [Ref. 19]. Nevertheless there is scope for further improvement, and Section 6.2 in this report provides an initial comparison of vertical flight efficiency in the arrival phase between the US and Europe which will help to provide a more complete picture in the future.

The focus of this section is on the horizontal component of the en-route phase. Two KPI's are reported. The first one compares the lengths of the en-route section of the last filed flight plan to a benchmark "achieved distance" (apportionment of great circle distance). The second KPI compares actual trajectories against "achieved distance."

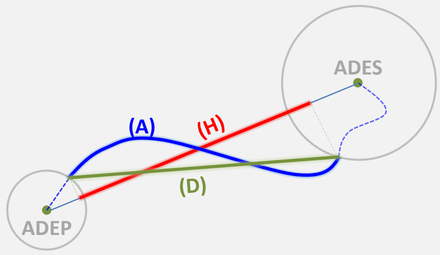
For a flight, the "inefficiency" is the difference between the length of the analysed trajectory (filed flight plan or actual flown) and an "achieved" reference distance (see also grey box). Where a flight departs or arrives outside the reference airspace, only that part inside the airspace is considered.

"En-route" is defined as the portion between a 40NM radius around the departure airport and a 100NM radius around the arrival airport. The indicator is calculated as the ratio of the sum, over all flights considered.

Horizontal en-route flight efficiency

Horizontal en-route flight efficiency compares the length of flight plan or actual trajectories (A) to the "achieved" distance (H).

The achieved distance apportions the Great Circle Distance between two airports. If the origin/ destination airport is located outside of the reference airspace, the entry/exit point into the airspace is used for the calculation.



The refined methodology enables to better differentiate between local inefficiency (deviations from GCD between local entry and exit points and the contribution to the network.

More information on horizontal en-route flight efficiency in Europe is available at www.ansperformance.eu.

The methodology used for the computation of horizontal en-route fight efficiency in this report is consistent with the flight efficiency indicators used in the Single European Sky performance scheme.

The flight efficiency in the last 100NM before landing which also includes airborne holdings is addressed in the next section of this report (5.2.4).

It is acknowledged that this distance-based approach does not necessarily correspond to the "optimum" trajectory when meteorological conditions or economic preferences of airspace users are considered for specific flights. However when used at the strategic level, the KPI will clearly point to areas where track distance is increasing or decreasing over time.

Opportunities and Limitations to Improving Horizontal Flight-Efficiency

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), route availability, or other reasons (differences in route charges[41], avoidance of congested areas) affect en-route flight efficiency.

En-route flight inefficiencies are predominantly driven by (1) route network design (2) route availability, (3) route utilisation (route selection by airspace users) and (4) ATC measures such as MIT in the US (but also more direct routings).

Although a certain level of inefficiency is inevitable, there are a number of opportunities for improvement. The following limiting factors should be borne in mind for the interpretation of the results:

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

- Basic rules of sectorisation and route design. For safety reasons, a minimum separation has to be applied between aircraft;
- Systematisation of traffic flows to reduce complexity and to generate more capacity;
- Strategic constraints on route/ airspace utilisation.
- Impact of Special Use Airspace (SUA) on flight efficiency.

  Figure 5-11 illustrates the impact of special use airspace on horizontal en-route flight efficiency in Europe in 2015. The filed routes of the 15 most penalising city pairs connecting the top 34 airports are plotted in blue and the actually flown trajectories are plotted in red. It is clearly visible how flights have to circumnavigate around SUA (brown areas). However, it also shows that directs are being provided by ATC on a tactical basis which improve flight efficiency in actual trajectories but which on the other hand introduce variability in the system.

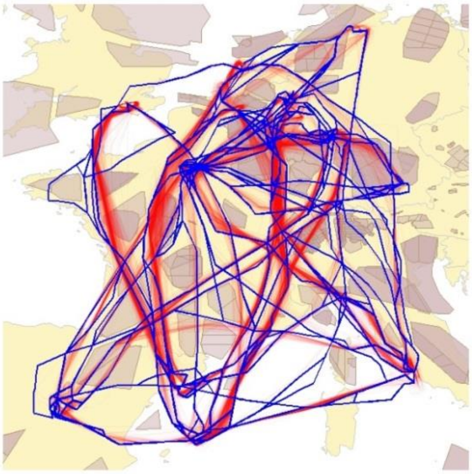


Figure 5-11: Impact of Special Use Airspace in Europe (2015)

- 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.
- Route availability and route planning. Once routes are made available for flight planning, their utilisation is in the hand of flight dispatchers and flow managers. Many airlines prepare flight plans based on fixed route catalogues and do not have the tools/resources to benefit from shorter routes when available. Aircraft operators often rely on tactical ATC routings.
- In Europe, en-route flight efficiency is also affected by the fragmentation of airspace (airspace design remains under the auspices of the States).
- For the US, the indicator includes the effect of en-route holding and vectoring.
- Lastly, planned cruise speeds or altitudes are not known by ATC systems and may require detailed performance modelling or information on airline intent.

While technologies, concepts, and procedures have helped to further optimise safety, add capacity, and increase efficiency (e.g. Reduced Vertical Separation Minima, RNAV) over the past years, it will remain challenging to maintain the same level of efficiency while absorbing forecast demand increases over the next 20 years.

Figure 5-12 shows the evolution of horizontal en-route flight efficiency (actual and flight plan) compared to achieved distance between 2008 and 2015.

An "inefficiency" of 5% means for instance that the extra distance over 1 000NM was 50NM.

Due to data availability, the KPIs for Europe are only shown as of 2011.

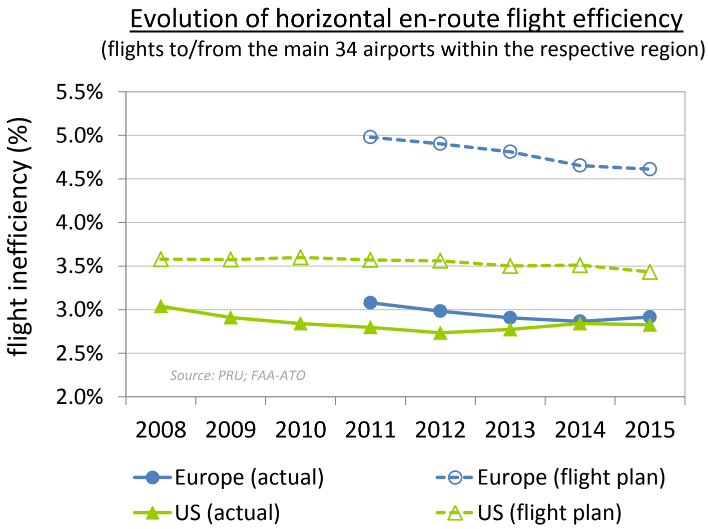


Figure 5-12: Evolution of horizontal flight efficiency (actual and flight plan) (2008-2015)

Although much smaller in the US, there is a notable gap between flight plan and actual flight inefficiency in the US and in Europe.

The difference between planned and actual operations reveals that in general flights fly more direct than their flight plan in both systems. This is most likely due to more direct tracks provided by ATC on a tactical basis when traffic and airspace availability permits.

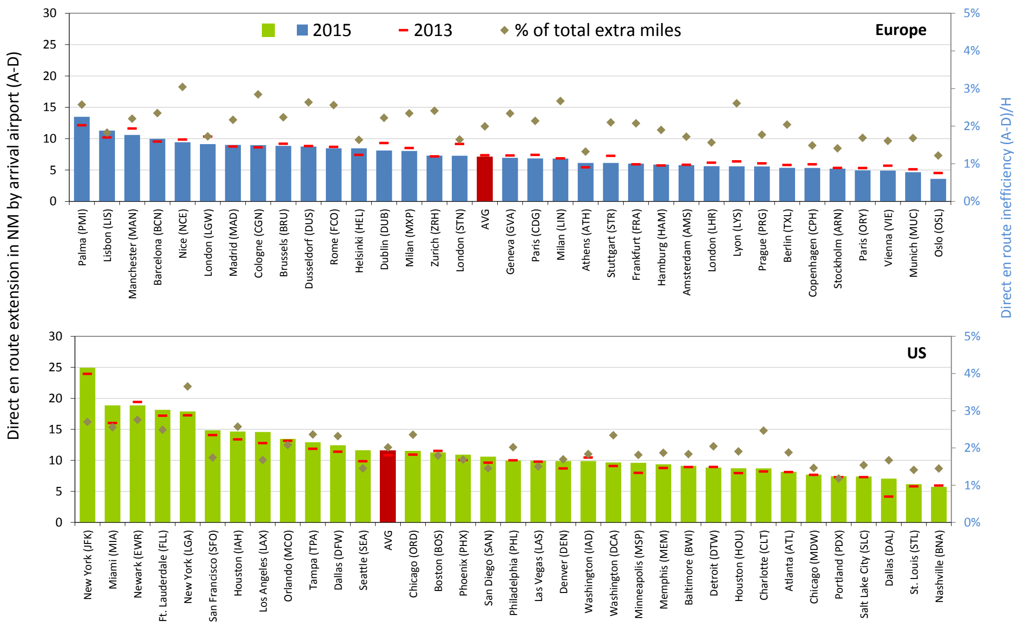
In general the US reports less "inefficiency" in this area. Although performance improved in Europe for both indicators over the past years, European airlines file on average some 4.6% greater than their achieved distance compared to 3.4% in the US in 2015. For the US, many of the heaviest travelled city pairs such as SFO to LAX or Chicago to the New York area both file direct flight and achieve direct flight for the majority of flights.

However when actuals are compared, the gap is much more narrow and much less in terms of an efficiency score. Between 2011 and 2014 there was a continuous improvement in Europe in terms of flight efficiency for flights to and from the top 34 airports, which narrowed the gap. However, flight efficiency deteriorated in Europe in 2015.

Actual Trajectory vs. Achieved Distance

The level of total horizontal en-route flight inefficiency [(A-H)/H] for flights to or from the main 34 airports in Europe in 2015 was 2.92% compared to 2.83% in the US. Overall, horizontal en-route flight inefficiency on flights to or from the main 34 airports in Europe is approximately 0.1% higher than in the US in 2015. In assessing the US trends, much of the increase from 2013-2014 can be traced to large additional distance incurred due to the effects of the fire at Chicago Air Route Traffic Control Center (ZAU) that predominantly affected flights from September 26 – October 12 of 2014. The overall increase that can be observed from 2013-2015 is directly linked to airports (and city pairs) that experienced increases in traffic levels (SEA, LAX and DAL).

Figure 5-13 shows the direct en-route extension on flights arriving at the main US and European airports.



Source: FAA/ PRU analysis

Figure 5-13: Direct en-route extension by destination airport

US airports show some clustering and patterns when values are summed by destination airport, particularly for New York Area and Florida airports. In assessing specific city pairs for these facilities, three causal reasons emerge. These include 1) Traffic into New York Area especially from Texas and Florida, 2) Effects of Special Activity Airspace on East Coast and around San Francisco and 3) Transcontinental Flights.

Almost all direct flights between the New York area and Florida airports would require flight through special use airspace. Many of the flights to East Coast and West Coast airport destinations involve long transcontinental flight where large values do not translate into high percentages. Furthermore, these transcontinental flights require much more scrutiny as the ideal flight would consider winds and not be limited to direct flight.

Lastly, existing route design into the New York area does not allow for direct flights for some key city pairs (DFW and IAH to New York Area). This may be due to congestion caused by high traffic and the presence of major airports located close together. Alternatively, it may be possible to fly more direct to the New York area as the FAA makes continued improvements to airspace design and more advanced traffic flow management is implemented.

In absolute terms, the average additional mileage in the US is higher due to the longer flights but in relative terms the level of flight inefficiency is lower (i.e. inefficiency per flown distance).

Figure 5-13 also provides insight into the facilities that contributed the most to the changes from 2013-2015. For the US, the routes that had the largest impact directly related to the airports that show the largest increase in traffic over this time period including Los Angeles (LAX), Seattle (SEA) and Dallas Love Field (DAL).

As traffic and the underlying network changed, the increase is a product of both increasing distance and the distribution of flights among the network.

For Dallas Love Field (DAL), this was significant with the expiration of the Wright Amendment in 2014 which allowed for many more city-pair services to DAL. Key city pairs contributing to the increase for Seattle (SEA) include west coast traffic (SAN, LAX and SFO into SEA).

Figure 5-14 shows flights tracks for the most popular filed flight plan (shown in blue) for SAN/LAX into SEA.

Improvements to en-route design are, by definition, a network issue which requires a holistic, centrally coordinated approach. Uncoordinated, local initiatives may not deliver the desired objective, especially if the airspace is comparatively small.

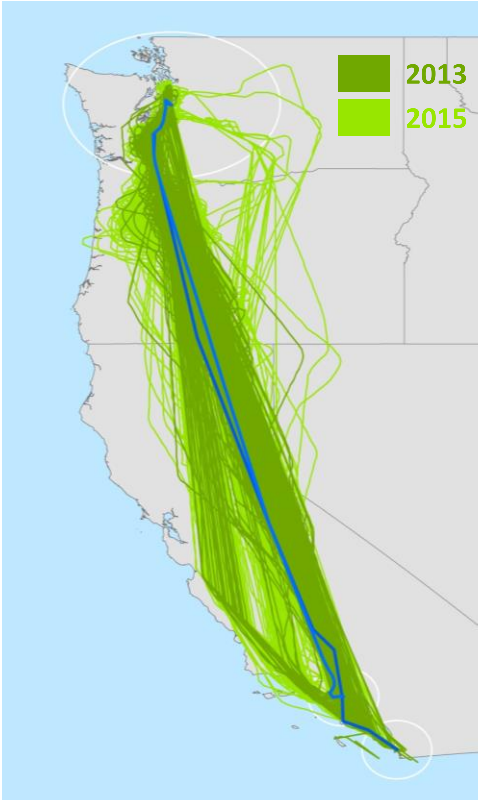


Figure 5-14: San Diego/Los Angeles to Seattle flights affecting horizontal flight efficiency

In view of the fragmented European ATM system, a harmonised and well-coordinated implementation of initiatives aimed at improving the route network at system level is more difficult to achieve in Europe than in the US where only one entity is responsible for the optimisation of the route network.

As technology for both aircraft and ATC has advanced, the need for such a rigid en-route structure has diminished, to the extent that free-route airspace (FRA) with a positive effect on flight efficiency would now be possible throughout Europe (see grey box). The airspace is undergoing significant change which requires all stakeholders to adapt.

The implementation of free route airspace mandated by EU legislation aims at enhancing en-route flight efficiency with subsequent benefits for airspace users in terms of time and fuel as well as a reduction of CO_2 emissions for the environment.

Free Route Airspace (FRA) Concept

Free route airspace (FRA) is a key development with a view to the implementation of shorter routes and more efficient use of the European airspace.

FRA refers to a specific portion of airspace within which airspace users may freely plan their routes between an entry point and an exit point without reference to the fixed Air Traffic Services (ATS) route network. Within this airspace, flights remain at all times subject to air traffic control and to any overriding airspace restrictions.

Deployment is ongoing, and EU Implementing Regulation 716/2014 (the Pilot Common Project regulation) stipulates that the Network Manager, air navigation service providers and airspace users shall operate direct routing (DCT) as from 1 January 2018 and FRA as from 1 January 2022 in the airspace for which the EU Member States are responsible at and above flight level 310 in the ICAO EUR region.

By the end of 2015, the Network Manager coordinated, through the European Route Network Improvement Plan (ERNIP) [Ref. 20], the development and/or implementation of more than 20 airspace improvement packages relating to various FRA projects (including Night Routes and direct routes (DCTs)).

Figure 5-15 shows Europe-wide free route implementation by the end of 2015. As can be seen Ireland, Portugal, Hungary and parts of Scandinavia are most advanced in Europe and already operate 24 hour FRA (Free Route Airspace).

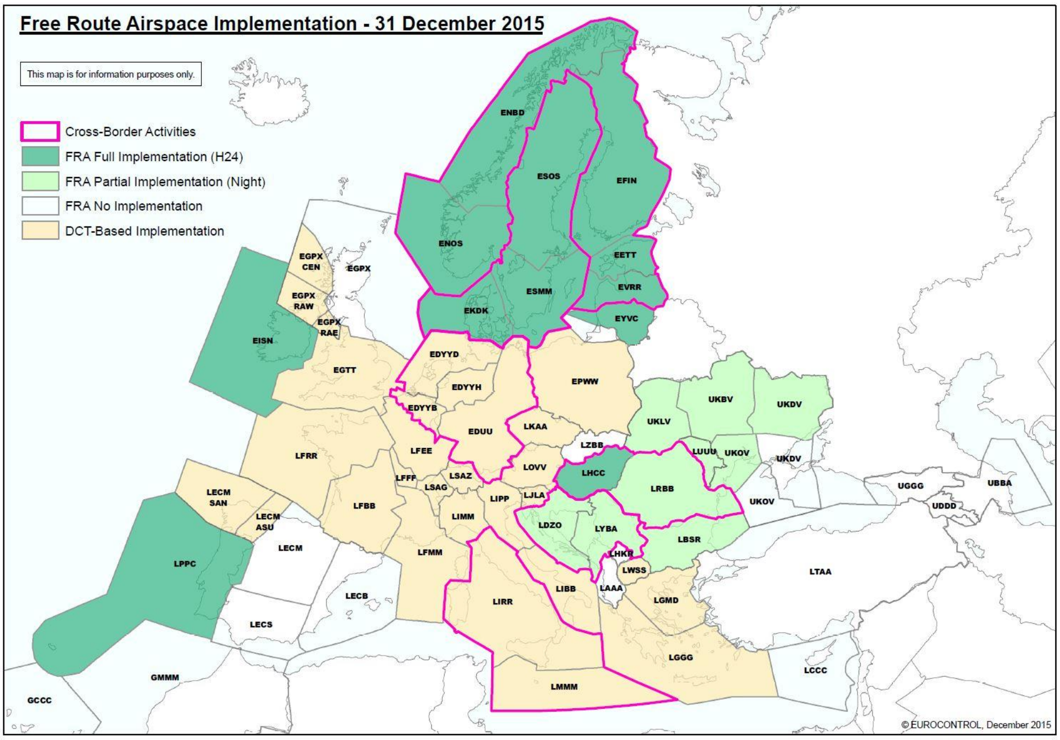
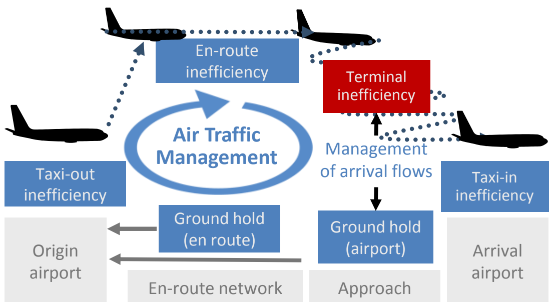


Figure 5-15: Free route development (2015)

The deployment of Flexible Airspace Management and Free Route functionality needs to be coordinated due to the potential network performance impact of delayed implementation in a wide geographical scope involving a number of stakeholders. From a technical perspective the deployment of targeted system and procedural changes is synchronised to ensure that the performance objectives are met. This synchronisation of investments involves multiple civil/military air navigation service providers, airspace users and the Network Manager. Furthermore, synchronisation during the related industrialisation phase needs to take place, in particular among the supply industry.

5.2.4 Flight efficiency within the last 100 NM

This section aims at estimating the level of inefficiencies that occur during the arrival/descent phase of flight. These inefficiencies are seen through larger downwinds or final, "S-turns" or in the worst case airborne holding patterns within the last 100 NM of flight.



For this exercise, the locally defined terminal manoeuvring area (TMA) is not suitable for comparisons due to variations in shape and size of TMAs and the ATM strategies and procedures applied within the different TMAs.

Hence, 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) was defined (see grey box for explanation). For the analyses, the 100NM ring was used.

Arrival Sequencing and Metering Area (ASMA)

ASMA (Arrival Sequencing and Metering Area) is defined as two consecutive rings with a radius of 40 NM and 100 NM around each airport.

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.

More information and data on additional ASMA time in Europe is available at www.ansperformance.eu.

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

The "additional" time is used as a proxy for the level of inefficiency within the last 100 NM. It is defined as the average additional time beyond the unimpeded transit time. The unimpeded times[42] are developed for each arrival fix, runway configuration and aircraft type combination.

Figure 5-16 shows the evolution of average additional time within the last 100 NM for the US and Europe from 2008 to 2015.

At system level, the additional time within the last 100 NM was similar in the two regions in 2008 but declined in the US between 2008 and 2010. At the same time, additional time within the last 100 NM increased in Europe.

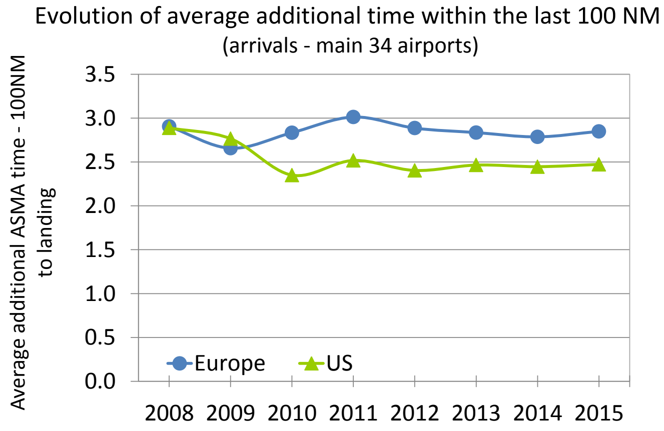


Figure 5-16: Evolution of average additional time within the last 100 NM (2008-2015)

Although at different levels, performance in the US and in Europe remained relatively stable since 2013.

However, the picture is contrasted across airports. Figure 5-17 shows the average additional time within the last 100 NM by airport in 2015. The difference in average additional time within the last 100 NM by airport is reported in Figure 5-18.

42 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 and the results should be interpreted with a note of caution.

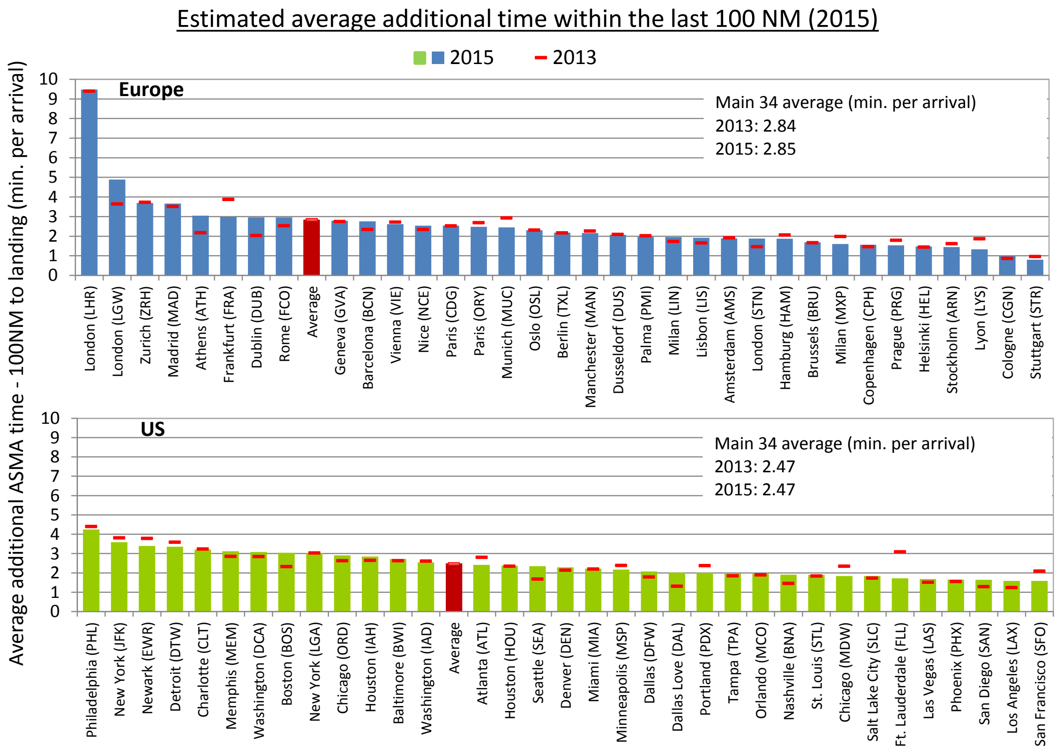


Figure 5-17: Estimated average additional time within the last 100 NM (2015)

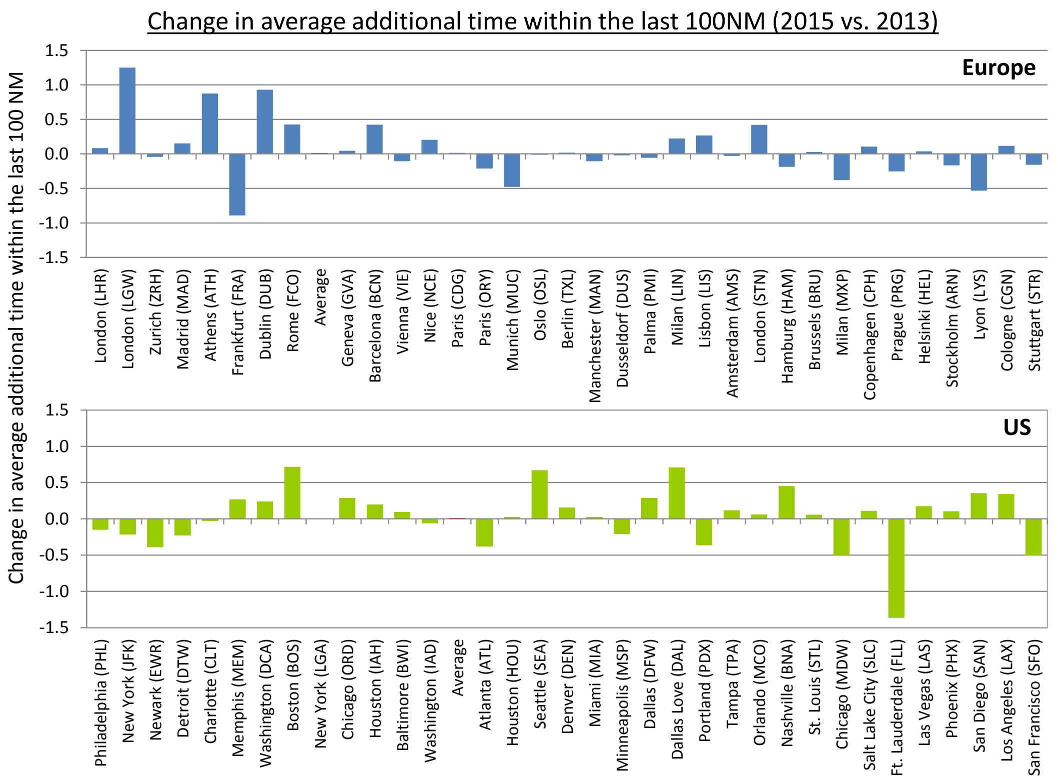


Figure 5-18: Difference in average additional time within the last 100 NM (2015 vs. 2013)

Europe shows a slight overall increase in 2015. At airport level, London Heathrow (LHR) is a clear outlier[43], having by far the highest level of additional time within the last 100 NM, followed by London Gatwick (LGW), Zurich (ZRH), and Madrid (MAD) which show less than half the level observed at London Heathrow. As seen in Figure 5-18, London Gatwick (LGW) and Dublin (DUB) were the two European airports with the highest increases in average additional time in the last 100 NM in 2015. A notable decrease in additional time was reported at Frankfurt (FRA) as a result of the new runway.

The US levels for average additional time held steady at 2.47 min from 2013 to 2015 with less contrast in additional time reported among airports. Similar to taxi-out performance, there is still a notable difference for the airports in the greater New York area, which show the highest level of additional time within the last 100 NM. A notable increase in additional time within the last 100 NM in 2015 was observed for Boston (BOS), Dallas Love (DAL), with Seattle (SEA) airport having the largest impact on the system wide trend. LAX and ORD also contributed to increases given the large number of operations at the airport. Similar to en-route efficiency, the increases are largely seen at airports with an increase in operations (SEA, DAL, LAX). These increases were balanced at the system level with improvements for Ft. Lauderdale (FLL), Detroit (DTW), San Francisco (SFO), Newark (EWR) and Chicago (MDW) with Atlanta (ATL) contributing the most to a system decrease with its large number of operations.

Due to the large number of variables involved, the direct ATM 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 by taking action in the en-route phase of flight, such as in trail spacing. Larger ATFM delay in the US also may indicate that much of this additional time is pushed back to the departure airport and taken on the ground.

In Europe, the support of the en-route function is limited and rarely extends beyond the national boundaries. Hence, most of the sequencing and holding 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.

On both sides of the Atlantic, the operations at high density traffic airports are vulnerable to adverse weather conditions and cause high levels of delay to airspace users.

There is a potential trade-off between additional time in terminal airspace (additional ASMA time) and airport capacity utilisation. This can be observed for London Heathrow (LHR) and the congested US airports. Although not quantified in this report, quantifying capacity utilisation and assessing this trade-off would be a worthwhile subject for further study. However, benchmarking the two systems would require a common understanding of how capacity and throughput is measured for comparable airports.

Complementary to the analysis of additional ASMA time in this section, section 6.2 of this report provides an initial comparison of vertical flight efficiency in the arrival phase between the US and Europe which will help to provide a more complete picture in the future.

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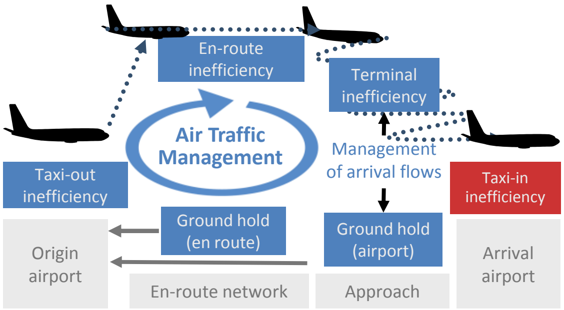
[43] It should be noted that performance at London Heathrow airport (LHR) is consistent with decisions taken during the airport scheduling process regarding average holding in stack. The performance is in line with the 10 minute

5.2.5 TAXI-IN EFFICIENCY

The analysis of taxi-in efficiency in this section refers to the period between the time when the aircraft landed and the time it arrived at the stand (actual in-block time). The additional time is measured as the average additional time beyond an unimpeded reference time.

The analysis in Figure 5-19 mirrors the methodology applied for taxi-out efficiency in Figure 5-7.



The method uses the 20th percentile of each service (same operator, airport, etc.) as a reference for the "unimpeded" time and compares it to the actual times. This can be easily computed with US and European data.

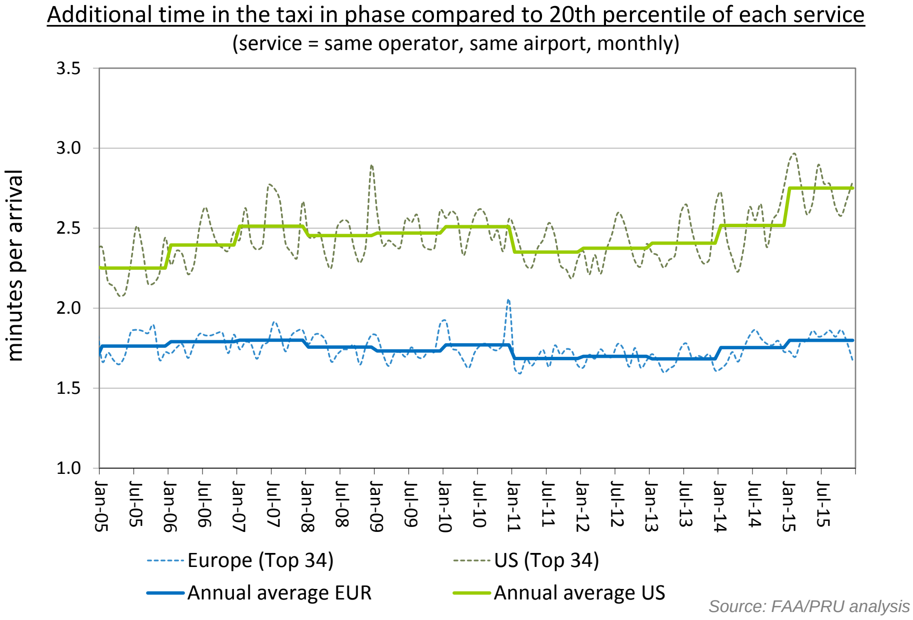


Figure 5-19: Additional times in the taxi-in phase (system level) (2005-2015)

As can be observed in Figure 5-19, at system level, additional time in the taxi-in phase is higher in the US than in Europe and remained relatively stable over time in both systems until 2015. For 2015, a notable increase can be observed in the US. Some seasonal patterns are visible (particularly in the US) where an increase can be noted during summer.

The taxi-in phase and hence the performance indicator is influenced by a number of factors, most of which cannot be directly influenced by ATM (i.e. airport/airline staffing, gate availability, apron limitations etc.).

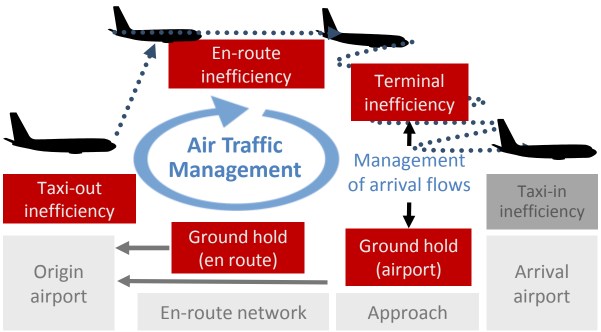
The taxi-in phase was included in the comparison for completeness reasons but, due to the number of factors outside the direct control of ATM, it was not included in the estimated benefit pool actionable by ATM in Chapter 5.3.

average delay criterion agreed.

5.3 Summary of main results & Estimated benefit pool actionable by ATM

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

This section 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.



Although included in this report for completeness reasons, due to the number of factors outside the direct control of ATM, the taxi-in phase was not included in the estimated benefit pool actionable by ATM. For the interpretation of the estimated benefit pool actionable by ATM in this section, 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 underutilisation of available resources.
- 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 delay may be required to maximise the use of scarce capacity. There are lessons however to be learned from both sides.
- A clear-cut allocation between ATM and non-ATM related causes are 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 the distribution of delay between air and ground and thus on costs to airspace users (see also Table 5-2 on page 70).
- The approach measures performance from a single airspace user perspective without considering inevitable operational trade-offs, and may include dependencies due to 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 indicators 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.).
- 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 subject to any constraints. This is the case for horizontal flight efficiency which compares actual flown distance to the great circle distance. Other indicators, such as ASMA flight efficiency, compare actual performance to an ideal scenario that is based on the best performance of flights observed in the system today. More analysis is needed to better understand what is and will be achievable in the future.

However, when used at a strategic level, the indicators do provide clear indications of regions, city-pair markets and facilities where additional time and distance are increasing or decreasing. In this way, ANSPs have a clear and stable procedure for identifying the constraints in their system, as well as a means of benchmarking performance on a global level.

5.3.1 ESTIMATED BENEFIT POOL ACTIONABLE BY ATM

By combining the analyses for individual phases of flight in Section 5.2, an estimate of the "improvement pool" actionable by ATM can be derived. It is important to stress that this "benefit pool" is based on a theoretical optimum (averages compared to unimpeded times), which is not achievable at system level due to inherent necessary (safety) or desired (capacity) limitations[44]. Moreover, the inefficiencies in the various flight phases (airborne versus ground) have a very different impact on airspace users in terms of predictability (strategic versus tactical – percent of flights affected) and fuel burn (engines on versus engines off).

Table 5-2 provides an overview of the ATM-related impact on airspace users' operations in terms of time, fuel burn and associated costs.

Table 5-2: Impact of ATM-related inefficiencies on airspace users' operations

ATM-related impact on airspace users' operations			Impact on punctuality	Engine status	Impact on fuel burn/ CO_2 emissions	Impact on airspace users' costs
ATM-related inefficiencies	At stand	Airport ATFM/TMI	High	OFF	Quasi nil	Time
		En-route ATFM/TMI				
	Gate-to-gate	Taxi-out phase	Low/ moderate	ON	High	Time + fuel
		En-route phase				
		Terminal area				

For ATM-related delays at the gate (ATFM/TMI departure restrictions) the fuel burn is quasi nil but the level of predictability in the scheduling phase for airspace users is low as the delays are not evenly spread among flights. Hence, the impact of those delays on on-time performance and associated costs to airspace users is significant but the impact on fuel burn and the environment is negligible. It is however acknowledged that – due to the first come, first served principle[45] applied at the arrival airports - in some cases aircraft operators try to make up for ground delay encountered at the origin airport through increased speed which in turn may have a negative impact on total fuel burn for the entire flight.

ATM-related inefficiencies in the gate-to-gate phase (taxi, en-route, terminal holdings) are generally more predictable than ATM-related departure restrictions at the gate as they are more related to inefficiencies embedded in the route network or congestion levels which are similar every day or season to season. From an airspace user point of view, the impact on on-time performance is usually low as those inefficiencies are usually already embedded in the scheduled block times by airlines. However, the impact in terms of additional time, fuel, associated costs, and the environment is significant.

The environmental impact of ATM on climate is closely related to operational performance which is largely driven by inefficiencies in the 4-D trajectory and associated fuel burn. There is a close link between user requirements to minimise fuel burn and reducing greenhouse gas emissions[46].

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[44] 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.

[45] "First come, first served" is generally applied to manage air traffic flows, as provided for in Annex 11 — Air Traffic Services and in the Procedures for Air Navigation Services — Air Traffic Management (PANS–ATM, Doc 4444) regarding the relative prioritisation of different flights.

[46] The emissions of CO_2 are directly proportional to fuel consumption (3.15 kg CO_2 /kg fuel).

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 savings in 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.

Previous research [Ref. 21] shows that at system level, the total estimated benefit pool actionable by ATM and associated fuel burn are of the same order of magnitude in the US and Europe (approx. 6-8% of the total fuel burn).

Figure 5-20 shows a summary of the operational performance on flights to or from the top 34 airports in the US and in Europe for four of the key indicators addressed in more detail in the previous sections of the report.

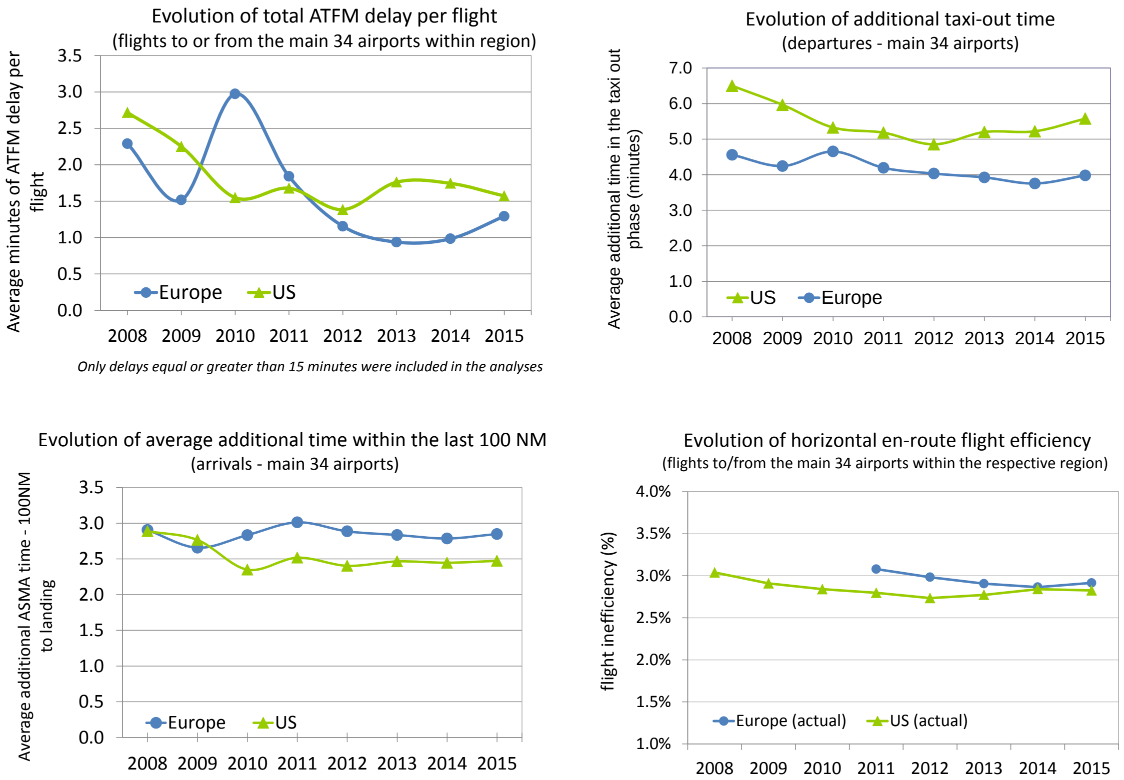

Figure 5-20: Evolution of operational performance in US/Europe between 2008 and 2015

Building on the results shown in Figure 5-20, Table 5-3 summarises the current best estimate of the ATM-related impact on operating time. Actual fuel burn depends on the respective aircraft mix (including mix of engines on the same type of aircraft, operating procedures) and therefore varies for different traffic samples.

For comparability reasons, the estimated benefit pool actionable by ATM in Table 5-3 is based on the assumption that the same aircraft type performs a flight of 450NM in the en-route phase in the US and the European ATM system (see also grey box for more information).

Although in a context of declining traffic, system-wide ATM performance improved considerably in the US and in Europe over the past five years. The resulting savings in terms of time and fuel in both ATM systems had a positive effect for airspace users and the environment.

The distribution of the estimated benefit pool along the phase of flight is consistent with the differences in flow management strategies described throughout the report.

The improvement in Europe over the past five years was mainly driven by a reduction of en-route ATFM delay at the departure gates and improvements in the level of horizontal flight efficiency.

Estimated benefit pool actionable by ATM

As outlined in Section 3.1, the two ATM systems differ in terms of average flight lengths and aircraft mix (see Figure 3-6 on page 26).

Those differences would lead to different results, as the "inefficiencies" depend on travelled distance and aircraft type.

For comparability reasons, the calculations in Table 5-3 are based on averages representing a "standard" aircraft in the system.

The calculations assume that a standard aircraft travels an average distance of 450NM in each ATM system.

The typical average fuel burn, was equally applied to the US and Europe (Taxi ≈ 15kg/min., Cruise.≈ 46kg/min., TMA holding 41kg/min.).

Table 5-3: Estimated benefit pool actionable by ATM (2015 vs. 2010)

Estimated benefit pool actionable by ATM for a typical flight (flights to or from the main 34 airports)		Estimated average additional time (min.)						Fuel burn	Estimated excess fuel burn (kg)[47]			
		EUR			US			engines	EUR		US	
		2010	2015		2010	2015			2010	2015	2010	2015
Holding at gate per departure (only delays >15min. included)	En-route-related (% of flights)	1.9 (5.7%)	0.6 (2.0%)	↓	0.2 (0.7%)	0.3 (0.8%)	→	OFF	≈0	≈0	≈0	≈0
	airport-related (% of flights)	1.1 (3.1%)	0.7 (2.3%)	↓	1.3 (2.5%)	1.3 (2.5%)	→	OFF	≈0	≈0	≈0	≈0
Taxi-out phase (min. per departure)		4.7	4.0	↓	5.8	5.6	↓	ON	70	60	87	84
Horizontal en-route flight efficiency		2.0[48]	1.8	↓	1.8	1.8	→	ON	94	84	82	82
Terminal areas (min. per arrival)		2.8	2.8	→	2.5	2.5	→	ON	116	117	101	101
Total estimated benefit pool		12.5	10.0	↓	11.6	11.4	↓		279	260	270	267

It is an open research question on whether current performance databases capture the full benefit pool as there may be additional efficiencies gained from using ideal cruise speeds or from making operations more predictable. Estimating these inefficiencies would require more information on aircraft performance and airline intent than is currently available to both groups.

Inefficiencies in the vertical flight profile for en-route and in the TMA departure phase (40NM ring around the departure airport) were not considered in the benefit pool. Vertical flight efficiency was addressed in a specific focus study (see Section 6.2) with a view to include it in future benefit pool estimations in order to get an even more complete picture.

However, just as there are facets of the benefit pool not covered, there are system constraints and interdependencies that would prevent the full recovery of the theoretical optimum identified in this section. Performance groups will need to work with all stakeholders to quantify these contrasting effects on the fuel benefits actionable by ATM.

47 Fuel burn calculations are based on averages representing a "standard" aircraft in the system.
48 The EUR 2010 figure is based on an estimate as the radar data was not yet available at system level in 2010.

6. SUPPORTING STUDIES

This chapter introduces two supporting studies aimed at expanding the scope and level of analysis of this US/Europe comparison report. Initial results are presented on the

- Analysis of air traffic flow and capacity management; and
- Vertical flight efficiency in the arrival phase.

Both studies demonstrated the general feasibility of the researched approach and offer opportunities to augment future editions of the benchmarking report.

6.1 Analysis of Air Traffic Flow and Capacity Management in the U.S. and in Europe

6.1.1 INTRODUCTION

In 2015, FAA and Europe initiated a joint study to evaluate the more complex performance issues associated with ATFCM. This section reports progress and results with work expected to continue. The general objective of this study is to deepen the understanding of Capacity Management (CM) and Demand Capacity Balancing (DCB) methods used in the US and Europe, and to better understand the differences and similarities between both regions. The various aspects of ATFCM that can be considered in such a study are shown in Figure 6-1 below. Past analysis has mainly focused on quantifying the performance outcome in terms of delays and flight efficiency. The ATFCM study will broaden this scope by looking at additional aspects shown on the figure. As a first priority the study has been looking into the application of Traffic Management Initiatives (TMIs) on both sides of the Atlantic.

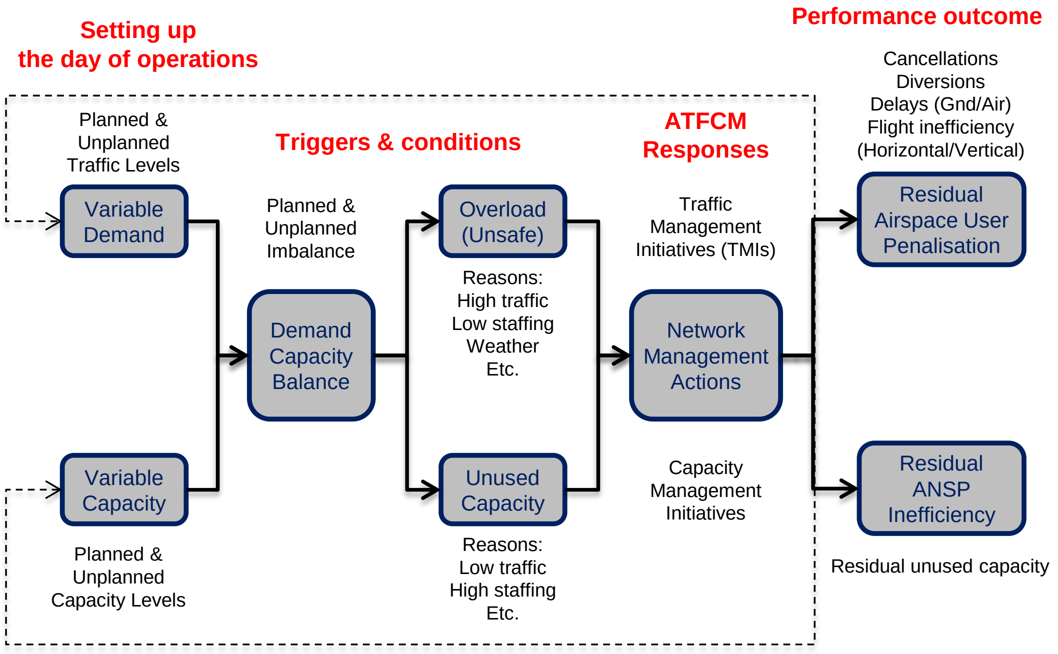

Figure 6-1: Overview of ATFCM study areas

Phase 1 of the study consisted of:

- Conceptual analysis of the various TMI types and their application.
- Identification of suitable (comparable) data in US and European data archives to support TMI analysis. It was decided to base the study on data covering the full calendar year 2015, and the same geographical scope as used in the US/Europe Comparison Report.

- Extraction and interpretation of the data.
- Preparation of the data for benchmarking (mapping US and European data sets to common terminology).

The prepared data set contains the following attributes:

- Metrics:
    - Number of TMIs
    - Duration of TMIs, with breakdown into actual duration and cancelled duration
    - Number of flights impacted, with breakdown into number of flights with TMI attributable delay ≥ 15 minutes, number of flights with 1 to 14 minutes delay, and number of flights without TMI attributable delay
    - Generated delay, with breakdown into delay for flights with TMI attributable delay ≥ 15 minutes, and delay for flights with 1 to 14 minutes delay
- Dimensions:
    - TMI type
    - TMI date
    - TMI cancellation category (Cancelled Before Start, Cancelled After Start, Not Cancelled)
    - Facility which is protected and to which the delay is charged
    - Reason for the TMI (delay causal factor)

Phase 1 has been completed and the study is ready to move to Phase 2: data analysis and the formulation of conclusions. Initial results are presented below.

6.1.2 Grouping of TMIs into Levels

For the purpose of the study, TMIs are grouped into four levels:

- TMI-L1 comprises "latent" TMIs which have been created during the strategic and pre-tactical ATFCM phases. They affect scheduling and/or flight planning. Examples: airport slot reservation programs, route programs and restrictions, permanent altitude segregation.
- TMI-L2 comprises ATFM TMIs applied on the day of operations, which may result in the allocation of a take-off slot (ATFM slot) and/or a rerouting, after flight plan filing but in principle prior to pushback. Examples: Ground Stops (GS), Ground Delay programs (GDP), Departure Stops (DS), Airspace Flow Programs (AFP), Collaborative Trajectory Options Programs (CTOP), Severe Weather Avoidance Programs (SWAP), voluntary and required rerouting.
- TMI-L3 TMIs are sequencing and metering measures that are used by ATC to fine-tune the traffic flow and that may have a delay impact on traffic prior to take-off. Examples: Miles In Trail (MIT), Minutes In Trail (MINIT), Minimum Departure Interval (MDI), Metering (Time Based Metering, TBM), Departure/En-route/Arrival Spacing (DSP, ESP, ASP).
- TMI-L4 TMIs are longitudinal (sequencing and metering, including airborne holding), lateral (load balancing) and vertical (level off) tactical measures that are used by ATC after take-off with the objective to fine-tune the traffic flow.

TMI-L1 has not been quantitatively analysed in the study.

TMI-L2 is well covered by data available in both the US and Europe. Most of the benchmarking focuses on this level. A limitation of the US data is that the measured TMI impact only includes delay from flights delayed by 15 minutes or more (reportable delay). The European data contains the same, but in addition also the number of flights and the associated delay of flights delayed

1 to 14 minutes, and all other flights 'captured' by the TMI but without any delay attributable to the TMI.

TMI-L3 and TMI-L4 are covered by the US data set, but for Europe such data was not present in the data used for the study. US TMI-L4 data covers airborne holding. In addition US data is available on the departure delay of flights not otherwise involved in a TMI. Such departure delays are attributed to conditions at the departure airport, and are associated with longer than normal taxi times or holding at the gate.

In the subsequent sections the terms 'delayed flight' and 'delay' refer to (flights with) reportable delay (≥ 15 minutes) unless otherwise specified. Likewise, unless otherwise specified all numbers refer to annual values for 2015, within the geographical scope of the study[49].

6.1.3 Analysis by TMI Level in the US

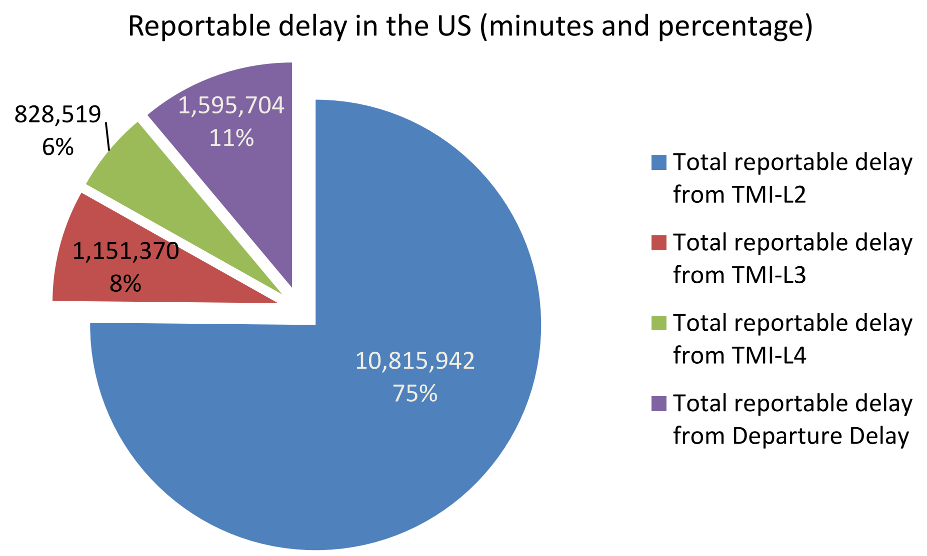

Figure 6-2 Reportable delay in the US (minutes and percentage)

In the US, 75% of the delay is generated by ATFM (TMI-L2), mostly by GDPs; 8% by TMI-L3 (with MIT taking 38% of that share); 6% by TMI-L4 (airborne holding, generating nearly twice as much delay as MIT), and 11% coming from departure delays. On average the delay per delayed flight is 61 minutes for TMI-L2, and less than half of that for TMI-L3, TMI-L4 and departure delay (26, 24 and 24 min respectively).

6.1.4 Rerouting and Level Capping TMIs in Europe

In addition to grouping into levels, TMI types are categorised according to their primary purpose:

- Delay
- Rerouting and level capping.

[49] The ATFCM study uses the same geographical same scope as the US/Europe comparison report, but is different in terms of flights considered: whereas the comparison report only considers delay of flights between the top 34 airports, the ATFCM study considers all TMIs, all delay and all flights in each region. For this reason the ATFCM study results are not identical to those shown in chapter 5.

Although the focus of the study was on Delay TMIs, it was possible to look at rerouting and level capping because ATFM regulations in Europe are used for both purposes.

Rerouting and level capping are used when a section of airspace has significantly decreased capacity or is predicted to have excessive occupancy.

In the US, reroutes are issued as an Advisory from the ATCSCC. The analysis of archived Advisories was not yet part of the current study scope. Hence no results on rerouting in the US are available at this stage.

In Europe, for each area expected to have a critical demand/capacity imbalance, a number of flows may be identified for which other routings may be suggested, that follow the general scheme, but avoid the critical area. These measures are known as scenarios. There are four types:

- Level capping scenarios (FL): carried out by means of zero-rate ATFM regulations with level restrictions, or through dynamic routing restrictions (e.g. RAD restrictions, EURO restrictions).
- Rerouting scenarios (RR): diversion of flows to off-load traffic from certain areas; implemented by means of zero-rate ATFM regulations or through dynamic routing restrictions.
- Alternative routing scenarios (AR): alternative routes which are exceptionally made available to off-load traffic from certain areas, implemented by ATFM regulations with a low rate. The other option is the application of dynamic routing restrictions.
- EU Restrictions: restrictions that affect the flight planning phase based on route or airspace closures.

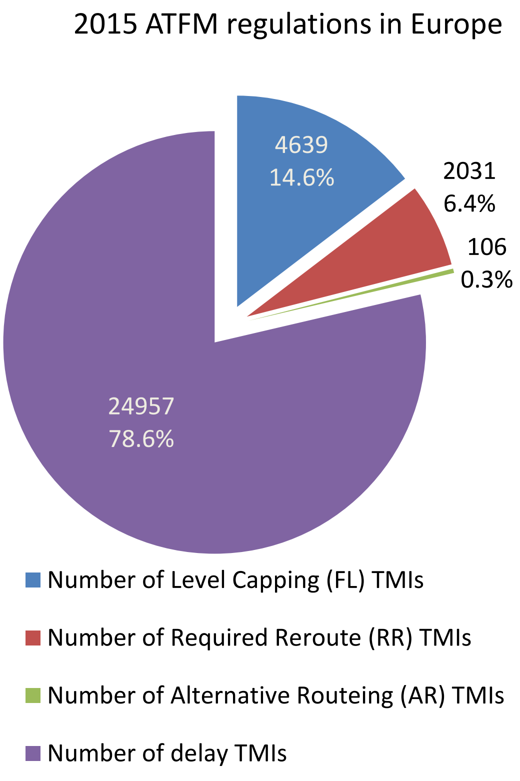

Figure 6-3 ATFM regulations in Europe

The rerouting (RR), level capping (FL) and Alternative Routing (AR) scenarios which are implemented through the ETFMS show up in the data as ATFM regulations with an RR, FL or AR suffix in their name. In 2015, 6670 ATFM regulations (21% of all European regulations) and 19.6% of all actual TMI time were for rerouting and level capping purposes in 2015. As the RR and FL regulations force traffic to fly around the protected area, they do not generate delay and the data does not show any delayed or captured traffic.

The average actual duration of rerouting and level capping TMIs is slightly longer than for delay TMIs: 2.7 hrs vs. 2.6 hrs. However when TMIs are initially created, the delay TMIs are on average longer, with more delay TMI time cancelled (0.6 hrs/TMI) than rerouting TMI time (0.1 hrs/TMI).

When broken down by TMI type, 68% of the rerouting and level capping TMIs are for level capping (FL), 30% for rerouting (RR) and only 2% are for alternative routing (AR). The average FL duration (2.3 hrs/TMI) is significantly shorter than the average RR duration (3.8 hrs/TMI) and the average AR duration (4.7 hrs/TMI).

6.1.5 US/Europe Comparison of TMI-L2 (delay TMIs only)

Figure 6-4 visualises the application of ATFM TMIs (TMI-L2) in the US and Europe. For comparison purposes, all values have been normalised to index 100 for Europe, meaning that the US values show the relative magnitude compared to Europe. The remainder of the section explains the differences in terms of absolute values.

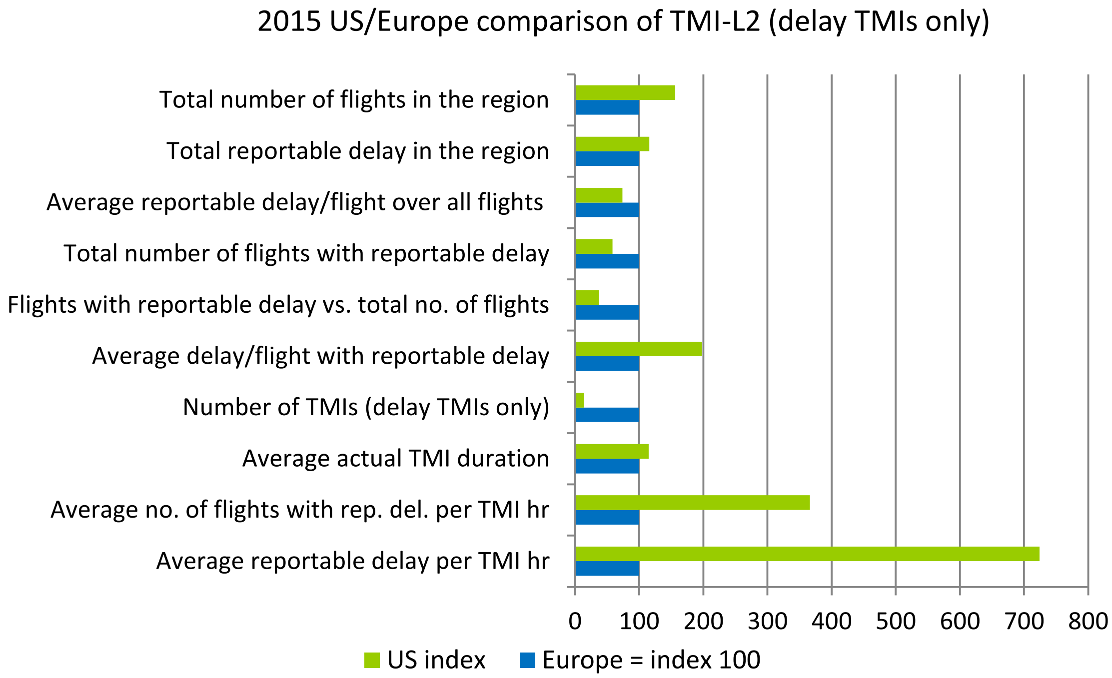

Figure 6-4 US/Europe comparison of TMI-L2 (delay TMIs only)

<u>TMI-L2</u> generates 10.8 million delay minutes in the US, and 9.3 million delay minutes in Europe: 12% more delay for 56% more total traffic (15.3 vs 9.8 million flights), which corresponds to 0.71 minutes reportable delay per flight in the US, vs 0.95 in Europe. When interpreting these numbers please bear in mind that this only covers ATFM delay (TMI-L2) of flights delayed by 15 minutes or more, and does not encompass certain other delay such as TMI-L3 in Europe for which no data was available.

A remarkable observation is that in the US all of this TMI-L2 delay is imposed on 178 000 Flights (1.16% of all flights, 61 minutes delay per delayed flight) and in Europe on 304 000 flights (3.10% of all flights, 31 minutes delay per delayed flight). To generate this delay, the US uses approximately 3 470 TMIs annually, whereas Europe uses more than seven times more (24 957 TMIs). The average actual duration of these TMIs is 3.0 hrs/TMI in the US, vs 2.6 hrs/TMI in Europe (comparable, the US TMIs being only 15% longer). Relating TMI duration to the number of delayed flights, we observe that 17.3 flights per TMI-hour are delayed in the US, vs 4.7 in Europe (3.7 times more). On average TMIs in the US generate 1 054 minutes delay per TMI-hour, vs 145 in Europe (more than 7 times more).

In summary, when not looking at tactical TMI-L3 and TMI-L4 flow restrictions, at annual level ATFM generates more or less the same amount of delay in the US as compared to Europe. However the operating practices are quite different: in the US the same delay outcome is generated with only a fraction of the European number of TMIs, and penalises roughly half of the flights as compared to Europe, and in relation to total annual traffic nearly three times less. In other words: ATFM TMIs are used less frequently in the US and affect fewer flights, but when they are used they penalise far more flights per TMI-hour and the delay per delayed flight is much higher. Apparently in Europe the delay penalisation is distributed much more evenly and over a wider population of flights. Continued work on this project will take a closer look at the reasons for these differences.

6.1.6 FURTHER WORK

The results presented above paint a very high level picture. Analysis work is ongoing to develop a more detailed understanding of US and European Traffic Management Initiatives, i.e. to reveal differences between:

- TMI types
- TMI cancellation categories
- Facility types (airports, terminal airspace, en-route airspace)
- TMI reasons
- Timing (month, weekday, day…), etc.

Further analysis will look at the network effects of Traffic Management Initiatives. The practices to predict and limit network effects when developing a TMI will be investigated and compared.

The future work will also focus on the capacity management practices to understand differences and commonalities in the en-route and airport capacity declaration practices, the sector definition and configuration practices and the sector capacity optimization practices.

6.2 Analysis of vertical flight efficiency in the U.S. and in Europe

6.2.1 INTRODUCTION

Flight efficiency KPIs measure the degree to which airspace users are offered the most efficient trajectory on the day of operation. So far the focus of assessing trajectory-based flight efficiency has been on horizontal measures in order to identify opportunities of ATM improvements in the US and European system. Throughout the recent years the focus has shifted to addresses the identification and measurement of ATM related constraints on vertical flight profiles. In particular the analysis of fuel-efficient continuous descent operations has gained a higher momentum.

With the recent developments and priorities on the ICAO level continuous descent operations are identified - inter alia – as one of the key improvement steps to enable various aspects of the “efficiency spectrum”. In particular:

- Fuel-efficiency – costs: airspace users have a strong interest in operating aircraft in a fuel-efficient manner by avoiding fuel-burn due to ATM/ATC related constraints and hence directly influencing the operational costs.
- Environment – emissions: emissions are directly related to fuel-burn. Lower fuel-burn will accordingly result in lower emissions. In that respect continuous descent operations are also linked with the CO_2 footprint of aviation and will support the ambitious goals set out for the contribution of aviation to the world-wide emissions.

- Environment – noise: Vertically efficient operations also positively affect the noise contour at and around airports. With an increasing sensitivity of the non-travelling public to aviation operations, the positive reduction of descent-related noise contributions can ensure higher acceptance in terms of traffic growth.

To address this spectrum the analysis of the vertical flight efficiency is a vital contribution as it supports the appraisal of the level of implementation of continuous descent operations and equally, the measurement of constraints imposed by ATC/ATM on such operations. Such constraints range from airspace and procedure design through tactical interventions by air traffic controllers, including arrangements between adjacent air traffic units.

The vertical flight efficiency study aimed at the identification, development, and parameterization of a common vertical flight efficiency algorithm, the demonstration of the feasibility of the analysis of vertical flight profiles on the basis of trajectory data, and the identification of an initial set of common key performance indicators, including the extension of the "benefit pool" estimates to account for inefficiencies in the vertical profile.

6.2.2 Approach

The underlying conceptual model of vertical flight operations is an abstraction of the flight profile in distinct portions (i.e. segments). This profile is based on measured trajectory data (4D position) of aircraft operations. A trajectory is therefore represented by the time-ordered set of 4D measurements associated to one flight, typically describing the flight path from the airport of departure to the airport of destination (c.f. Figure 6-5). Based on the jointly agreed criteria for describing level flight, the trajectory is mapped to level segments for further analysis. The analysis focused on the arrival phase of a flight in terms of the top-of-descent within a 200NM radius around the arrival airport.

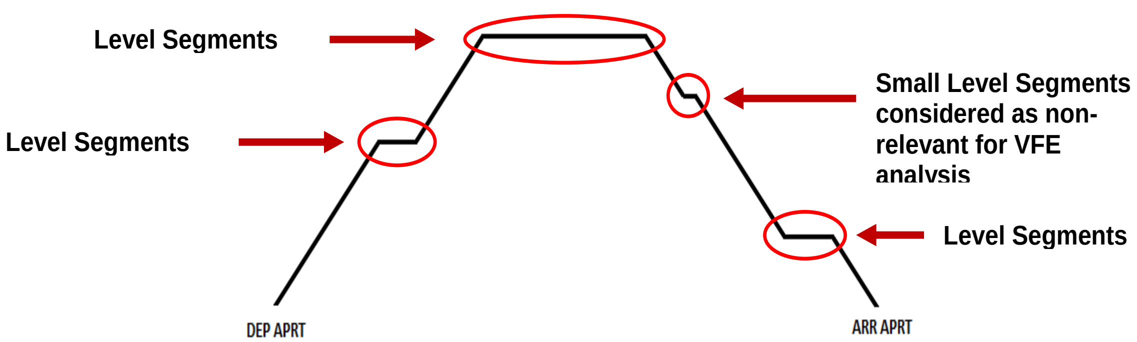

Figure 6-5 Vertical Flight Profile – Level Segments

For this initial comparison, the analysis of vertical flight efficiency was performed for the top-ten of US and European airports in terms of movements in the calendar year 2015. For this subset of airports the following metrics have been identified:

- Total level distance (in NM) or associated total level time (in minutes);
- Average level distance (in NM) or associated average level time (in minute) per arrival;
- Cumulative distribution function of the level distance or time;
- Monthly variation of the average level distance or time; and
- Variation of the level distance per altitude band.

While the distance- and time-based metrics report on the same phenomenon, it must be noted that distance-based metrics are of higher relevance for the ANS community (e.g. procedural airspace characterized by geographical positions that support the evaluation of ground distances). Airspace users gain more insight from the time-based measures as these translate directly into aircraft performance and fuel-burn.

6.2.3 Initial Comparison – Level Distance

For both regions, the analysis of the total distance and time in level flight shows the same pattern. Airports with a higher share of traffic accrue more total level distance and time. The direct relationship between level distance and level time in terms of ground speed for the respective fleet mix confirms this general conclusion. As can be derived from Figure 6-6 (top row), the total level distance in the US is significantly higher than in Europe with the average of level distance observed in 2015 for the top ten airports totalling to 8 636 688 NM in the US and 3 027 365 NM in Europe.

Considering the average level distance for arrivals at the top-ten airports (Figure 6-6 bottom row) a more accentuated pattern emerges. Interestingly the ranking of the individual airports changes showing the impact of the number of movements on the determined average level distance and time.

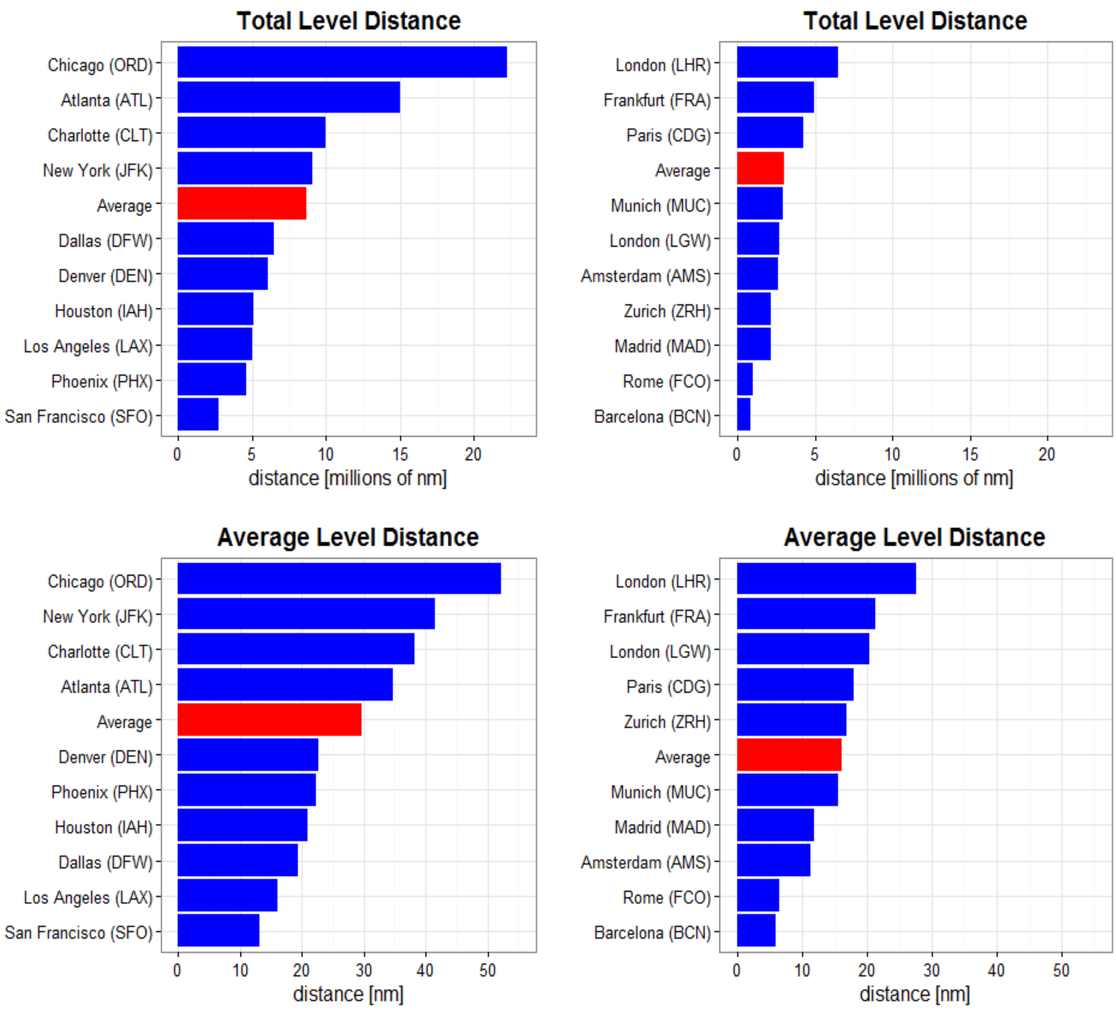

Figure 6-6 US/Europe Comparison – Vertical Flight Efficiency – Average Level Distance

This change in ranking is more pronounced in the European case, where also the calculated numerical average of the local averages changes its ranking. The exact causes for this behaviour need to be studied in more detail. For example, in the case of Amsterdam, the higher number of turbo-props has an impact on the observed airspeed and thus time at level. However, this observation does not hold for other airports showing a distinct off-set of the average level distance and average time at level.

Both in the US and Europe a significant share of the level flight is accrued below FL140. This is directly linked with the procedural airspace for final approach at the different airports. Nuances apply for the level bands between FL70 and FL140 that may be linked with specific cut-off altitudes for operations or hand-overs between adjacent control sectors. Level segments below FL70 can typically be mapped to procedure altitudes for the local traffic patterns at airports and the associated vectoring to ensure synchronisation and separation of arriving traffic.

It follows that for this heavily procedurally characterised portion of the flight, a significant high level of inefficiencies in the vertical profile applies. This also describes the major challenge and opportunity for mitigating the inefficiency during this phase of the arrival. Improving the observed performance in terms of reducing the number of level segments requires advanced synchronisation and separation of the air traffic. Such benefits can be expected from the implementation of extended arrival management operations (XMAN) that comprises the establishment of the arrival sequence much earlier, leading to speed adjustments 150-250 NM away from the arrival airport.

6.2.4 Initial Comparison – Benefit Pool

One defining characteristic of the US/Europe comparison report is the combination of the analyses of individual phases of flight and the estimation of the "benefit pool", i.e. the potential improvements actionable by ANS. Next to a qualitative judgement of the impact on punctuality, the major focus is on the additional fuel burn that drives airspace users' costs.

To provide an initial appreciation of such an impact analysis, the initial comparison for the chosen subset of airports summarises the potential total fuel savings per arrival (kg fuel, c.f. Figure 6-7). With the results presented above it follows that improvements in reducing the share of level segments for approaching aircraft can contribute to a lower fuel-burn by airspace users. Further research is required to address the relationship between the level of traffic and demand at the top ten airports, its associated requirements in terms of synchronisation and separation of aircraft, and the level of implementation of continuous descent operations at these airports.

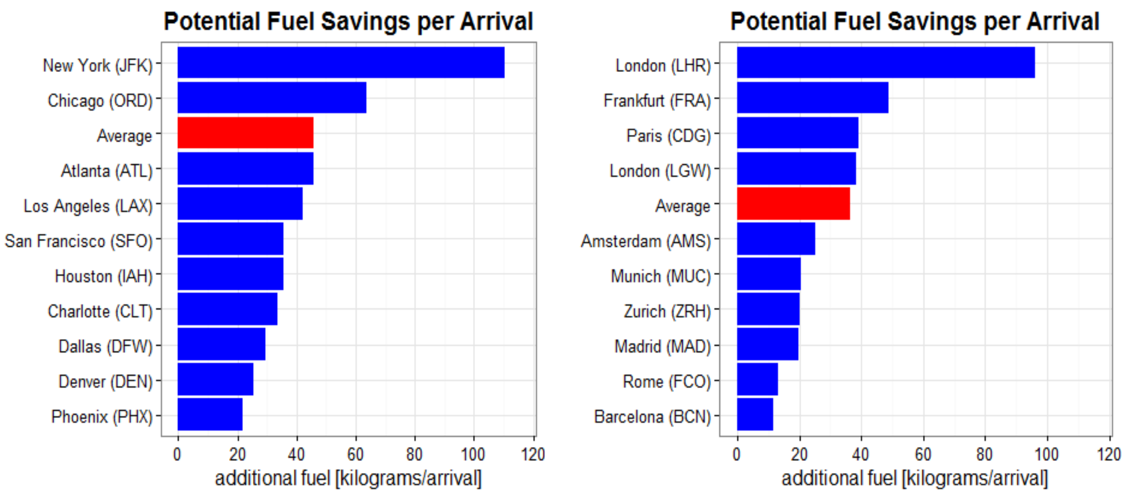

Figure 6-7 US/Europe Comparison – Vertical Flight Efficiency – Potential Fuel Savings

6.2.5 FURTHER WORK

The results reported are derived for the calendar year 2015 for the top ten of airports in the U.S. and Europe. Based on the limited subset of airports, the initial results need to be validated for a wider set of airports (i.e. the 34 airports of this comparison report) and multiple years. The latter will allow for reporting on trends in the metrics presented. This will be essential to address the question of the level of implementation of continuous descent operations and to appraise the respective level of implementation or associated constraints by ANS on airspace user operations.

The focus of this initial study was on the vertical flight efficiency of the arrival phase. Conceptually, the approach and metrics presented can be extended to other phases of flight, e.g. vertical efficiency during the en-route phase or climb-out phase. Accordingly, the findings of this report can inform a richer set of analyses of the vertical flight efficiency and an associated extension of the "benefit pool" in terms of gate-to-gate trajectory analysis.

7. CONCLUSIONS

This report is the 5th in a series of joint ATM operational performance comparisons between the US and Europe. It represents the 2nd edition under the Memorandum of Cooperation between the United States and European Union. The harmonized Key Performance Indicators used in this report provide demonstrated examples of the KPIs listed in the 2016 ICAO Global Air Navigation Plan (GANP). The ability to work with harmonized KPIs fosters a unique opportunity for both groups to learn each other's strengths and identify opportunities for improvement across all phases of flight.

Complementary to the well-established indicators already used in previous versions of the comparison reports, this edition also features two supporting studies on 1) Air Traffic Flow and Capacity Management (ATFCM) and 2) Vertical Flight Efficiency in the arrival phase, aimed at expanding the scope and level of analysis of future reports.

The first part of the report examines commonalities and differences in terms of air traffic management and performance influencing factors, such as air traffic demand characteristics and weather, which can have a large influence on the observed performance.

Overall, air navigation service provision is more fragmented in Europe with more ANSPs and physical facilities than in the US. Europe is made up of individual sovereign states. As a consequence the European study area comprises 37 Air Navigation Service Providers (ANSPs). Together they operate 62 en-route centres[50] and 16 stand-alone Approach Control (APP) units (total: 78 facilities). The US study area (CONUS) has 20 en-route centres supplemented by 26 stand-alone Terminal Radar Approach Control (TRACON) units (total: 46 facilities), operated by one ANSP.

Although the US CONUS airspace is 10% smaller than the European airspace, the US controlled approximately 57% more flights operating under Instrument Flight Rules (IFR) with 24% fewer full time Air Traffic Controllers (ATCOs) than in Europe in 2015. US airspace density is, on average, higher and airports tend to be notably larger than in Europe.

In terms of traffic evolution, there was a notable decoupling between the US and Europe in 2004 when the traffic in Europe continued to grow while US traffic started to decline. The effect of the economic crisis starting in 2008 impacted traffic growth on both sides of the Atlantic. While traffic in Europe decreased by 3.3%, air traffic in the US decreased by 9.9% between 2008 and 2015 reaching a low of traffic in 2013. For 2013-2015, the US CONUS experienced traffic growth of 1.6%.

While weekly traffic profiles in Europe and the US are similar (lowest level of traffic during weekends), the seasonal variation is higher in Europe. European traffic shows a clear peak during the summer months. Compared to average, traffic in Europe is in summer about 15% higher whereas in the US the seasonal variation is more moderate.

At system level, the US has a notably higher share of general aviation than Europe which accounted for 22% and 3.7% of total traffic in 2015, respectively. In order to improve

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[50] A 63rd en-route center is located in the Canaries, outside of the geographical scope of the study.

comparability of datasets, the more detailed analyses were limited to controlled flights either originating from or arriving at the main 34 US and European airports. The samples are more comparable as this removes a large share of the smaller piston and turboprop aircraft (general aviation traffic), particularly in the US. Air traffic to or from the main 34 airports in Europe and in the US in 2015 represented some 64% of all flights.

There are a number of differences between the two systems. In the US, the Air Traffic Control System Command Center - which is the equivalent of Network Manager Operations Centre in Europe, is in a stronger position than its European counterpart with more active involvement of tactically managing traffic on the day of operations.

The US also operates with fewer airports applying schedule limitations which may lead to a better utilization of available airport capacity in ideal weather conditions. The analysis of meteorological reports suggests that weather conditions at the main 34 airports in Europe are, on average, less favourable than in the US. In 2015, 84.5% of the year was spent in visual meteorological conditions at the main 34 US airports compared to 77.8% in Europe. Europe shows more airports operating closer to their declared capacity with more IFR flights per active runway. The US operates many airports with complex runways with highly variable capacity and several are operating at close to peak capacity. For airports with more than 3 runways, US declared rates are in general higher than Europe. For Europe, London Heathrow, Frankfurt, and Paris Charles de Gaulle clearly have demand/capacity characteristics comparable to the slot coordinated airports in the US.

Each system has areas that are highly impacted by Special Use Airspace (SUA), often due to operations of a military nature. For Europe, SUA permeates all regions and adds complexity in some of the most densely traveled areas of Europe. For the US, those areas are more concentrated, particularly in coastal regions. The impact of SUA on flight efficiency indicators can be clearly seen but its unique impact is not quantified in this report.

Building on established operational key performance indicators, the second part of the comparison report evaluates operational performance in both systems from an airline and from an ANSP point of view. The airline perspective evaluates efficiency and predictability compared to published schedules whereas the ANSP perspective provides a more in depth analysis of ATM-related performance by phase of flight compared to an ideal benchmark distance or time. For the majority of indicators, trends are provided from 2008 to 2015 with a focus on the change in performance from 2013 to 2015.

Punctuality is generally considered to be the industry standard indicator for air transport service quality. The trend in punctuality was similar in the US and Europe between 2005 and 2009 when both systems reached a comparable level of around 82% of arrivals delayed by 15 minutes or less in 2009. Whereas in the US performance remained stable in 2010, punctuality in Europe degraded to the worst level on record mainly due to weather-related delays (snow, freezing conditions) and strikes. From 2010 to 2012, punctuality in Europe improved again and continued to improve in the US. However in 2013 and 2014, whereas punctuality in Europe remained largely unchanged, punctuality in the US saw a sharp decline. In 2015 both systems reached again a similar performance level due to notable improvements in the US and performance degradation in Europe.

In Europe and the US, a clear pattern of summer and winter peaks is visible. 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 by a lack of en-route capacity in Europe.

While the evaluation of air transport performance compared to airline schedules provides valuable first insights, the involvement of many different stakeholders and the inclusion of time buffers in airline schedules limit the analysis from an air traffic management point of view.

Hence, the evaluation of ATM-related performance in this comparison aims to better understand and quantify constraints imposed on airspace users through the application of air traffic flow measures and therefore focuses more on the efficiency of operations by phase of flight compared to an unconstrained benchmark distance or time.

In order to minimize the effects of ATM system constraints, the US and Europe use a comparable methodology to balance demand and capacity. This is accomplished through the application of an "ATFM planning and management" process, which is a collaborative, interactive capacity and airspace planning process, where airport operators, ANSPs, Airspace Users (AUs), military authorities, and other stakeholders work together to improve the performance of the ATM system.

ATM-RELATED DEPARTURE RESTRICTIONS (GROUND HOLDING)

Ground delays imposed by ATM-related departure restrictions were analysed by constraining environment (en-route or airport/terminal) and by causal factor (weather, capacity, etc.).

After the poor performance due to weather and strikes in 2010, average ATM-related departure delay in Europe decreased again until 2013. Between 2013 and 2015, total ATM-related ground delays increased in Europe by 43.4% whereas traffic grew by 4.1% during the same time. The US has also shown an improvement since 2008 some of which can be attributed to improving weather and declining traffic levels. Between 2013 and 2015, total ATM-related ground delay in the US decreased by 12.7% (mainly due to fewer weather-related delays) with traffic levels increasing by 1.6% during the same time. In Europe, the notable performance deterioration between 2013 and 2015 was due to a significant increase in capacity/volume related delays and to a lesser extent due to weather.

ATM-related ground delay per flight in Europe (en-route and airport) was lower than in the US in 2015 (1.3 vs. 1.6 minutes per flight) but the underlying reasons and the application of ATM-related departure restrictions among facilities differ notably between the two systems. Europe ascribes a greater percentage of delay to en-route facilities (43% of total delay in 2015) while in the US the large majority is ascribed to constraints at the airport (82.1% of total delay in 2015).

The share of flights affected by ATM-related departure restrictions at origin airports differs considerably between the US and Europe. Despite a reduction from 5.0% of all flights in 2008 to 2.0% in 2015, flights in Europe are still over twice more likely to be held at the gate or on the ground for en-route constraints than in the US where the share of flights affected by ATM-related departure restrictions was 0.8% in 2015.

For airport-related ground delays, the percentage of delayed flights at the gate or on the surface is slightly lower in Europe than in the US (2.3% vs. 2.5% in 2015). However, with 51 minutes, the delay per delayed flight in the US is notably higher than in Europe in 2015 (33 mins). In the US, the airports which make up a large percentage of those delays are airports like New York (LGA), Chicago (ORD), Newark (EWR), San Francisco (SFO), New York (JFK), and Philadelphia (PHL) which report a large number of hours with demand near or over capacity and have lower predictability of capacity.

Whereas in the US, en-route-related ground delays are mostly driven by convective weather, in Europe they are mainly the result of capacity and staffing constraints (including ATC industrial actions) driven by significant variations in demand in some European States during summer. At system level, the causes for airport-related ground delays are more similar in the US and in Europe. Weather is by far the predominant driver of ATM-related departure restrictions but Europe has also a notable share of capacity-related delays.

ATM-RELATED OPERATIONAL EFFICIENCY (GATE-TO-GATE)

ATM-related flight gate-to-gate efficiency is measured by phase of flight (taxi-out, en-route, arrival/descent and taxi-in) with reference to a benchmark time or distance.

Taxi-out efficiency improved continuously between 2007 and 2012 in the US but deteriorated again by 0.5 minutes per departure between 2012 and 2015. During the same period, with the exception of 2010 where taxi-out efficiency decreased due to the strong winter, performance in Europe improved continuously at a moderate rate but also showed a slight deterioration in 2015.

After a notable closure of the gap between the US and Europe until 2012, the performance gap is widening again and in 2015 average additional taxi-out time in the US is, on average, some 1.5 minutes higher per departure than in Europe. This is largely driven by different flow control policies and the absence of scheduling caps at most US airports. Whereas in Europe inefficiency in the taxi-out phase is more evenly spread among airports, the observed taxi-out performance in the US was predominantly driven by the New York airports, Philadelphia (PHL), and Chicago (ORD).

Horizontal en-route flight efficiency (between a 40NM radius around the departure airport and a 100NM radius around the arrival airport) in filed flight plans and in actual trajectories is still better in the US than in Europe in 2015. Overall, horizontal en-route efficiency on flights to or from the main 34 airports in the US is approximately 0.1% better than in Europe in 2015.

Although the level of inefficiency in Europe increased again slightly in 2015, there has been a continuous improvement over the past few years in Europe which resulted in a continuous narrowing of the gap between Europe and the US. In view of the mandatory deployment of free route airspace in EU Member States by 2022, the en-route efficiency improvements in Europe are expected to continue over the next years. US flight inefficiency as measured by this KPI, also increased slightly in the 2013-2015 time frame largely driven by airports with increasing traffic.

Flight efficiency in both systems is affected by a number of factors including, inter alia, route network design, route availability, flight planning, route charges in Europe, and the number and location of special use airspace. The level of inefficiency in flight plan and in actual trajectory in the US and in Europe reveal that both in the US and Europe, airlines fly a shorter distance than they file. Particularly the large gap between planned and actual trajectories observed in Europe suggests that more direct tracks are provided by ATC on a tactical basis not considered in filed flight plans which improves efficiency but at the same time lowers the level of overall predictability in the network.

Similar to en-route flight efficiency, the US also continued to show a higher level of efficiency in the last 100NM before landing. Overall, average additional time within the last 100 NM (Arrival Sequencing and Maneuvering Area (ASMA)) was similar in the two regions in 2008 but decreased in the US between 2008 and 2010. At the same time, flight efficiency within the last 100 NM deteriorated in Europe. Although at different levels, performance in the US and in Europe remained relatively stable between 2013 and 2015.

At system level, average additional ASMA time was 2.5 minutes per arrival in the US in 2015 which was 0.4 minutes lower than in Europe. The result in Europe was significantly affected by London Heathrow (LHR) which had an additional time of 9.5 minutes per arrival - almost twice the level of London Gatwick (LGW) with 4.9 minutes per arrival in 2015. In the US, efficiency levels in the terminal area are more homogenous.

Due to the large number of variables involved, the direct ATM 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 by taking action in the en-route phase of flight, such as in trail spacing. In Europe strategies can differ from airport to airport and the impact of the respective air traffic management systems on airport capacity utilisation in the US and in Europe was not quantified in this report, but would be a worthwhile subject for further study.

Although the direct ATM-related influence is limited, additional time in the taxi-in phase was included for completeness reasons. The level of efficiency is slightly higher in Europe and remained relatively stable over time in both systems although there has been an increase in average additional time between 2013 and 2015.

ESTIMATED BENEFIT POOL ACTIONABLE BY ATM

As there are many trade-offs between flight phases, the aggregation of the observed results enables a high level comparison of the “benefit pool” actionable by ATM in both systems. For each flight phase, the benefit pool is computed in terms of additional time and fuel burn as the inefficiencies in the various flight phases (airborne versus ground) have a different impact on airspace users. For comparability reasons, the computation was based on the assumption that the same aircraft type performs a flight of 450NM in the en-route phase in the US and the European ATM system.

For the interpretation of the observed results, it is important to stress that the determined “benefit pool” is based on a theoretical optimum (averages compared to unimpeded times), which is, due to inherent necessary (safety) or desired (capacity) limitations, clearly not achievable at system level.

Although in a context of declining traffic, system-wide ATM performance improved notably in the US and in Europe between 2010 and 2015. The resulting savings in terms of time and fuel in both ATM systems had a positive effect for airspace users and the environment.

The improvement in Europe over the past five years was mainly driven by a notable reduction of ATM-related departure delay, improvements in taxi-out efficiency, and better en-route flight efficiency. In this context it is however important to point out that 2010 was a year with comparatively high delays in Europe due to adverse weather and ATC strikes. The performance improvement in the US was mainly due to a substantial improvement of taxi-out efficiency, although average additional time in the taxi-out phase in the US increased again slightly in 2015.

Overall, the relative distribution of the ATM-related inefficiencies associated with the different phases of flight is consistent with the differences in flow management strategies described throughout the report and confirmed by a the more detailed supplementary section addressing differences in Air Traffic Flow and Capacity Management (ATFCM) between Europe and the US.

In Europe ATM-related departure delays are much more frequently used for balancing demand with en-route and airport capacity than in the US, which leads to a notably higher share of traffic affected but with a lower average delay per delayed flight. Moreover the share of en-route-related TMIs in Europe is close to 50% while in the US more than 80% of TMIs are airport-related during 2015.

Consequently, in Europe flights are over twice more likely to be held at the gate or on the ground for en-route constraints than in the US. The comparatively small amount of en-route-related TMIs in the US are mostly driven by convective weather whereas in Europe en-route-related TMIs are mainly the result of capacity and staffing constraints with only a smaller share of weather-related constraints.

For TMIs related to arrival airport constraints the situation is different. The percentage of delayed flights at the departure gate or on the surface is slightly higher in the US than in Europe and the delay per delayed flights in the US is almost twice as high as in Europe. Most of this delay in the US is generally linked to weather-related constraints at a number of high density airports including, New York (LGA), Chicago (ORD), Newark (EWR), San Francisco (SFO), New York (JFK), and Philadelphia (PHL).

Overall it can be concluded that the two systems differ notably in the way TMIs are applied. In the US, TMIs are used less frequently, are mostly airport- and weather-related, and affect fewer flights, but when they are used the delay per delayed flight is much higher than in Europe.

ANNEX I - LIST OF AIRPORTS INCLUDED IN THIS STUDY

Table I-1: Top 34 European airports included in the study (2015)

EUROPE	ICAO	IATA	COUNTRY	Avg. daily IFR departures in 2015	2015 vs. 2013	2015 vs. 2010
Paris (CDG)	LFPG	CDG	FRANCE	652	-0.5%	-4.9%
London (LHR)	EGLL	LHR	UNITED KINGDOM	649	0.5%	4.1%
Frankfurt (FRA)	EDDF	FRA	GERMANY	641	-1.0%	0.8%
Amsterdam (AMS)	EHAM	AMS	NETHERLANDS	633	5.9%	16.4%
Munich (MUC)	EDDM	MUC	GERMANY	517	-0.5%	-2.5%
Madrid (MAD)	LEMD	MAD	SPAIN	502	10.1%	-15.5%
Rome (FCO)	LIRF	FCO	ITALY	432	4.4%	-4.3%
Barcelona (BCN)	LEBL	BCN	SPAIN	396	4.5%	4.0%
London (LGW)	EGKK	LGW	UNITED KINGDOM	367	6.9%	11.1%
Zurich (ZRH)	LSZH	ZRH	SWITZERLAND	353	1.1%	0.5%
Copenhagen (CPH)	EKCH	CPH	DENMARK	349	4.0%	3.6%
Vienna (VIE)	LOWW	VIE	AUSTRIA	332	-2.1%	-8.2%
Oslo (OSL)	ENGM	OSL	NORWAY	331	0.2%	11.1%
Paris (ORY)	LFPO	ORY	FRANCE	321	0.3%	6.7%
Brussels (BRU)	EBBR	BRU	BELGIUM	320	10.5%	6.6%
Stockholm (ARN)	ESSA	ARN	SWEDEN	310	2.9%	18.4%
Dusseldorf (DUS)	EDDL	DUS	GERMANY	287	-0.4%	-2.5%
Dublin (DUB)	EIDW	DUB	IRELAND	269	16.2%	23.6%
Berlin (TXL)	EDDT	TXL	GERMANY	250	5.5%	16.9%
Geneva (GVA)	LSGG	GVA	SWITZERLAND	249	2.2%	10.4%
Palma (PMI)	LEPA	PMI	SPAIN	244	5.2%	2.1%
Manchester (MAN)	EGCC	MAN	UNITED KINGDOM	237	2.4%	9.4%
Helsinki (HEL)	EFHK	HEL	FINLAND	232	0.7%	-0.8%
Athens (ATH)	LGAV	ATH	GREECE	232	24.9%	-9.9%
London (STN)	EGSS	STN	UNITED KINGDOM	230	17.1%	8.9%
Lisbon (LIS)	LPPT	LIS	PORTUGAL	227	13.7%	16.6%
Milan (MXP)	LIMC	MXP	ITALY	220	-2.7%	-17.4%
Hamburg (HAM)	EDDH	HAM	GERMANY	206	10.0%	1.1%
Nice (NCE)	LFMN	NCE	FRANCE	186	-3.1%	4.6%
Cologne (CGN)	EDDK	CGN	GERMANY	172	7.2%	-4.2%
Prague (PRG)	LKPR	PRG	CZECH REPUBLIC	169	-0.9%	-18.7%
Stuttgart (STR)	EDDS	STR	GERMANY	163	4.4%	-3.4%
Milan (LIN)	LIML	LIN	ITALY	160	4.7%	-1.3%
Lyon (LYS)	LFLL	LYS	FRANCE	149	-6.6%	-9.4%
Average				**323**	**3.6%**	**1.5%**

Table I-2: US main 34 airports included in the study (2015)

USA	ICAO	IATA	COUNTRY	Avg. daily IFR departures in 2015	2015 vs. 2013	2015 vs. 2010
Atlanta (ATL)	KATL	ATL	United States	1197	-3.3%	-7.6%
Chicago (ORD)	KORD	ORD	United States	1187	-1.3%	-1.3%
Dallas (DFW)	KDFW	DFW	United States	931	0.4%	4.5%
Los Angeles (LAX)	KLAX	LAX	United States	878	5.1%	13.8%
Denver (DEN)	KDEN	DEN	United States	749	-6.9%	-14.0%
Charlotte (CLT)	KCLT	CLT	United States	737	-2.7%	3.0%
Houston (IAH)	KIAH	IAH	United States	685	-0.8%	-7.0%
New York (JFK)	KJFK	JFK	United States	601	8.0%	9.4%
Phoenix (PHX)	KPHX	PHX	United States	595	-0.1%	-3.1%
San Francisco (SFO)	KSFO	SFO	United States	580	1.3%	11.6%
Las Vegas (LAS)	KLAS	LAS	United States	568	2.4%	2.3%
Miami (MIA)	KMIA	MIA	United States	566	4.8%	9.7%
Philadelphia (PHL)	KPHL	PHL	United States	562	-5.1%	-8.5%
Newark (EWR)	KEWR	EWR	United States	559	-0.9%	1.0%
Minneapolis (MSP)	KMSP	MSP	United States	552	-6.6%	-7.5%
Detroit (DTW)	KDTW	DTW	United States	519	-10.9%	-16.6%
Seattle (SEA)	KSEA	SEA	United States	516	20.1%	21.0%
Boston (BOS)	KBOS	BOS	United States	514	3.9%	2.8%
New York (LGA)	KLGA	LGA	United States	498	-2.1%	-0.5%
Orlando (MCO)	KMCO	MCO	United States	428	5.4%	-0.2%
Washington (IAD)	KIAD	IAD	United States	401	-11.1%	-19.4%
Washington (DCA)	KDCA	DCA	United States	399	0.2%	7.4%
Salt Lake City (SLC)	KSLC	SLC	United States	388	-1.1%	-13.2%
Ft. Lauderdale (FLL)	KFLL	FLL	United States	365	9.9%	3.6%
Chicago (MDW)	KMDW	MDW	United States	330	-0.7%	3.6%
Baltimore (BWI)	KBWI	BWI	United States	326	-5.2%	-11.2%
Memphis (MEM)	KMEM	MEM	United States	296	-6.5%	-36.0%
Dallas Love (DAL)	KDAL	DAL	United States	288	23.5%	28.6%
Portland (PDX)	KPDX	PDX	United States	281	0.8%	-7.6%
San Diego (SAN)	KSAN	SAN	United States	264	3.3%	2.5%
Houston (HOU)	IHOU	HOU	United States	255	-1.3%	7.9%
Tampa (TPA)	KTPA	TPA	United States	252	3.1%	-1.4%
St. Louis (STL)	KSTL	STL	United States	250	-2.2%	-0.8%
Nashville (BNA)	KBNA	BNA	United States	241	4.0%	4.9%
Average				**522**	**-0.1%**	**-1.6%**

ANNEX II - DEMAND CAPACITY BALANCING

In order to minimize the effects of ATM system constraints, the US and Europe use a comparable methodology to balance demand and capacity[51]. This is accomplished through the application of an "ATFM planning and management" process, which is a collaborative, interactive capacity and airspace planning process, where airport operators, ANSPs, Airspace Users (AUs), military authorities, and other stakeholders work together to improve the performance of the ATM system.

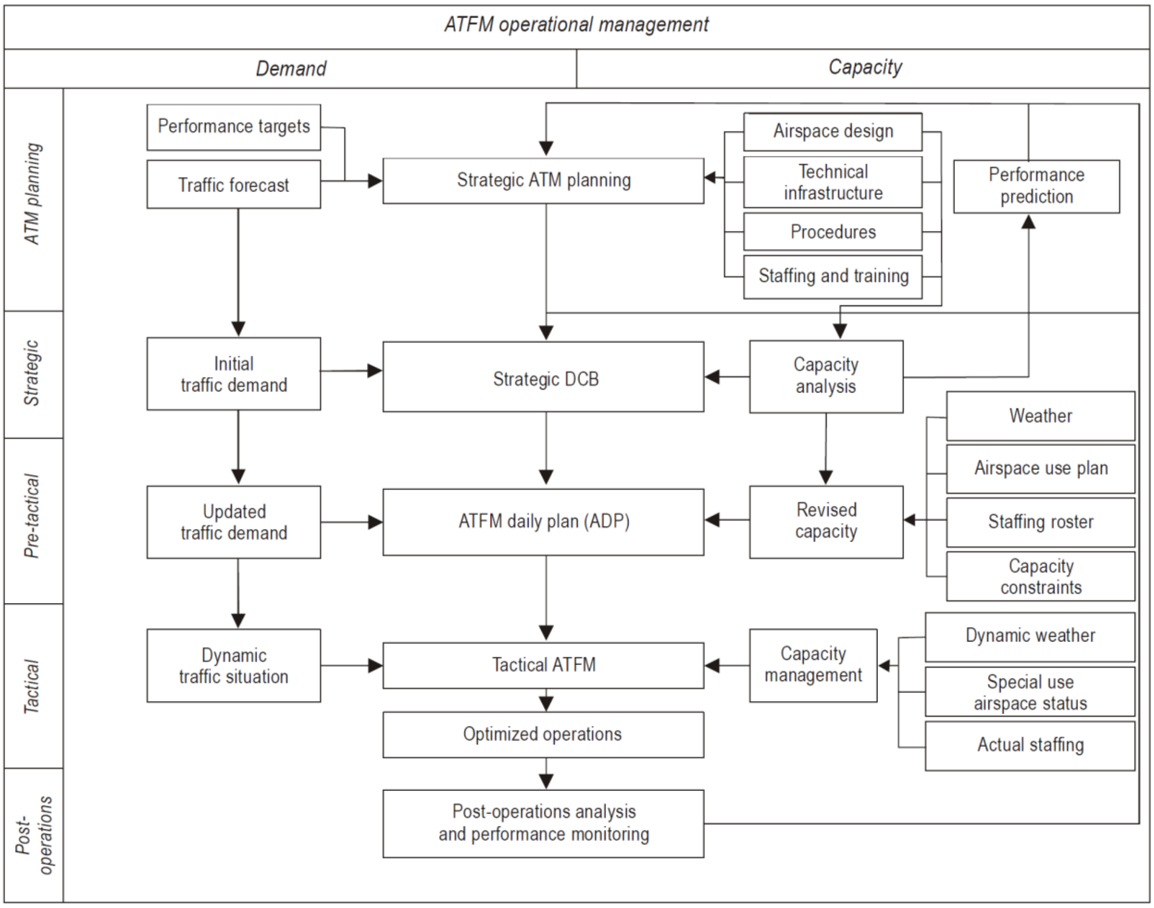

Figure II-1: Generic ATFM process (ICAO Doc 9971)

This CDM process allows AUs to optimize their participation in the ATM system while mitigating the impact of constraints on airspace and airport capacity. It also allows for the full realization of the benefits of improved integration of airspace design, ASM and ATFM.

[51] In line with the guidance in ICAO Doc 9971 (Manual on Collaborative Air Traffic Flow Management).

The process contains a number of equally important phases:

- ATM planning
- ATFM execution
  - Strategic ATFM
  - Pre-tactical ATFM
  - Tactical ATFM
  - Fine-tuning of traffic flows by ATC (shown in Figure as Optimized operations)
    - TMIs that have an impact on traffic prior to take-off
    - TMIs acting on airborne traffic
- Post-operations analysis.

<u>ATFM PLANNING</u>

In order to optimize ATM system performance in the ATM planning phase, available capacity is established and then compared to the forecasted demand and to the established performance targets. Measures taken in this step include:

- reviewing airspace design (route structure and ATS sectors) and airspace utilization policies to look for potential capacity improvements;
- reviewing the technical infrastructure to assess the possibility of improving capacity. This is typically accomplished by upgrading various ATM support tools or enabling navigation, communications or surveillance infrastructure;
- reviewing and updating ATM procedures induced by changes to airspace design and technical infrastructure;
- reviewing staffing practices to evaluate the potential for matching staffing resources with workload and the eventual need for adjustments in staffing levels; and
- reviewing the training that has been developed and delivered to ATFM stakeholders.

Such an analysis quantifies the magnitude of any possible imbalance between demand and capacity. Mitigating actions may then be identified to correct that imbalance. However, before they are implemented, it is very important to:

- establish an accurate picture of the expected traffic demand through the collection, collation, and analysis of air traffic data, bearing in mind that it is useful to:
  - monitor airports and airspaces in order to quantify excessive demand and significant changes in forecast demand and ATM system performance targets;
  - obtain demand data from different sources such as:
    - comparison of recent traffic history (e.g. comparing the same day of the previous week or comparing seasonal high-demand periods);
    - traffic trends provided by national authorities, user organizations (e.g. International Air Transport Association (IATA)); and
    - other related information (e.g. air shows, major sports events, large-scale military manoeuvres); and
- take into account the complexity and cost of these measures in order to ensure optimum performance, not only from a capacity point of view but also from an economic (and cost-effectiveness) perspective.

The next phase is built on declared ATC capacity. It aims at facilitating the delivery of optimal ATM services.

Table II-1: Planning layer

US	Europe
The FAA publishes a variety of plans that take a multi-year view on the evolution of the NAS. This includes for example: • Aerospace forecasts • Terminal area forecast • Airport capacity profiles • Air Traffic Controller Workforce Plan • National Airspace System Capital Investment Plan	The European ATM Network Operations Plan represents a view, at any moment in time, of the expected demand on the ATM Network at a particular time in the future and the resources available across the network, together with a set of agreed actions to accommodate this demand, to mitigate known constraints and to optimise ATM Network performance. The time-frame of the Network Operations Plan is medium to short-term, moving into pre-tactical planning. However, this document is strategically focussed, listing the medium to short-term activities that contribute to the safe provision of additional capacity and improved flight efficiency at European ATM network level. The Plan is developed through the formal Cooperative Decision Making (CDM) Process established between the Network Manager and its operational stakeholders and is a consolidation of all network and local capacity plans to provide an outlook of the expected network performance for the **next five year period** by comparing the expected benefit from planned capacity enhancement initiatives with the requirements at network and local level, as determined by the Single European Sky Performance Framework. The objectives of the NOP are: • to ensure coordinated planning, execution, assessment and reporting of all measures agreed at operational level; • to be used as a tool in the execution of the network management functions, under the governance of the Network Management Board and the Network Directors of Operations; • to assist Network Manager stakeholders, mainly ANSPs, in carrying out agreed activities towards enhancing and/or optimising performance; • to provide references for the monitoring and reporting as a part of Network Management activities; and, • to ensure formal commitment of all operational stakeholders towards the implementation of the agreed measures. The document identifies potential bottlenecks and gives early indications to the European Commission, Network Manager, States, ANSPs, Airports and Aircraft Operators for the need to plan better use of existing resources or, if required, to plan for additional resources, on network interactions and on the need to implement improvements coordinated at Network level.

Strategic ATFM

The ATFM strategic phase encompasses measures taken more than one day prior to the day of operation. Much of this work is accomplished two months or more in advance.

This phase applies the outcomes of the ATM planning activities and takes advantage of the increased dialogue between AUs and capacity providers, such as ANSPs and airports, in order to analyse airspace, airport and ATS restrictions, seasonal meteorological condition changes and significant meteorological phenomena. It also seeks to identify, as soon as possible, any discrepancies between demand and capacity in order to jointly define possible solutions which would have the least impact on traffic flows. These solutions may be adjusted according to the demand foreseen in this phase.

The strategic phase includes:

- a continuous data collection and interpretation process that involves a systematic and regular review of procedures and measures;
- a process to review available capacity; and,
- a series of steps to be taken if imbalances are identified. They should aim at maximizing and optimizing the available capacity in order to cope with projected demand and, consequently, at achieving performance targets.

The main output of this phase is the creation of a plan, composed of a list of hypotheses and resulting capacity forecasts and contingency measures. Some elements of the plan will be disseminated in aeronautical information publications. Planners will use them to resolve anticipated congestion in problematic areas. This will, in turn, enhance ATFM as a whole as solutions to potential issues are disseminated well in advance.

Scheduling at airports is not really part of ATFM, but it is a strategic demand capacity balancing activity with a time horizon of several months, and is therefore included in the table below.

Airport coordination levels

IATA has defined three levels:

- A non-coordinated airport (Level 1) is one where the capacities of all the systems at the airport are adequate to meet the demands of users.
- A schedules facilitated airport (Level 2) is one where there is potential for congestion at some periods of the day, week or scheduling period, which is amenable to resolution by voluntary cooperation between airlines and where a schedules facilitator has been appointed to facilitate the operations of airlines conducting services or intending to conduct services at that airport.
- A coordinated airport (Level 3) is one where the expansion of capacity, in the short term, is highly improbable and congestion is at such a high level that:
  - the demand for airport infrastructure exceeds the coordination parameters during the relevant period;
  - attempts to resolve problems through voluntary schedule changes have failed;
  - airlines must have been allocated slots before they can operate at that airport.

Table II-2: Strategic scheduling and ATFM solutions

<table>
<tr><th>US</th><th>Europe</th></tr>
<tr><td><u>Scheduling at airports</u>

With regard to airline scheduling, only two airports are slot coordinated (IATA level 3) in the US: JFK and EWR. However EWR will become Level 2 as of winter 2016. Four airports are schedules facilitated (IATA level 2): ORD, LAX, MCO, SFO.

For DCA and LGA, schedule restrictions are in effect based on Federal and local regulations.

STMPs (Special Traffic Management Programs) may be put in place. These are reservation programs implemented to regulate arrivals and/or departures at airports that are in areas hosting special events such as the Masters Golf Tournament, Indianapolis 500, Denver Ski Country. STMP reservations provide a long-range planning capability for such events.</td><td><u>Scheduling at airports</u>

In Europe, approximately 100 airports are slot coordinated (IATA level 3).

Approximately 70 are schedules facilitated (IATA level 2).</td></tr>
<tr><td><u>North American Route Program (NRP)</u>

The North American Route Program (NRP) specifies provisions for flight planning at flight level 290 (FL290) and above, within the conterminous U.S. and Canada.

It enables flexible route planning for aircraft operating at FL290 and above, without reference to the ATS route network, from a point 200 nautical miles (NM) from their point of departure to a point 200 NM from their destination. Additional flexibility is available by utilizing specified Departure Procedures (DP) and Standard Terminal Arrival Routes (STAR) that have been identified within 200 NM of the airport(s).

Beyond 200 NM from point of departure or destination, operators must ensure that the route of flight contains no less than one waypoint or NAVAID, per each ARTCC that a direct route segment traverses and these waypoints or NAVAIDs must be located within 200 NM of the preceding ARTCC's boundary. Additional route description fixes for each turning point in the route must be defined.

Operators must ensure that the route of flight avoids active restricted areas and prohibited areas by at least 3 NM unless permission has been obtained from the using agency to operate in that airspace and the appropriate air traffic control facility is advised.

The ARTCCs must avoid issuing route and/or altitude changes for aircraft which display the remarks “NRP" except when due to strategic, meteorological or other dynamic conditions. They must coordinate with ATCSCC before implementing any reroute to NRP flights beyond 200 NM from point of departure or destination. The ATCSCC has the authority to suspend and/or modify NRP operations for specific</td><td><u>Free Route Airspace (FRA)</u>

In Europe FRA is a specified airspace within which users may freely plan a route between a defined entry point and a defined exit point. Subject to airspace availability, the route can be planned directly from one to the other or via intermediate (published or unpublished) way points, without reference to the ATS route network. Within this airspace, flights remain subject to air traffic control.

Free route operations can be:
• Time limited (e.g. at night) – this is usually a transitional step that facilitates early implementation and allows field evaluation of the FRA while minimising the safety risks.
• Structurally or geographically limited (e.g. restricting entry or exit points for certain traffic flows, applicable within CTAs or upper airspace only) – this is done in complex airspaces where full implementation could have a negative impact on capacity.
• Implemented in a Functional Airspace Block (FAB) environment – a further stage in the implementation of FRA. The operators should treat the FAB as one large FIR.
• Within SES airspace – this is the ultimate goal of FRA deployment in Europe.

<u>Route Availability Document (RAD)</u>

The RAD is a common reference document containing the policies, procedures and description for route and traffic orientation. It also includes route network and free route airspace (FRA) utilisation rules and availability.

The RAD is also an Air Traffic Flow and Capacity</td></tr>
</table>

geographical areas or airports. Suspensions may be implemented for severe weather reroutes, special events, or as traffic/equipment conditions warrant.

Pre-defined routes

Pre-planned rerouting options are contained in the National Playbook. It is a collection of Severe Weather Avoidance Plan (SWAP) routes that have been pre-validated and coordinated with impacted ARTCCs. They have been designed to mitigate the potential adverse impact to the FAA and users during periods of severe weather or other events that affect coordination of routes. These events include, but are not limited to, convective weather, military operations, communications, and other situations.

Other examples of predefined routes include:

- Coded Departure Routes (CDR). These are a combination of coded air traffic routings and refined coordination procedures.
- Preferred routes: routes that have been published by ATC to inform users of the "normal" traffic flows between airports. They were developed to increase system efficiency and capacity by having balanced traffic flows among high-density airports, as well as de-conflicting traffic flows where possible.

Altitude segregation

Altitude segregation measures are predefined in US facilities through capping and tunnelling plans:

- Capping: indicates that aircraft will be cleared to an altitude lower than their requested altitude until they are clear of a particular airspace. Capping may apply to the initial segment of the flight or for the entire flight.
- Tunnelling: descending traffic prior to the normal descent point at an arrival airport to keep aircraft clear of an airspace situation on the route of flight. It is used to avoid conflicting flows of traffic and holding patterns.

Severe Weather Avoidance Plan (SWAP)

A SWAP is a formalized program that is developed for areas susceptible to disruption in air traffic flows caused by thunderstorms.

This is mainly used for the Northeast, to balance throughput of arrivals and departures at the New York City-area airports for those days that convective weather is forecast.

There a three-tier system is used, based upon the severity of the weather as well as the location of the convective activity:

- SWAP Level 1: Weather is expected to be 100

Management (ATFCM) tool that is designed as a sole-source flight-planning document, which integrates both structural and ATFCM requirements, geographically and vertically.

The content of the RAD is agreed between the Network Manager and the Operational Stakeholders through an appropriate cooperative decision making (CDM) process.

Each State ensures that the RAD is compatible with their AIP with regard to the airspace organisation inside the relevant FIR/UIR.

EUROCONTROL is responsible for preparing of a common RAD reference document, collating, coordinating, validating and publishing it, following the CDM process as described above.

Scenarios

Scenarios are the European means by which the best possible airspace organisation combined with the best ATFCM measures can be implemented to meet airspace demand and to take into account traffic flows, airport and ATC capabilities.

A scenario is a coherent set of measures combining airspace organisation, route flow restrictions, sector configuration plan, capacity plan, rerouting plan and/or regulation plan. Each scenario is accompanied by its particular modus operandi for use of the network in relation with the ATC sector configuration, the route and airspace availability, special events, etc.

Scenarios are characterised by:

- the traffic origin
- the traffic destination
- the scenario type(s)
- the On-load Areas
- the Off-load Areas
- suggested alternative routes

There are four types of scenario:

- Level capping scenarios (FL): carried out by means of level restrictions or through dynamic routeing restrictions (RAD restrictions, EURO restrictions).
- Rerouteing scenarios (RR): diversion of flows to off-load traffic from certain areas.
- Alternative routeing scenarios (AR): alternative routes which are exceptionally made available to off-load traffic from certain areas, implemented by regulations with a low rate.
- EU Restrictions: airspace restrictions that affect the flight planning phase based on route or airspace closures.

miles or more from N90 (NY TRACON) airspace and/or there is minor impact expected to ZNY (NY Center) arrival/departure gates, and to over flight routes. This level of SWAP provides for developing some basic structure, route expectations, and planning capability. The objective is to manage expectations and complexity early. Customers should begin filing appropriate route solutions and managing their flights in response to the actions taken or planned. • SWAP Level 2: Weather is expected to be between 50-100 miles from N90 airspace and/or there is moderate impact expected to ZNY arrival/departure gates, and possibly to over flight routes. This level of SWAP provides for increasing structure and reducing holding, diversions, and other serious complexity issues. The objective is to prioritize airspace availability, reduce airborne inventory, and manage surface congestion issues. All initiatives in SWAP Level 1 are included. • SWAP Level 3: Weather is expected to be within 50 miles from N90 airspace and/or there is moderate or greater impact expected to ZNY arrival/departure gates, and possibly to over flight routes. This level of SWAP provides real-time constraint, route and volume management. The focus of this stage is to prioritize traffic that requires more expeditious handling, and that requires a much higher priority than other traffic sharing the same airspace. The objective is to reduce diversions, holding, surface delays and taxi-back situations. All initiatives in SWAP Level 1 and 2 are included.	**<u>Event management</u>** Event management is used to resolve potential capacity/demand imbalances caused by seasonal or significant events, by applying ATFCM solutions. These solutions are a set of ATFCM measures, including routeing scenarios, to deliver optimum network performance; they take the constraints of both AOs and ANSPs into consideration. ATFCM events are: • Seasonal events happen every year at the same time and impact on the ATFCM network in a relatively predictable way. Examples of seasonal events include: the South-West Axis flows, the North-East Axis flows, the ski season traffic flows etc. • Significant events are those that generate a strong traffic demand in a relatively small area, generating local congestion. Examples of significant events are: the Olympic Games, the Football World Cup Finals, or Summits of Heads of States. • Military events refer primarily to military exercises. They are coordinated with the national AMC (Airspace Management Cells) and addressed through specific scenarios. The general process consists of preparing scenarios under the Network Manager Operations Centre's (NMOC) supervision, in coordination with FMPs from the ACCs concerned, and the operations staff from the airlines involved. **<u>Axis management</u>** The above mentioned seasonal events are dealt with through the axis management process. This is a CDM process which starts in advance and has as an output ATFCM Measures (e.g., re-routings, FL capping or alternative routings) that would be further consolidated and applied on the day of operations. This output is discussed and agreed through dedicated CDM conferences (either via a meeting or an e-conference) and there is a monitoring process to fine-tune the event management as well.

PRE-TACTICAL ATFM

The ATFM pre-tactical phase encompasses measures taken one day prior to operations.

During this phase, the traffic demand for the day is analysed and compared to the predicted available capacity. The plan, developed during the strategic phase, is adapted and adjusted accordingly.

The main objective of the pre-tactical phase is to optimize capacity through an effective organization of resources (e.g. sector configuration management, use of alternate flight procedures).

The work methodology is based on a CDM process established between the stakeholders (e.g. FMU, airspace managers, AUs).

The tasks to be performed during this phase may include the following:

- determine the capacity available in the various areas, based on the particular situation that day;
- determine or estimate the demand;
- study the airspace or the flows expected to be affected and the airports expected to be saturated, calculating the acceptance rates to be applied according to system capacity;
- conduct a comparative demand/capacity analysis;
- prepare a summary of ATFM measures to be proposed and submit them to the ATFM community for collaborative analysis and discussion; and,
- at an agreed-upon number of hours before operations, conduct a last review consultation involving the affected ATS units and the relevant stakeholders, in order to fine-tune and determine which ATFM measures should be published through the corresponding ATFM messaging system.

The final result of this phase is the ATFM Daily Plan (ADP), which describes the necessary capacity resources and, if needed, the measures to manage the traffic. This activity is based on hypotheses developed in the strategic phase and refined to the expected situation. It should be noted that the time limits of the pre-tactical phase may vary, as they depend on forecast precision, the nature of operations within the airspace and the capabilities of the various stakeholders.

The ADP is developed collaboratively and aims at optimizing the efficiency of the ATM system and balancing demand and capacity. The objective is to develop strategic and tactical outlooks for a given airspace volume or airport that can be used by stakeholders as a planning forecast.

The ADP covers, as a minimum, a 24-hour period. The plan may however cover a shorter period, provided mechanisms are in place to update the plan regularly.

The operational intentions of AUs should be consistent with the ADP (developed during the strategic phase and adjusted during the pre-tactical phase).

Once the process has been completed, the agreed measures, including the ATFM measures, are disseminated using an ATFM message, which may be distributed using the various aeronautical communications networks or any other suitable means of communication, such as internet and email.

Table II-3: Pre-tactical planning

US	Europe

Operations Plan (OP)
The FAA ATCSCC Operations Plan represents a view of the NAS performance, constraints, and risks that are accurate at the time it is published.
The time-frame of the Operations Plan is **pre-tactical/tactical**. The Operations Plan is developed through a collaborative process and the ATCSCC host a Planning Webinar (PW) with FAA facilities (ARTCCs, Large TRACONs, and large ATCTs), with flight operators, and other stakeholders as needed. Unless otherwise announced, the first Operations Plan is published by FAA ATCSCC Advisory no later than 6:00 a.m. Eastern Time. Unless otherwise announced, the first PW is conducted at 7:15 am Eastern Time and every 2 hours thereafter until 9:15 pm Eastern Time.
The ATCSCC has a designated Planner position that is staffed by a supervisor - National Traffic Management Officer (NTMO) at the ATCSCC. The Planner is responsible for developing, collaborating, conducting the PW and for publishing the Operations Plan by Advisory immediately following the PW. An operations agenda web-page is available to all stakeholders for submitting proposed constraints and mitigations between the PWs. The Planner is responsible for managing that web-page.
The Operations Plan has the following sections:
• Terminal (airport) constraints
• En-route constraints
• Plain language description of the Operations Plan
• Actual and anticipated traffic management initiatives (TMIs), such as Ground Delay Programs (GDPs), Airspace Flow Programs (AFPs), Ground Stops (GS)
• Actual and Planned Routes (sometimes referred to as reroutes) are published. Actual TMIs and routes include a valid time while anticipated TMIs and routes include both a projected valid time and a qualifying description of the confidence that it may be needed. The qualifiers are:
  o Possible – indicates that an initiative may be needed if the constraint develops as forecast; timing is broad and confidence is low;
  o Probable – indicates that a TMI is very likely and confidence is high; timing is less certain; and,
  o Expected – indicates there is high confidence the TMI will be implemented when the projected time is reached.
• Valid time
• Three PWs contain specialized information:
  o at 9:15 am Eastern Time, an extended discussion of potential structured routes is conducted;
  o at 7:15 pm Eastern Time Overnight or "Cargo" operations are discussed;
  o at 9:15 pm Eastern Time a Next Day Outlook is discussed.
	ATFCM Daily Plan (ADP)
	The ADP is a proposed set of tactical ATFCM measures (TMIs) prepared pre-tactically and agreed between all partners concerned to optimise the European Network. It covers a 24-hour period (the day prior to the day of operation) for each day.
	Normally the ADP starts as a draft on D-2 and it is finalised and promulgated on D-1 by means of the ATFCM Notification Message (ANM) and the ATFCM Information Message (AIM) Network News. During tactical operations the ADP is further modified according to the developments of the day.
	
	Airspace Use Plan (AUP)
	Agencies responsible for airspace activities submit their requests for the allocation of airspace or routes – Temporary Segregated Areas (TSAs) or Conditional Routes (CDRs) – to the appropriate national AMC (Airspace Management Cell).
	After the AMC has received, evaluated and de-conflicted the airspace requests, the notification of the airspace allocation is published in advance in a daily AUP.
	• The Airspace Use Plan activates Conditional Routes and allocates Temporary Segregated Areas and Cross-Border Areas for specific periods of time.
	• If necessary, changes to the pre-tactical airspace allocation can be made by AMCs through the publication of an Updated Airspace Use Plan. This UUP notifies the changes to the airspace allocation on the actual day of operations. The process of update of airspace use requests is very dynamic.
	• The AUP and the UUP are published nationally and internationally in a harmonised format.

Tactical ATFM

During the ATFM tactical phase, measures are adopted on the day of the operation. Traffic flows and capacities are managed in real time. The ADP is amended taking due account of any event likely to affect it.

The tactical phase aims at ensuring that:

- the measures taken during the strategic and pre-tactical phases actually address the demand/capacity imbalances;
- the measures applied are absolutely necessary and that unnecessary measures be avoided;
- capacity is maximized without jeopardizing safety; and
- the measures are applied taking due account of equity and overall system optimization.

During this phase, any opportunity to mitigate disturbances will be used. The need to adjust the original ADP may result from staffing problems, significant meteorological phenomena, crises and special events, unexpected opportunities or limitations related to ground or air infrastructure, more precise flight plan data, the revision of capacity values, etc.

The provision of accurate information is of paramount importance in this phase, since the aim is to mitigate the impact of any event using short-term forecasts. Various solutions will be applied, depending on whether the aircraft are already airborne or about to depart.

Proactive planning and tactical management require the use of all information available. It is of vital importance to continuously assess the impact of ATFM measures and to adjust them, in a collaborative manner, using the information received from the various stakeholders.

Table II-4: Tactical ATFM

US	Europe
Managing airport constraints Airport TMIs in the US are designed to manage inbound traffic flows (arrivals): Ground Delay Program (GDP): GDPs will normally be implemented at airports where capacity has been reduced because of weather—such as low ceilings, thunderstorms or wind—or when demand exceeds capacity for a sustained period. GDPs are implemented to ensure the arrival demand at an airport is kept at a manageable level to preclude extensive holding and to prevent aircraft from having to divert to other airports. They are also used in support of Severe Weather Avoidance Plan (SWAP). A ground stop (GS) is a procedure requiring aircraft that meet specific criteria to remain on the ground. Ground Stops are implemented for a number of reasons. The most common reasons are: • To control air traffic volume to airports when the projected traffic demand is expected to exceed the airport´s acceptance rate for a short period of time. • To temporarily stop traffic allowing for the	**Managing airport constraints** Europe uses ATFM regulations to manage airport traffic flows. Airport ATFM regulations can apply: • To a single aerodrome (AD) or to a set of aerodromes (AZ). This is called the Reference Location (RL). • For the AD or AZ: to all or just to a subset of the traffic; i.e. to arrivals only, departures only, or both (called 'global'). This is called the traffic volume (TV). In most cases only arrival regulations are used. Airport ATFM regulations with a non-zero rate are the equivalent of a GDP. Airport ATFM regulations with a zero rate are the equivalent of a GS. In some cases, an airport ATFM regulation starts off with a zero rate, which is later increased to accept a limited amount of traffic. This is the equivalent of a combined GS+GDP.

implementation of a longer-term solution, such as a Ground Delay Program. • The affected airport´s acceptance rate has been reduced to zero. A facility may initiate a local GS when the facilities impacted are wholly contained within the facility's area of responsibility and conditions are not expected to last more than 30 minutes. Local GSs must not be extended without prior approval of the ATCSCC. The ATCSCC may implement a national GS upon receipt of information that an immediate constraint is needed to manage a condition, after less restrictive TMIs have been evaluated. Not all inbound traffic is affected by a GDP or GS. The scope (departure scope) indicates which traffic is included in the TMI. Traffic departing from airports under the jurisdiction of the listed facilities will be subjected to the TMI. The scope can be distance based or tier based, eg the local ARTCC, the First Tier ARTCCs (neighbours), or the Second Tier ARTCCs (neighbours of neighbours).	

Managing airspace constraints
 	
A Departure Stop is similar to a GS. It assigns a departure stop for a specific NAS element other than a destination airport, such as an airway, fix, departure gate, or sector.
 	
An Airspace Flow Program (AFP) is a delay TMI with parameters similar to that of a GDP. The major difference between the two types of initiatives is that AFPs control the flow of aircraft into or through a volume of airspace versus controlling the flow of aircraft to a particular airport. The volume of airspace used is often one-dimensional (i.e. a border). All of these volumes are referred to as Flow Constrained Areas (FCA).
 	
Flow Evaluation Areas (FEA) are developed on an ad hoc basis. Just like FCAs, they are three-dimensional volumes of airspace, along with flight filters and a time interval, used to identify flights. They may be drawn graphically, around weather, or they may be based on a NAS element. They are used to evaluate demand on a resource. FEAs and FCAs are different because an Evaluation Area is just under study while a Constrained Area requires action to address a particular situation.
 	
FEA/FCAs provide reroutes using the Create Reroute capability and are published through a reroute advisory with an optional flight list attached. Stakeholders can monitor FEA/FCAs through reroute monitor in traffic situation display (TSD), web situation display (WSD) or collaborative constraint situation display (CCSD).
	Managing airspace constraints
	
	Europe uses ATFM regulations to manage en-route traffic flows. En-route ATFM regulations can apply:
	• To an airspace volume (AS) or to a special point (SP). This is called the Reference Location (RL).
	• To all or just to a subset of the traffic crossing the RL. This is called a traffic volume (TV).
	
	En-route ATFM regulations can either take the form of
	• A delay TMI. Those are comparable to AFPs.
	• A TMI for rerouting purposes, not generating delay (normally part of a scenario see above):
	  o Level capping (FL): implemented by a zero-rate regulation with vertical restriction
	  o Required rerouting (RR): implemented by a zero-rate regulation
	  o Alternative routeing (AR): implemented by a regulation with a low rate through airspace normally not accessible to the traffic flow.
	
	In Europe the Network Manager has – in collaboration with aircraft operators – put in place a process called the Flight Efficiency Initiative (FEI). It is based on voluntary participation by aircraft operators and aims at offering them the most efficient routes on the day of operation. It entails scrutinising their flight plans and seeing if there is not a quicker or more cost-effective way for their aircraft to fly.
	
	The FEI operates on the basis of a dynamic route generator and an automatically maintained catalogue of routes flown in the past. The routes are evaluated on the basis of subjective cost criteria provided by the airline operators, such as:

The Required Reroutes (RR) TMI is often applied in conjunction with delay programs to move flows around en-route constraints. The impact of the reroute is dependent on how it is implemented and what type of delay program it is interacting with. Required reroutes are issued by Departure (ETD), Arrival (ETA) or FCA entry time. CTOP (Collaborative Trajectory Options Program) is a new type of TMI, which automatically assigns delay and/or reroutes around one or more FCA-based airspace constraints in order to balance demand with available capacity. The unique feature of CTOP is that it allows for user preferences in route selection. Under a CTOP initiative, operators submit alternative routes of their choice around or away from a constraint, thus providing additional options for air traffic controllers to expedite flights away from congested airspace. Flights that have submitted a trajectory option set (TOS) could be exempt from ground delays or in-flight reroutes associated with such constraints. ICR (Integrated Collaborative Rerouting) is a process that builds on the FCA technology. The ICR process requires that a constraint be identified early. ICR allows airspace users to take action with their trajectory preferences in response to an identified system constraint. They have an opportunity to consider the area of concern and provide EI (Early Intent) messages that communicate their decisions in response to the constraint. At the expiration of the EI window, traffic managers can analyze the customer responses and decide if the actions taken have resolved the issue or decide if recommended routes, required routes, airspace flow programs, or other traffic management initiatives (TMI) will be necessary to further reduce demand.	• flying time costs, • fuel costs and • the cost of air traffic flow and capacity management (ATFCM) delays. The FEI is based on a re-routing process that can take place on the day of operations up to two hours before the flight. It takes place in two phases: • First phase: AOs and computerized flight plan service providers (CFSPs) can use an NM tool to compare their flight plans with the best filed flight plan accepted by the NM for a given city pair • Second phase: Re-routing proposals from the NM to AOs The FEI also contributes to a strategic and continuous improvement of the airlines' route catalogues.
Slot substitution (subbing) The substitution process provides a way for airspace users, henceforth referred to as users, to manage their flights during a GDP, GS or AFP. Users can, for example, swap slots between a high priority flight and a less important flight, reducing the delay on one at the cost of increasing the delay for another. Users may only sub for their own flights; there is no trading or bartering for slots.	**Slot swapping** In Europe the ETFMS slot swapping functionality is used to swap flights requested by AOs or FMPs. Additionally it may be used to improve another flight if an aircraft operator requests a slot extension (i.e. instead of forcing the flight). AOs shall only request swaps concerning flights for which they are the responsible operator or where there is a formal agreement between both AOs to swap flights. For regulated flights departing from an A-CDM, AOs shall request the swap via the FMP / TWR. FMPs may request swaps for two flights of the same AO or, during critical events at airports, also between any different AOs.

In the tactical phase Europe also uses STAM, Short Term ATFCM Measures, such as minor ground delays, flight level capping and minor re-routings applied to a limited number of flights, both airborne and pre-departure. STAM application allows reducing the complexity and/or demand of anticipated/identified traffic peaks and to prevent or limit the penalization that would result from the implementation of standard ATFCM measures.

Europe is also moving its first steps in Target Time Operations, by including the Target Time Over in the ATFM Slot Allocation Messages. At now this is provided to create operational awareness of the planned time at the congestion point. Further developments are planned to use Target Time over to optimise ATFM delivery.

FINE-TUNING OF TRAFFIC FLOWS BY ATC

After ATFM measures are taken, traffic flows are further fine-tuned by ATC.

A distinction can be made between TMIs that have an impact on traffic prior to take-off, and those acting on airborne traffic.

TMIs that have an impact on traffic prior to take-off

These are sequencing and metering measures that are used by ATC to fine-tune the traffic flow and that may have a delay impact on traffic prior to take-off.

The resulting cleared-for-take-off time (Call For Release Time – CFR) may be different from the slot time (EDCT/CTOT) produced by ATFM. Normally this adjustment falls within the ATFM tolerance window:

- In the US this called the EDCT Window: -5/+5min;
- In Europe it is the STW (Slot Tolerance Window): -5/+10min during normal conditions and during adverse conditions up to 15/+30min.

In specific cases sequencing and metering may create additional delay beyond the ATFM tolerance window.

In the US the CFR Window (Call For Release Window) for ATOT is -2/+1min around the assigned CFR time.

In Europe, for flights without an ATFM slot there is a DTW (Departure Tolerance Window) for ATOT of -15/+15min around the ETOT during normal conditions, during adverse conditions possibly extended to -15/+30min.

The TMIs in this category include:

- CFR (Call for Release) [52] (US)
- DSP (Departure Spacing) (US)
- ESP (En-route Spacing)
- ASP (Arrival Spacing)
- Metering (en-route metering)
- MDI (Minimum Departure Interval) (Europe)
- MIT (Miles In Trail)
- MINIT (Minutes In Trail)

[52] Also known as Approval Request (APREQ).

TMIs acting on airborne traffic

This TMI category comprises longitudinal (sequencing and metering), lateral (load balancing) and vertical (level off) tactical measures that are used by ATC after take-off with the objective to fine-tune the traffic flow.

- TBM (Time Based Metering) not propagating to the departure airport (US)
  - TBFM Speed Advisories (US) / XMAN (Cross-border Arrival Management) speed advisories (Europe)
- AH (Airborne Holding)
  - Planned Holding
  - Unplanned Holding
- Vectoring
- Tactical level offs
- Point Merge (Europe)
- Fix Balancing

POST-OPERATIONS ANALYSIS

The final step in the ATFM planning and management process is the post-operations analysis phase.

During this phase, an analytical process is carried out to measure, investigate and report on operational processes and activities. This process is the cornerstone of the development of best practices and/or lessons learned that will further improve the operational processes and activities. It covers all ATFM domains and all the external units relevant to an ATFM service.

While most of the post-operations analysis process may be carried out within the ATFM unit, close coordination and collaboration with ATFM stakeholders will yield better and more reliable results.

Post-operations analysis is accomplished by evaluating the ADP and its results. Reported issues and operational statistics are evaluated and analysed in order to learn from experience and to make appropriate adjustments and improvements in the future.

Post-operations analysis includes analysis of items such as anticipated and unanticipated events, ATFM measures and delays, the use of predefined scenarios, flight planning and airspace data issues. They compare the anticipated outcome (where assessed) with the actual measured outcome, generally in terms of delay and route extension, while taking into account performance targets.

All stakeholders within the ATFM service can provide feedback, preferably in a standardized electronic format, enabling the information to be used in the post-operations analysis in an automated manner.

Post-operations analysis is used to:

- identify operational trends or opportunities for improvement;
- further investigate the cause and effect relationship of ATFM measures to assist in the selection and development of future actions and strategies;
- gather additional information with the goal of optimizing ATM system efficiency in general or for on-going events;
- perform analysis of specific areas of interest, such as irregular operations, special events, or the use of re-route proposals; and
- make recommendations on how to optimize ATM system performance and to minimize the negative impact of ATFM measures on operations.

It is important to ensure that the relevant ATFM stakeholders are made aware of the results. The following processes support this:

- collection and assessment of data including comparison with targets;
- broad review and further information gathering at a daily briefing;
- weekly operations management meeting to assess results and recommend procedural, training and system changes where necessary to improve performance; and
- periodic operations review meetings with stakeholders.

Table II-5: Post-Ops

US	Europe
There are different levels of post operations analysis: • At 8:30 am Eastern time the ATCSCC conducts a post-ops review for ATCSCC management and staff. • At 10:00 am Eastern Time there is a National System review (NSR) post-ops telcon that includes flight operators and FAA Deputy Director System Operations and ATCSCC QC. • At 10:30 am Eastern Time, the Deputy Chief Operating Officer at FAA HQ conducts a post-ops review that includes safety, security, system operations (ATFM), and other significant events from the prior day's operation. A NAS-AERO product that is an interactive web product is used in the briefings and is published widely within FAA. NAS performance, delay, airborne holding, diversions, TMIs, and other NAS performance data is available. There are many national, regional, and facility level products that are created for post-ops review, including video replays. Traffic Management Reviews (TMRs) may be conducted on significantly positive NAS performance results as well as on poor results. The TMR is a very detailed review of a particular event or constraint and may take several days to perform.	The Network Manager provides traffic and delay forecasts and analysis to support the global performance of the European aviation network. The Network Manager: • continuously assesses the performance of the network functions and has established pan-network processes of monitoring, analysing and reporting on all network operational performance aspects; • recommends measures and/or take the actions needed to ensure the network performance; • compares these performance against the objectives established in the network Strategy Plan (NSP), Network Operations Plan (NOP) & Performance Plans identifying gaps and proposing remedial actions. This way NM provides a consolidated and coordinated approach to all planning & operational activities of the network. **<u>Playbook</u>** The playbook is a tool that combines historical data (5 years and the last 4 weeks) to indicate the risk of delay occurring in a particular area of the Network. A daily delay target is allocated globally for en-route and airports and individually for ACCs and airports based on the relevant en-route and airport annual targets. An advanced playbook is produced at D-6 to facilitate planning; this forms the template for production of the D+1 playbook which contains actual delay data from the day of operation for comparison and further post operations analysis. The Post Operations team is responsible for the production of the en-route ATC Capacity and Staffing and Airport playbooks.

ANNEX III - GLOSSARY

A-CDM	Airport Collaborative Decision Making
AAR	Airport Arrival Acceptance Rate
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.
Achieved distance	The portion of the Great Circle distance between two airports that corresponds to a given portion of a flight trajectory. This can be computed for the actual trajectory as well as for the flight-plan trajectory. Regardless of the shape of the trajectory (and the actual or flight-planned distance), the achieved distance of the entire flight is equal to the Great Circle distance between the two airports.
ACI	Airports Council International (http://www.aci-europe.org/)
AD	Aerodrome
ADP	ATFM Daily Plan
ADR	Airport Departure Rate
AFP	Airspace Flow Program (US)
AIG	Accident and Incident Investigation (ICAO)
AIM	ATFCM Information Message (Europe)
AIP	Aeronautical Information Publication, sets out procedures used by pilots and air traffic controllers
AIS	Aeronautical Information Service
AMC	Airspace Management Cell (Europe)
ANM	ATFCM Notification Message (Europe)
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
AO	Aircraft Operator
APP	Approach Control Unit
AR	Alternative routeing scenario (Europe)
ARTCC	Air Route Traffic Control Center, the equivalent of an ACC in Europe.
ASBU	Aviation System Block Upgrade (ICAO)
ASM	Airspace Management
ASMA	Arrival Sequencing and Metering Area
ASP	Arrival Spacing (US)
ASPM	FAA Aviation System Performance Metrics
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
ATCSCC	US Air Traffic Control System Command Centre
ATCT	Air Traffic Control Tower (US)
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.
ATO	Air Traffic Organization (FAA)
ATS	Air Traffic Service. A generic term meaning variously, flight information service, alerting

	service, air traffic advisory service, air traffic control service.
AU	Airspace User
AUP	Airspace Use Plan (Europe)
AZ	Aerodrome Zone (Europe)
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.
BTS	Bureau of Transportation Statistics (US)
CAA	Civil Aviation Authority
CANSO	Civil Air Navigation Services Organisation (http://www.canso.org)
CBA	Cross-Border Area (Europe)
CCF	Combined Control Facility (US): An air traffic control facility that provides approach control services for one or more airports as well as en-route air traffic control (center control) for a large area of airspace. Some may provide tower services along with approach control and en-route services. Also includes Combined Center Radar Approach (CERAP) facilities.
CDA	Continuous Descent Approach
CDM	Collaborative Decision Making
CDR	Conditional Route (Europe)
CDR	Coded Departure Route (US)
CFMU	See NMOC
CFR	Call For Release Time (US)
CM	Capacity Management
CO_2	Carbon dioxide
CODA	EUROCONTROL Central Office for Delay Analysis
CONUS	see US CONUS
CTA	Control Area
CTOP	Collaborative Trajectory Options Program
CTOT	Calculated take-off Time
DCB	Demand Capacity Balancing
DP	Departure Procedure
DSP	Departure Spacing (US)
DTW	Departure Tolerance Window (Europe)
EC	European Commission
ECAC	European Civil Aviation Conference.
EDA	European Defence Agency (EU)
EDCT	Estimate Departure Clearance Time. EDCT is a long-term Ground Delay Programme (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.
EI	Early Intent (US)
ESP	En-route Spacing (US)
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
ETFMS	Enhanced Tactical Flow Management System (Europe)
EU	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom. All these 28 States are also Members of the ECAC.
EUROCONTROL	The European Organisation for the Safety of Air Navigation. It comprises Member States and the Agency.
EUROCONTROL Member States (2015)	Albania, Armenia, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Monaco, Montenegro, The Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, The former Yugoslav Republic of Macedonia, Turkey, Ukraine and United Kingdom of Great Britain and Northern Ireland
FAA	US Federal Aviation Administration
FAA-ATO	US Federal Aviation Administration - Air Traffic Organization
FAB	Functional Airspace Block (Europe)

FCA	Flow Constrained Area (US)
FDP	Flight data processing
FEA	Flow Evaluation Area (US)
FEI	Flight Efficiency Initiative (Europe)
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-foot 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 are flight levels used to indicate altitude; below the transition level, feet are used.
FL	Level capping scenario (Europe)
FMP	Flow Management Position (Europe). The FMP's role is, in partnership with the NM, to act in such a manner so as to provide the most effective ATFCM service to ATC and AOs. Each FMP area of responsibility is normally limited to the area for which the parent ACC is responsible including the area(s) of responsibility of associated Air Traffic Services (ATS) units as defined in the NM Agreement. However, depending on the internal organisation within a State, some FMPs may cover the area of responsibility of several ACCs, either for all ATFCM phases or only for part of them. All FMPs within the NM area have equal status. The size of individual FMPs will vary according to the demands and complexities of the area served.
FMS	Flight Management System
FMU	Flow Management Unit
FRA	Free Route Airspace (Europe)
FUA Level 1 Level 2 Level 3	Flexible Use of Airspace Strategic Airspace Management Pre-tactical Airspace Management Tactical Airspace Management
GANP	Global Air Navigation Plan (ICAO)
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)
GDP	Ground Delay Program (US)
General Aviation	All flights classified as "G" (general aviation) in the flight plan submitted to the appropriate authorities.
GS	Ground Stop (US)
IATA	International Air Transport Association (www.iata.org)
ICAO	International Civil Aviation Organisation
ICR	Integrated Collaborative Rerouting (US)
IFR	Instrument Flight Rules. Properly equipped aircraft with properly qualified flight crews are allowed to fly under bad-weather conditions following instrument flight rules.
ILS	Instrument landing System; a lateral and vertical beam aligned with the runway centreline in order to guide aircraft in a straight line approach to the runway threshold for landing.
IMC	Instrument Meteorological Conditions
KPA	Key Performance Area
KPI	Key Performance Indicator
M	Million
MDI	Minimum Departure Interval
MET	Meteorological Services for Air Navigation
MIL	Military flights
MINIT	Minutes In Trail
MIT	Miles in Trail

MTOW	Maximum Take-off Weight
NAS	National Airspace System
NextGen	The Next Generation Air Transportation System (NextGen) is the name given to a new National Airspace System due for implementation across the United States in stages between 2012 and 2025.
NM	Nautical mile (1.852 km)
NMOC	Eurocontrol Network Management Operations Centre located in Brussels (formerly CFMU)
NOP	Network Operations Plan (Europe)
NRP	North American Route Program (US – Canada)
NSP	Network Strategy Plan (Europe)
NSR	National System Review (US)
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).
OJT	On the Job Training
OP	Operations Plan (US)
OPS	Operational Services
OPSNET	The Operations Network is the official source of NAS air traffic operations and delay data. The data is used to analyse the performance of the FAA's air traffic control facilities.
PBFA	DoD Policy Board on Federal Aviation (US)
Percentile	A percentile is the value of a variable below which a certain per cent of observations fall. For example, the 80th percentile is the value below which 80 per cent of the observations may be found.
PPS	Purchasing power standard
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
PW	Planning Webinar (US)
RAD	Route availability document
Reactionary delay	Delay caused by late arrival of aircraft or crew from previous journeys
RL	Reference Location (Europe)
RR	Rerouteing scenario (Europe)
RR	Required Reroutes TMI (US)
RTCA	Radio Technical Commission for Aeronautics, Inc.
Separation minima	The minimum required distance between aircraft. Vertically usually 1,000 ft below flight level 290, 2,000 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://ec.europa.eu/transport/modes/air/single_european_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
SP	Special Point (Europe)
STAM	Short Term ATFCM Measure (Europe)
STAR	Standard Terminal Arrival Route
STATFOR	EUROCONTROL Statistics & Forecasts Service
STMP	Special Traffic Management Program (US)
STW	Slot Tolerance Window (Europe)
SUA	Special Use Airspace
Summer period	May to October inclusive
SWAP	Severe Weather Avoidance Plan (US)
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.
TBFM	Time Based Flow Management (US)
TBM	Time Based Metering (US)
TFMS	Traffic Flow Management System (US)
TMA	Terminal Manoeuvring Area

TMI	Traffic Management Initiative
TMR	Traffic Management Review (US)
TMS	Traffic Management System
TMU	Traffic Management Unit (US). TMUs use TFMS workstations to participate in traffic flow management. They are located at Air Route Traffic Control Centers (ARTCCs), Terminal Radar Approach Control (TRACON) facilities and large/stand-alone Airport Traffic Control Towers (ATCTs).
TOS	Trajectory Option Set (US)
TRACON	Terminal Radar Approach Control
TSA	Temporary Segregated Area (Europe)
TSD	Traffic Situation Display (US)
TV	Traffic Volume (Europe)
TWR	Tower
UAC	Upper Airspace Area Control Centre
UIR	Upper Information Region
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
UUP	Updated Airspace Use Plan (Europe)
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
XMAN	Cross-border Arrival Management / Extended Arrival Management (Europe)

ANNEX IV - REFERENCES

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