European Idle Network Capacity – An Assessment of Capacity, Demand and Delay of 33 European Airports

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-FINAL DRAFT VERSION-

Introduction

In Europe there is a big concern among air traffic forecasters that the current runway capacity will not meet the expected demand for air travel over the next 10 to twenty years, resulting in strong network delays and overcrowded airport facilities. In order to allow more growth, the only two options are either extending capacity by building more runways and/or passenger facilities at the most congested airports or freeing unused idle or spare capacity. Some of the biggest European hubs, especially London-Heathrow (LHR) and Frankfurt-Main (FRA) airport, are already highly congested and operate at full capacity during core hours[2]. Due to the resistance of nearby residents, environmental groups and associated lawsuits towards airport expansion programmes, the enhancement of runway capacity at airports has become a lengthy process, taking up to ten years planning and construction time.

This paper aims at investigating the runway capacity utilization, idle slots and idle runway capacity of 33 European airports, which represent about 75% of the overall European air traffic in terms of handled aircraft operations. By looking at capacity and demand at each airport during peak periods, it should be possible to get an overview about the current minimum amount of available idle capacity. The airport sample, which has been chosen from a previous unpublished study of 60 European airports[3], includes airports with signs of congestion, which means that capacity is over 75% utilized and further growth of demand will result in increasing delays. The relationship between demand and capacity will be shown on an annual, daily and hourly basis. Five different kinds of capacity measures have been chosen for individual analysis: Annual Service Volume (ASV) in Operations per year, design peak day (DPD) core hour ultimate Instrumental Flight Rules (IFR) runway capacity (IFRCAP), design peak hour (DPH) slots and DPH IFRCAP in operations per day or per hour. Visual Flight Rules (VFR), which result in higher hourly ultimate capacities due to less separation between succeeding aircraft under favourable weather conditions, are exempted from the study, since they have generally no importance for commercial European air traffic.
The first part of this paper includes a short literature review and gives advice on freely available data sources. The second part deals with the methodology for estimating the ASV and IFRCAP and the third part finally looks at the capacity utilization and idle capacity. The paper finishes with a summary of findings and a future outlook.

Literature Review

All used methodologies can be found in the following publications:
As a reference for air transportation studies and airport planning, there are to mention four outstanding books: "Airport System – Planning, Design and Management" written by Richard de Neufville and Amedeo Odoni (de Neufville 2003), "Planning and Design of Airports" written by Robert Horonjeff (Horonjeff 1994), "Airport Engineering" written by Norman Ashford and Paul Wright (Ashford 1992) and the outstanding work of Milan Janic "The Sustainability of Air Transportation: A Quantitative Analysis and Assessment" (Janic 2007). Another excellent source and a good starting point for the studies involved in airport

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[2] Core Hours: 06:00 until 22:59
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expansion, either landside or airside, is the 9th edition of IATA's "Airport Development Reference Manual" (ADRM) (IATA 2004). The 8th edition of the ADRM from 1995 (IATA 1995) additionally offers some practical guidance to calculate terminal capacities. A main source for the ASV and IFRCAP calculations are the freely available publications of the U.S. Department of Transport (DOT) Federal Aviation Administration (FAA), which offers downloadable guidelines and handbooks, the advisory circulars (AC), for air traffic control, pilots, airport operators and managers (http://rgl.faa.gov/).

For the purpose of calculating airport capacity and delay, the FAA published the AC 150/5060-5 "airport capacity and delay" in 1983 (FAA 1983), which can be downloaded from the FAA website. The most recent update is from 1995. The calculations presented in this paper use the order-of-magnitude long-range planning instructions of (FAA 1983) for calculating the ASV and ultimate IFR CAP's.

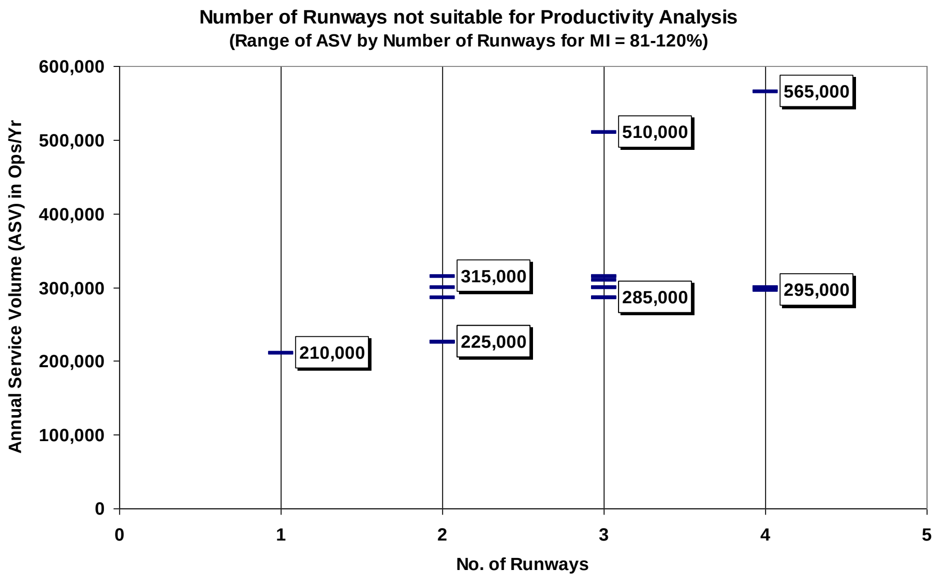

Figure 1, Range of Annual Ultimate Capacity of different Runway-use Configurations by Number of Runways

Another goal of this study is to overcome the drawbacks of previous airport performance benchmarking studies, which used number of runways as an input for productivity analysis (Ulku 2008, Graham 2005 & 2008). Figure 1 shows that the range of annual capacity of an airport can be significant at airports with a similar number of runways but different runway-use configurations, therefore an "apple versus apple" comparison just by the number of runways is not possible. The figure is derived from FAA (1983) and the origin of its numbers will be explained later (table 3).

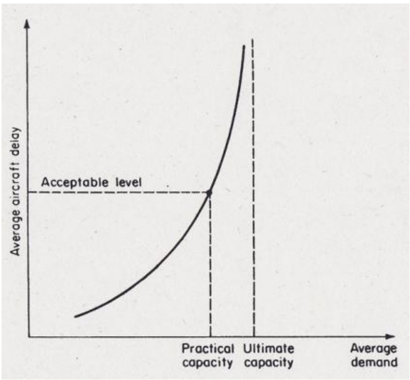

Figure 2, Relationship between Demand, Capacity and Delay (Horonjeff 1992)

The fundamental relationship between capacity, demand and delay is presented in figure 2. An airport should operate and serve demand below or at the practical capacity, where an acceptable level of delay is guaranteed for the customers. The closer an airport operates towards the ultimate capacity of an airport system, the stronger delays increase beyond an acceptable level (of e.g. 4 minutes).

Actually that is the case not only for the runways or passenger facilities, but also for any other process involved in serving passengers or aircrafts (e.g. Number of security checks and personnel or available push-back tractors)

Data Sources and Methodology

For this paper only freely available sources for data and literature have been used. Public data and guidelines for methodologies were collected from the FAA Advisory Circular archive, EUROCONROL's various subdivisions, EUROSTATS, Flightstats.com and others.

Design Peak Day Assumptions

From the EUROCONTROL Pan-European Airport Capacity and Delay Analysis Support (PACS) and OneSky Central Flow Management Unit (CFMU) online sources and databases relevant traffic data, such as daily, weekly and monthly reports of overall European traffic and delays for the years 2000 to 2008, have been collected.
Each CFMU weekly report provides a diagram of preceding week's traffic and delay development, therefore in the weekly report of week 52 or 53 an annual diagram, which includes the traffic development over the past year, could be found (Figure 3).

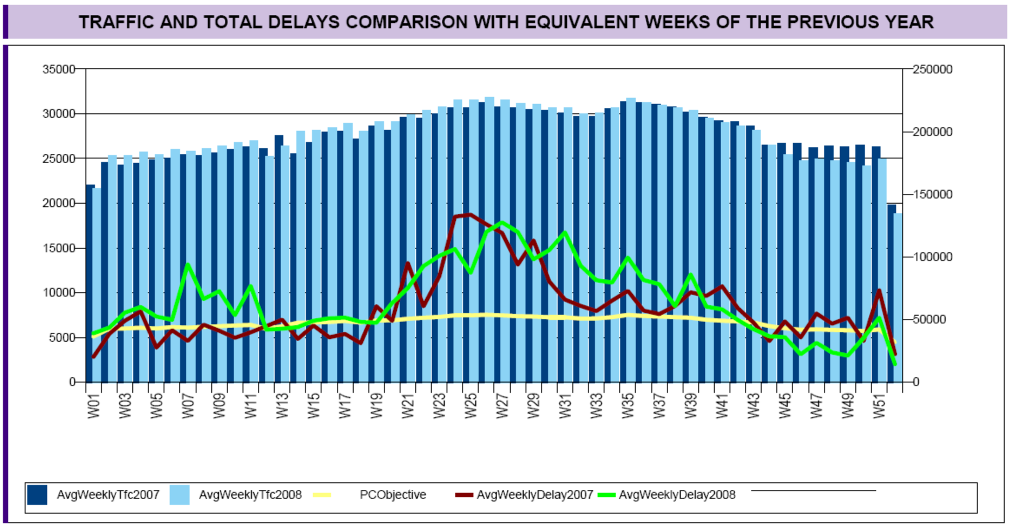

Figure 3, Traffic and total delays comparison with equivalent weeks of the previous year; PC Objective set to 1.7 min of delay per flight (Source: Weekly report 52/2008 EUROCONTROL CFMU 2008)

The development of European air traffic over the year reveals a repeating pattern. It is obvious, that in weeks 25, 26, 35 and 36 the traffic is peaking strongest. The weekly average delays per are also the highest during these four representative weeks.
Chapter 24 of de Neufville (2003, p.851) notes what considerations must be made when isolating "peak days" (PD), "design peak hours" (DPH) or peak periods in general. From further analysis of weekly traffic pattern and de Neufville's (2003) suggestions it is known, that generally Thursdays and Fridays are the busiest days of the whole week at airports. Therefore in one of the representative peak weeks a Thursday or Friday must be the busiest day of the whole year (Table 1).

Top 5 Traffic Days in Europe 2005 - 2008

2005			2006			2007			2008		
Day	Week of the year	Flights	Day	Week of the year	Flights	Day	Week of the year	Flights	Day	Week of the year	Flights
Fri 17/06/2005	24	30663	Fri 15/09/2006	37	31914	Fri 31/08/2007	35	33506	Fri 27/06/2008	26	34476
Fri 01/07/2005	26	30569	Fri 01/09/2006	35	31841	Fri 29/06/2007	26	33480	Thu 26/06/2008	26	33895
Fri 02/09/2005	35	30469	Fri 30/06/2006	26	31686	Fri 14/09/2007	37	33371	Fri 13/06/2008	24	33833
Fri 16/09/2005	37	30338	Fri 08/09/2007	36	31553	Fri 07/09/2007	36	33279	Thu 19/06/2008	25	33383
Fri 09/09/2005	36	30169	Fri 22/09/2006	38	31550	Fri 21/09/2007	38	32971	Fri 04/07/2008	27	33342

Table 1, Top Five Traffic Days 2005-08. (Source: EUROCONTROL CFMU 2008)

What can also be seen from the weekly demand diagram (Figure 3) is that the peak weeks of the current year exceeds the traffic of previous years, at least as long as there is growth. This will not be true for 2009 figures.

The isolation of peak weeks must be made due to the lack of precise schedule data for a whole year of each airport. Depending on the source, per definition: “The design peak hour (DPH) is a busy hour, but not the busiest hour - the peak hour (PH), of the year, maybe the 20th, 30th, 40th PH, or the 95th percentile of the busiest day [ed. (PD), or the PH of the average day of the peak month of the year, or the PH of the average day of the two peak months of the year […]” (de Neufville 2003, p.853).

IATA (1981) gives a more general definition for the peak period: “A period that is representative of a normal busy period, and not one related to peak time, such as religious festivals or some other short holiday period.”

Most sources point out that it largely depends on the study and availability of data, which definition for estimating the DPH will be the best. Due to the lack of detailed flight schedule data for all 33 sample airports for a whole year period, certain simplifications had to be made.

The peak week 26 always falls into the top 5 busiest weeks of the year. Therefore the Thursday of week 26 (PDTHUW26) is suggested being used as a representative DPD for all airports. This proposal makes the assumption that overall air traffic in Europe on PDTHUW26 is so high, that through interconnected traffic it will have an effect on all airports in the network. Although there is no actual proof, the PH of PDTHUW26 should be roughly the range of 1st to 30th [4] busiest hour during the whole year at each airport, which would meet IATA’s DPH criteria.

The PH of PDTHUW26 will thus be used as the DPH of each airport.

For peak day traffic information the website FlightStats.com has been used as a main source. Flightstats.com provides information, which has been generated from various other sources, like Official Airline Guide (OAG), FAA and SITA, weather data and flight tracking data. Information about recent and historic flights, like scheduled and actual times can be found freely available. For the 33 sample airports peak day flight schedules data was extracted for the years 2007-2009. As PDTHUW26 for the years the following dates have been selected for this study: 28 June 2007, 26 June 2008 and 25 June 2009.

By making this DPD simplification much less data and effort is needed to calculate peak day or peak hour capacity utilization or idle capacity. The order of magnitude should definitely be the same as in other similar studies and it surely assesses the capacity situation during peak periods at the studied airports.

The FAA (1983) “Airport Capacity and Delay” handbook and the IATA ADRM suggests what kind of data is necessary for the capacity and delay calculations. The runway capacity of an airport is mainly defined by the configuration and usage of the runways and the fleet mix of operating aircrafts. One main indicator for the calculations is the Mix Index (MI), which represents an airport’s traffic mix, based on maximum take-off weight (MTOW), of the

[4] This largely depends on the individual peak hours over the peak days. Usually airport have one to five peak hours on those days, when considering arrivals and departures separately, they have even more. So there is variation which can be finetuned.

various aircraft types and which is calculated from the percentages of category C type aircrafts or D type aircrafts (Table 2).[5]

Aircraft Class	MTOW (tons)	No. of Engines	WTC
A	< 7	Single	Small (S)
B	< 7	Multi	Small (S)
C	7 – 136	Multi	Large (L)/Medium(M)
D	> 136	Multi	Heavy (H)

Table 2, Aircraft Classifications (Source: FAA 1983, p.2 and IATA 2004, p.167)

To calculate the MI it is therefore necessary to analyse the aircraft types operating at a specific airport. This information can be extracted from the collected flight schedule data. Flight schedule data should at least include: Aircraft type, airline name, flight number, departure or arrival times and origin and destination. Additional detailed information on above threshold times, used runway and used gate and/or parking position could be very beneficial for further capacity analyses.
Using an aircraft conversion table the equipment or aircraft type code can be converted into the corresponding MTOW and furthermore the aircraft classes A/B, C and D.
The MI is then calculated by the formula $MI = \%(\%C + 3*\%D)$ with the percentages of C and D class aircraft over a certain period of time.
For this paper the MI has been calculated from daily flights on the PDTHUW26 2007-2009.

Preferential Runway Configurations

Now the matching runway-use configuration must be found from the FAA runway schemes. The (FAA 1983) gives the advice to use the runway system which is operated at least 80% of the time and produces the greatest hourly capacity. From the EUROCONTROL European AIS Database (EAD) website it is possible to download aerodrome charts, flight routes and AD 2 airport information documents (www.ead.eurocontrol.int).

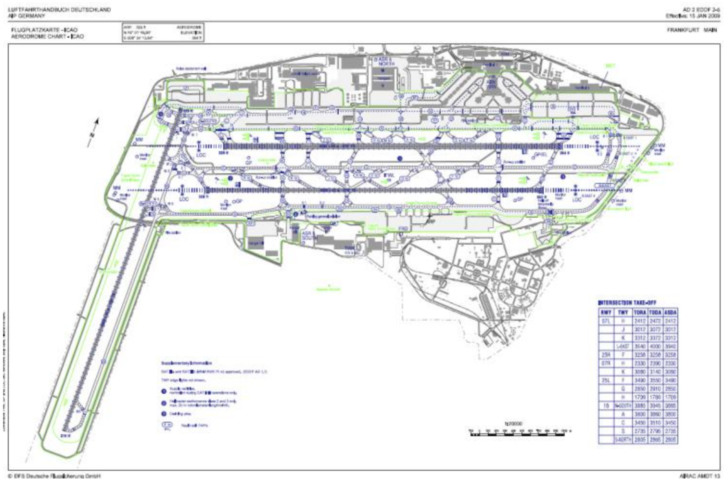

Figure 4, Aerodrome Chart of FRA airport
(Source: EUROCONTROL2009, DFS 2009)

The AD 2 usually points out the operational procedures run at the analysed airport at certain conditions, regarding the preferential use of runways for departures and arrivals under the preferential runway system. Coordinates and number of aircraft parking positions, runway thresholds, declared distances, noise abatement procedures and night flying restrictions are also noted.

The AIP information of the example of FRA airport on runway operations shows that the preferential landing direction is from (north-east) east to (south-west) west direction on the close space parallel runways 25 (R and L). In that case the preferred take-off runways are 25R and 18 (south).

[5] Category C and D stands for wake turbulence classification[5] (WTC) large (L) aircraft, with between 7 and 136 tons maximum take-off weight (MTOW), and heavy (H) aircraft, with over 140 tons MTOW.

This means that runways 25R/L are alternately used for arrivals, and 25R and 18 are alternately used for departures (Fig. 3). Runway 25R is the most often used runway, mainly because of its close distance to the main terminals. Arrivals or departures on runway 25L would require aircrafts to taxi long distances or to cross runway 25R, which is a great disadvantage for maximum utilization of the installed runway system.

Figure 5, Simplified runway-use configuration of FRA airport
(Source: Bubalo 2009)

For the example of FRA the closest matching runway-use configuration is number 16 , with parallel operations on the close parallel runways 25R/L, with a close runway separation of 1700ft or 520 meters, and outbound flights from the separated runway 18 (Figure 4 & 5).

Airport Peer Groups by Annual Productivity

FAA 1983 furthermore gives the according ultimate capacities, ASV, Visual Flight Rule (VFR) capacity and IFR CAP, for each airport's runway-use configuration number and MI. Sorting the runway-use configurations by ASV, as a measure of annual productivity, reveals similar values for different configurations and allows isolation of three main characteristic peer groups (Figure 6) and eleven smaller sub groups (Table 3).

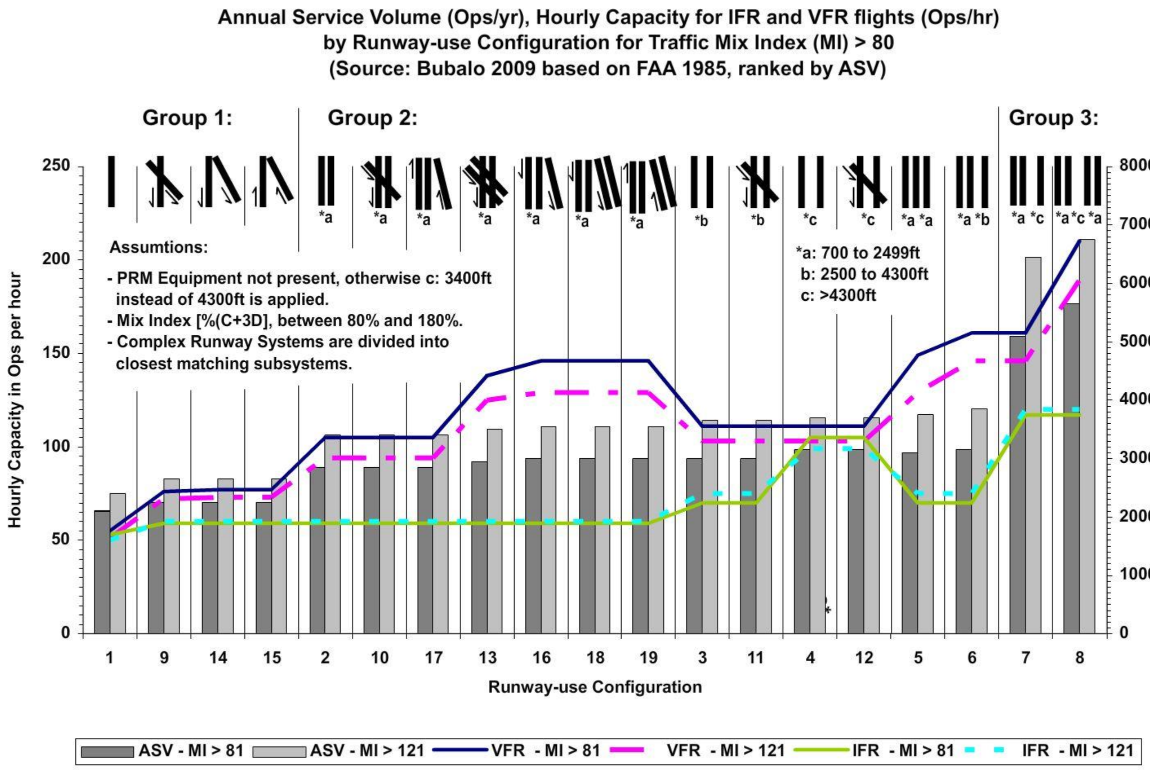

Figure 6, ASV and Hourly Capacity by Runway-use Configuration and Groups
(Source: Bubalo 2009 adapted from FAA (1983)).

			MI=81-120		MI=>121			
Group	Subgroup	Runway Config No	ASV	IFR Hourly Capacity	ASV	IFR Hourly Capacity	Best-in-class MDRC	Airport
I	a	1	210,000	53	240,000	50	50	STN
I	b	9	225,000	59	265,000	60	52	CGN
I	b	14	225,000	69	265,000	60	66	VIE
I	b	15	225,000	69	265,000	60		
II	a	2	285,000	59	340,000	60	61	MAN
II	a	10	285,000	59	340,000	60	66	ZRH
II	a	17	285,000	59	340,000	60		
II	b	13	295,000	59	350,000	60		
II	c	16	300,000	59	355,000	60	82	FRA
II	c	18	300,000	59	355,000	60		
II	c	19	300,000	59	355,000	60		
II	d	3	300,000	70	365,000	75	70	MXP
II	d	11	300,000	70	365,000	75		
II	e	4	315,000	105	370,000	99	88	LHR
II	e	12	315,000	105	370,000	99	90	FCO
III	a	5	310,000	70	375,000	75		
III	b	6	315,000	70	385,000	75		
III	c	7	510,000	117	645,000	120		
III	d	8	565,000	117	675,000	120	106	CDG

Table 3, Peer Groups by Annual Productivity (FAA 1983, National Airport Coordination) (Ranked by ASV with MI=81-120%; MDRC=Hourly Slots)

For every sample airport the AIP information on preferential runway system has been examined and a runway-use configuration has been assigned as was shown in the above example of FRA airport. Table 4 incorporates basic data, like MI, runway-use configuration number, annual passengers and annual movements, of the sample airports needed for the FAA capacity calculation methodology. Charles-de-Gaulle airport in Paris (CDG) tops the table with 569,000 annual flights, followed by FRA and LHR with 486,000 and 476,000 flights. The MI of 170% indicates that LHR mainly serves heavy-class aircrafts resulting in handling the highest number of passengers of all European airports, with 68 million annual passengers. The MI of Nice airport (NCE) is with 55% a very low number and results from a large share of light-weight helicopter flights.

The sum of all sample airport operations and flights is 810 million served passengers and 8.1 million operations. In terms of operations this means that the sample represents 80% of roughly 10 million annual flights in Europe.

Furthermore table 4 shows that German hub airports Munich (MUC), FRA and Düsseldorf (DUS) have clear disadvantages regarding operating hours. The curfew by national law from 23:00 to 6:00 at German airports is a strong limitation and comparative disadvantage, especially during the summer season, which brings additional scheduled charter flights and delayed incoming flights from other congested airports. To be able to compare and benchmark the sample airport, a core hour period from 6:00 to 23:00 has been defined for this study.

Previous examination of the demand diagrams of all airports has shown that there is some network activity in off-peak times from 5:00 to 6:00 or from 23:00 to 24:00 at most analysed airports, which serves as buffer for additional seasonal demand. For capacity calculations the off-peak periods are insignificant, since there are enough slots available at any time.

Rank	Airport	Operating Hours	No. of Runways	Mix Index in %	FAA Runway-use Config. No.	Group	2007 Annual PAX in million	2007 Annual Ops
1	CDG	24/7	4	140	8	3	59.55	569,281
2	MAD	24/7	4	118	8	3	51.40	470,315
3	AMS	24/7	5.5	136	4 + 9	3	47.85	443,677
4	FRA	6-23	3	149	16	2	54.50	486,195
5	LHR	24/7	2	170	4	2	68.28	475,786
6	MUC	6-23	2	112	4	2	34.07	409,654
7	BCN	24/7	3	103	12	2	32.81	339,020
8	FCO	24/7	3	114	12	2	33.62	328,213
9	LGW	24/7	2	118	2	2	35.27	258,917
10	CPH	24/7	2.5	109	12	2	21.40	250,170
11	BRU	24/7	3	123	12	2	17.93	240,341
12	ORY	6-23:30	2.5	112	12	2	26.42	238,384
13	OSL	24/7	2	101	4	2	19.04	226,221
14	ZRH	6-23	3	121	10	2	20.81	223,707
15	DUS	6-23	2	107	2	2	17.85	223,410
16	MAN	24/7	2	116	2	2	22.33	206,498
17	IST	24/7	3	117	16	2	25.49	206,188
18	ARN	24/7	3	106	12	2	18.01	205,251
19	PMI	24/7	2	100	4	2	23.10	184,605
20	HEL	24/7	3	107	12	2	13.10	174,751
21	NCE	24/7	2	55	2	2	10.38	173,584
22	TXL	6-23	2	107	2	2	13.37	145,451
23	LYS	24/7 6-23 coord	2	102	2	2	7.19	132,076
24	VIE	24/7	2	109	14	1	18.77	251,216
25	DUB	24/7	3	108	14	1	23.31	200,891
26	STN	24/7	1	102	1	1	23.80	191,520
27	PRG	24/7	2	102	9	1	12.40	164,055
28	HAM	6-23	2	106	9	1	12.85	151,752
29	WAW	24/7	2	103	9	1	9.29	147,985
30	LIS	6-24	2	117	1	1	13.52	141,905
31	STR	6-23	1	101	1	1	10.35	139,757
32	BHX	24/7	1	104	1	1	9.32	104,480
33	LCY	6-22	1	100	1	1	2.91	77,274
	Total						810	8,182,530
	Mean		2	112			25	247,955

Table 4, Sample Airports Basic Data (Source: Bubalo 2009, FAA 1983, EUROSTAT, National Slot Coordination, Airport websites; Ranked by group and annual Ops; Runways < 7500 ft are counted 0.5; Due to the complexity of AMS' runway system of 6 runways, it has been split into two separate runway systems)

Annual Service Volumes, Peak Day and Peak Hour Capacity

From table 3 and figure 6 each airport's capacity is obtained. Since the MI and runway-use configuration number are now known, we get the corresponding values of ASV and IFR hourly capacity. For scheduling purposes all sample European airports have to declare their capacity, which means that Air traffic control (ATC), the airport authority and other officials define the hourly capacity (or smaller time period) in flights per time period being served at the particular airport. This maximum declared capacity is the basis for the slot allocation and biyearly scheduling process. The summer season 2009 number of slots per hour or maximum declared capacity by time of day has been collected for this analysis from the national slot coordination websites. The daily maximum slots are included in table 5.

In table 5 five different capacities over different time periods are presented: ASV, daily IFR CAP and slots (cumulated during core hours) and peak hourly IFR CAP and slots. Assuming the maximum declared capacity or slots being a "practical capacity" in the range of 80% of the ultimate capacity and which can be sustained over long time periods, an average runway service rate as a reciprocal of slots per hour has been calculated for each airport. LHR for example has a service frequency of one flight (departure or arrival) every 42 seconds on one of the two parallel runways.

The total of the ASV shows that the overall annual capacity of all sample airports is about 10.3 million flights per year compared to the total annual demand of 8.1 million flights (table 5).

Rank	Airport	Annual Capa Annual Service Volume (ASV)	Daily Capacity 2009 Core Hours: 06:00 - 22:59 DPD Core Hours Ultimate IFR CAP	DPD Core Hours Slots Summer Season	Hourly Capacity 2009 DPD ultimate IFR CAP Ops/hr	Slots per hour Summer Season	Runway Service Rate (based on Slots per hour) in Seconds per Ops
1	AMS	635,000	2703	1652	159	108	33.3
2	CDG	675,000	2040	1742	120	105	34.3
3	MAD	565,000	1989	1326	117	78	46.2
4	MUC	315,000	1785	1530	105	90	40
5	FCO	315,000	1785	1530	105	90	40
6	LHR	370,000	1683	1354	99	86	41.9
7	FRA	355,000	1360	1395	80	83	43.4
8	CPH	315,000	1785	1411	105	83	43.4
9	ARN	315,000	1785	1356	105	80	45
10	HEL	315,000	1785	1336	105	80	45
11	BRU	370,000	1683	1229	99	74	48.6
12	ORY	315,000	1785	1131	105	70	51.4
13	ZRH	340,000	1020	1122	60	66	54.5
14	BCN	315,000	1785	1020	105	60	60
15	OSL	315,000	1785	1025	105	60	60
16	PMI	315,000	1785	1020	105	60	60
17	TXL	285,000	1003	884	59	52	69.2
18	LYS	285,000	1003	867	59	51	70.6
19	NCE	260,000	952	794	56	50	72
20	DUS	285,000	1003	771	59	47	76.6
21	LGW	285,000	1003	797	59	46	78.3
22	MAN	285,000	1003	883	59	46	78.3
23	IST	300,000	1003	680	59	40	90
24	VIE	225,000	1003	1044	59	66	54.5
25	HAM	225,000	1003	901	59	53	67.9
26	DUB	225,000	1003	703	59	46	78.3
27	PRG	225,000	1003	676	59	46	78.3
28	STR	210,000	901	714	53	42	85.7
29	BHX	210,000	901	680	53	40	90
30	STN	210,000	901	733	53	38	94.7
31	LIS	210,000	901	612	53	36	100
32	WAW	225,000	1003	578	59	34	105.9
33	LCY	210,000	901	384	53	24	150
	Total	10,305,000	45,033	33,880	2,649	2,030	2,187
	Mean	312,273	1,365	1,027	80	62	66

Table 5, Sample Airport Capacities (Bubalo 2009)

With known capacity it is time to look at the existing demand at the sample airports. The daily and hourly demand on PDTHUW26 for the years 2007-2009 has been extracted from the collected flight schedule data. The daily values only take operations during core hours into account.

The annual demand for 2007 is taken from EUROSTAT.

Table 6 gives an overview on annual, daily and hourly demand at all sample airports and is another important prerequisite to calculate idle capacity, capacity utilization or delay.

From the small time series it is observable how strong the impact of the global financial crisis is on air traffic demand. Daily and hourly demand has peaked in 2007 and 2008 and dropped considerably in 2009. Recent signs of an ending of the crisis will also translate in an increase in demand in 2010.

		Annual Dema	Daily Demand			Hourly Demand		
		2007	2007	2008	2009	2007	2008	2009
Rank	Airport	Annual Ops *2007 EUROSTAT	Design Peak Day (DPD) Ops	Design Peak Day (DPD) Ops	Design Peak Day (DPD) Ops	Design Peak Hour (DPH) Ops	DPH Ops	DPH Ops
1	CDG	569,281	1624	1657	1424	114	126	107
2	MAD	470,315	1412	1478	1370	96	112	112
3	AMS	443,677	1321	1392	1188	109	111	106
4	FRA	486,195	1373	1342	1274	92	89	87
5	LHR	475,786	1530	1530	1386	103	103	90
6	MUC	409,654	1258	1277	1144	99	93	92
7	BCN	339,020	1071	940	866	86	80	74
8	FCO	328,213	1076	1338	1110	109	103	100
9	LGW	258,917	757	802	678	55	56	49
10	CPH	250,170	811	776	712	67	70	62
11	BRU	240,341	784	800	736	77	71	67
12	ORY	238,384	765	749	710	62	63	60
13	OSL	226,221	678	693	577	66	60	49
14	ZRH	223,707	754	681	654	69	57	57
15	DUS	223,410	713	718	701	58	51	58
16	MAN	206,498	671	669	499	60	69	51
17	IST	206,188	593	607	663	42	44	47
18	ARN	205,251	666	727	528	61	61	50
19	PMI	184,605	529	551	502	50	44	45
20	HEL	174,751	497	496	434	47	41	44
21	NCE	173,584	515	610	469	47	52	48
22	TXL	145,451	496	531	482	43	42	42
23	LYS	132,076	411	351	376	47	44	43
24	VIE	251,216	794	795	726	66	67	59
25	DUB	200,891	545	560	467	42	44	43
26	STN	191,520	549	516	408	51	47	38
27	PRG	164,055	529	573	445	48	57	39
28	HAM	151,752	516	509	458	46	44	38
29	WAW	147,985	422	425	322	35	32	26
30	LIS	141,905	405	350	326	38	37	34
31	STR	139,757	656	427	370	54	41	35
32	BHX	104,480	340	348	307	32	29	28
33	LCY	77,274	298	332	239	34	36	36
	Total	8,182,530	25,359	25,550	22,551	2,105	2,076	1,916
	Mean	247,955	768	774	683	64	63	58

Table 6, Sample Airport Demand (Bubalo 2009)

Idle Airport and Network Capacity and Capacity Utilization

Finally the collected values for capacity and demand are analysed with regard to the amount of idle capacity and capacity utilization at each airport (table 7 & table 10).

Idle capacity results from the difference of available slots or capacity to demand. To further explain the methodology of further calculations figure 7 shows each core hour demand and capacity over time of day for Madrid airport (MAD). Total daily operations during core hours add up to 1370 flights; there are 1326 total slots and a total additional idle IFR capacity of 663 flights available each day. That leaves 44 peak daily flights with unavailable slots (Table 7).

more Ops than available Slots

Rank	Airport	Daily Idle Capacity 2009 Additional IFR Runway Capacity (IFRCAP - DPD Slots)	2007 Daily Idle Core Hours Slots	2008 Daily Idle Core Hours Slots	2009 Daily Idle Core Hours Slots	Hourly Idle Capacity 2007 DPH Idle Slots	2008 DPH Idle Slots	2009 DPH Idle Slots
1	MAD	663	-86	-152	-44	-18	-34	-34
2	CDG	298	118	85	318	-9	-21	-2
3	AMS	1051	331	260	464	-1	-3	2
4	BCN	765	-51	80	154	-26	-20	-14
5	DUS	232	58	53	70	-11	-4	-11
6	FCO	255	454	192	420	-19	-13	-10
7	IST	323	87	73	17	-2	-4	-7
8	MAN	120	212	214	384	-14	-23	-5
9	FRA	-35	22	53	121	-9	-6	-4
10	LHR	329	-176	-176	-32	-17	-17	-4
11	LGW	206	40	-5	119	-9	-10	-3
12	MUC	255	272	253	386	-9	-3	-2
13	NCE	158	279	184	325	3	-2	2
14	BRU	454	445	429	493	-3	3	7
15	LYS	136	456	516	491	4	7	8
16	ZRH	-102	368	441	468	-3	9	9
17	ORY	654	366	382	421	8	7	10
18	TXL	119	388	353	402	9	10	10
19	OSL	760	347	332	448	-6	0	11
20	PMI	765	491	469	518	10	16	15
21	CPH	374	600	635	699	16	13	21
22	ARN	429	690	629	828	19	19	30
23	HEL	449	839	840	902	33	39	36
24	LCY	517	86	52	145	-10	-12	-12
25	STN	168	184	217	325	-13	-9	0
26	LIS	289	207	262	286	-2	-1	2
27	DUB	300	158	143	236	4	2	3
28	VIE	-41	250	249	318	0	-1	7
29	PRG	327	147	103	231	-2	-11	7
30	STR	187	58	287	344	-12	1	7
31	WAW	425	156	153	256	-1	2	8
32	BHX	221	340	332	373	8	11	12
33	HAM	102	385	392	443	7	9	15
	Total	11,153	8,521	8,330	11,329	-75	-46	114
	Mean	338	258	252	343	-2	-1	3

Table 7, Idle Capacity at Sample Airports (Bubalo 2009)

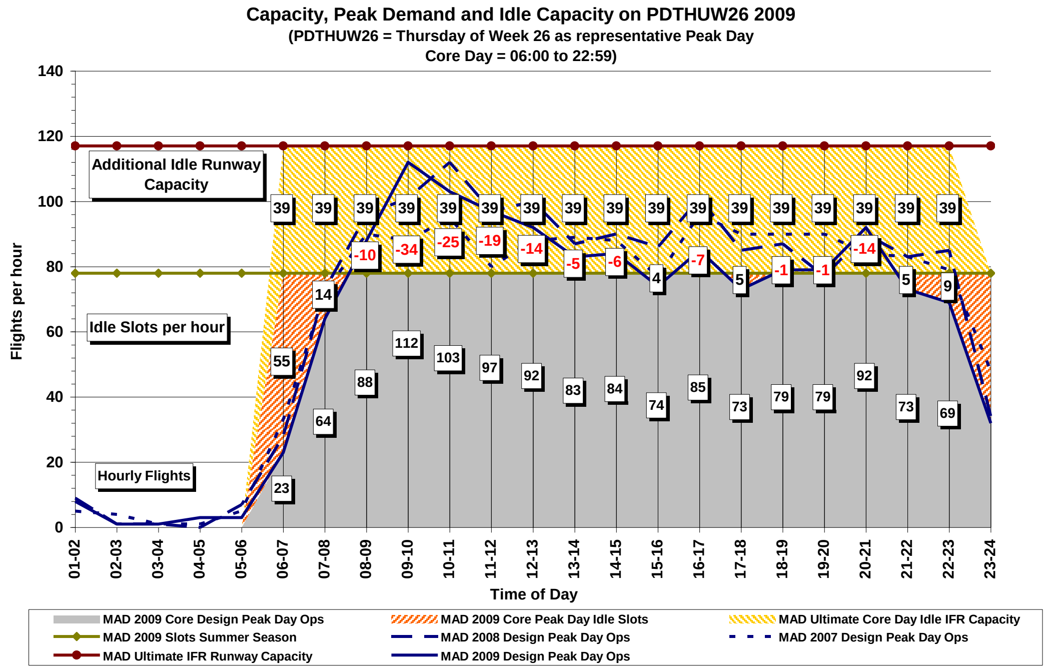

Figure 7, Capacity and demand on DPD for MAD airport (Bubalo 2009)

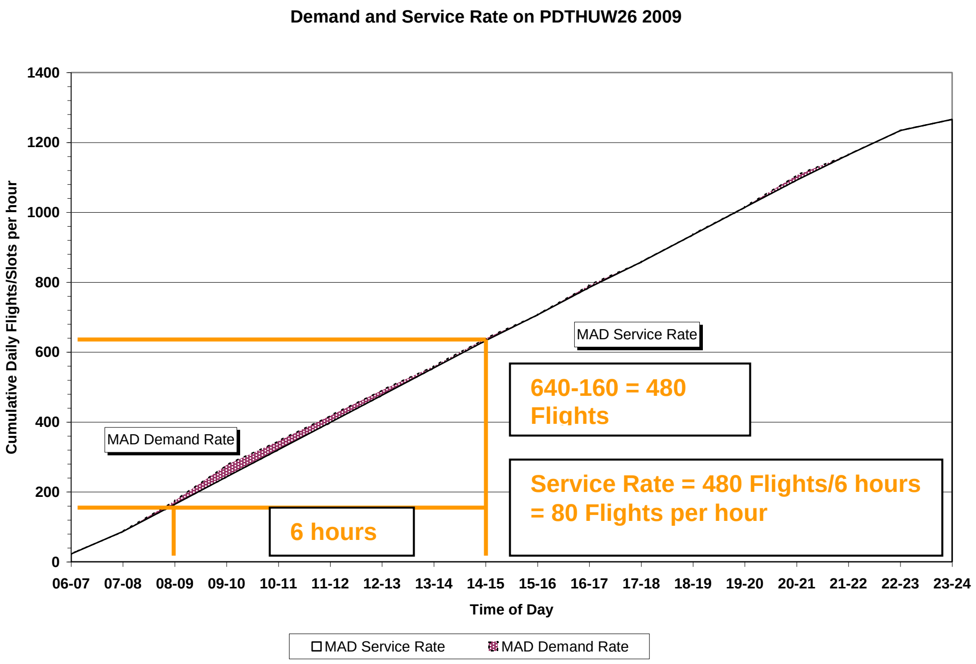

Figure 8, Flow Chart of Service and Demand Rate for MAD airport (Bubalo 2009)

The capacity and demand diagram of MAD airport on PDTHUW26 2009 shows a significant over-utilization of slot capacity between 8:00 and 14:00, 16:00 to 17:00 and 18:00 to 21:00. The slots per hour represent the number of aircraft being served at a given time of day. The cumulative slots per hour represent the airport service rate, which is the maximum throughput of the runway system, and the cumulative demand shows the demand rate.
The shaded area between the two curves represents the queued or delayed aircraft (Figure 8).

Since the area between service and demand curve is very small, it is difficult to calculate delay and delayed aircraft through these flow charts. A better representation is the demand – capacity chart (Figure 9), which allows a much better estimation of delayed aircraft.

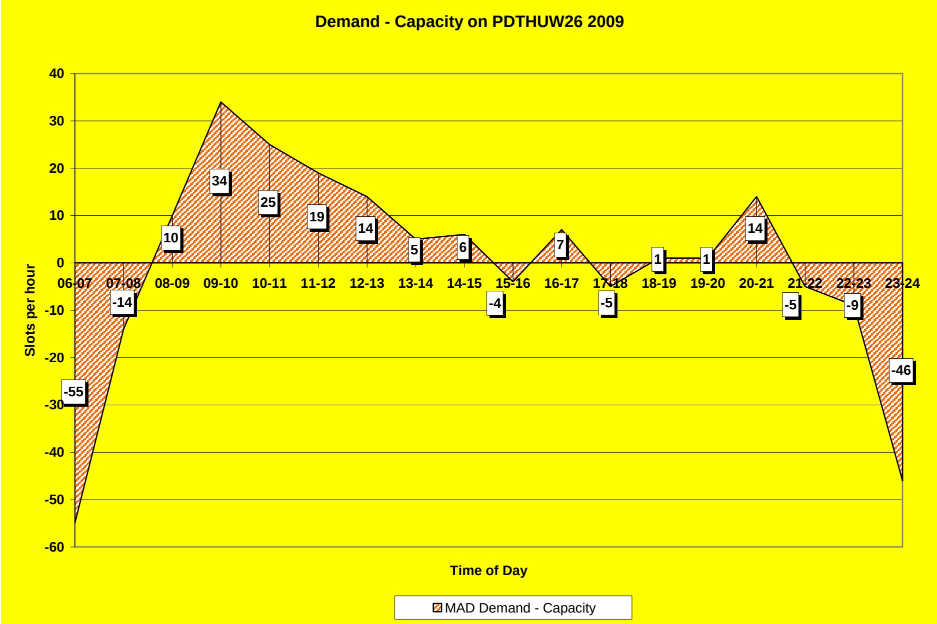

Figure 9, Demand-Capacity Chart for MAD airport

The positive values of the demand-capacity chart are all delayed aircraft. In the case of MAD airport on PDTHUW26 2009 this amounts to a maximum of 34 aircraft being potentially delayed between 9:00 and 10:00 and a daily total of 136 delayed aircraft-hours between the time delayed aircrafts build up at 8:00 and the time the service rate catches up at 21:00 (table 8).

During that time the service rate as the inverse of the slot capacity is 1/78 slots per hour = 0.013 hours per operation or 0.769 minutes per operation or 46 seconds per operation. Thus the 34th delayed aircraft experiences a delay of 34 operations x 0.769 minutes per operation = 26.15 minutes of delay. The average delay per aircraft on this day at MAD airport is 136 aircraft-hours/ 1370 operations = 0.099h or 5.96 minutes (table 9). MAD airport caused the highest average delay per aircraft in 2009.

		Daily Delayed Aircraft			Max. Delayed Aircraft		
		2007	2008	2009	2007	2008	2009
Rank	Airport	Delayed Aircraft in Core Hours	Delayed Aircraft in Core Hours	Delayed Aircraft in Core Hours	max. Delayed Aircraft per hour	max. Delayed Aircraft per hour	max. Delayed Aircraft per hour
1	MAD	138	208	136	18	34	34
2	AMS	55	46	40	20	21	16
3	CDG	17	70	0	8	20	0
4	LHR	193	184	69	37	44	32
5	IST	3	5	29	2	4	7
6	BCN	110	45	27	26	20	14
7	DUS	22	16	23	11	6	11
8	FCO	26	50	14	19	13	10
9	FRA	36	17	7	9	6	4
10	MUC	29	10	2	9	3	2
11	LGW	15	30	0	6	6	0
12	CPH	0	0	0	0	0	0
13	BRU	3	0	0	3	0	0
14	ORY	0	0	0	0	0	0
15	OSL	1	0	0	1	0	0
16	ZRH	3	0	0	3	0	0
17	MAN	4	12	0	3	12	0
18	ARN	0	0	0	0	0	0
19	PMI	0	0	0	0	0	0
20	HEL	0	0	0	0	0	0
21	NCE	0	4	0	0	2	0
22	TXL	0	0	0	0	0	0
23	LYS	0	0	0	0	0	0
24	PRG	60	73	43	27	28	21
25	LCY	34	55	22	10	12	12
26	VIE	9	2	7	9	1	5
27	DUB	3	0	0	3	0	0
28	STN	6	1	0	3	1	0
29	HAM	0	0	0	0	0	0
30	WAW	1	0	0	1	0	0
31	LIS	4	1	0	2	1	0
32	STR	41	0	0	12	0	0
33	BHX	0	0	0	0	0	0
	Total	813	829	419	242	234	168
	Mean	25	25	13	7	7	5

Table 8, Delayed Aircraft in Core Hours and Maximum Delayed Aircraft per hour

Table 9 indicates the airports that cause major delays in the European air traffic network. Especially in the summer season of 2008 many flights experienced a considerable amount of delay with e.g. up to 30 minutes at LHR airport.

To have another comparison for the delay calculations, data from the FAA Airport Design Software (http://www.faa.gov/airports/engineering/design_software/) has been used for delay calculation. Values indicated in light blue fell out-of-range in the software and represent minimum values for delay that are actually much higher. The FAA software calculates annual delay minutes and annual average delay per aircraft for a high medium and a low scenario.

Variations in the DPD delay calculations and the FAA annual calculations do not necessarily show the same amount of average delay per aircraft due to the different observation periods. Moreover strong DPD delays result from exceptional high peaks and over utilization of slot capacity.

Still the calculations give a suggestion about the state of capacity utilization at airports for different time periods. Candidates at top of the list by the FAA annual calculations are also in the higher ranks of DPD calculations. To get an impression of the intensity of delays, fields with a delay > 4 minutes per flight are highlighted.

		Minimum estimate		Delay > 4 minutes per Aircraft		Max. Delay per Aircraft on DPD			Average Delay per Aircraft on DPD		
		Annual Delay 2007				2007	2008	2009	2007	2008	2009
Rank	Airport	Annual Delay Medium ('000 minutes)	Annual Delay High ('000 minutes)	Avg. Delay per Aircraft Medium in minutes	Avg. Delay per Aircraft High in minutes	Max. Delay per Aircraft in min	Max. Delay per Aircraft in min	Max. Delay per Aircraft in min	Avg. Delay per Aircraft in min	Avg. Delay per Aircraft in min	Avg. Delay per Aircraft in min
1	AMS	752	1146	0.25	1.02	11.11	11.67	8.89	2.5	1.98	2.02
2	CDG	626	968	1.15	1.75	4.57	11.43	0	0.63	2.53	0
3	MAD	470	752	1	1.6	13.85	26.15	26.15	5.86	8.44	5.96
4	LHR	1795	2856	4.4	7	25.81	30.7	22.33	7.57	7.22	2.99
5	FRA	1725	2744	4.4	7	6.51	4.34	2.89	1.57	0.76	0.33
6	MUC	1531	2436	4.4	7	6	2	1.33	1.38	0.47	0.1
7	BCN	1254	2034	3.69	6.03	26	20	14	6.16	2.87	1.87
8	FCO	985	1608	3.02	4.88	12.67	8.67	6.67	1.45	2.24	0.76
9	LGW	388	621	1.48	2.36	7.83	7.83	0	1.19	2.24	0
10	CPH	225	350	0.93	1.43	0	0	0	0	0	0
11	DUS	201	313	0.91	1.38	14.04	7.66	14.04	1.85	1.34	1.97
12	ORY	191	310	0.83	1.26	0	0	0	0	0	0
13	OSL	158	249	0.73	1.1	1	0	0	0.09	0	0
14	MAN	145	227	0.75	1.13	3.91	15.65	0	0.36	1.08	0
15	BRU	144	216	0.58	0.89	2.43	0	0	0.23	0	0
16	IST	144	206	0.66	0.99	3	6	10.5	0.3	0.49	2.62
17	ZRH	134	201	0.6	0.91	2.73	0	0	0.24	0	0
18	ARN	123	185	0.59	0.89	0	0	0	0	0	0
19	NCE	104	156	0.62	0.94	0	2.4	0	0	0.39	0
20	PMI	92	129	0.47	0.72	0	0	0	0	0	0
21	HEL	70	105	0.43	0.64	0	0	0	0	0	0
22	TXL	58	73	0.36	0.53	0	0	0	0	0	0
23	LYS	40	53	0.31	0.43	0	0	0	0	0	0
24	VIE	1091	1736	4.4	7	8.18	0.91	4.55	0.68	0.15	0.58
25	STN	287	460	1.51	2.4	4.74	1.58	0	0.66	0.12	0
26	DUB	281	442	1.37	2.16	3.91	0	0	0.33	0	0
27	PRG	131	180	0.76	1.15	35.22	36.52	27.39	6.81	7.64	5.8
28	HAM	91	152	0.63	0.95	0	0	0	0	0	0
29	LIS	85	142	0.63	0.96	3.33	1.67	0	0.59	0.17	0
30	WAW	89	133	0.6	0.91	1.76	0	0	0.14	0	0
31	STR	84	126	0.61	0.93	17.14	0	0	3.75	0	0
32	BHX	31	52	0.35	0.5	0	0	0	0	0	0
33	LCY	15	23	0.23	0.27	25	30	30	6.85	9.94	5.52
	Total	13,543	21,385								
	Mean	410	648	1.32	2.09	7.3	6.82	5.11	1.55	1.52	0.92

Table 9, Calculated Delays at Sample Airports (Ranked by Annual Delay)

The capacity utilization assessment table (table 10) incorporates all quotients of demand and capacity. Annual capacity utilization for the year 2007 is given. For the years 2007 to 2009 the peak hourly and peak daily ultimate capacity utilization and slot utilization is also calculated. It is quite striking that at most airports there is a considerable amount of high or over utilization of slots observable during peak periods. Some pressure was released with the decline in traffic during the year 2009, but in general it can be said, that European airports suffer from slot shortage. So an effort must be made in close examination of the amount of potential idle IFR capacity at each airport.

Congested >75% / Saturated > 95%		Annual Capacity Utilization	Daily Capacity Utilization						Hourly Capacity Utilization					
Rank	Airport	Annual Capacity Utilization	2007 Ultimate Capacity Utilization = DPD Ops/DPD IFR CAP	Slot Utilization = DPD Ops/DPD Slots	2008 Ultimate Capacity Utilization = DPD Ops/DPD IFR CAP	Slot Utilization = DPD Ops/DPD Slots	2009 Ultimate Capacity Utilization = DPD Ops/DPD IFR CAP	Slot Utilization = DPD Ops/DPD Slots	2007 Ultimate Capacity Utilization = DPH Ops/IFR CAP	Slot Utilization = DPH Ops/Slots	2008 Ultimate Capacity Utilization = DPH Ops/IFR CAP	Slot Utilization = DPH Ops/Slots	2009 Ultimate Capacity Utilization = DPH Ops/IFR CAP	Slot Utilization = DPH Ops/Slots
1	MAD	83%	71%	106%	74%	111%	69%	103%	82%	123%	96%	144%	96%	144%
2	CDG	84%	80%	93%	81%	95%	70%	82%	95%	109%	105%	120%	89%	102%
3	AMS	70%	49%	80%	51%	84%	44%	72%	69%	101%	70%	103%	67%	98%
4	DUS	78%	71%	92%	72%	93%	70%	91%	98%	123%	86%	109%	98%	123%
5	BCN	108%	60%	105%	53%	92%	49%	85%	82%	143%	76%	133%	70%	123%
6	IST	69%	59%	87%	61%	89%	66%	98%	71%	105%	75%	110%	80%	118%
7	FCO	104%	60%	70%	75%	87%	62%	73%	104%	121%	98%	114%	95%	111%
8	MAN	72%	67%	76%	67%	76%	50%	57%	102%	130%	117%	150%	86%	111%
9	LGW	91%	75%	95%	80%	101%	68%	85%	93%	120%	95%	122%	83%	107%
10	FRA	137%	101%	98%	99%	96%	94%	91%	115%	111%	111%	107%	109%	105%
11	LHR	129%	91%	113%	91%	113%	82%	102%	104%	120%	104%	120%	91%	105%
12	MUC	130%	70%	82%	72%	83%	64%	75%	94%	110%	89%	103%	88%	102%
13	NCE	67%	54%	65%	64%	77%	49%	59%	84%	94%	93%	104%	86%	96%
14	BRU	65%	47%	64%	48%	65%	44%	60%	78%	104%	72%	96%	68%	91%
15	ZRH	66%	74%	67%	67%	61%	64%	58%	115%	105%	95%	86%	95%	86%
16	ORY	76%	43%	68%	42%	66%	40%	63%	59%	89%	60%	90%	57%	86%
17	LYS	46%	41%	47%	35%	40%	37%	43%	80%	92%	75%	86%	73%	84%
18	OSL	72%	38%	66%	39%	68%	32%	56%	63%	110%	57%	100%	47%	82%
19	TXL	51%	49%	56%	53%	60%	48%	55%	73%	83%	71%	81%	71%	81%
20	PMI	59%	30%	52%	31%	54%	28%	49%	48%	83%	42%	73%	43%	75%
21	CPH	79%	45%	57%	43%	55%	40%	50%	64%	81%	67%	84%	59%	75%
22	ARN	65%	37%	49%	41%	54%	30%	39%	58%	76%	58%	76%	48%	63%
23	HEL	55%	28%	37%	28%	37%	24%	32%	45%	59%	39%	51%	42%	55%
24	LCY	37%	33%	78%	37%	86%	27%	62%	64%	142%	68%	150%	68%	150%
25	STN	91%	61%	75%	57%	70%	45%	56%	96%	134%	89%	124%	72%	100%
26	LIS	68%	45%	66%	39%	57%	36%	53%	72%	106%	70%	103%	64%	94%
27	DUB	89%	54%	78%	56%	80%	47%	66%	71%	91%	75%	96%	73%	93%
28	VIE	112%	79%	76%	79%	76%	72%	70%	112%	100%	114%	102%	100%	89%
29	PRG	73%	53%	78%	57%	85%	44%	66%	81%	104%	97%	124%	66%	85%
30	STR	67%	73%	92%	47%	60%	41%	52%	102%	129%	77%	98%	66%	83%
31	WAW	66%	42%	73%	42%	74%	32%	56%	59%	103%	54%	94%	44%	76%
32	HAM	67%	51%	57%	51%	56%	46%	51%	78%	87%	75%	83%	64%	72%
33	BHX	50%	38%	50%	39%	51%	34%	45%	60%	80%	55%	73%	53%	70%
	Mean	78%	57%	74%	57%	74%	50%	65%	81%	105%	79%	103%	73%	95%

Table 10, Annual, Daily and Hourly Capacity Utilizations for 2007-2009

Summary of Findings

The study of different capacities and demand over various time periods at European airports is a first step towards clearer answers concerning the overall capacity situation. It has been found that there is still some capacity left that could be freed. In 2009 there where 11,329 idle slots available compared to 22,551 daily flights, which is about one-third of all available slots. In addition to that a potential idle IFR CAP of an additional 33% of capacity or 11153 daily flights could possibly be freed.
The capacity utilization varies substantially depending on the observed time period.
The declaration of capacities during the scheduling process must be carefully made in order to avoid the underestimation of the real capacity and service-rate. Regardless of the over utilization of slots at Barcelona (BCN), Rome (FCO), Frankfurt (FRA), London-Heathrow (LHR), Munich (MUC) and Vienna (VIE), traffic is still flowing during peak times (Table 10). Therefore it can be assumed that there might be an artificial shortage of slots, which doesn't reveal the true network capacity in Europe (figure 10).
For example FRA airport had a maximum declared capacity of 60 flights per hour in 1990 (SRI 1990). Through operational changes and new technological equipment today over 80 slots are allocated each hour, with no changes to the runway system. This shows that the available number of slots is steadily increasing at most airports over the years towards an unknown ultimate capacity.

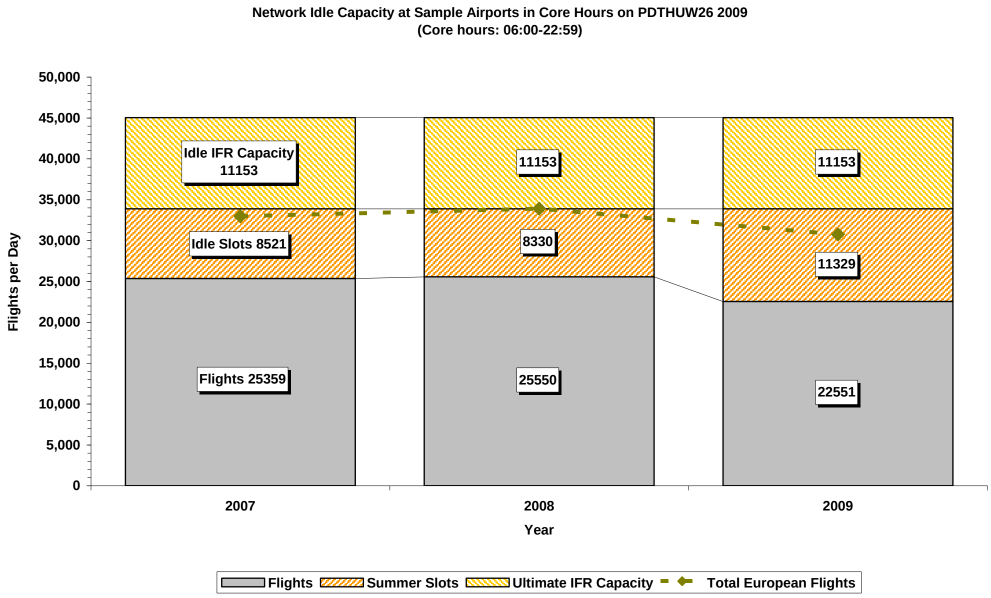

Figure 10, Network Idle Capacity and Total Daily European Flights

Through simulation of airfield operations it is possible to determine the "real" ultimate capacity or practical capacity of a runway system, without violating the level-of-service of around 4 minutes average delay per aircraft. Further research should concentrate on making liable capacity approximations through fast-time simulation, by constantly fine-tuning the variables and inputs. Simulation should work as an automated process, where little knowledge about the internal model should be required. A starting point has been set with a study of 22 single runway European airports, which should be expanded to more complex configurations in the future. The simulation outputs can than be used for the calculation presented in this paper.

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