COMPARISON OF ATFM PRACTICES AND PERFORMANCE IN THE U.S. AND EUROPE (2015-2018)

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March 2019 - MANUSCRIPT

Abstract

Traditionally, regional Air Traffic Management benchmarking focuses on comparing delay statistics to foster a better understanding of the different practices in the different regional systems. As part of the FAA and EUROCONTROL's ongoing U.S./Europe comparison activity, a closer look at Air Traffic Flow Management was taken to compare the operational practices and performance in each system and the application of Traffic Management Initiatives (TMI). A joint typology of traffic management initiatives was developed supporting the mapping of the varying regional concepts and terminology. Initial findings based on 2015 were previously presented. Meanwhile, the data covers a period of four years (2015-2018), supporting not only a regional comparison in a snapshot of time, but also a broader study of trends and their underlying causes. When ATFM actions (i.e. TMIs) resulted in more reportable delay, the data shows that in both systems this is primarily driven by an increase in the number of delayed flights, rather than changes in average delay per delayed flight. However, the study shows that there still are significant differences in how this extra delay is generated through ATFM. This research helps both groups improve their ability to analyze the effectiveness of ATFM and learn from each other's experience, and will form an essential basis for future regional comparisons.

Introduction

As part of Air Traffic Flow Management (ATFM), the FAA Air Traffic Control System Command Center (ATCSCC) and EUROCONTROL Network Operations Centre (NMOC) employ a range of Traffic Management Initiatives (TMI) that are tailored to handle situations ranging from normal variation in demand-capacity imbalances to more extreme and disruptive events like thunderstorms, winter operations and other severe conditions. Both FAA and EUROCONTROL record key elements of these actions including minutes of delay, causal reason for delay, constraining facility and ATFM action taken. Joint performance benchmarking using this data has been performed as part of the *U.S./Europe Comparison of Air Traffic Management Related Operational Performance* [1]. At the ICAO level, the measurement of ATFM delay attributable to terminal and en-route facilities is expressed in terms of Key Performance Indicators (KPI) included in the *2019 Global Air Navigation Plan* (GANP) [2].

As part of their performance analysis function, both EUROCONTROL and FAA use these KPIs to identify constraints in the system and alert decision makers to areas where mitigation through training, improved procedures or investment would bring the most benefit to the aviation stakeholders. For this process to work, the performance data systems and KPIs must correctly identify the origins of performance constraints and be reported in a way supporting improvement oriented decision making. Towards this goal, both groups wanted to develop a better understanding of how each other's systems generated the delay statistics reported in the traditional analysis benchmarking work.

In 2015, they agreed to take a closer look at Air Traffic Flow Management (ATFM) operational practices and performance, including the application of Traffic Management Initiatives (TMI). In an initial study summarized in *Comparison of ATFM practices and performance in the U.S. and Europe* [3], the participants developed an understanding of conceptual and terminology differences between the U.S. and Europe and established a joint typology of the TMIs employed in each region. Data sources that would support benchmarking were identified

and a common framework of metrics, indicators, and data dimensions enabled them to build a harmonized TMI database.

This paper provides a summary of the FAA and EUROCONTROL's continuation of that previous work. Utilizing the conceptual framework and data harmonization infrastructure previously developed, the joint TMI database has grown to cover the four years between 2015 and 2018. The analysis not only considers comparison of each region in a moment of time, but also looks towards joint and regional trends.

Background

Demand-Capacity Balancing

Both the U.S. and Europe use a phased approach for the above demand-capacity balancing, in line with the guidance in ICAO Doc 9971 (*Manual on Collaborative Air Traffic Flow Management*) [4]. The purpose of ATFM is to (1) accurately predict demand-capacity imbalance at various time horizons and (2) to mitigate this by suitable ATFM responses: by acting on the demand through TMIs and/or by acting on the Air Traffic Control (ATC) capacity offered by Air Navigation Service Providers (ANSP) through Capacity Management Initiatives as shown in Figure 1.

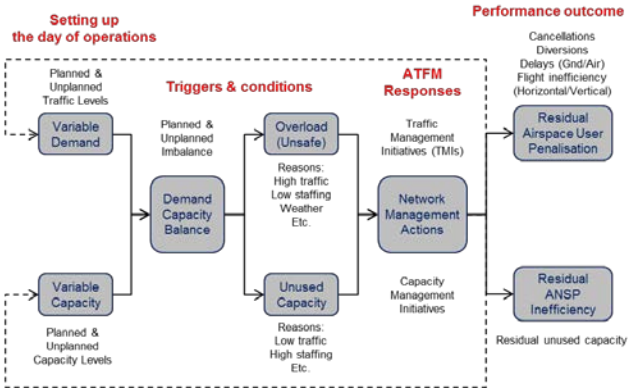

Figure 1. Schematic Representation of ATFM and its Performance Outcome

In an ideal world all performance inefficiencies would have been solved before the day of operations. In reality, even though ATFM actions aim to optimize network operations, there is still some residual airspace user penalization (cancellations, diversions, delays, rerouting and level capping) and/or ANSP inefficiency (unused capacity). In addition, unexpected events may lead to new demand-capacity issues at short notice. The dotted lines on the diagram illustrate that the modified demand and capacity levels are fed back into a more tactical ATFM (or ATC) process which will – within the constraints of what's possible – reassess the imbalance and try to improve the performance outcome at an even shorter time horizon.

Physical Organization of ATFM/ATC Service Provision

Both the U.S. and Europe have established system-wide, centralized facilities (the ATCSCC and NMOC respectively) responsible for the above mentioned forward looking ATFM processes at strategic, pre-tactical and tactical level. The delivery of ATC capacity and the fine-tuning of traffic flows is the responsibility of a large number of en-route, terminal and airport ATC facilities.

The key difference between both regions is that the European ATM system is composed of a large number of individual ANSPs whereas the U.S. system is operated by a single ANSP. This puts the ATCSCC in a much

stronger position with more active involvement of tactically managing traffic on the day of operations than is the case for the NMOC in Europe.

Research Approach

The work reported in this paper builds on the participants' initial study of traffic management initiatives [3]. As a part of that work a conceptual model and TMI database were developed. This included the categorization of TMIs into different levels. Given the overlap in data availability, the analysis focuses mostly on comparison of TMI-L2, or ATFM, flow management actions. The first half of the paper first presents high level trends and comparisons of annual TMI-L2 delay between the two regions, while the second half presents analysis that deals with a higher granularity of the data and derived indicators in order to understand how each system is generating its aggregate performance outcome.

TMI Typology

A fuller description of the taxonomy of TMI levels and types can be found in [3], but for quick reference, the definition of TMI-L2 is included here. A table that summarizes the entire typology is also included (Table 1).

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.

This is U.S. terminology which has also been adopted in ICAO Doc 9971 [4]. In Europe the generic terms "ATFM measure" and "ATFM regulation" are commonly used for all these TMIs, but for the purpose of the U.S./Europe comparison studies we have categorized the European TMIs in our data so that we can use the more specific U.S./ICAO terminology for Europe as well.

We have also categorized TMIs according to their primary purpose: manage delay, manage rerouting, or mixed (a combination of both).

The facility class (AIR=airspace, GND=airports) in Table 1 shows to which facility class(es) a TMI type has been attributed (in the data set). The "US" and "Eur" columns show in which regions the TMIs are used. "N/A" means data is (currently) not available or not yet decoded.

Table 1. TMI Typology

Level	Purpose	Facility class	TMI code	US	Eur	TMI name
TMI-L2	Delay	AIR	AFP	●	●	Airspace Flow Program
TMI-L2	Delay	AIR/GND	DS	●	N/A	Departure Stop
TMI-L2	Delay	GND	GDP	●	●	Ground Delay Program
TMI-L2	Delay	GND	GS	●	●	Ground Stop
TMI-L2	Delay	GND	GDP+GS		●	GDP+GS combined in one TMI
TMI-L2	Mixed	AIR	CTOP	●		Collaborative Trajectory Options Program
TMI-L2	Mixed	AIR/GND	SWAP	●		Severe Weather Avoidance Program
TMI-L2	Reroute	AIR	AFP FL		●	Zero-rate AFP for level capping
TMI-L2	Reroute	AIR	AFP RR		●	Zero-rate AFP for Required Rerouting
TMI-L2	Reroute	AIR	AFP ZR		●	Other zero-rate AFP
TMI-L2	Reroute	AIR	AFP AR		●	AFP for Alternative Routing

Level	Purpose	Facility class	TMI code	US	Eur	TMI name
TMI-L3	Delay	AIR/GND	ASP	●	N/A	Arrival Sequencing Program
TMI-L3	Delay	AIR/GND	DSP	●	N/A	Departure Sequencing Program
TMI-L3	Delay	AIR/GND	ESP	●	N/A	En route Sequencing Program
TMI-L3	Delay	AIR/GND	Metering	●	N/A	Metering / time based metering
TMI-L3	Delay	AIR/GND	MINIT	●	N/A	Minutes In Trail
TMI-L3	Delay	AIR/GND	MIT	●	N/A	Miles In Trail
TMI-L4	Delay	AIR/GND	AH	●	N/A	Airborne Holding
TMI-L5	Delay	GND	DEP	●	N/A	Airport Departure Delay

TMI Metrics and Indicators

The data sources provided information at the level of individual TMIs: the number of TMIs applied, their duration, the number of flights "captured" by each TMI, and the amount of delay generated.

From this a number of indicators were computed which express the metrics as values per TMI, per TMI hour and per delayed flight.

An overview of the full set of indicators can be found in Figure 2 on the next page.

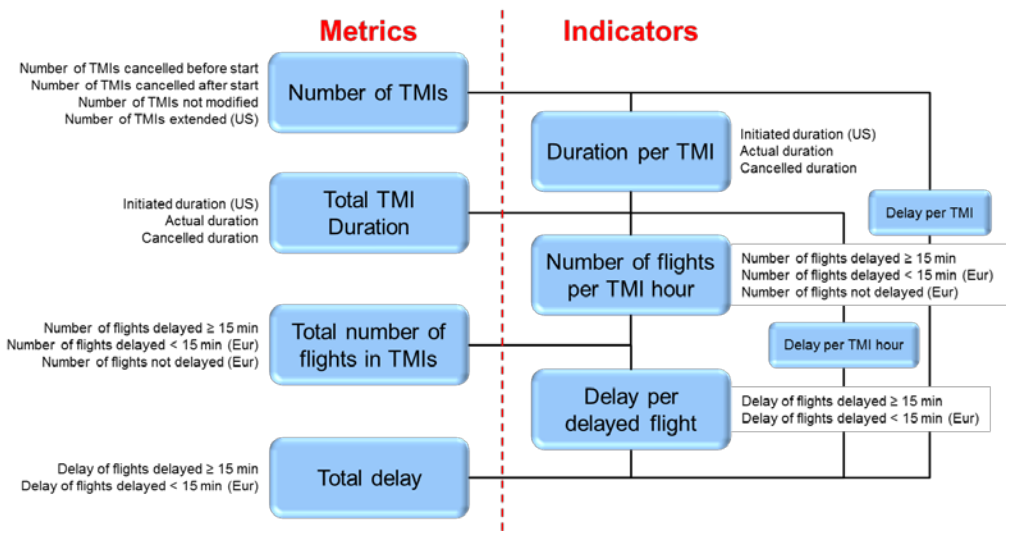

Figure 2. TMI Metrics and Indicators

Data Sources

This study has used archived TMI data for the full calendar years 2015-2018.

For Europe, the primary source was the Network Manager's Enhanced Tactical Flow Management System (ETFMS). The data was retrieved through NMIR (Network Manager Interactive Reporting) which is a protected application that allows operational users to build reports on Network Manager operational archived data and derived performance and quality indicators.

For the U.S., the number and duration of TMIs was derived from the National Traffic Management Log (NTML). This was supplemented by TMI impact data from the Operations Network (OPSNET) which is the official source of National Airspace System (NAS) air traffic operations and delay data.

Geographic Scope of the Comparison

For compatibility reasons, this paper restricts the analysis to the same geographical scope as [1]:

- "Europe" and "EU" refer to the geographical area where the Air Navigation Services (ANS) are provided by EUROCONTROL member States, excluding Oceanic areas, Georgia and the Canary Islands.
- "U.S." and "US" refer 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 (U.S. CONUS).

Data Coverage

TMI-L1 comprising "latent" TMIs has not been quantitatively analyzed in this study and while TMI-L3, TMI-L4 and TMI-L5 are covered by the U.S. data set, such data was not present in the European data.

Table 2. Data Coverage

	Delay TMIs	**Reroute + Level Capping TMIs**
ATFM TMI-L2	Europe: 75-85% of TMIs U.S.: 75% of recorded delay	Europe: 15-25% of TMIs (no delay) U.S.: data N/A
ATC TMI-L3 + L4 + L5	Europe: data N/A U.S.: 25% of recorded delay	Europe: data N/A U.S.: data N/A

TMI-L2 delay TMIs are well covered by data available in both the U.S. and Europe. The benchmarking discussed in this paper focuses on this subset of the data: for Europe it ranges from 75 to 85% of the total number of TMIs at TMI-L2, for the U.S. 75% of the total delay measured at all TMI levels.

In this paper we use the terms TMI-L2 delay and ATFM delay interchangeably.

Reportable Delay

A limitation of the U.S. data is that the measured TMI impact only includes delay from flights delayed by 15 minutes or more. This is called 'reportable delay' [5]. The European data contains the same, but also includes the number of flights and the associated delay of flights delayed 1 to 14 minutes and all other flights 'captured' by a TMI but without any delay attributable to the TMI. In order to make appropriate comparisons, the European data is filtered to only include flights with 'reportable delay' according to the U.S. definition.

Results & Discussion

Traffic and Delay – The Big Picture

Figure 3 depicts the general evolution of traffic in the U.S. and Europe from 2015 through 2018 and gives context to subsequent analysis. Within this period, the annual volume of IFR traffic in the U.S. remained relatively stable. There was a slight dip in 2016 (-2%) followed by two years of growth which resulted in 15.6 million flights in 2018, or a 2% increase from 2015. During the same period, Europe saw a steady growth from 9.7 million in 2015 to 10.8 million flights in 2018, an increase of 10%.

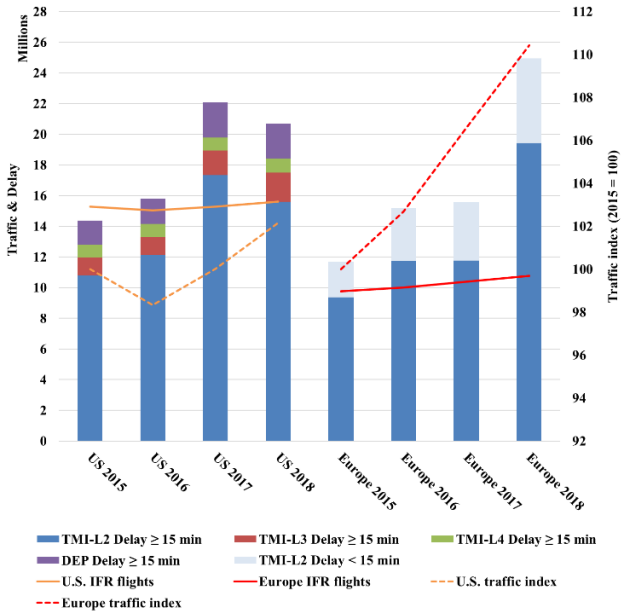

Figure 3 Annual Traffic (flights) and Delay (min) – The Big Picture

In terms of reportable ATFM delay (TMI-L2 delay ≥ 15 min), described by the dark blue bars in Figure 3, the U.S. experienced a significant performance deterioration in 2017, followed by a slight recovery in 2018. In Europe, delay increased in 2016 and stayed level in 2017 despite continued traffic growth. However, delay in 2018 increased dramatically, where total delay more than doubled since 2015, representing a real delay crisis.

Figure 3 also shows that in the U.S., reportable ATC delay (at TMI levels 3 and beyond) is relatively small compared to the ATFM (TMI-L2) delay. Likewise, in Europe the shorter ATFM delays (associated with flights delayed < 15 min) constitute a relatively small portion of the overall ATFM delay. Subsequently, we focus our attention on reportable ATFM delay (TMI-L2 delay ≥ 15 min).

Is There a Relationship Between Traffic and Delay?

Intuitively one would surmise that delay increases exponentially if traffic increases and capacity remains constant. While this may be closer to the truth on a more granular level, we are dealing with highly aggregated data, annual values at regional level, with many factors interacting. Hence the observed performance at the network level may not match expectations.

Figure 4 shows that there was no clear relationship between traffic and delay in the past four years in the U.S. For Europe, Figure 4 suggests that a 10% increase in traffic doubles delay, but without the 2018 data the answer would have been quite different.

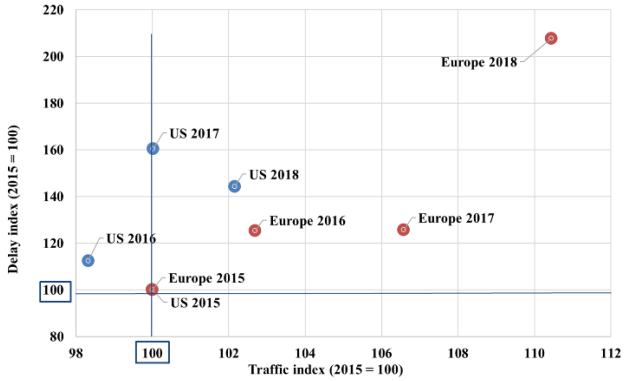

Figure 4 Annual Traffic and Annual Delay Compared to 2015

How Did We Get to These Annual Delay Values?

The values in the previous graphs (Figure 3 and Figure 4) show the delay accumulated by the end of each year. It is also useful to look at the evolution of those delay totals throughout the year, the year-to-date (YTD) values. In 2015, in both the U.S. and Europe, there were no major events that uniquely impacted the systems' demand-capacity balance, therefore, we find it to be a suitable reference year.

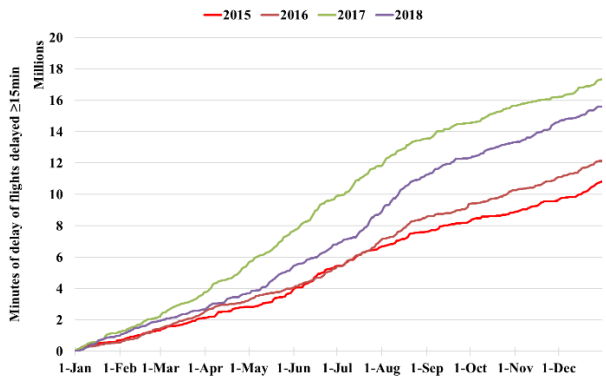

Figure 5 Year-to-date Minutes of ATFM Delay in the U.S.

In the U.S., the cumulative 2016 YTD aggregation of ATFM delay followed the reference profile until the end of July, from which point onward there is upward shift from the 2015 trend. In 2017, the increase started early in the year, with the gap significantly widened by May. Finally, 2018 was nominal during the first 4 months, started to grow in May, and underwent a large increase in the month of August.

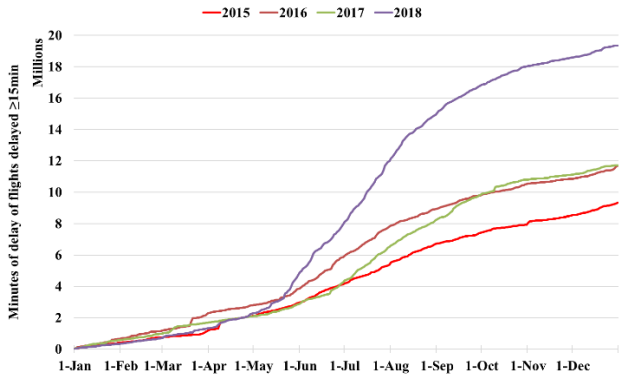

Figure 6 Year-to-date Minutes of ATFM Delay in Europe

In Europe, 2016 was relatively normal until May, when additional ATFM delay was incurred during the summer; the year never recovered. In 2017, the problems started much later, in July, but still ended the year at the same level as 2016. The next year, 2018, showed a similar linear trend to that of the other years until mid-May. An extremely high level of delay was recorded during these summer months and only flattening out towards the end of the year.

Figure 7 looks at the data binned by month, with the U.S. on the left side, and Europe on the right side. We see that the seasonal peaks in delay steadily increase in both regions, year after year.

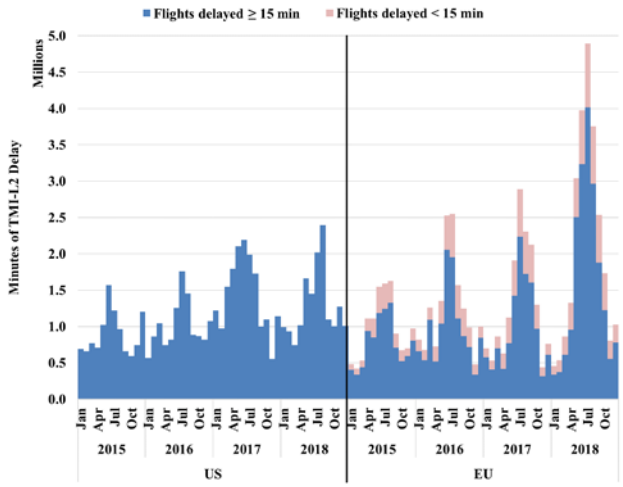

Figure 7 Monthly ATFM Delay in the U.S. and Europe

Another observation is that the U.S. has much higher delay levels outside the peak season than Europe. However, Europe is much more sensitive to seasonal effects. Notice that the high U.S. annual value in 2017 (Figure 5) was caused by the fact that the delay peak lasted for a full six months in that year (clearly visible in Figure 7).

Where Are the Main Bottlenecks?

For analysis purposes, we have subdivided the U.S. and Europe into areas:

- In the U.S., each area is the Flight Information Region (FIR) corresponding to one Air Route Traffic Control Center (ARTCC). The area also includes all underlying TRACONs and airports.

- In Europe, the areas are generally at the level of individual countries, each with their Area Control Centres (ACC), terminal facilities and airports. The multinational Maastricht upper airspace center (UAC) is a separate area; its airspace is excluded from the Germany, Netherlands and Belgium/Luxembourg areas.

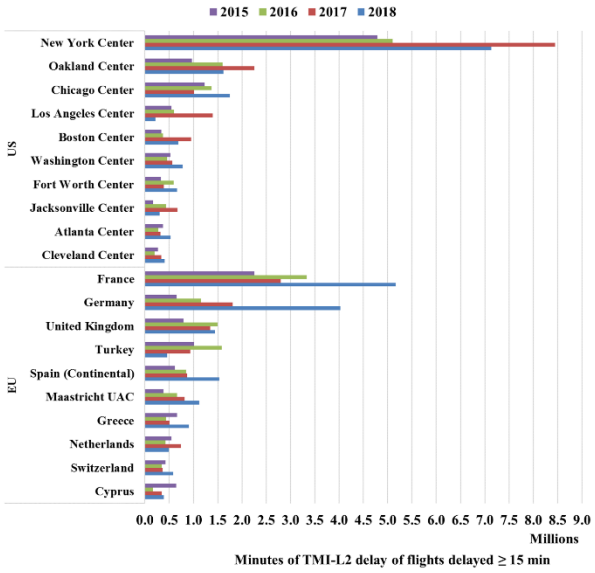

Figure 8 Top-10 Areas Generating Delay

In the U.S., the New York area is by far the biggest source of delay. In addition its delay level has significantly increased in 2017, with only a modest improvement in 2018.

France traditionally was and Germany has become the biggest source of delay in Europe. Their delay levels continue to increase.

Note that in the year 2017, the delay level of the New York area was almost twice the value of France and Germany combined. In 2018, despite the improvement of New York and the deterioration of the situation in Europe, the New York area still generated 40% more delay than all airspace and airports in France.

Zooming in further with Figure 9, we can see the top-10 delay generating facilities on each side of the Atlantic.

In the U.S., 8 out of 10 facilities in the top-10 are airports. The two other ones are en-route centers (ARTCC). Newark Airport (EWR) has become the biggest source of delay in the U.S. in the past 2 years. At the end of 2016, EWR was reclassified from an IATA Level 3 slot-controlled airport to a Level 2 schedule-facilitated airport, allowing for increased traffic to the airport.

In Europe, only 4 out of 10 facilities in the top-10 are airports, with slightly more than half (6 / 10) being en-route centers. The Karlsruhe and Marseille ACCs have developed into the biggest source of delay in Europe over the past 4 years.

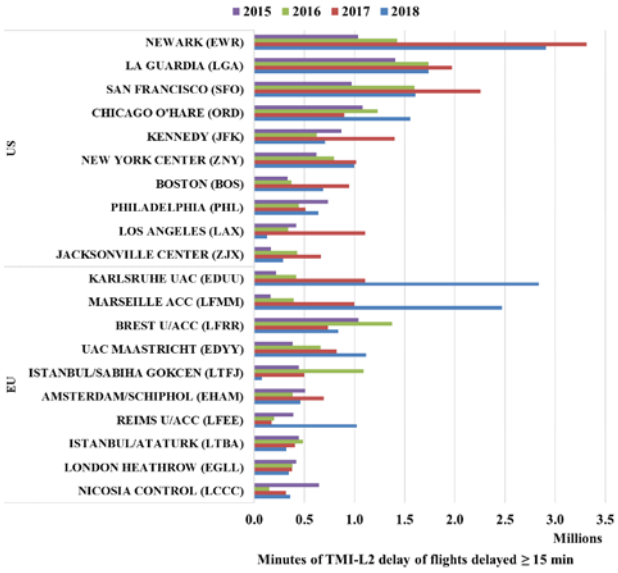

Figure 9 Top-10 Facilities Generating Delay

Contrasting both regions, it is interesting to note that Newark airport and Karlsruhe ACC generated ± the same amount of delay in 2018.

What Are the Primary Reasons for Delay?

Figure 10 shows the main causes of delay in the U.S.

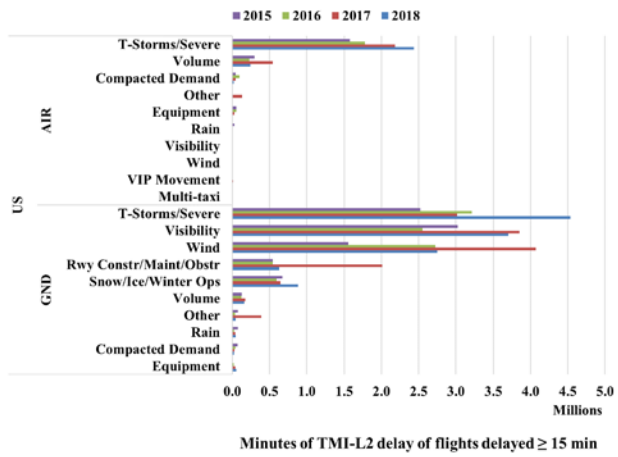

Figure 10 Top-10 Causes of Delay in the U.S.

The predominant cause of ARTCC/TRACON associated delay is thunderstorms/severe weather. Thunderstorms are also a large contributor to ATFM delay at the airport level, with the severe weather being the largest contributor of delay in 2018. Wind, the biggest contributor in 2017, and visibility/low ceilings also comprise a large portion of delay.

The year 2017 was impacted by runway construction/maintenance/obstructions. In that year, the magnitude of the runway-related delays was comparable to the ARTCC/TRACON thunderstorm related delay.

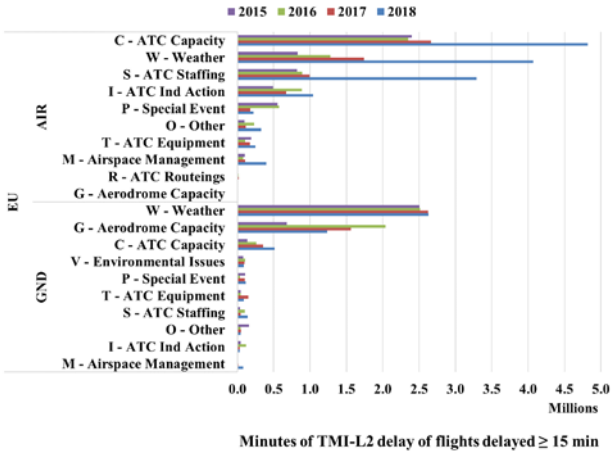

Figure 11 Top-10 Causes of Delay in Europe

At European airports, weather is the most common cause of delay, just like in the U.S., however with little variation over the years. Nevertheless, there is one other important cause of demand-capacity imbalance: aerodrome capacity. In 2016, this category of delay had almost tripled, but since then the situation is gradually improving.

Comparing the U.S. and Europe in 2018, weather related delay (thunderstorms, visibility & wind) at airports was approximately four times higher in the U.S. than in Europe.

In the European airspace, ATC capacity shortfall is the primary delay contributor, while ATC staffing problems are the 3rd. Weather is the 2nd most significant cause. In 2018 each of these 3 delay causes accounted for 2 million additional minutes of delay compared to 2017. The blue bars in Figure 11 show that the current European ATFM delay situation is caused by the en-route environment, not by the airports.

The European en-route delay attributed to weather has more than quadrupled in four years' time; ATC staffing delay has more than tripled in that period and ATC capacity delay has doubled.

Searching for the Mechanisms behind the U.S./Europe Differences

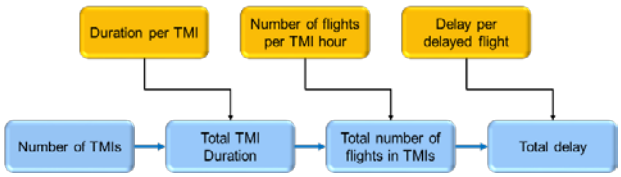

Figure 12 How ATFM Delay is Manufactured

Figure 12 shows conceptually how delay is 'manufactured'. Flow managers apply TMIs as mitigation measures for anticipated and/or imminent demand-capacity imbalances and as such we can use the number of TMIs in each region as an indication for the number of imbalance events. They will then choose a duration for each TMI. This represents the length of the imbalance event. The number of events multiplied with their individual duration gives the total duration of the imbalance condition. Next, the number of delayed flights per TMI hour is a proxy for the impact-level of a given imbalance condition. Combining both factors leads to the total number of delayed flights. Finally, the amount of '*delay per delayed flight*' in combination with the number of delayed flights determines what the total delay will be.

Is 'Delay per Delayed Flight' a Good Indicator?

Figure 13 plots the annual number of delayed flights against annual delay, by TMI level and region, for 2015 to 2018. The gray lines depict reference values of the *delay per delayed flight* indicator.

Based on 4 years of data, for both the U.S. and Europe, we observe an almost linear relationship between the annual delay and the annual number of delayed flights.

For ATFM delay (TMI-L2):

- U.S. reportable ATFM delay is close to 60 min per delayed flight. It slightly increases in years with higher numbers of delayed flights, but still maintains a mostly linear relationship.
- European reportable ATFM delay is close to 30 min per delayed flight.
- European small ATFM delay (associated with flights delayed < 15 min) is about 8.5 min per delayed flight. It slightly decreases in years with higher numbers of delayed flights, but still maintains a mostly linear relationship.

U.S. reportable delay at all ATC TMI levels is somewhat less than half an hour per delayed flight with TMI-L3, TMI-L4, and DEP delay around 26, 24, and 24 min per delayed flight.

Given the relationship between minutes of delay and delayed flights, we make the following observation: while there are big differences in annual delay, these are almost exclusively driven by differences in the *number of delayed flights* because variations in the annual *delay per delayed flight* are orders of magnitude smaller that the differences observed.

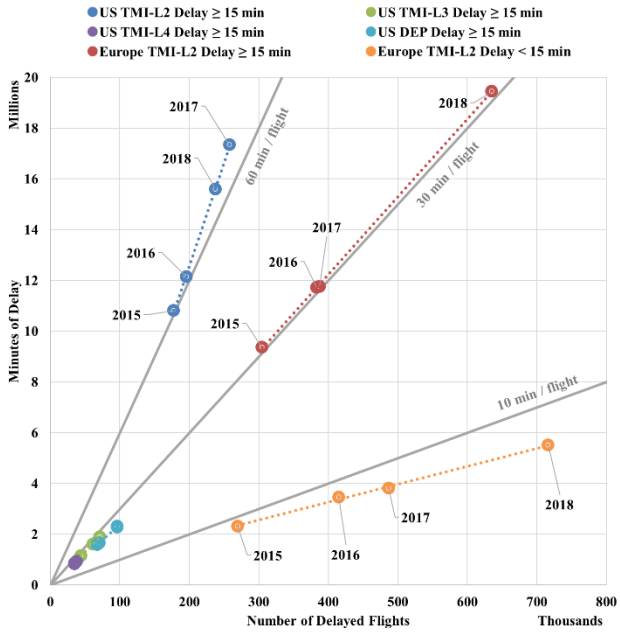

Figure 13 Annual Number of Delayed Flights vs Minutes of Delay

Hence, it makes more sense to consider the parameter *delay per delayed flight* as a system constant, characterizing a kind of hard-wired difference between the U.S. and Europe, instead of using it as a regional performance indicator for measuring annual trends. It is important to add that this conclusion is specific to the annual aggregation of delay on a regional level. As discussed later on, this does not hold at daily or local level.

Again, How Do We Get to These Annual Values?

The previous section looked at the *delay per delayed flight* indicator, as it is measured at the end of the year. As was the case for annual delay, it is also useful to look at the evolution of this indicator throughout the year with year-to-date values. Figure 14 further confirms the conclusion derived from Figure 13: regardless of the outcome on 31st of December (the circle markers on the end of each line), each year follows more or less the same (almost linear) trajectory in its build-up of delay and number of delayed flights. The difference between a good and a bad year is mainly the position of the end-point of the trajectory, not its average slope compared to other years.

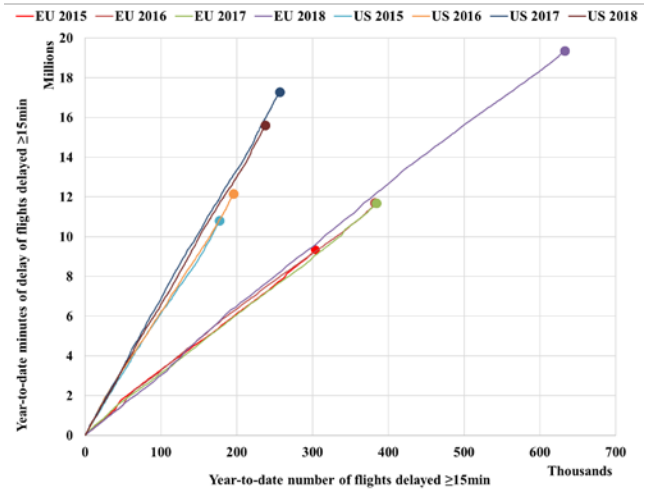

Figure 14 Year-to-date Build-up of ATFM Delay and Number of Delayed Flights in the U.S. and Europe

Note again the difference between the U.S. and Europe. In the U.S., delay is concentrated in a relatively small number of flights, whereas in Europe the same delay is distributed over many flights.

We can take an even more granular look at this data. Figure 15 shows delay and number of delayed flights at regional level, with each data point representing an individual day. Individual days are a suitable level of detail because this allows us to distinguish between 'good' and 'bad' days at network level.

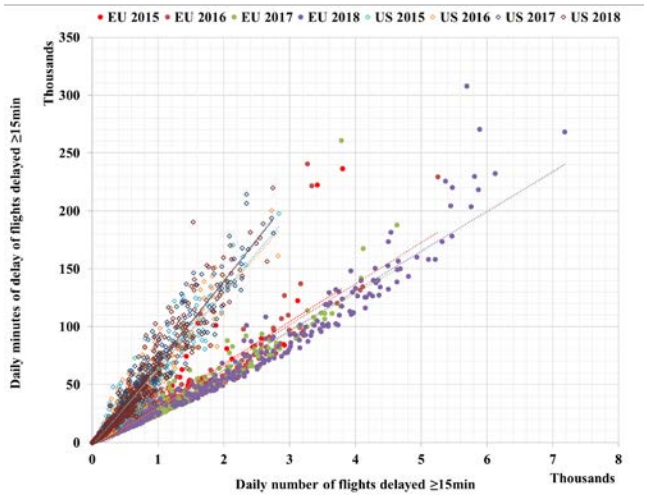

Figure 15 Daily ATFM Delay and the Number of Delayed Flights in the U.S. and Europe

In Europe, delay per delayed flight is more predictable, with a clear lower Pareto boundary of 25 min/flight and a modest dispersion above that. Note that the Pareto boundary is not strictly linear.

In the U.S. there is a bigger dispersion of individual days in both directions around the average daily value of about 60 min/flight. This is even more obvious if we plot the *delay per delayed flight* at daily level throughout the calendar year, as shown in Figure 16.

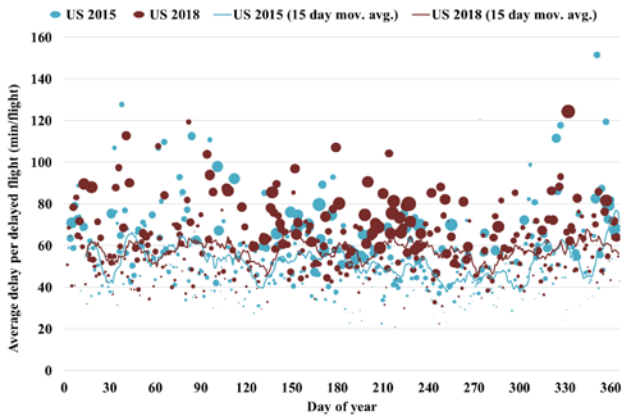

Figure 16 Daily ATFM Delay per Delayed Flight in the U.S. (2015 & 2018)

In Figure 16 and Figure 17, each bubble on the chart is one day of the year, where the color corresponds to the year (2015 or 2018) and where the size of the bubble is proportional to the total daily delay. This visually gives more weight to days with high delays. In addition to the bubbles, there is a line showing the 15-day moving average of the delay per delayed flight. Also note the different vertical scales in the two graphs, due to the fact that the average delay per delayed flight is much smaller in Europe than in the U.S.

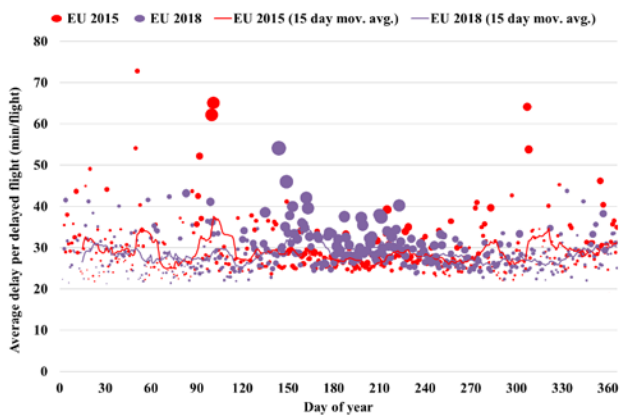

Figure 17 Daily ATFM Delay per Delayed Flight in Europe (2015 & 2018)

On both sides of the Atlantic, each day tends to be quite different from the previous day. This is a challenge for the pre-tactical (next-day) planning. However, one can see in the figures that in Europe, days with large delay are less disperse than in the U.S., illustrating a more predictable situation.

Note that in terms of *delay per delayed flight*, there is not an obvious seasonal effect; on average the *delay per delayed flight* is more or less the same. This is in line with Figure 14, which shows a close to linear build-up of delay against the number of delayed flights throughout the year.

Translation of TMI Duration into Number of Delayed Flights

If we go one step back in Figure 12, we can take a look at how the duration of (and hence exposure to) demand-capacity imbalance is translated into the number of delayed flights.

Figure 18 plots TMI hours against the number of delayed flights. The graph is limited to ATFM (TMI-L2) and excludes the duration of rerouting and level capping TMIs in Europe (because these do not generate delay).

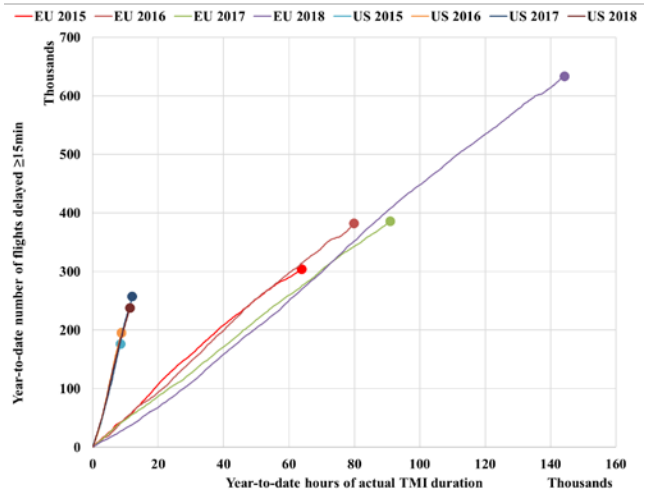

Figure 18 Year-to-date Build-up of ATFM Delayed Flights and TMI Duration in the U.S. and Europe

In the U.S., over the years there is well-defined relationship between TMI hours and the number of delayed flights. This is much less the case in Europe, as can also be seen in Figure 19.

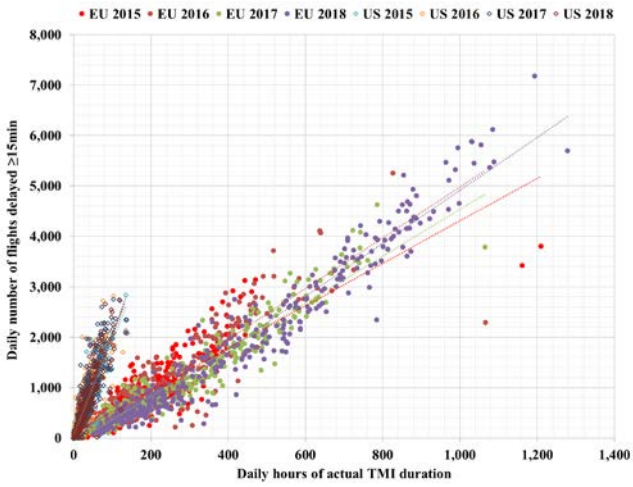

Figure 19 Daily Number of ATFM Delayed Flights and TMI-hours in the U.S. and Europe

Note in that 2017 and particularly in 2018 in Europe, the number of delayed flights per TMI hour has been going down on days with a small number of TMI hours. These days were in the first half of the year as can be seen in Figure 21.

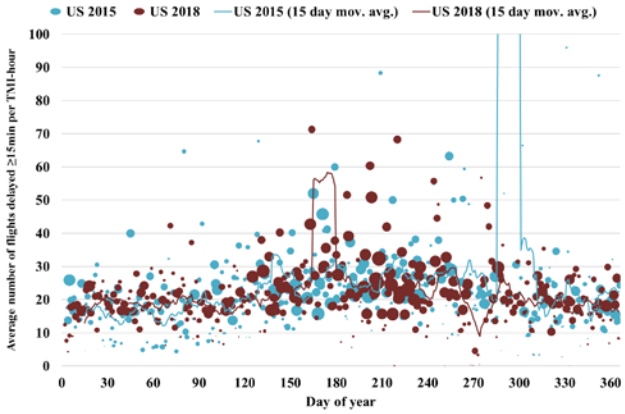

Figure 20 Daily Number of ATFM Delayed Flights per TMI-hour in the U.S. (2015 & 2018)

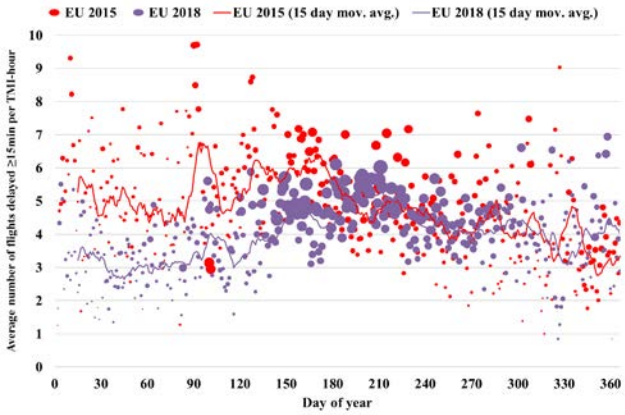

Figure 21 Daily number of ATFM Delayed Flights per TMI-hour in Europe (2015 & 2018)

Translation of Number of TMIs into TMI Duration

Finally, let us look at the number of TMIs used by flow managers to deal with demand-capacity imbalance events.

The U.S. uses about 3,500 to 4,500 ATFM TMIs annually. Europe has been using approximately 25,000 delay generating ATFM TMIs in 2015 (i.e. excluding a significant number of rerouting and level capping TMIs), but this number has been steadily growing to 55,000 in 2018.

This huge difference in the number of ATFM TMIs is not due to a corresponding difference in the number of constrained facilities for which TMIs are necessary: for example to cover 90% of all TMIs in 2018, we only need to look at 40 constrained facilities in the U.S. (29 airports, 9 ARTCCs, 2 TRACONs), and in Europe this is somewhat more: 65 constrained facilities (31 airports, 30 ACCs, 4 APP facilities). In other words, on average the U.S. applied approximately 110 TMIs per year per constrained facility, compared to 850 in Europe.

Because of the significant difference in number of TMIs, we are showing the U.S. and Europe in separate graphs below. Also because the average TMI durations are roughly the same on both sides of the Atlantic, the U.S. and Europe data would be fully overlapping if shown in the same graph.

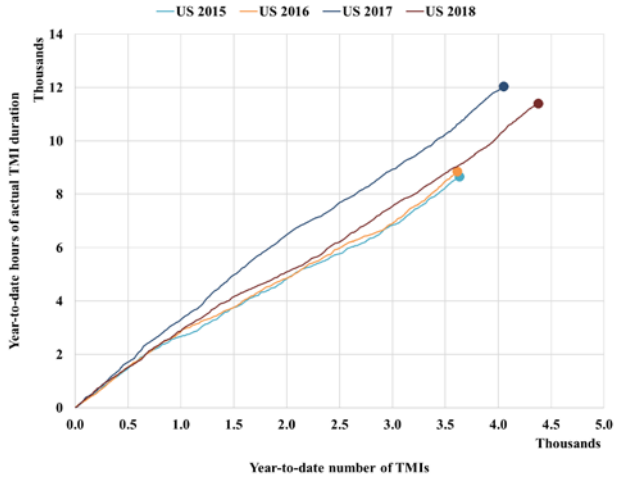

Figure 22 Year-to-date Build-up of TMI Duration and Number of TMIs in the U.S.

In the U.S., 2015 and 2016 were very comparable. A larger number of TMIs, with a significantly longer duration, characterized the year 2017. In 2018, slightly more TMIs were used than in 2017, but with an average duration more like in 2015 and 2016.

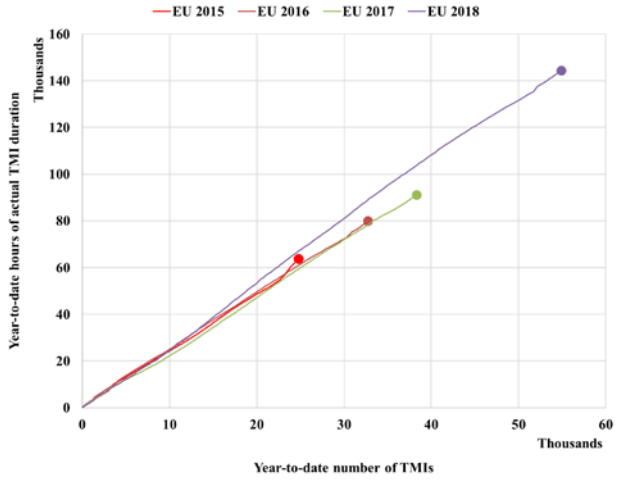

Figure 23 Year-to-date Build-up of TMI Duration and Number of TMIs in Europe

We already mentioned that in Europe, each year, more TMIs were used: the value doubled between 2015 and 2018. The average TMI duration was more or less the same in 2015, 2016 and 2017. However, in 2018, Europe also started applying longer duration TMIs. This was mainly due to the summer season (see Figure 25).

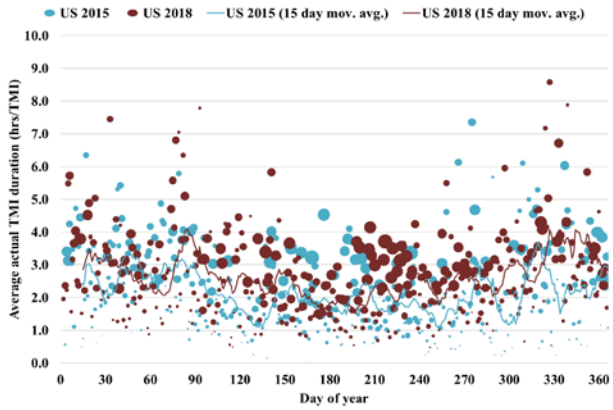

Figure 24 Daily Average TMI Duration in the U.S. (2015 & 2018)

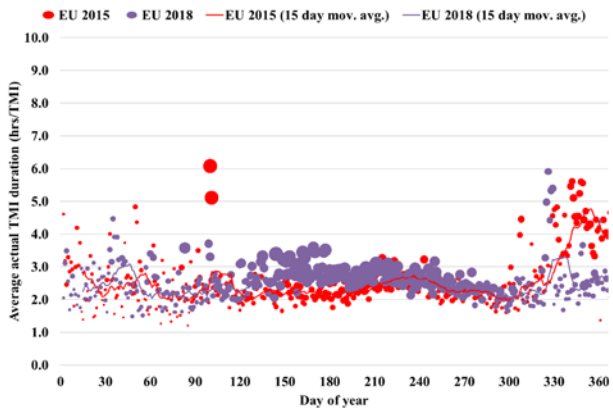

Figure 25 Daily Average TMI Duration in Europe (2015 & 2018)

In December of 2015 (c.f. Figure 25) Europe had quite some days with long duration TMIs. This did not translate into higher delay values, as can be seen by comparing the December months of the different years in Figure 7.

The two red outliers with average TMI durations of 5 and 6 hours were 8th and 9th of April 2015. These were days that a national ATC strike took place in France, impacting the entire European ATM network. These days can be easily identified in some other graphs as well, for example in Figure 17 and Figure 30.

How Are Airspace Users Affected by the Actions of Flow Managers?

In the previous sections we analyzed the different stages of the 'delay production process' shown in Figure 12. We observed at each stage that because of a relatively stable input/output ratio, 'more input' always results in 'more output'. Does that mean that due to transitivity we can use the number of TMIs as a proxy for the total delay at the end of the year? The following graphs explore this end-to-end relationship, which relates the actions taken by flow managers (high level view in terms of number of TMIs) to the delay impact experienced by airspace users.

Figure 26 shows that in the U.S. a small number of TMIs is sufficient to generate extreme delay, with higher annual delay linked to higher average delay per TMI. In Europe the delay builds up at a much lower ratio and in a similar fashion in each year, but the paths followed in 2017-2018 were quite different from 2015-2016.

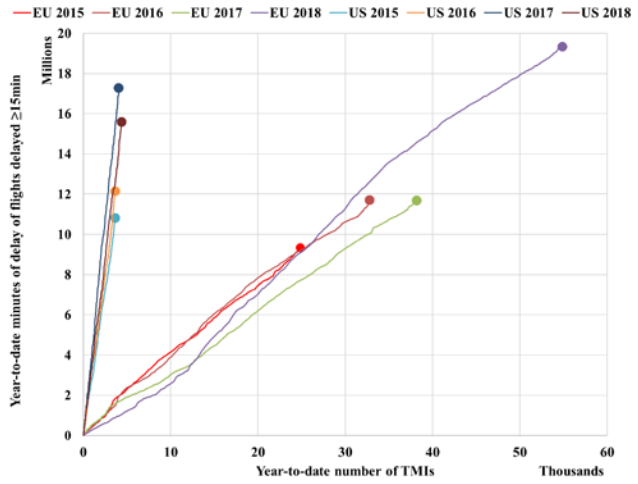

Figure 26 Year-to-date Build-up of ATFM Delay and Number of TMIs in the U.S. and Europe

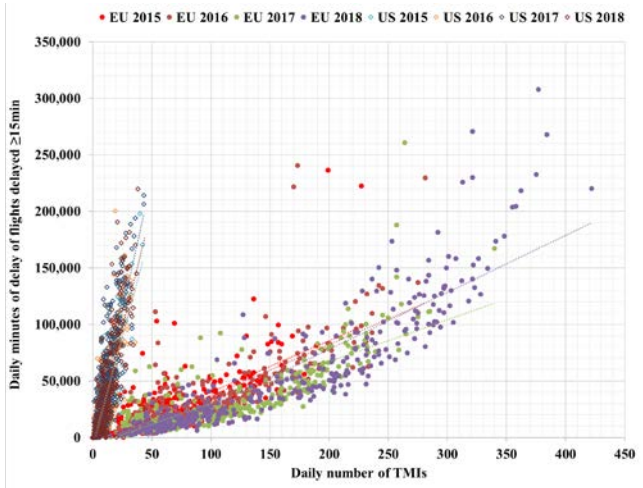

Figure 27 Daily ATFM Delay and Number of TMIs in the U.S. and Europe

Figure 27 suggests that there is a linear relationship between the daily number of TMIs and the resulting delay for the U.S., but when we zoom in (Figure 28) we see that the behavior is quite amorphous. Europe is quite different: we see an exponential Pareto boundary which gets lower each year. In other words: a given number of TMIs on a particular day is likely to generate less and less delay; but also: over the years, a given level of delay is associated with more and more TMIs.

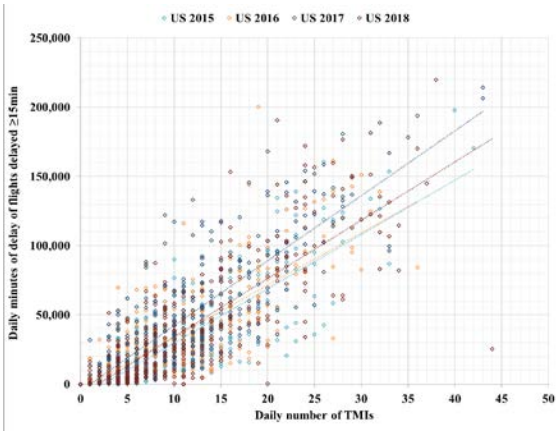

Figure 28 Daily ATFM Delay and Number of TMIs in the U.S.

Figure 29 shows that in the U.S., on days with lots of delay, TMIs will generate between 3,000 and 7,000 minutes delay per TMI on average.

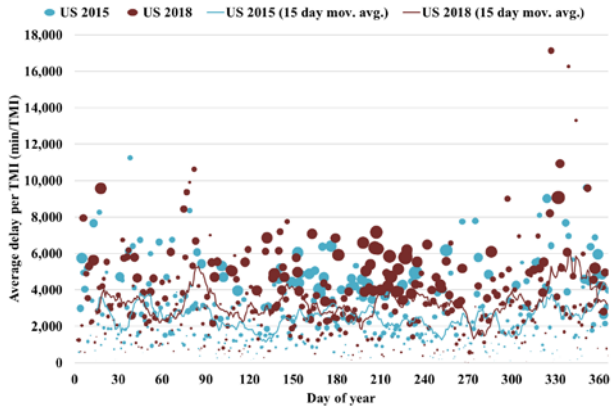

Figure 29 Daily ATFM Delay per TMI in the U.S. (2015 & 2018)

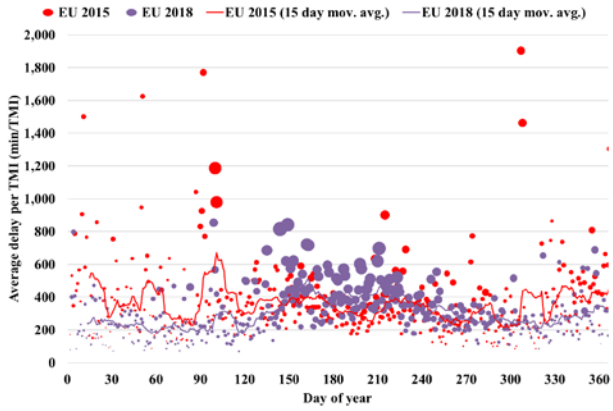

Figure 30 Daily ATFM Delay per TMI in Europe (2015 & 2018)

In Europe (Figure 30), this ranges between 300 and 800 minutes per TMI on days with heavy delay. These are very much concentrated in the summer season.

Conclusions

The FAA and EUROCONTROL have been collaborating for many years to benchmark the operational Air Traffic Management-related operational performance of the U.S. and Europe. In 2015, work started exploring a novel approach to look at ATFM practices and performance. Initial results for 2015 data were presented in [3]. This paper presents the results of further work on this subject covering the period 2015-2018. This also includes looking at the data in new ways, which has brought interesting new insights.

The 'classic' analysis led to the following conclusions:

- Within the analyzed period, the overall IFR traffic levels in the U.S. remained more or less stable, whereas in Europe traffic grew by 10%.
- The U.S. saw a significant increase of ATFM delay in 2017; in Europe this happened in 2018.
- At the regional-annual level, there was no clear relationship between traffic and delay in the past 4 years.
- At the monthly level, we see that the delay peak gets higher and higher in both regions, year after year.
- The U.S. has much higher delay levels outside the peak season than Europe. However, Europe is much more sensitive to seasonal effects.
- In the U.S. the New York area is by far the biggest source of delay. In 2017, this area generated almost twice the value of France and Germany combined. France traditionally was and Germany has become the biggest source of delay in Europe.
- At the level of individual facilities, airports dominate the U.S. top-10 of delay generators, whereas in Europe it is more of a mix of airports and en-route facilities (ACC). In the U.S. the top-10 is led by Newark (EWR). In Europe the top is populated by the Karlsruhe and Marseille ACCs. Newark Airport and Karlsruhe ACC generated about the same amount of delay in 2018.
- In the U.S., the main cause of ATFM delay is thunderstorms/severe weather. In Europe, weather is the main cause at airports; in en-route airspace the top-3 causes are, in order, ATC capacity shortfall, weather and ATC staffing problems.

We also scrutinized the "delay production process" which transforms demand-capacity imbalance events via numbers of TMIs into TMI hours, which in turn result in numbers of delayed flights, and finally result in minutes of ATFM delay. We found the following:

- The U.S. uses about 3,500 to 4,500 ATFM TMIs annually. Europe has been using approximately 25,000 delay generating ATFM TMIs in 2015 (excluding a significant number of rerouting and level capping TMIs), but this number has been steadily growing to 55,000 in 2018.
- This huge difference in the number of ATFM TMIs is not due to a corresponding difference in the number of constrained facilities for which TMIs are necessary: for example to cover 90% of all TMIs in 2018, we only need to look at 40 constrained facilities in the U.S. (29 airports, 9 ARTCCs, 2 TRACONs), and in Europe this is somewhat more: 65 constrained facilities (31 airports, 30 ACCs, 4 APP facilities). In other words, on average the U.S. applied approximately 110 TMIs per year per constrained facility, compared to 850 in Europe.
- On average, the TMI durations are roughly the same on both sides of the Atlantic. However, in the U.S. there are big variations between days, whereas in Europe the daily average is much more predictable.
- In the U.S., each TMI hour leads to a large number of delayed flights: more than 20 flights/hour, whereas in Europe this is less than 4 flights/hour. This value is largely independent of the number of TMI hours and hence the number of TMIs.
- Likewise, the delay per delayed flight is significantly different between the U.S. and Europe (60 vs 30 min/flight), and to a large extent independent of the number of delayed flights.

- Finally, the authors combined the above to explore how the actions taken by flow managers, in terms of number of TMIs, relate to the delay impact experienced by airspace users. In the U.S. there appears to be a linear relationship between the daily number of TMIs and the resulting delay, whereas in Europe this is more of an exponential relationship, where – despite the increasing delay levels – we observe a Pareto boundary which progressively gets lowered in the period 2015-2018. In other words, for a given number of TMIs, the lower boundary of generated delay is reduced each year.

Future Directions

The available data has not yet been fully exploited. We foresee deep dives and case studies to improve our understanding, and plan to tap into other data (e.g. flow rates of TMIs) and other subjects like rerouting and level capping as well. This further work will inform future regional comparison studies.

References

[1] EUROCONTROL and Federal Aviation Administration, forthcoming, 2017 Comparison of Air Traffic Management-Related Operational Performance: U.S./Europe.

[2] International Civil Aviation Organization (ICAO), forthcoming, Global Air Navigation Plan 2019, Doc 9750, www4.icao.int/ganpportal/ASBU/KPI

[3] Shetty, Kamala, et al., 2017, Comparison of ATFM practices and performance in the U.S. and Europe, Integrated Communications, Navigation and Surveillance Conference (ICNS), IEEE.

[4] International Civil Aviation Organization (ICAO), 2018, Manual on Collaborative Air Traffic Flow Management (ATFM), Doc 9971.

[5] Federal Aviation Administration, 2015, JO 7210.55F - Operational Data Reporting Requirements.

Acknowledgements

This work was carried out in the context of Memorandum of Cooperation NAT-I-9406A between the United States of America and the European Union on Air Traffic Management modernization, civil aviation research and development and global interoperability, specifically its Annex 1 Appendix 2, collaboration on Air Traffic Management performance measurement.

The authors wish to thank the FAA ATO Performance Analysis Office, the FAA Air Traffic Control System Command Center, the EUROCONTROL Performance Review Unit and the EUROCONTROL Network Manager for their support in conducting this research.

Disclaimer

The views expressed in this paper are the authors' own and do not represent a policy or position of the FAA or EUROCONTROL.

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