

# Determinants of an Airport Productivity Benchmark

Today's airports are expansive and expensive infrastructures with considerable impact on population and the environment. In the past, we have seen almost unconstrained exponential growth of air transportation in the Western world, which has been fueled by deregulation and partial privatization of air transportation in the U.S. and in Europe. Today, North-American and European markets as well as major routes have matured considerably. Therefore, future growth of demand will happen in the Asian and in the Middle-Eastern markets, simultaneous with increasing wealth, consumption, and education. Having a functional and efficient infrastructure is essential for future growth in all economies. The European market will not stagnate at the current level; Europe will continue to serve as a gateway between the Americas and Asia, and it will grow, on average, at a comparably lower rate. There will be considerable growth at Eastern European airports. This results in a doubling of traffic or passengers in the next 16 to 20 years, putting currently congested airports under enormous pressure. The question for European institutions and policy is: Do European airports have the capacity to serve future demand or will there be a widening capacity gap?



by: Branko Bubalo

## Airport Productivity and Demand

When looking at "airports" as a company, its output can arguably be divided into the following two streams of "products": airside productivity and landside productivity. These should be analyzed separately, because each stream requires different staffing, infrastructure and investments, and are operated under different rules and regulations:

Airside productivity is measured in the number of arrivals and departures or total movements over a certain period of time, and includes aircraft-handling on the airside, between the runways, apron, aircraft parking positions and gates, which is coordinated by local air traffic control.

Landside productivity is measured in the number of passengers, tons of cargo and tons of mail over a certain period of time, and includes passenger or cargo handling on the landside between the parked aircraft, the gates and inside the terminal or cargo facilities coordinated by ground-handling and logistics companies or airport management.

The International Air Transport Association (IATA) suggests the first step of analyzing the output of an airport should involve busy-period traffic observations, which are required for detailed airport capacity planning of both airside and landside (de Neufville 2003, pp. 851, IATA 1981). It must be noted that, for a holistic view of airport capacity and demand, airside and landside must be assessed together; otherwise, the picture will lack consistency and may lead to ambivalent conclusions (de Neufville 2003, p. 607).

### Airside Productivity and Capacity

The airside, and the runway system in particular, is the most critical element required for the operation of an airport. With regard to the creation of additional runway capacity, a time-frame of approximately ten years should be taken into account, which consists of planning, legal approval, property acquisitions, and construction (EU COMMISSION 2007). Therefore, capacity bottlenecks must be recognized and anticipated years in advance.

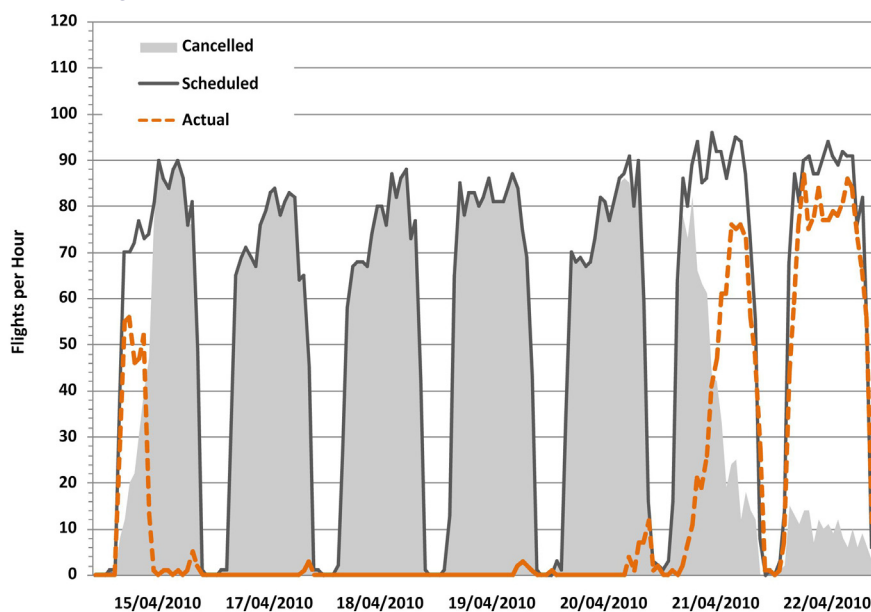
Perhaps the most important prerequisite for the analysis of airports is the projected or actual flight schedule at each airport. Flight schedule information should include the following information: Airline name, aircraft type, time of arrival or departure, destination and origin and flight number (IATA 2004, p.93). Popular sources for schedule data for European airports are the Official Airline Guide (OAG) for scheduled flights or FlightStats.com for scheduled and actual flights.

With available flight schedule data over longer periods of time, preferably over several days, weeks or months, but at least one representative “design” peak day, many observations on airport performance, runway and terminal efficiency, aircraft mix, demand variability or seasonality can be made. Through airline and aircraft type coding, and by decoding further information on aircraft weight, number of available seats, engine type and emissions can be linked (TRB 2010).

Daily demand profiles are typically plotted by the hour of day

**Figure 1:** Volcano ash cloud disruption at London-Heathrow airport in April 2010

Source: FlightStats.com



over a twenty-four hour period (de Neufville 2003, p. 468) (TRB 2010). To emphasize the importance of these patterns and to show the simplicity to read its information, figure 1 shows the hourly flights at London-Heathrow, with up to 95 total scheduled flights per hour. Due to the European airspace closure between April 15th and April 22nd 2010, which resulted from the eruption and following ash cloud of Iceland’s volcano Eyjafjallajökull, most of the scheduled flights on these days were cancelled.

### Landside Productivity and Capacity

The assessment of landside productivity includes service quality measures of processes inside the airport terminal, creating aeronautical and non-aeronautical revenues. These are

not easy to calculate or estimate without detailed information on processing speeds and availability of the various servers, e.g. check-in counters or baggage claim units (de Neufville, pp. 655) (IATA 2004, p. 189). For best results, a passenger simulation study from the terminal corridors, waiting areas, checkpoints and gates should be conducted with realistic assumptions regarding passenger flows, dwell time, available terminal space and waiting queues (IATA 2004, pp. 178) (FAA 1988, pp. 15).

A general measure in practice for terminal efficiency is the Minimum Connecting Time, which is used in the flight booking process to adequately connect transfer flights, offering the quickest travel route for passengers (TRB 1987, p. 143). It is striking that international connection flights from one terminal to the other at e.g. London-Heathrow (LHR) airport can span between 45 minutes (Terminal 1 to Terminal 1) and 2 hours (Terminal 1, 2, 3, and 4 to Terminal 5). Therefore, a large city like London with an airport system of five airports might offer more comfortable connections over the alternative airports London-Stansted (STN), London-Gatwick (LGW) or London-City (LCY) or London Luton (LTN).

### Airport Peer Groups based on Runway Capacity

When dealing with different airports in size, location and stage of maturity, it becomes obvious that a comparison among airports, e.g. benchmarking, is a difficult undertaking. This is even so more for financial comparisons, where different landing fees, accounting standards, national laws and regulations, levels of outsourcing and level of privatization frequently distort the study results. Various sources point out these complexities, and offer promising solutions regarding the improvement of systematic airport comparison (Graham 2008). For an engineering perspective on airport benchmarking, these difficulties exist in other ways, but comparisons of operations among European airports are usually possible. This mainly requires airports being categorized into peer groups with similar characteristics (Forsyth 2004).

### Aircraft Mix and Minimum Separation

The main limitation for runway operations at airports result from safety separations between successive landing and departing aircrafts on the same runway and lateral separations between parallel runways, due to wake turbulences created by the wingtips of aircrafts. Encountering turbulences from preceding aircrafts during the critical landing phase can have serious effects on the stability of an aircraft in the air, and may cause it to roll. This is why air traffic control applies separation minima for aircrafts of different maximum take-off weights (MTOW). During the approach to an airport, a “Small” aircraft (<7 tons MTOW) following a “Large” aircraft (7-136 tons MTOW) will experience a separation minima of approximately 4 nautical miles, in comparison a “Large” aircraft following a “Small” aircraft will be separated by 3 nautical miles (NATS 2009) (Horonjeff 2010). So the mix and sequencing of aircraft types obviously has a direct impact on runway capacity.

If aircraft types and corresponding weights are known from the design flight schedule of the airport under investigation, we may derive the shares of aircraft weight and turbulence class – the traffic mix. Since “Heavy” aircraft (>136 tons MTOW) in the mix of an airport influence its overall throughput, a mathematical expression, the Mix Index, has been adopted from (FAA 1995). The Mix Index (MI) adds to the (usually predominant) percentage share of “Large” aircraft in the mix, the three-fold percentage share of “Heavy” aircraft (Horonjeff 2010, p. 515).

It is important to note that only separation minima under Instrument Flight Rules (IFR) are relevant for European air traffic. IFR conditions offer less capacity than flights operated under Visual Flight Rules (VFR) due to higher required separation minima between following aircraft. In contrast to the U.S., most commercial air traffic in Europe is operated and controlled under instrumental meteorological conditions (EUROCONTROL 2009b).

### Estimating Capacity by Runway Configuration

The FAA Advisory Circular “Airport Capacity and Delay” (FAA 1995) is used to isolate peer groups based on maximum airport productivity measured in airport operations, which are the annual service volume and hourly capacity of an airport (Bubalo 2009).

FAA (1995) developed a simple technique to estimate the capacity of an airport (for long-range planning), where the closest matching of 19 different runway schemes is chosen, which represents the preferential runway system as explained in the Aeronautical Information Publication (AIP)(FAA 1995, Horonjeff 2010, p. 532). For each runway scheme (and corresponding mix index), estimates for annual and hourly capacity are listed. Three main groups have been isolated with approximately similar annual airport capacity. Group 1 represents airports with a single runway, which could have an additional crosswind runway for changing wind directions. The extra crosswind runway will therefore not increase the overall runway capacity of an airport significantly. The best-practice in this group is London-Gatwick airport with an estimated capacity of 240,000 flights per year compared to a demand of 259,000 flights per year in 2007. Group 2 represents airports with parallel runways, which are less than 4,300 feet (~1.3 kilometers) apart from each other. Most of the airports in this group with a separation of 700-2,500 feet and 2,500-4,300 feet can only be operated dependently due to safety regulations. Wake vortex turbulences caused by aircrafts on one of the dependent runways can be shifted by winds into lateral direction and possibly impact aircraft at the parallel runway. Exceptions are configurations with more than 4,300 feet separation,

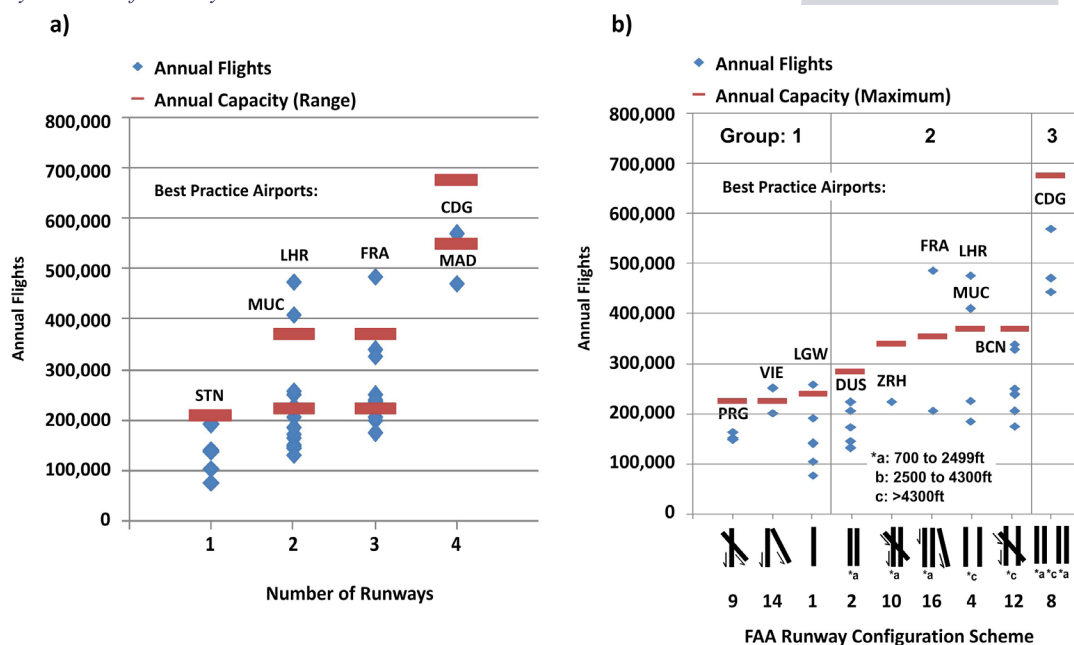
which allow independent operation of the runways and therefore have higher hourly capacities than its peers. The best-practice in Group 2 is London-Heathrow airport with a capacity of 370,000 flights per year and a demand of 476,000 flights in 2007. Group 3 includes all runway systems with complex configurations, which have a minimum of two independent parallel runways plus a third (dependent) parallel runway on one of the sides. The best-practice in Group 3 is Charles-de-Gaule airport (CDG) with an estimated capacity of 675,000 annual flights compared to 569.000 flights in 2007.

London Gatwick has, strictly speaking, two runways, but the AIP of the airport states that the airport only operates one runway under its preferential runway system. The second runway is only used for taxiing aircrafts and emergency landings. So only the FAA methodology, which requires the study of the operational characteristics of an airport, would return the true capacity estimate. AIP information can be downloaded from the European AIS Database (EAD) for any European airport (EUROCONTROL 2010).

### Airport Utilization

When looking at the annual capacities from the FAA methodology and the actual flights of different European airports, it is revealed that many main airports are highly utilized. If capacity and demand are plotted by the number of runways, as shown in figure 2a, it can be seen that a doubling of number of runways would not always result in a doubling of capacity, so the classification by the number of runways as an indicator for

**Figure 2a and 2b:** Comparison of Annual Capacity and Demand (2007) by FAA Runway Scheme Number and by Number of Runways. Source Bubalo 2010

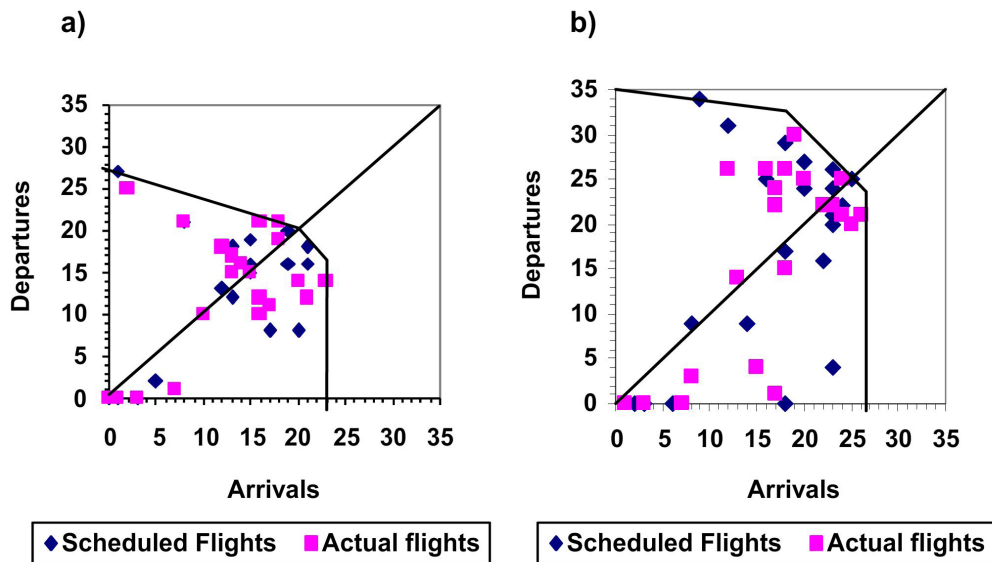


productivity analysis leaves too much variation for upper and lower levels of capacity.

Figure 2b gives a more detailed picture of different best-practice airports, their runway configuration and utilization. Frankfurt and London Heathrow are extreme examples of airports, which operate significantly above their estimated capacities.

London Gatwick (LGW) airport is a prominent example for a highly productive, yet severely congested, single-runway airport. Even on a global scale, the 259,000 flights per year in 2007 are without comparison. On busy days, this extra-

inary performance of London-Gatwick can be put into an even better perspective. For comparison, the biggest single-runway airport in the U.S., San-Diego airport (SAN), reaches a far lower number of hourly operations than its European counterpart. As can be seen in the hourly arrival and departure plot of busy day traffic, San-Diego airport (Figures 3a) serves up to 41 hourly flights (20 arrivals and 21 departures per hour), and London-Gatwick airport (Figure 3b) reaches 50 flights (25 arrivals and 25 departures) during the peak day.

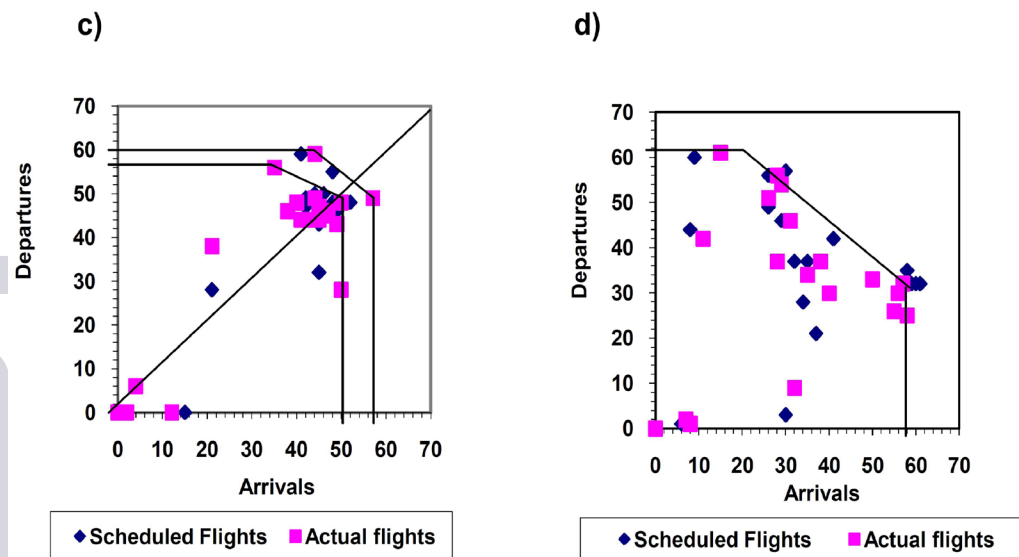


**Figure 3 a and b:** Gilbo Diagram of Single Runway Airports a) San Diego, USA and b) London Gatwick, UK on Busy Day 2010

The practical capacity for the maximum sustainable landings and departures at a particular airport can be estimated by constructing the capacity envelope in the “Gilbo Diagram” of a specific airport of interest (Gilbo 1993).

With data of consecutive operating hours, the Gilbo diagrams deliver a sufficient estimate of practical capacity in maximum possible arrivals and departures under existing airport conditions. In the case of London-Heathrow airport (Figure 3c), the practical capacity is 100 flights per hour (50 arrivals and 50 departures per hour) and for Munich airport (Figure 3d) 82 flights per hour (41 arrivals and 41 departures per hour). Actually, the Gilbo diagram for Munich reveals that the airport achieves its best operational performance with a 64% share of arrivals (57 arrivals per hour) to a 36% share of departures (32 departures per hour), resulting in a total of 89 hourly flights. The diagrams can be modified to include the frequency of each data point. This has been done by Kellner (2009) to derive so-called “density plots”. The density plots can then be used to isolate outliers and to establish confidence intervals, e.g. defining the practical capacity as 90% of the envelope.

**Figure 3 c, d:** Gilbo Diagram for Parallel Runway Airport c) London Heathrow and d) Munich on Busy Day 2008



### Airport Delay and Congestion Costs

Figure 4 reveals that the high productivity comes at the expense of on-time performance, which in the case of London-Gatwick resulted in approximately 80,000 delay minutes in 2006. Using estimations for average cost per minute of delay for airlines, from the “Standard Inputs for EUROCONTROL Cost Benefit Analyses” (EUROCONTROL 2009a), it is possible to derive annual delay costs for the top 21 congested airports in Europe. Value of time is estimated at €42 per minute of delay on average for departures and landings. These are the direct costs to airlines from fuel, crew and passenger compensation, which results in an approximate total of €3.3 million at London-Gatwick in 2006 (“reactionary delays” (Jetzki 2009) not included). It is not surprising that London-Heathrow airport ranks first, causing an enormous 9-fold delay compared to London-Gatwick (Rank 16) of 715,761 minutes of delay, resulting in annual delay costs of approximately €30 million (EUROCONTROL 2008b).

But what exactly is the critical relationship between airport capacity and delays? Airport capacity represents the limit of productivity under current conditions in a specific time unit, usually per hour, per day, per month or per year. An airport operator should make it clear that the airport operates and serves demand below a practical capacity, where an acceptable level-of-service, of e.g. five minutes average delay per flight, is guaranteed for the airport users. The practical or sustainable capacity should never be exceeded for longer periods. In theory, the closer an airport operates towards its ultimate or “physical” throughput capacity, the stronger delays increase beyond an acceptable level of service, and eventually, delays reach infinity, which means

Rank	Airport Name	IATA	ICAO	Annual-Flights (2006)	Annual-Flights (2007)	Experienced Delay in Minutes (2006)	Average Delay per Flight in Minutes	Annual Delay Costs at 42€ per Minute (Eurocontrol 2009)
1	LONDON HEATHROW	LHR	EGLL	470,890	475,786	715,761	1.5	30,061,962
2	FRANKFURT MAIN	FRA	EDDF	480,510	486,195	671,693	1.4	28,211,106
3	MILANO MALPENSA	MPX	LIMC	241,474	257,361	626,853	2.6	26,327,826
4	WIEN	VIE	LOWW	233,474	251,216	534,717	2.3	22,458,114
5	ROMA FIUMICINO	FCO	LIRF	308,578	328,213	464,088	1.5	19,491,696
6	MADRID BARAJAS	MAD	LEMD	422,172	470,315	388,094	0.9	16,299,948
7	MUENCHEN	MUC	EDDM	387,807	409,654	343,938	0.9	14,445,396
8	ZURICH	ZRH	LSZH	220,188	223,707	248,709	1.1	10,445,778
9	PARIS ORLY	ORY	LFPO	234,886	238,384	242,897	1.0	10,201,674
10	SCHIPHOL	AMS	EHAM	429,502	443,677	151,918	0.4	6,380,556
11	COPENHAGEN/KASTRUP	CPH	EKCH	251,384	250,170	124,148	0.5	5,214,216
12	LONDON CITY	LCY	EGLC	66,129	77,274	111,567	1.7	4,685,814
13	PRAHA RUZYNE	PRG	LKPR	155,481	164,055	105,861	0.7	4,446,162
14	PARIS CH DE GAULLE	CDG	LFPG	559,705	569,281	81,062	0.1	3,404,604
15	LONDON GATWICK	LGW	EGKK	254,411	258,917	79,190	0.3	3,325,980
16	ROMA CIAMPINO	CIA	LIRA	51,876	54,870	60,362	1.2	2,535,204
17	MANCHESTER	MAN	EGCC	213,026	206,498	59,495	0.3	2,498,790
18	TEGEL-BERLIN	TXL	EDDT	134,226	145,451	55,816	0.4	2,344,272
19	LONDON STANSTED	STN	EGSS	189,983	191,520	53,408	0.3	2,243,136
20	PALMA DE MAL-LORCA	PMI	LEPA	175,580	184,605	44,508	0.3	1,869,336
	<b>Total</b>			<b>5,481,282</b>	<b>5,687,149</b>	<b>5,164,085</b>	<b>0.97</b>	<b>216,891,570</b>

## Conclusions

As it could be shown for the European airports of London-Heathrow and London-Gatwick, the high productivity of both airports comes with huge amounts of experienced delays and delay costs for airport users. There is ongoing research on how this externality of highly productive airports can be included in productivity and efficiency analysis in order to make fair assumptions and comparisons of airports with regard to service quality and externalities. Nevertheless, it should be observed

**Figure 4:** Annual delays and calculated delay costs of European airports, ranked by annual delay (Source: Eurocontrol 2009, 2008b)

flights never leave the gate or wait an infinite time in the holding pattern in the airspace. Therefore, the arriving and landing aircraft have priority over departing aircraft, due to limited fuel reserves, which allow waiting in the holding stack in airspace only for a certain period of maybe maximum 20 to 30 minutes.

Furthermore, it can make a huge difference in service quality measured in average delay per flight, when an airport operates at a capacity utilization of 65%, 75%, 85% or more. Practical capacity usually serves as declared capacity for the slot coordinator and should never exceed 85-90% of the ultimate capacity during consecutive busy hours, otherwise the airport system is unstable and sensitive to changes in demand or available capacity, e.g. due to unscheduled flights, runway incursions or weather (de Neufville 2003).

At congested airports, which are slot-coordinated, the amount of hourly capacity must be declared by the airport operator (IATA 2010b). The declared capacity is the common denominator of all processes at an airport involved in serving passengers, aircrafts or cargo. Ideally, declared capacity is close to practical capacity. It is indeed always possible for demand to exceed capacity for short periods of time due to fluctuations of demand at the airport. The situation becomes more critical when capacity is utilized more than 100% over a minimum of one hour and measurable waiting queues and delay develop (Horonjeff 2010).

how the whole European air traffic network reacts to major changes in airport capacity. It is no doubt that delays could be reduced significantly, if new runways at amongst others Frankfurt and London-Heathrow airport went into service on time. A number of airport improvements are planned for European airports, but it remains questionable whether these are sufficient.

Another crucial externality of air transportation, which is not discussed here, is annoyance caused by aircraft noise on the communities around airports. Aircraft noise and transportation noise in general and their resulting health effects are currently being studied at an EU level under the guidelines of the World Health Organization. Further research will yield more insight in simulating and modeling of environmental impact of airport systems.

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**Photo References**

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