“Newark Airport (EWR) vs. Frankfurt am Main Airport (FRA) - A detailed operations benchmarking.”

Wilhelm Drotleff
European Center for Aviation Development GmbH, 64289 Darmstadt, Germany
Tel. +49 (6151) 3605412
wilhelm.drotleff@ecad-aviation.de

Thomas Morisset
Massachusetts Institute of Technology
Dept. of Aeronautics and Astronautics
Tel. +86 (136) 51752146
morisset@alum.mit.edu

Florian Oesterle
European Center for Aviation Development GmbH, 64289 Darmstadt, Germany
Tel. +49 (6151) 3605400
florian.oesterle@web.de

Alexander Zock
European Center for Aviation Development GmbH, 64289 Darmstadt, Germany
Tel. +49 (6151) 3605400
Alexander.zock@ecad-aviation.de

Amedeo Odoni
Massachusetts Institute of Technology
Dept. of Aeronautics and Astronautics
Tel. +001 (617) 253-7439,
arodoni@mit.edu

The airside performance of airports is determined by many factors, including infrastructure geometry, ATM technology and human resources, demand scheduling, traffic mix, operating strategies, and environmental constraints. As part of a broader effort comparing performance at major airports in the United States and Europe, an in-depth study of operations at Newark International Airport (EWR) and Frankfurt/Main International (FRA) has been carried out, focusing on 2007, when airport congestion reached a peak. The two airports were selected because of the similarities in their runway layouts, regional importance, and air traffic characteristics. The analysis relies on the ASPM database of the FAA and on internal and METAR data of DFS. The first part describes demand, weather conditions, traffic mix and runway utilization and indicates significant differences in the scheduling of movements and the usage patterns of the third runway at the two airports. Next, the maximum throughput capacities of the two airports, under a full range of weather conditions, is estimated from the empirical data. Capacities clearly vary significantly with weather conditions at both airports, with FRA achieving higher throughput values, largely because of how the third runway there can be utilized. Finally, delays, punctuality, and schedule reliability at the two airports were compared. Slot controls at FRA that spread demand evenly during the day at levels consistent with the airport’s capacity under instrument meteorological conditions are primarily responsible for lower arrival and departure delays and significantly higher punctuality values. In contrast, schedule reliability deteriorates sharply at EWR in the afternoon and evening. A detailed analysis of gate delays versus taxi-out delays on departure also demonstrated striking differences in the ways the two airports are operated. In summary, the study highlights the impact of different operational regimes on the operational performance of congested airports.

1 INTRODUCTION

Europe and the United States are two areas of the world where air transport has developed extensively over the past decades and has established itself as the dominant mode of long-distance transportation, supported by an infrastructure consisting of a large set of major commercial airports, connected by means of some of the most advanced air traffic management (ATM) systems in the world.

In 2008, the Federal Aviation Administration (FAA) and EUROCONTROL undertook an extensive study aimed at understanding the differences and similarities of the ATM and airport systems in the US and in Europe and at identifying, when possible, best practices. A joint report has been issued (Gulding et al 2009; FAA and EUROCONTROL 2009) that presents the first relevant findings, comparing many aspects of the two systems' performance, including flow management, en route, terminal area, and taxiway operations. A second related study (Morisset and Odoni 2010; Morisset 2010) has concentrated on making some broad comparisons between some performance characteristics of the 34 busiest airports in Europe and in the US. In this paper, we report some early results from ongoing research that supplements this broader effort by comparing in more detail certain important aspects of the performance of two specific major commercial airports, Frankfurt (FRA) and Newark (EWR). The focus here is on the specific questions of how (i) airside airport capacities, (ii) airport scheduling practices, (iii) airport air traffic delays and (iv) flight schedule punctuality compare at the two airports. As will be seen, some significant differences do exist in all these respects between the two airports with the most striking ones being the divergent philosophies vis-à-vis scheduling and the major consequences this has for airport delays and schedule punctuality.

Section II provides a short description of the data used for this project. In section III the main characteristics of the two airports are described briefly for background. Section IV presents airside capacity comparisons between the two airports. Section V deals with air traffic delays and punctuality and their implications for airline scheduling. Finally, Section VI summarizes the principal conclusions.

2 DATA

In order to perform the planned benchmarking analysis, a wide set of data had to be collected and evaluated.

Weather data were retrieved from RAW Aviation Routine Weather Report[1] (METAR) messages for FRA and from processed METAR data extracted from the ASPM database (see below) for EWR. For FRA, METAR messages were available at intervals of 20 min for the entire year 2007. EWR METAR messages were available every 15 min for all of 2007. The METAR messages contained descriptive data about wind speed and direction, precipitation, cloud cover and cloud heights as well as runway visual range indications.

In addition to the weather data, recordings of actual movements (arrivals and departures) were also used in this study. For FRA movement data were derived from COPPER, an integrated information platform designed by DFS, Fraport AG and Deutsche Lufthansa AG in order to monitor punctuality, delays and other performance indicators at FRA. For each movement, the provided datasets contained attributes such as the flight date and time, DEP/ARR airport, scheduled time of arrival/departure, estimated time of arrival, actual time of arrival, taxi-time in, runway used, actual in-block time, actual time of arrival, scheduled in-block time and actual taxi-time in. For EWR, the FAA's Aviation System Performance Metric (ASPM[2]) database was used – a very comprehensive database that merges several different data sources and tools (flight data, statistical analysis, database linkage and exploration) to provide the means for flight data analysis and interpretation. To a great extent, ASPM records parallel the COPPER records, thus permitting direct comparisons even though ASPM's functionality is of a broader scope than COPPER's.

In addition to the above, flight schedule data from OAG[3] Back Solutions were also included in order to obtain information about the planned aircraft mix, such as the percentage of heavy aircraft, at each airport.

---

[1] FEDERAL METEOROLOGICAL HANDBOOK No. 1, Surface Weather Observations and Reports FCM-H1-2005; September 2005

[2] http://ASPM.arc.nasa.gov/ (13th of Nov 2010)

[3] http://www.oagaviation.com/

3 DESCRIPTIVE ANALYSIS

Newark International (EWR) and Frankfurt am Main International (FRA) are two major airports located in the US and Germany that are of major importance to their regional aviation systems. Both have already been the subject of detailed investigation and performance measurement by the respective local and national authorities. These two airports were chosen for this in-depth benchmarking study because they i) are considered to be congested airports, ii) operate with three runways in a similar configuration, and iii) handle a comparable number of annual movements (see Table 1 for details). Furthermore, both airports qualify as good examples of the American and European ATM operations models and schedule-setting practices. FRA is a fully coordinated airport that applies the slot coordination process specified by the EU regulations, while EWR was not subject to slot constraints in 2007.

	FRA	EWR
No. of pax	54,2 mln	36,4 mln
No. of movements	479.874	443.952
pax/movement	113	82
No. of runways	3	3
Cargo volume (t)	2,2 mln	0,9 mln
% intern. Pax	85%	29%
Carrier	LH	CO

Table 1 Comparative overview[4] of the two airports

3.1 *Airport Layouts & Setting*

The geometric layouts of the two runway systems are quite similar (each airport has two close-spaced parallel runways that do not allow independent parallel operations) and a third runway at a nearly right angle with the parallel runways. FRA's third runway, 18(W), does not intersect the parallel runways and is used for departures only, so that the majority of departures from the airport can be handled by this runway (Section 3.2). EWR's third runway intersects the close parallels and its use is constrained by noise abatement regulations. FRA is subject to night curfew regulations between 1 and 4 a.m., whereas EWR is not.

Both airports function as hubs for an international carrier. For FRA this is Deutsche Lufthansa and its STAR alliance partners. At EWR Continental Airlines (now United Continental) is the dominant carrier.

An important difference between the two airports is that EWR is part of the world's busiest multi-airport system, due to its proximity to the airports of LaGuardia (LGA), Kennedy (JFK) and Teterboro (TEB), whereas FRA is only somewhat influenced operationally by two small general aviation airports in its vicinity.

3.2 *Runway utilization*

In FRA, approximately 65-75% of the arrivals operate on runways 25R and 25L. The remaining arrivals use runways 07L and 07R. Runway 18(W) operates largely independently of the two close parallel runways. This operational pattern is mainly determined by the wind regime in the FRA area, which is characterized by predominately Western winds. Runway 18(W) is restricted to operations to the south, due to obstacles in the northern direction. Additionally, 18(W) at FRA is subject to special wind conditions, e.g., a northern wind or strong western or eastern shear wind components may lead to the occasional closing of this runway.

Due to the fact that only departures are performed on 18(W), it serves as a crucial "reliever" of the parallel runways and serves approximately 60% of the total departures from FRA. Runway 25R, next to the major terminals, serves 25% of all departures, while 25L serves only a small number of departures. Currently, FRA is upgrading its runway system with a fourth runway to the Northeast of the existing runway system. This runway, scheduled to open in 2011, is expected to serve arrivals only. The new runway will be able to operate independently from the other runways. The runway-usage patterns at EWR differ from those at FRA. Due to noise abatement regulations and terminal airspace (TMA) constraints associated with the multi-airport system, EWR's third runway, 11-29 is mainly

[4] Source: ACI World Traffic Report 2007

used during afternoon hours in the 29 direction and very seldom during the morning hours. When in use in the afternoon, the third runway is operated in tandem with runway 22L and 22R and handles about 50% of all arrivals. In the very few cases when the runway is utilized in the morning, it handles a few departures and almost never any arrivals.

3.3 *Daily traffic and aircraft mix*

A detailed analysis of the daily traffic patterns at both airports reveals interesting differences.

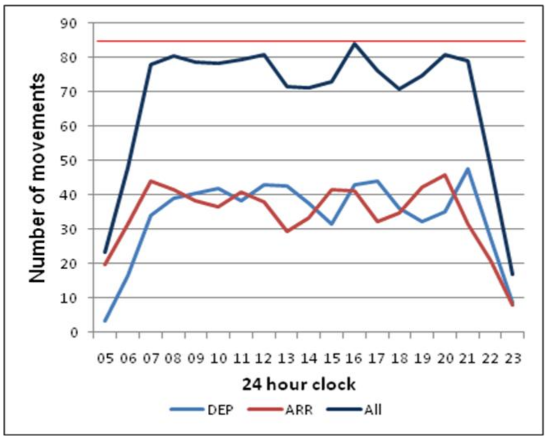

Figure 1 Scheduled movements FRA (total, DEP, ARR) from 5am to 23pm

First the overall daily traffic profile at FRA is very even with only a slightly peaked structure (Figure 1). Total movements scheduled during peak times are close to the coordinated threshold value of 84 movements per hour (red horizontal line in Figure 1).

Despite this overall even traffic profile, there are clear departure and arrival peaks at 6 a.m., 9 a.m., 12 a.m., 3 p.m., 4 p.m., 8 p.m. and 9 p.m.

The overall traffic profile at EWR is significantly different: it is highly asymmetrical as far as the number of movements between 6 and 12 a.m. and between 13 and 22 p.m. are concerned. In the morning hours there is a short but pronounced peak at 8 a.m., followed by a steady increase in traffic volume starting at 10 a.m. that reaches a maximum at about 4 p.m. The peak is driven by arrivals as well as by departures, with arrivals contributing a slightly higher volume. Traffic declines in the late evening hours starting around 9 p.m.

Traffic also varies by day-of-the-week at both airports, with the main difference being between workdays and the weekend. Variability is negligible across workdays. A typical summer-winter cycle can also be observed at both airports, with significantly higher traffic numbers in the summer and early fall. FRA’s busiest month is October and EWR’s August.

A further important difference can be found in the daily aircraft mix (see Figure 3 for arrivals). The number of movements by “heavy” aircraft and the distribution of these movements by time-of-day is of great interest, as it strongly impacts the maximum throughput

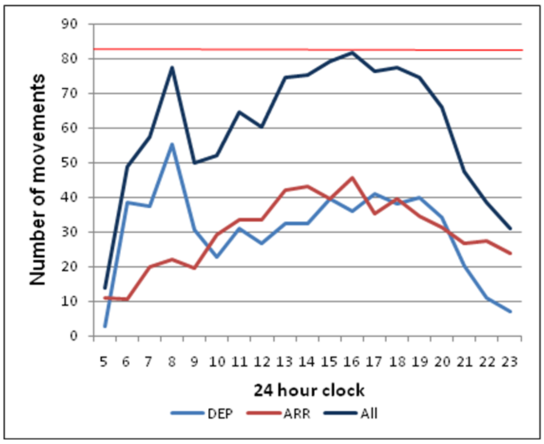

Figure 2 Scheduled movements EWR (total, DEP, ARR) from 5am to 23pm

capacity of the two airports. FRA has a significantly higher overall share of heavy aircraft traffic than EWR. This can be explained by the fact that FRA serves as one of the main intercontinental hubs for Lufthansa and its STAR alliance partners. EWR’s function is in that respect more that of a continental hub

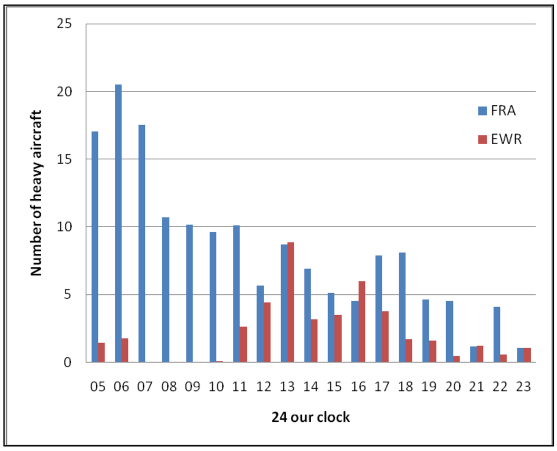

Figure 3 Arrival-share of heavy aircraft for FRA and EWR (whole year 2007)

with overall lower figures of international, as well as of connecting passengers. At FRA traffic peaks for heavy aircraft are evident in the early morning between 5 a.m. and 11 a.m.. followed by two smaller ones around 1 p.m. and 6 p.m. The corresponding peaks at EWR consist of a small peak in the early morning between 5 and 6 a.m. followed by more pronounced peaks at 1 p.m. and 4 p.m.

3.4 *Weather Conditions*

Similarities between the two airports were also observed with respect to weather conditions in 2007. EWR experienced instrument meteorological conditions (IMC) for 16% of the time and FRA for 12 %. Interestingly, not only the overall percent of days with IMC was similar at both airports, but so was the monthly distribution of these days. It is known that 2007 had an extraordinarily high amount of good weather. Normally FRA's share of IMC weather is expected to be higher than what is experienced at US East Coast airports such as EWR. It should be noted that in the US the use of visual flight rules (VFR) in VMC is much more extensive than in Europe (Morisset and Odoni 2010; Morisset 2010).

	VFR	MVFR	IFR	LIFR
EWR	70%	16%	10%	4%
FRA	52%	34%	7%	7%

Table 2 Occurrence of different categories of weather conditions at EWR and FRA; statistics for EWR are based on 57% of all observations (see text).

4 AGGREGATED CAPACITY ESTIMATION

A fundamental performance measure of any airport is its maximum throughput capacity, defined as the expected number of aircraft movements (landings and takeoffs) that can be performed on the airport's runway system in the presence of continuous demand (de Neufville and Odoni 2003). The maximum throughput capacity (CAPA henceforth) is generally a function of several variables, including, for example, weather conditions,

Category	Ceiling		Visibility
VFR	greater than 3000 feet AGL	and	greater than 5 miles
MVFR	1000 to 3000 feet AGL	and/ or	3 to 5 miles
IFR	500 to 1000 feet AGL	and/ or	1 to 3 miles
LIFR	less than 500 ft AGL	and/ or	less than 1 mile

Table 3 Classification of weather conditions

runway configuration in use, aircraft mix, and operations mix (arrivals vs. departures).

CAPA can be determined from empirical data or can be estimated theoretically with a "capacity model". The former method is more reliable when good-quality and plentiful data are available, since the theoretical models cannot capture all the details of local operating conditions, especially for airports that, like FRA and EWR, utilize complex configurations with interdependent movements on different runways. However, there is no alternative to utilizing the theoretical estimation approach when assessing the impact of future operating conditions or of potential modifications to existing airport configurations, ATM technologies and procedures, etc.

Since the focus of the present study was on the empirical performance of FRA and EWR, an extensive data analysis was carried out. The study concentrated on estimating CAPA under various types of weather conditions at times when all three runways were in use at each airport. Weather conditions were classified into four categories – VFR, MVFR (for "Marginal" VFR), IFR, and LIFR (for "Low" IFR) – depending on ceiling and visibility, as shown in Table 3.

It should be noted that the term "VFR" does not necessarily imply that visual separations were used during the corresponding periods of time. It only ascertains the presence of visual meteorological conditions (VMC) that might permit the use of VFR, if desired (see also Section 3.4). Unfortunately, no data were available, either at FRA or at EWR, to indicate whether, in fact, visual separation procedures were used for some (or all) movements during such periods.

The frequency of the occurrence of the above conditions was reasonably similar at the two airports in 2007, as suggested by Table 2. It should be noted, however, that the percentages shown for EWR in Table 2 are based on only 57% of all 15-minute intervals of the year. For the remaining 43%, weather data were not sufficiently fine-grained to permit distinction between VFR and MVFR or between IFR and LIFR.

To estimate the overall CAPA for both airports all 15-minute observations available for 2007, were ranked by the total number of movements actually performed at each airport in the respective interval. The CAPA of the considered airport was then assumed to be identical with the 98-th percentile of these observations. This procedure shows for FRA a CAPA value of 24 movements in 15 min (96 movements per hour) and for EWR a value of 22 movements in 15 min (88 movements per hour).

In a second step the observed throughputs in 15 min intervals of both airports were categorized according to the prevailing weather conditions during these time intervals. To estimate the weather dependent CAPA values for each airport and each weather category the 95-th percentile in each category was used. For all the values of CAPA that were estimated in this way, we reviewed the data carefully to make sure that the number of movements resulted under "saturated" conditions, i.e., there was a continuous presence of a queue during the respective time intervals so that the runway system was operating at its full capacity. The principal results of this analysis are summarized in Figures 4 and 5 for FRA and EWR, respectively.

The results clearly show that the CAPA at each airport is highly sensitive to weather conditions in both cases. On an hourly basis, the maximum throughput capacity of FRA falls from roughly 96 (=4x24) movements per hour under VFR weather conditions to about 84 (the coordinated threshold value at FRA in 2007) per hour under IFR and LIFR, a loss of about 13% in capacity. Similarly, for EWR, CAPA declines from roughly 84 under VFR to 72-76 in IFR and LIFR conditions, a loss of 10-14% in capacity. The values of CAPA at FRA are also consistently 10-12 movements per hour higher than the values observed at EWR for the same weather conditions This difference may be attributable, in large part, to the fact that the third runway in FRA is operated largely independently of the two close parallel runways (and used only for departures) while the third runway at EWR intersects with the two close parallel runways. It is also worth noting that FRA achieves its high throughputs despite handling a significantly higher percentage of wide-body aircraft than EWR.

Finally, we note that the estimates of CAPA shown in Figures 4 and 5 are quite insensitive to changes in the precise value of the percentile value selected. If instead of the 95-th percentile, one chooses the 98-th or the 90-th percentile, the estimates of CAPA either

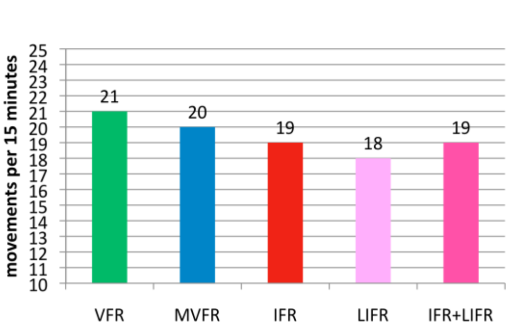

Figure 4 Maximum throughput capacity (CAPA) estimates for EWR, measured by number of movements per 15 minutes; based on 95-th percentile of actual observations for each set of weather conditions.

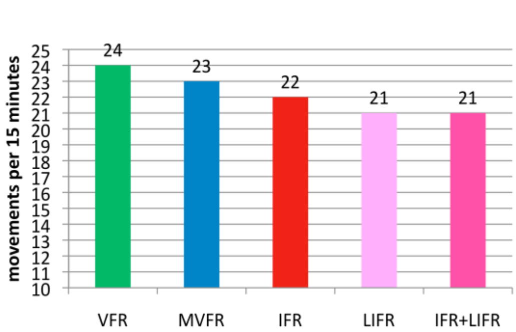

Figure 5 Maximum throughput capacity (CAPA) estimates for FRA, measured by number of movements per 15 minutes; based on 95-th percentile of actual observations for each set of weather conditions.

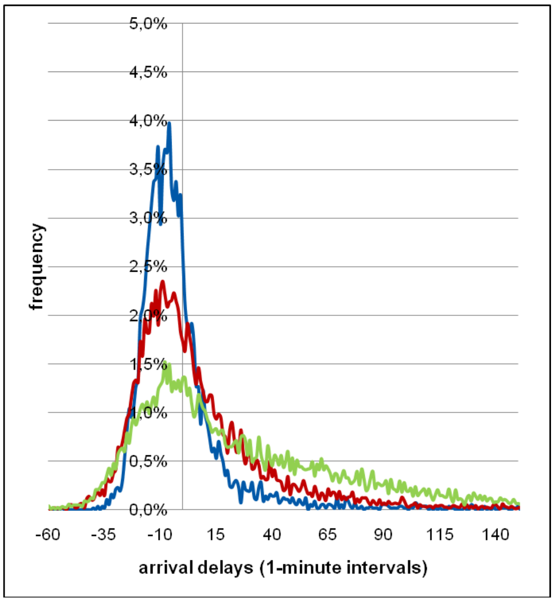

Figure 6 Occurrence of arrival delays (1-minute intervals) at EWR at different times of the day (blue 8 a.m. - 9 a.m., red 12 a.m. - 1 p.m., green 4 p.m. – 5 p.m.). The later the point in time, the higher the arrival delay spread (standard deviation).

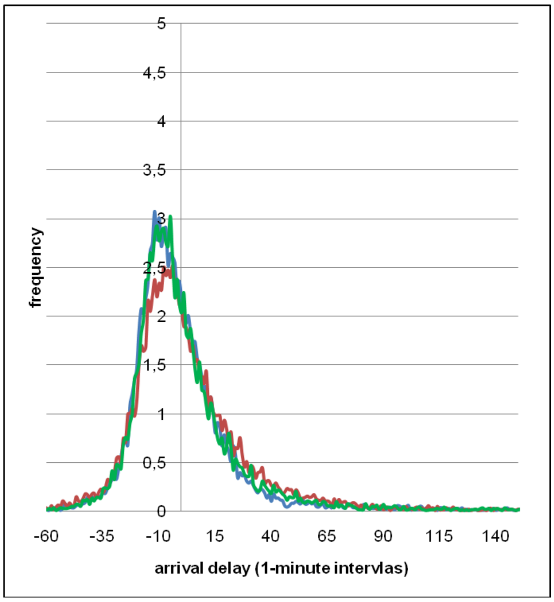

Figure 7 Occurrence of arrival delays (1-minute intervals) at FRA at different times of the day (blue 8 a.m. - 9 a.m., red 12 a.m. - 1 p.m., green 4 p.m. – 5 p.m.). Steady delay spread throughout the day.

remain the same or change by at most one movement (higher for the 98-th percentile and lower for the 90-th percentile) per 15-minute period. The highest observed hourly values of CAPA in 2007 were 100 movements at FRA and 92 movements at EWR and occurred on three occasions at each airport in VFR weather, probably under highly favorable conditions, such as a homogeneous mix of mostly narrow-body aircraft.

5 PUNCTUALITY AND SCHEDULE RELIABILITY

CAPA and its related throughput rates (departures throughput, arrivals throughput, etc) are of great importance for schedule reliability and punctuality at any airport. In this section the relevant analysis that was performed for FRA and EWR will be summarized.

	FRA	EWR
8am-9am	0,9 min	-0,2 min
12am-1pm	4,1 min	8,1 min
4pm-5pm	1,7 min	30,1 min

Table 4 Variation of average arrival delays at FRA and EWR over the day

Reliability will be understood in this context as the measure of conformance between a planned schedule and the corresponding realized schedule. A reliable schedule is of great importance to the operational stability of an airline’s flight schedule operational and is thus a driver of costs that are related to operational disruptions, such as missed passenger connections and flight cancelations. In general, the planned number of movements per time interval (e.g., 1 hour) foreseen by an airport’s schedule can never be met fully by actual operations. Early as well as late flights will generally result in a deviation between planned and actual figures. Given this understanding schedule reliability was measured in this study by the average difference between planned and actual arrival times as well as by the daily “drift” of this measure. In addition, the variance and standard deviation of the observed arrival delays was calculated at several times of the day to obtain a picture of whether schedule reliability remains constant or deteriorates in later hours. The results of this analysis are shown in Figures 6 and 7.

An overall comparison of the entire 2007 flight schedule and all recorded actual movements indicates that FRA’s arrival delays are more stable and lower overall throughout the day with temporary increases during traffic

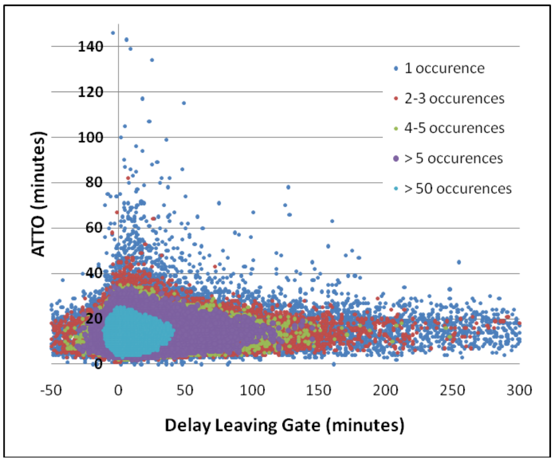

Figure 8 Actual taxi-out time vs. DEP delays at FRA categorized by occurrence.

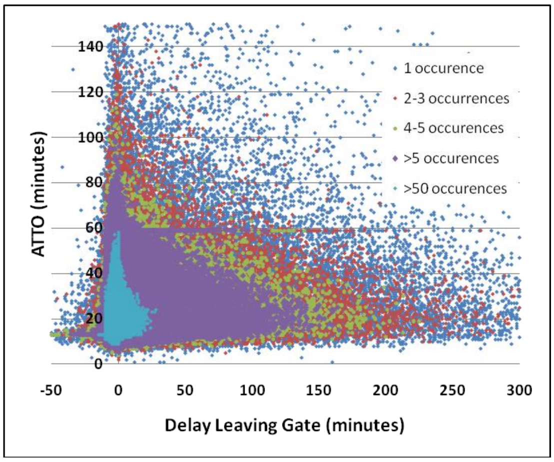

Figure 9 Actual taxi-out time vs. DEP delays at EWR categorized by occurrences.

peak hours (as described in Section 3.3) and a quick recovery in non-peak periods. As a result of this recovery, arrival delays at FRA remain almost constant in the course of a typical day.

The schedule reliability analysis for EWR shows a strikingly different pattern. On the one hand the arrival delay is in general higher in EWR than in FRA.

This fact is especially visible in the afternoon hours when the average arrival delay reaches excessive levels of more than 30 min (Table 4).

The strong deterioration of the arrival delay in the afternoon hours is caused by the fact that at this time of the day the level of scheduled arrivals is significantly greater than actual arrivals which indicates that the airport is not capable to reach (in peak hours) its planned throughput. Moreover, EWR is unable to reduce delays soon after they accumulate, in contrast to what was observed in FRA. Schedule reliability at EWR is therefore notably poor in the afternoon hours, as can also be seen from the obviously increasing standard deviation of the arrival delay at EWR shown in Figure 7. Overall, this aspect of EWR's performance seems to be a consequence of over-scheduling during the afternoon hours: demand for aircraft movements simply exceeds the capacity of the airport infrastructure to handle it.

In addition to arrival delays, taxi-out delays at both airports also differ considerably. This becomes clearly evident when comparing the actual taxi-time out (ATTO) times at the two airports. The daily (5 a.m. -11p.m.) mean value of ATTO at FRA is approximately 13 min and, for some cases, is smaller than the standard "unimpeded" taxi-time (8-16 min, gate specific). FRA has basically insignificant taxi-out delays. This can be attributed in large part to the operating policy of FRA and EUROCONTROL (CFMU slot allocation) which calls for keeping aircraft at the gate, instead of having them queue on the taxiways.

EWR shows a daily mean ATTO of approximately 30 min, with values as high as 35-40 min in the morning (8 a.m. and 9 a.m.) and in the afternoon and evening (5 p.m. to 8 p.m.). These ATTO values lead to substantial taxi-out delays with peaks of approximately 25 min under VMC and approximately 34 min under IMC. A gate-holding policy comparable to the one used in the EU did not exist at EWR in 2007.

Figures 8 and 9 provide another perspective for the practices outlined in the previous two paragraphs. They plot observations of ATTO and total departure delay at FRA and EWR in 2007. Note in Figure 8 that at FRA large departure delays do not translate into large ATTO values on a one-to-one basis: a very long departure delay does not have a different effect on ATTO than a moderate departure delay. In contrast, one can see in Figure 9 the significantly higher level of ATTO associated with large departure delays at EWR.

6 SUMMARY (JOINT)

The airside performance of FRA and EWR were found to have major differences, as far as airside performance is concerned. The most notable among these concerned: airside delays; schedule predictability/reliability; and the allocation of departure delays between delay absorbed at the gate and delay suffered during the taxi-out phase. The most important factor at the root of these differences is the different approaches used at the two airports to schedule flights. In one case (FRA) there is full slot coordination and the setting of slot limits at approximately the level of the maximum throughput capacity when the airport is operating under IFR. In the other (EWR) no slot limits existed in 2007 and the number of runway movements scheduled during the afternoon and evening peak hours was equal or exceeded the maximum throughput capacity of EWR when operating under VFR. Beginning in 2008, the FAA specified slot limits for EWR. Coupled with a roughly 8% reduction in demand between 2007 and 2010 and with some ATM initiatives, delays at EWR have by now (2010) declined by roughly 35% from the record 2007 levels.

The research team of ECAD and MIT is currently continuing its empirical analysis of performance of major European and US airports with an expanded scope. One of the issues being examined is the attribution of the aforementioned reduction in EWR delays to such factors as reduced demand, slot limits and improved ATM procedures.

REFERENCES

Gulding, J., D. Knorr, M. Rose, J. Bonn, P. Enaud, and H. Hegendoerfer, H. (2009). US/ Europe comparison of ATM-related operational performance. *Eighth USA/Europe Air Traffic Management Research and Development*, Napa, California, USA.

de Neufville, R. and A. Odoni (2003). *Airport Systems : Planning, Design, and Management.* McGraw-Hill, New York.

Morisset, Thomas. (2010). *Comparing Capacities and Delays at Major European and American Airports*. SM Thesis, Technology and Policy Program, Massachusetts Institute of Technology, Cambridge, MA.

Morisset, T., and A. Odoni (2010). *Capacity, Delays and Schedule Reliability ar Major Airports in Europe and the United States.* Working Paper, Dept. of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, MA, USA. (Under review for journal publication.)

EUROCONTROL and U.S. Federal Aviation Administration (2009) *US/Europe Comparison of ATM-Related Operational Performance,* Report 2009-AJG-333 prepared by the Air Traffic Organization Strategy and Performance Business Unit (FAA) and the Performance Review Unit (EUROCONTROL), Washington, DC and Brussels.