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CONSTRAINED AND UNDERUTILISED AIRPORTS: TWO SIDES OF A COIN

Peter Berster, Marc Gelhausen, Dieter Wilken
German Aerospace Center (DLR)
Institute of Air Transport and Airport Research
51147 Cologne, Germany
Phone: +49 2203 601 2567
E-Mail: Dieter.Wilken@dlr.de

ABSTRACT

The global airport network consists of several thousand airports, of which around 2,500 are connected to the network of scheduled airline services. These services are concentrated on a relatively small number of high volume airports, i. e. hub airports. Analyses have shown that the top 100 airports worldwide handle about 50 % of the total scheduled air traffic. On the other side there are more than 1,500 airports with traffic volumes that represent just 5 % of the total traffic. This traffic distribution shows that besides the concentration on a relatively small number of airports the majority of airports worldwide handle traffic volumes well below their capacity limits. In fact these airports have a high interest to attract more traffic in order to cover the costs. In the research to be presented we will quantitatively show the amount of traffic concentration and constraints on the one hand and correspondingly the degree of low or "under"-utilisation of other airports, globally and for a sample of countries in different world regions. In addition, it is intended to show the change in traffic distribution over all airports of country networks over time and analyse the reasons of concentration and the dynamics of changes in airport utilization. Preliminary analysis in European countries has shown that the concentration of already congested airports has grown in recent years and that small airports have lost traffic due to the deployment of aircraft with higher seat capacity.

TOPIC AREA

Airport and airline performance; airline network development;

KEYWORDS

Spatial air traffic concentration; airport underutilization; traffic concentration and airport congestion.

1. Introduction

It is a well-known fact that traffic, regardless of the mode, is neither equally distributed over the network nor over the time of the day, week or the year. The spatial distribution of land uses and the temporal distribution of human activities and movements between different land uses causes concentrations of traffic flows on network sections and in time windows. Air traffic is no exception to this rule. In a former study on the global airport constraint situation (Gelhausen et al, 2013) it has been shown that in 2008 the cumulative distribution of air traffic in the global network of around 2400 airports was characterised by a high degree of concentration on a rather limited number of important airports as was indicated by a Gini coefficient value of 0.8.

Knowing about this global concentration of air traffic the research interest of this paper is to describe the traffic distribution in more detail, on the global scale as well in world regions and selected countries. This includes statements on the great number of airports with rather small traffic volumes. Since we have to assume a correlation between traffic volumes and capacity utilization we analyse the degree of capacity utilization by estimating airport capacities and volume-capacity ratios. As a result we show that many of the high volume airports are identical with those that operate in near capacity conditions. On the other side, all airports with low traffic volumes have ample capacity reserves and would welcome additional traffic. In fact the majority of airports worldwide are far away from capacity problems in the near future.

An interesting question is whether or not the degree of traffic concentration has changed in the past. With smaller commercial aircraft in the market and more airports having been added to the network in some markets one would assume that traffic has deconcentrated. As will be shown this is the case on the global scale, however, only to a small degree, air traffic remains very concentrated. Similar developments have occurred in world regions and countries, however with some variation.

The structure of the paper is as follows:

- The global airport network
- Traffic distribution in the global airport network, in major world regions and in selected countries
- Traffic concentration in the global airport network, in major world regions and in selected countries
- Development of traffic concentration in the global airport network and in selected countries
- A first analysis of airports with high and with low capacity utilization
- Distribution of capacity utilization of airports in the global network and in major world regions
- Results and discussion

2. The global airport network

Air traffic as described in the following is given by the number of flights or flight movements (take-offs and landings, also air transport movements ATM's) at airports. Supply characteristics of flights were derived from the Official Airline Guide (OAG, various years). All airports listed in the OAG data file, which provide scheduled air services to other airports, have been included in the analysis of traffic distribution and capacity utilization.

While it is obvious that the biggest airports at the top end like Chicago O'Hare and Atlanta are contained in the list of all airports, the network defined by OAG counts airports at the low end which may have only a few regular services within a week or a year. Since there are only relatively few airports with high traffic volumes of say over 100 Thousand ATM's per year, however, many airports with rather low traffic volumes of over some Hundred or Thousand ATM's, the average annual traffic volume in 2014 was only just over 16 Thousand ATM's per airport.

The total number of airports varies from year to year depending on the existence of scheduled services, in some countries airport networks get bigger with growing demand, whereas in other countries the number of airports served by regular flights decreases. In total the number of airports with scheduled services has slightly decreased from 4,035 in 2000 to 3,944 in 2014 as can be seen in the following table:

Year	# of Airports	# of Take-offs
2000	4035	27,938,423
2001	3962	27,662,485
2002	3911	26,514,658
2003	3826	26,278,155
2004	3826	27,589,145
2005	3816	28,581,862
2006	3786	28,899,965
2007	3782	30,145,403
2008	3790	30,274,483
2009	3835	29,189,147
2010	3850	30,577,632
2011	3883	31,596,311
2012	3811	31,847,041
2013	3936	32,220,615
2014	3944	33,002,972

Table1: Development of the Number of Airports and Take-offs (Source: OAG, 2000-2014, DLR)

In contrast, the traffic volume has grown from 27.9 Million flights (corresponding to 55.8 Million ATM's) in 2000 to 33.0 Million flights. Since the number of airports did not increase the average traffic volume per airports has grown from 6.9 Thousand in 2000 to 8.4 Thousand flights in 2014. The corresponding average daily traffic volume has thus increased from just 19 to 23 flights.

As has been mentioned the analysis of traffic distribution and concentration has been carried out for major world regions as well as for some countries. The world regions are:

- Europe
- Asia
- North America
- South Pacific
- Africa
- South America
- Middle East.

The selected countries are two big states, China representing a growing air transport market, and the US as a huge market with more or less saturated demand, and two European states with a centralized and a less centralized network, namely France and Germany. The number of airports in each region with the corresponding traffic volume in 2014 is shown in the following table:

World Region	# of Airports	# of Flights (10^3)
Europe	679	7,634
Asia	875	8,700
North America	1,022	10,107
Southwest Pacific	340	1,085
Africa	376	1,102
South America	531	3,307
Middle East	121	1,067
World	**3,944**	**33,003**

Table 2: Number of Airports and Flights by World Region (Source: OAG, 2014, DLR)

World Region	# of Airports	# of Flights (10^3)
China	200	3,483
USA	723	8,985
France	63	696
Germany	33	896

Table 3: Number of Airports and Flights for selected Countries (Source: OAG, 2014, DLR)

The North American market, dominated by the US market, is still the most important air traffic region among the listed world regions, and counts more than one Thousand airports, which handled in 2014 over 10 Million flights, equal to 20 Million ATM's. The Asian market follows with 875 airports with regular services and 8.7 Million flights; Europe is on the third place with 679 airports, which handled 7.6 Million flights. 80 % of the total air traffic of 33 Million flights is concentrated on these three regions, which have, however, just 65 % (2,576) of all airports worldwide.

While the total number of airports with regular services has slightly decreased from 2000 to 2014, the networks in world regions have developed in different ways. In North America the number of airports has decreased from 1,069 in 2000 to 1,022 in 2014, whereas in Asia networks have grown strongly from 650 to 875 airports. Equally in the Middle East, airport density has grown from 99 to 121 airports. In Europe the number of airports has practically not changed in that time span of 14 years. In the other regions Africa, South America and South West Pacific network density has gone down.

3. Traffic distribution and concentration in the global airport network

By ranking airports by traffic volume we can show the traffic distribution over all airports, both in a direct and in a cumulative way. In Fig. 1, the distribution of the global air traffic is shown for the year 2014. For reasons of comparability between charts the number of flights (y-axis) and of airports (x-axis) are shown as shares of the total number. Each airport in the global network counts therefore for 0.0254 % of all airports. The airport Dallas/Fort Worth (DFW) had for example a traffic volume of 333 Thousand flights in 2014, which corresponds to roughly 1 % of the total flight volume of 33 Million flights worldwide (see Fig. 1).

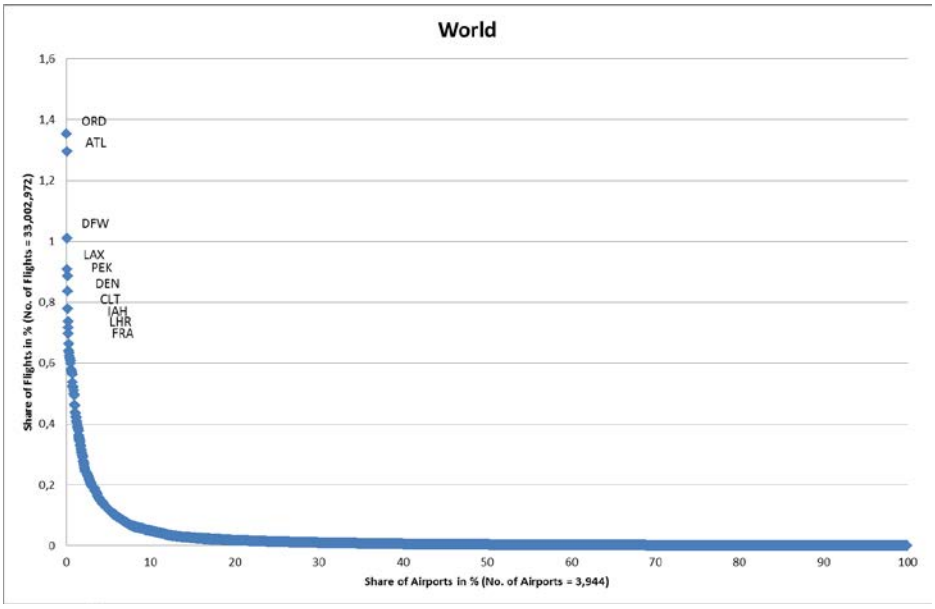


Fig. 1: Air Traffic Distribution in the Global Airport Network 2014 (Source: OAG, 2014, DLR)

The average traffic volume per airport in 2014 is about 8.4 Thousand flights, which corresponds to 0.0254 % of the total flight volume. The biggest airport in terms of ATM’s is Chicago O’Hare with 462 Thousand flights which is 55 times the average airport traffic. The distribution as shown in Fig. 1 shows that only about 15 % of all airports have higher than average volumes, which means, too, that 85 % of all airports worldwide have traffic volumes below 8.4 Thousand flights per year. Traffic is thus not equally distributed over all airports, but rather concentrated on a relatively small number of airports.

The concentration of traffic becomes even more evident if one refers to the cumulative distribution, which is shown in Fig. 2. The two axes have the same dimensions as in Fig. 1. As can be seen traffic share increases sharply over just a small share of all airports, 50 % of total traffic is handled by only 3 % and 90 % is handled by 24 % of all airports. In other words, the biggest 122 airports (3 %) handle half of the total traffic, that is 16.5 Million flights, while the other 3,822 airports handle the same volume of traffic, on average each one 4.3 Thousand flights per year. Furthermore, the biggest 949 airports (24 %) handle almost 30 Million flights, while the other nearly 3,000 airports handle just 3 Million flights, on average thus one Thousand flights per year. Converted to a daily volume this would mean almost 3 flights per day. The skewedness of the distribution function is typically described by the Gini coefficient, which is in this case equal to 0.782.

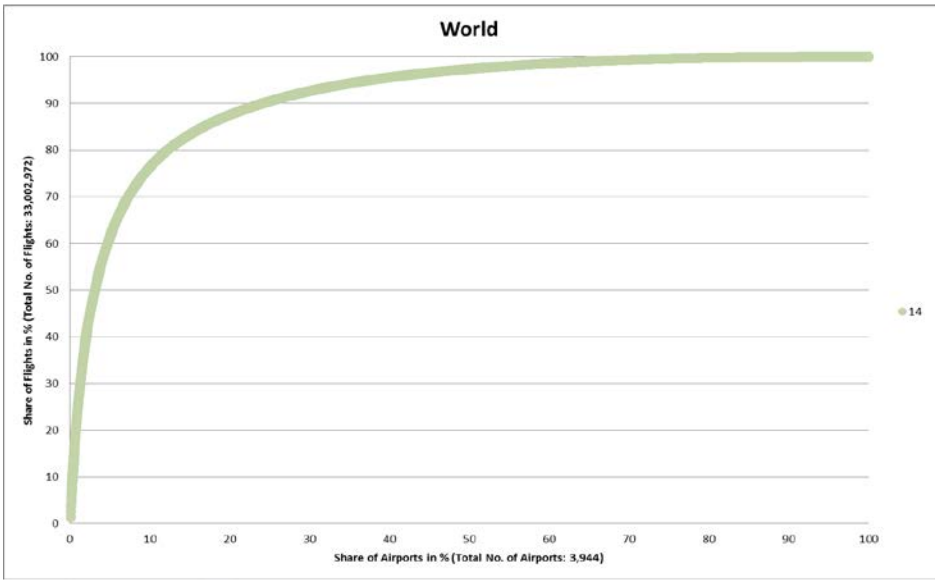


Fig. 2: Cumulative Distribution of Air Traffic in the Global Airport Network in 2014 (Source: OAG, 2014, DLR)

The global airport network consists thus of a small number of airports with high traffic volumes, while on the great number of airports traffic volumes are in the order of just a few flights a day. This latter group of airports does not have capacity problems as airports in the first group may have to struggle with; their main concern is probably to attract more traffic to the airport in order to cover the cost of operations.

4. Traffic distribution and concentration in major world regions

If on the global scale traffic is spatially distributed in such a way that a relatively small number of airports with big flight volumes, in many instances identical with hub airports, handle a great portion of the total traffic, can we assume similar concentration patterns in world regions? For this, the traffic distribution and cumulative distribution have been analysed region by region for the year 2014. As an example, the traffic distribution in **Asia** is shown in Fig. 3.

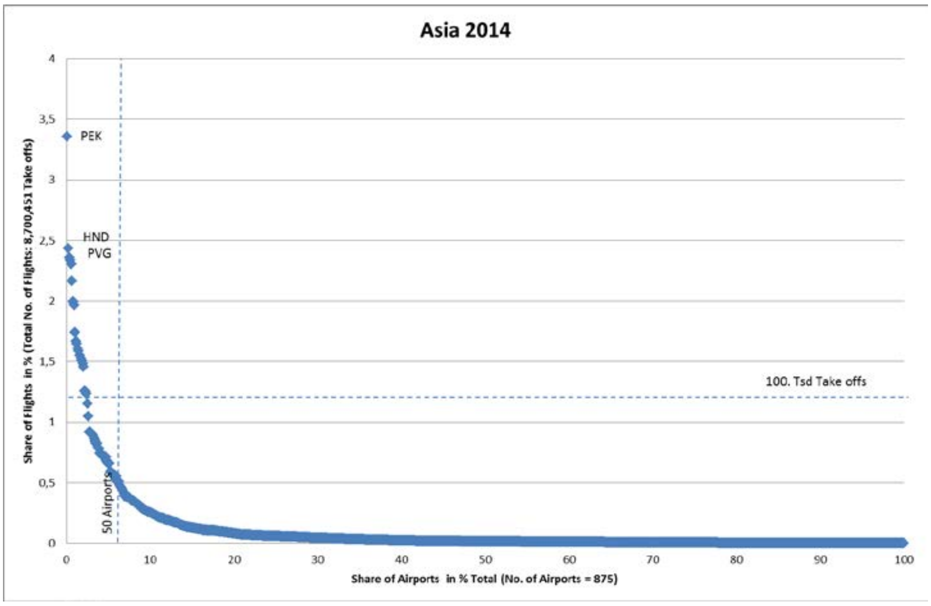


Fig. 3: Air Traffic Distribution in the Asian Airport Network 2014 (Source: OAG, 2014, DLR)

As can be seen the distribution of traffic is similar to the global distribution; traffic is concentrated on a relatively small number of big airports, i. e. Beijing (PEK), Tokio/Haneda (HND), Shanghai/Pudong (PVG) and a few others. Only 22 airports out of 875 airports in Asia have traffic volumes of over 100 Thousand flights, and 50 airports have traffic volumes of more than 40 Thousand flights per year. Over 800 airports in Asia have on the other side traffic volumes of less than 40 Thousand flights, or on average less than about 110 flights a day.

Looking at the cumulative traffic distribution in Asia (see Fig. 4) the concentration of traffic becomes evident through the skewedness of the distribution function; the Gini coefficient results in a rather high value of 0.7847, indicating a high degree of concentration.

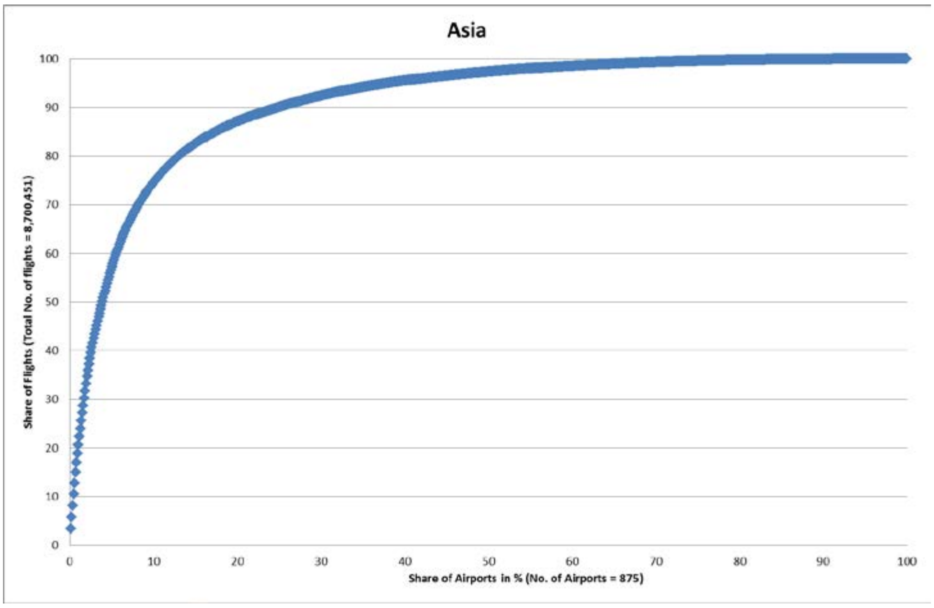


Fig. 4: Cumulative Distribution of Air Traffic in the Asian Airport Network 2014 (Source: OAG, 2014, DLR)

Not surprisingly we find similar distribution functions in all world regions: air traffic is highly concentrated on a few airports, often identical with hub airports, whereas the majority of airports have rather small flight volumes, absolutely and compared with airport capacity.

The biggest airports in **Europe** are London/Heathrow (LHR), Frankfurt (FRA) and Paris/Charles de Gaulle (CDG), 19 airports out of the total of 679 airports in Europe have traffic volumes of over 100 Thousand flights, and 50 % of the total traffic of Europe (7.6 Million flights) is handled by just 31 airports. The other 638 airports handle altogether 3.8 Million flights, each airport on average roughly 6 Thousand flights per year. **North America** is the region with the greatest number of airports, 1022 airports have been identified as airports with regular scheduled services in 2014. Furthermore, the airports with the highest traffic volume in terms of flights are to be found in North America. The biggest airports worldwide are Chicago O'Hare (ORD) with 446 Thousand flights, followed by Atlanta (ATL) with 428 Thousand and Dallas Fort Worth (DFW) with 333 Thousand flights. There are 27 airports with more than 100 Thousand flights and 50 % of the total traffic of North America (10.1 Million flights) is handled by just 22 airports (2.2 %). The Gini coefficient of the cumulative distribution has a value of 0.824, which is the highest value of all regions.

The main contributor to the air traffic of **South West Pacific** Region is Australia, and the three biggest airports of this region are the Australian airports of Sydney (SYD), Melbourne (MEL) and Brisbane (BNE). Only SYD and MEL airports have traffic volumes exceeding 100 Thousand flights, the other 338 airports have smaller volumes. 50 % of the total traffic of 1.1 Million flights is handled by just 7 airports, which means that the other 333 airports have on average traffic volumes of 3,250 flights per year. **Africa** is like the South West Pacific and Middle East a region with still rather moderate traffic volumes, however, growing traffic demand. Johannesburg (JNB), Cairo (CAI) and Nairobi (NBO) are the biggest airports of Africa, however, none of them reaches a traffic volume of 100 Thousand flights. 18 of the 376 airports handle 50 % of the total traffic of Africa, which counted I 2014 about 1.1 Million flights.

The **Middle East** region has about the same traffic as Africa and the South West Pacific, namely 1.1 Million flights. The number of airports, however, is with 121 significantly smaller than in the other regions. By far the biggest airport of the Middle East is Dubai (DXB), followed by Doha (DOH) and Jeddah (JED), and only DXB has with 173 Thousand more than 100 Thousand flights. These three airports and Riad (RUH), Abu Dhabi (AUH) and Tel Aviv (TLV) handle 50 % of the total air traffic of the Middle East. **South America** has a network of 531 airports with scheduled services, which make up a volume of 3.3 Million flights. The three biggest airports are Mexico (MEX), Sao Paulo (GRU) and Bogota (BOG), which are the only airports in South America with volumes exceeding 100 Thousand flights in 2014. All other airports are much smaller. These three airports alone handle with about 1.65 Million flights 50 % of the total traffic of South America.

In the following table the main indicators of traffic concentration in the world regions are summarized for the year 2014. These are the Gini coefficient and the share of airports which handle 50 % and 90 % respectively of the total traffic and the number of airports of the region.

World Region	Gini Coefficient	Share of Airports with 50 % of Region Traffic	Share of Airports with 90 % of Region Traffic	# of Airports
Europe	0.7794	4.56%	27.98%	679
Asia	0.7847	3.88%	25.00%	875
North America	0.824	2.20%	18.60%	1022
South West Pacific	0.8076	2.00%	26.20%	340
Africa	0.7429	4.70%	32.45%	376
South America	0.7414	5.08%	35.40%	531
Middle East	0.8026	4.95%	22.30%	121
World	**0.782**	**3.09%**	**24.06%**	**3,944**

Table 4: Traffic Concentration by World Region (Source: OAG, 2014, DLR)

As can be seen, all regional Gini coefficients are rather high and vary only slightly around the global value of 0.7820. North America is the region with the highest degree of traffic concentration as measured by the Gini coefficient of 0.8240. A further indicator of concentration is the share of airports which handle a certain share of the total traffic, for instance 90 %. With this measure, too, North America has the highest concentration of traffic on airports. Only 18.6 % of all airports, equal to 190 airports, handle 90 % of the North American air traffic. The other 833 airports share just 10 % of the total traffic. In contrast, in South America more than one third of all airports (35.4 %) have the 90 % traffic share.

5. Traffic distribution and concentration in selected countries

In theory one could extend the concentration analysis to each country of the world in order to study the variation of concentration. Clearly, that is unsurmountable, instead, four countries have been selected, France and Germany in Europe, the USA in North America and China in Asia. France has a network which is concentrated on Paris, most other regional airports have strong links with the capital airports, however, much smaller volumes than the Paris airports Orly and Charles de Gaulle. Germany has a less centralized network, however, with Frankfurt and Munich two principal hub airports. The US and China are of course much bigger countries than the European ones. And the US has been for long the most important air transport market worldwide, followed in recent years by the strongly growing Chinese market. While the US air transport market is rather saturated, and the European markets are more or less approaching saturation in the coming years, the Chinese market is still growing strongly.

In Fig. 5, the traffic distribution in the airport networks of these countries is shown for the year 2014. While in Germany and France there are only 3 airports with more than 100 Thousand flights a year there are many more airports in China and especially in the US with traffic volumes exceeding 100 Thousand take offs. It can be seen that the biggest airports differ partly strongly in traffic volume and that the decline in traffic is particularly pronounced in the US, but exists among the big airports in the other countries alike.

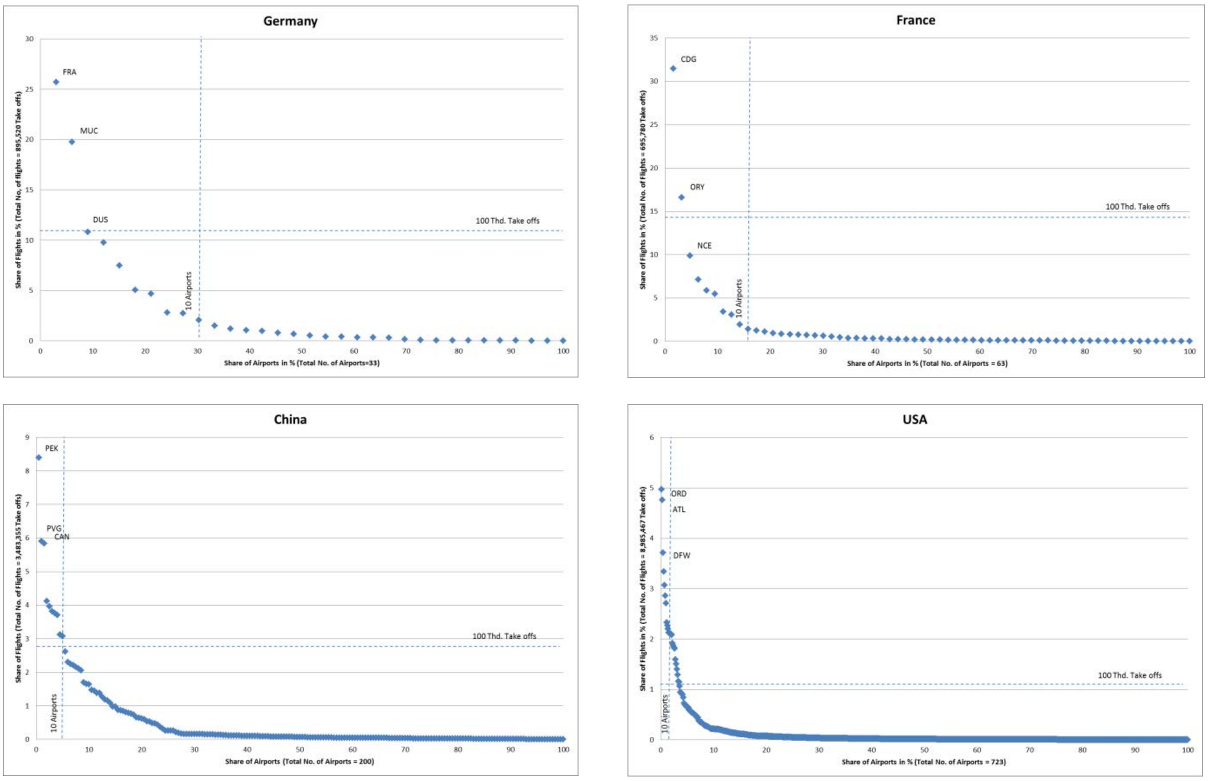


Fig. 5: Air Traffic Distribution in the Airport Network of Germany, France, China and the US in 2014 (Source: OAG, 2014, DLR)

If we concentrate on the biggest 10 airports in each country we see that the volume span between the biggest and the 10th biggest airport in Germany reaches from about just 20 thousand flights to 230 Thousand at Frankfurt airport (FRA), in France from 10 thousand to about 220 thousand at Paris Charles de Gaulle airport, in China from 110 Thousand to 290

Thousand take offs at the biggest airport in Beijing (PEK), and in the US from 190 thousand to about 450 thousand flights in Chicago O Hare (ORD). In Germany and France the 10th biggest airports are already airports with small traffic volumes, whereas in China and the US the 10th biggest airports are big airports with volumes exceeding 100 thousand flight movements.

The cumulative distribution of air traffic reveals more of the concentration of traffic than just the direct distribution. In Fig. 6 we show the cumulative distribution of traffic in each of the four selected countries.

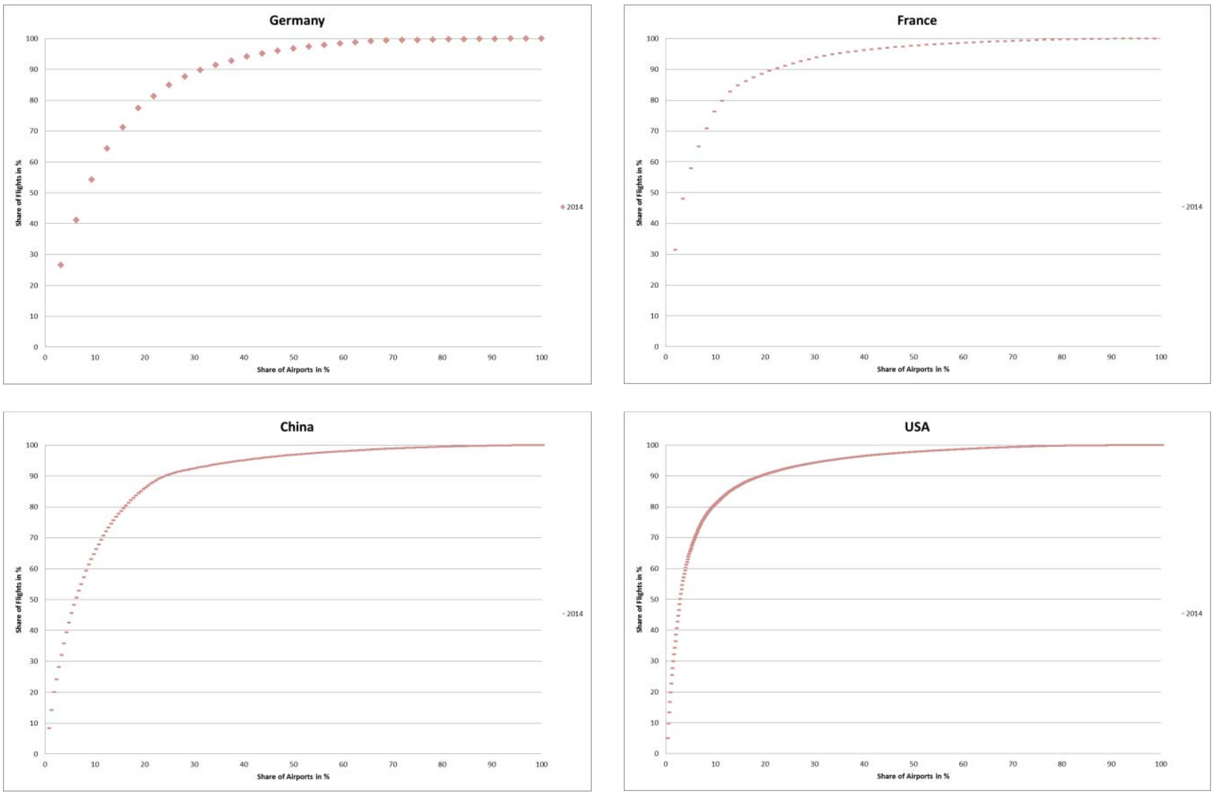


Fig. 6: Cumulative Air Traffic Distribution in Airport Networks of Germany, France, China and the US in 2014 (Source: OAG, 2014, DLR)

As can be seen the country specific distribution functions are similar to those of the corresponding world regions, their skewedness signals the high degree of traffic concentration on the biggest airports in the country, which form a relatively small part of the overall network, and the great number and share of airports with small traffic volumes. Traffic concentration is rather high in Germany – 90 % of the total traffic is handled by 32 % of all airports – however, the concentration is higher in the other countries. The US concentrate on just 19 % of the 723 airports 90 % of total traffic, while the other 81 % of airports handle just 10 % of total traffic. The biggest 25 airports of the US are responsible for 50 % of total flight volume of almost 9 Million take offs.

Traffic in France is concentrated on Paris, the two Parisian airports Charles de Gaulle and Orly handle 44 % of the total traffic of France (696 Thousand flights in 2014) while 90 % of the total traffic concentrates on 22 % of all airports (63). In China, traffic is concentrated on 9 airports (of 200 in total) which handle about 50 % and 35 airports respectively which handle 90 % of total traffic of 3.5 Million flights. This means on the other side that 165 airports have an overall traffic of 350 thousand flights in 2014, or on average a traffic volume of just over 2,000 flights per airports and year.

Air traffic is thus rather concentrated in the selected countries and many other countries, as the distribution functions of the world region have shown, on a relatively small number of airports, and in most cases only these airports handle high flight volumes of say more than 100 thousand flights, while the great majority of airports deals with only small traffic volumes of some thousand flights a year. These volumes are well below the capacity of airports so that these airports are at least theoretically in a position to take over a much greater share of the total traffic. Due to the hub and spoke concept followed by many scheduled carriers traffic tends to concentrate on hub airports creating thus high traffic volumes at peak times and often also high degrees of capacity utilization. Other airports depend very much on their catchment in the surrounding area whether or not high traffic volumes are achieved. Many regional and peripheral airports do not have a strong catchment area so that they are and will be lacking traffic. In recent years these airports have partly lost traffic because of low growth rates of demand and the change in aircraft size (seats per aircraft). Airlines have in general increased seat capacity per aircraft to be more competitive, at regional airport this has often led to suspending routes with insufficient demand. As a consequence these airports suffer from low traffic volumes, since airports have problems to economically survive because the number of ATM's often is not high enough to cover operating costs. Many airports are thus underutilized.

6. Development of traffic concentration in the global airport network and in selected countries

For the year 2014 we have analysed the traffic distribution globally and in networks of world regions and some selected countries, and have found a high degree of traffic concentration on a relatively small number of important airports, often hub airports, and have identified a great number of airports with rather small traffic volumes well below the capacity limit. How did this concentration pattern develop over time? For a series of years since 2000 we have carried out the distribution analysis and measured concentration indicators like the Gini coefficient and the share of airports which handle 50 % and 90 % respectively of the total traffic volume. In Fig. 7 the cumulative distribution functions of global air traffic are shown for the years from 2000 to 2014.

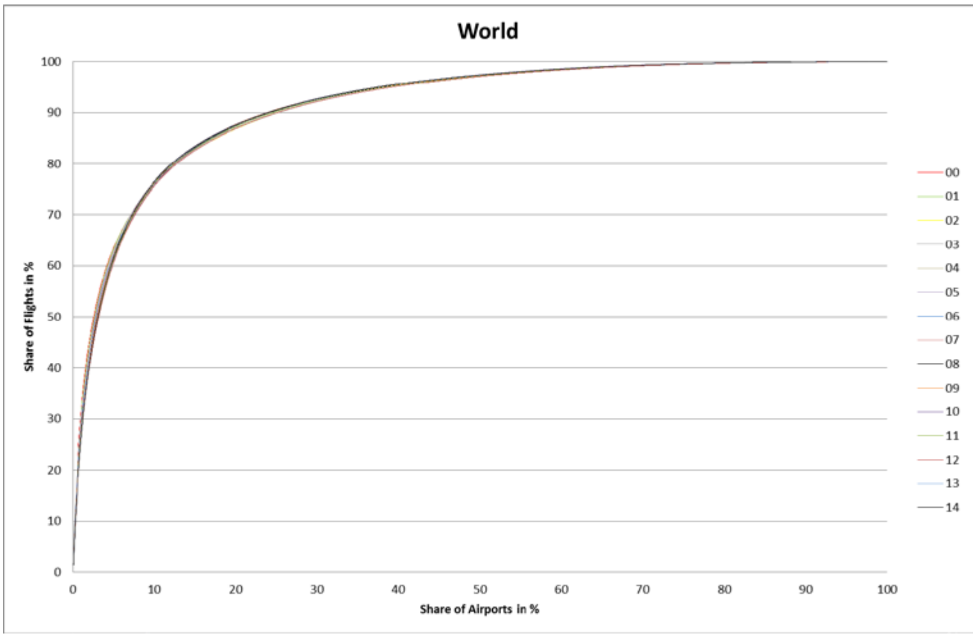


Fig. 7: Cumulative Distribution of Air Traffic in the Global Airport Network for the Years from 2000 to 2014 (Source: OAG, 2014, DLR)

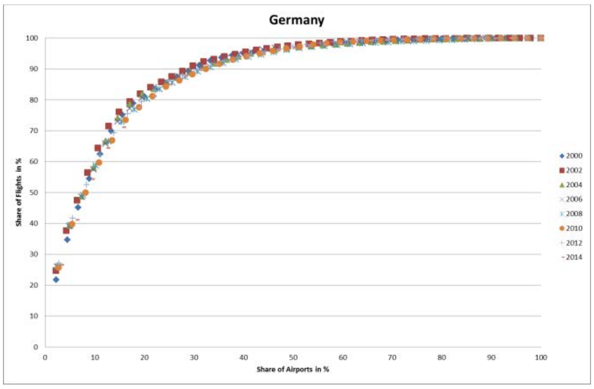
As can be seen the distribution pattern hardly changed over time, the global air traffic was concentrated in 2000 and has been concentrated since then. In 2000 the global airport network with scheduled services consisted of 4,035 airports and in 2014 the network size was nearly the same with 3,944 airports, however, traffic grew from 27.9 to 33.0 Million flights. Nevertheless, the Gini coefficient and the share of airports with a 50 % and 90 % traffic share as indicators of traffic concentration changed only slightly as can be seen in the following table:

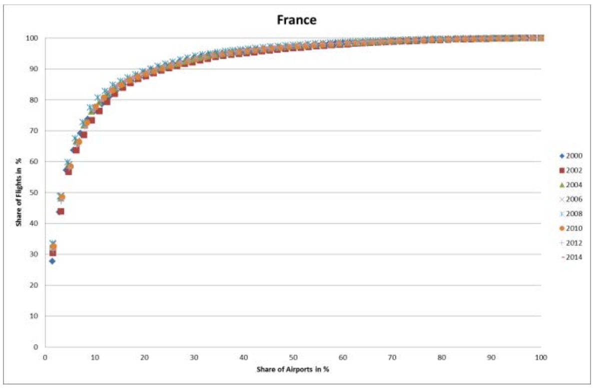
World Region	Gini Coefficient	Share of Airports with 50 % of Region Traffic	Share of Airports with 90 % of Region Traffic
2000	0.8100	2.60%	25.23%
2006	0.8078	2.85%	24.00%
2008	0.7998	3.00%	24.18%
2010	0.7974	3.12%	24.53%
2011	0.7932	3.12%	24.50%
2012	0.7952	3.18%	25.14%
2013	0.7899	3.09%	24.13%
2014	0.7820	3.09%	24.06%

Table 5: Development of the Global Gini Coefficient from 2000 to 2015 (Source: OAG, 2000-2014, DLR)

The Gini coefficient had in all years values of around 0.8 and thus stands for a highly concentrated distribution of traffic. The value decreased slightly from 0.81 in 2000 to 0.78 in 2014, indicating a marginal deconcentration of traffic, however, the degree of concentration stayed very high during the whole period of 14 years. If we look at the share of airports which handle 50 % of the total traffic we see a slight decrease of concentration, in 2000 only 2.6 % of all airports handled half of the total traffic, 14 years later this share increased to 3.1 %. On the other hand, the share of airports which handle 90 % of total traffic, decreased slightly from 25 % to 24 %, thus indicating a marginal growth of concentration.

A look into the development of traffic distribution in the four selected countries shows a similar picture as on the global scale: Traffic has been concentrated on important airports and the level of concentration did not change significantly (see Fig. 8).





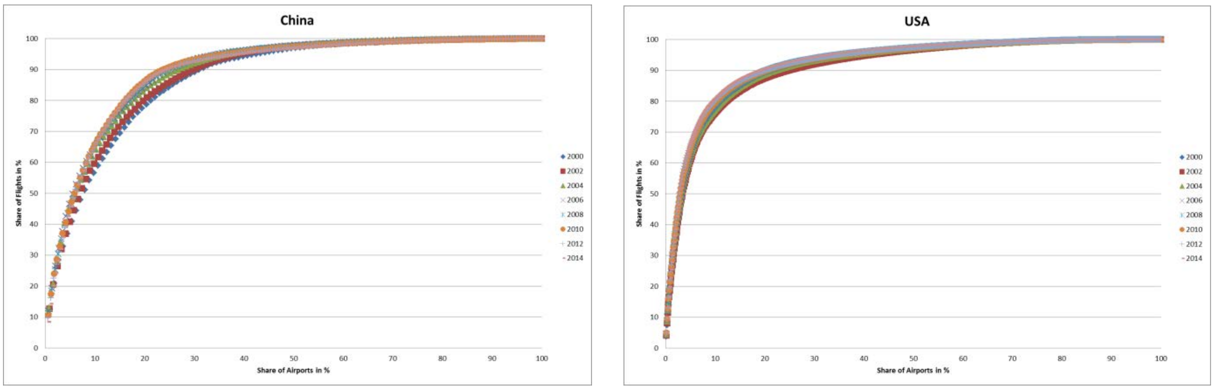


Fig. 8: Cumulative Air Traffic Distribution in Airport Networks in Germany, France, China and the US from 2000 to 2014 (Source: OAG, DLR)

In both Germany and France the degree of concentration has increased over time, if we look at the traffic share of the most important airports. In Germany, the four top airports out of 33 airports handled in 2000 a traffic share 54 % and in 2014 over 64 %. In France, the two Parisian airports as the most important ones had a traffic share in 2000 of 44 %, this share increased to 48 % in 2014. If we look at the share of airports which handled 90 % of total traffic we see in Germany an increase of airport share, corresponding to an increase of the number of airports, from 29 % to 32 %, thus a slight decrease of traffic concentration. In France, the share of airports with 90 % traffic share stayed constant over time with 22 %.

The development of traffic concentration in China and the US has been similar to the development in the two European countries, however, against a fundamentally diverging background of network and traffic development in China and the US. While in China both the number of airports and of flights has grown substantially the contrary occurred in the US: Both the traffic and network size decreased. In China, the share of airports that handled 50 % of total traffic decreased from 8 % in 2000 to 6 % in 2014, equivalent to an increase in traffic concentration. The absolute number of corresponding airports increased from 8 to 12 airports, however, the total number of airports with regular services increased significantly from 113 to 200 airports. In the US, the share of airports that handled half of total traffic decreased from just 3.2 % in 2000 to 2.6 % in 2014, indicating not only a high degree of concentration, but an even further increase of concentration. If we look at the share of airports which handled 90 % of total traffic, this share decreased in China from 31 % in 2000 to 24 % in 2014, and in the US from 24 % to just 19 % in 2014. By both indicators, the 50 % and 90 % traffic share, the already high level concentration of traffic increased in both countries.

7. Modelling annual service volume of an airport

So far we have analysed the concentration of traffic on a few high volume airports and have indicated the degree of concentration by quantifying the number and share of airports with a 50 % and 90 % traffic share and thus stating the high number of airports with rather small traffic volumes. The interesting question is then, whether or not the airports with high traffic volumes are operating at capacity level and are therefore constrained or still have enough capacity reserves for further growth. For answering this question we have to know besides the traffic volume the capacity of airports and by relating volume with capacity measure the capacity utilization.

For detailed planning and dimensioning of infrastructure facilities, the hourly capacity is normally retained, since the significance of the annual capacity is lower because of strong seasonal and daily variations of traffic, which the annual capacity has to account for by applying reduction factors. Night hours, Sundays, some holidays, and other off-peak periods are typically times of low traffic demand, which are therefore not well suited for being included as such in that time span which serves as a base for capacity calculation. The time unit of measuring capacity should be defined in such a way as to allow for a continuous utilisation of the runway by the demand for aircraft movements. In practical terms, that means that a period of not more than one hour or two should be taken. Since the demand, and thus the peak hour traffic volume, cannot exceed the capacity of the runway system, the level of which is dependent on the number of runways and their configuration, six capacity classes have been identified (Wilken et al., 2011):

- Single runway,
- two runways, independent parallel,
- two runways, dependent parallel,
- two runways, crossing,
- three runways, and
- four runways and more.

Functions relating the 5% peak hour traffic volume with the annual traffic have been derived for these six runway capacity classes of airports, based on data of 200 airports worldwide with high traffic volumes. We collected data on traffic schedules (OAG, 2008) and runway configurations (DAFIF, 2008) and calculated traffic ranking curves with 5 % peak hour volumes and the number of hours in day and night operation. In order to verify the functional relationship between peak hour volume measured in hourly aircraft movements and annual traffic volume measured in yearly aircraft movements we studied several functional types in regression analysis. The overall best result was obtained by a function describing the 5 % peak hour volume in relation to annual volume (YACM) or the logarithm of annual volume, LN(YACM), respectively, a factor of annual utilisation of the runway (GF), and a binary variable which describes whether an airport is located in Europe (EUR) and thus operating under conditions of slot coordination and instrument flight rules (IFR) in air traffic control or not. We have chosen the number of hours with more than five aircraft movements per hour (GF) to describe annual runway utilisation, roughly corresponding to the number of day hours (as contrasted to night hours) and which describe the time period with high demand. Therefore, the variable “GF” is included to account for differences in opening hours, flight restrictions (especially night curfews), etc. Table 6 (Wilken et al., 2011) shows the calibration results for the selected categories of runway system. The variables are all highly significant at levels of 1% or less and, despite the many different airports in a given class of runway system, we have identified a surprisingly stable relationship between the 5 % peak hour volume, the yearly aircraft movements, the number of hours with more than five aircraft movements per hour, and whether the airport is located in Europe and thus slot coordinated and operating under IFR conditions or not: Depending on the capacity class of an airport, the model explains between 90% and 99% of the observed variance (R-squared, R^2) in the data sample.

RWY System	Variable	Coefficient		Mean	Min/Max	R-squared	# of Obs.
	Constant	-213.085347	***			**89.41%**	**58**
Single RWY	LN(YACM)	22.9069415	***	87473	72360/197511		
	GF	-0.00409076	***	5831	4388/7481		
Two RWYs,	Constant	49.9137726	***			**98.12%**	**23**
independent parallel	YACM	0.00020994	***	180545	75668/430154		
	GF	-0.00703262	***	6966	5927/8581		
Two RWYs,	Constant	34.9994481	***			**96.29%**	**29**
dependent parallel	YACM	0.00020215	***	155934	73367/347602		
	GF	-0.00478635	***	6735	5124/8784		
Two RWYs,	Constant	-353.486327	***			**98.51%**	**21**
crossing	LN(YACM)	37.4226666	***	139783	74270/386757		
	GF	-0.00811951	***	6613	5466/8783		
	EUR	-3.14929516	***				
Three RWYs	Constant	-500.055692	***			**93.49%**	**40**
	LN(YACM)	47.7821666	***	210778	72261/479294		
	GF	-0.00452502	***	6781	5990/8641		
	EUR	-4.22136284	***				
Four RWYs	Constant	77.0506432	***			**99.15%**	**29**
and more	YACM	0.0002053	***	377438	113195/956380		
	GF	-0.01064904	***	6928	5782/8334		
	EUR	-0.0010366	***				

** Significant at the 5% Level
*** Significant at the 1% Level

Table 6: Estimation results (dependent variable: 5% peak hour volume of an airport) (Wilken et al., 2011)

The next step comprises maximum annual capacity of a particular airport, i.e. its maximum annual service volume. We therefore need to define the saturation level of an airport’s capacity utilisation. In order to measure the degree of capacity utilisation of a particular airport the concepts of the 5% peak hour and the average hour volume are applied. The average hour volume is defined by the yearly aircraft movements divided by the yearly operating hours of the airport. However, details of computing the average hour volume depend on the number of aircraft movements of an airport and will be described later in this paper. The capacity utilisation index (CUI) is therefore defined by the ratio of the average hour to the 5% peak hour volume:

$$\text{Capacity utilisation index (CUI)} = \frac{\text{Average hour volume}}{\text{5\% peak hour volume}}$$

The selection of the average hour volume seems to be an intuitively sound choice; however, it is more or less arbitrary. Basically, any different hour in the neighborhood of the average hour may be employed and thus it is only a matter of calibration, i.e. setting a critical value or a bandwidth of values, respectively, to separate constrained airports from those which are not constrained. The key point is to take two points on the curve to define a metric which approximates the slope of the curve in a fashion that should be quite representative and comparable between airports of a minimum size (aircraft movements > 70,000 – 100,000 per year).

CUI value, 5% peak hour volume, yearly aircraft movements and effective operating hours interdepend by means of the model described in Table 6 and the CUI formula. Thereby we have derived average annual airport capacities per effective operating hour (ApCapEffOpH) by runway system and slot coordination scheme. Basically, we have taken a highly saturated single runway airport and simulated a CUI value of 0.85, as we have observed in London Heathrow, with the model of Table 6. Here, a key assumption is that the 5% peak hour volume is a suitable indicator for the hourly capacity. Then we have estimated appropriate capacity relationships between the different runway systems empirically. As a result, the base case is a maximum annual service volume of a single runway airport (no slot coordination & IFR) of around 240,000 ATM's (= 120,000 landings and take-offs), depending on the number of effective operating hours per year (in this case: 6559 hours per year, i.e. on average 18 hours per day) and slot coordination & IFR scheme (no slot coordination & IFR in the case of San Diego). Table 7 summarises the results by runway system and slot coordination & IFR scheme.[1]

RWY System	ApCapEffOpH No Slot Coordination	5% Peak Hour $Volume_{max}$ (ApCapEffOpH No Slot Coordination)	ApCapEffOpH Slot Coordination	5% Peak Hour $Volume_{max}$ (ApCapEffOpH Slot Coordination)
Single RWY	37.07	43.61	33.70	39.65
Two RWYs, independent parallel	74.14	87.22	67.40	79.29
Two RWYs, dependent parallel	52.96	62.30	48.14	56.64
Two RWYs, crossing	52.96	62.30	48.14	56.64
Three RWYs	79.44	93.45	72.21	84.96
Four RWYs & more	105.92 +	124.61 +	96.29 +	113.28 +

Table 7: Average Annual Airport Capacity per effective Operating Hour ≡ Average Hourly $Volume_{max}$ by Runway System & Slot Coordination & IFR Scheme – 5% Peak Hour $Volume_{max}$ = Average Hourly $Volume_{max}$ / 0.85

The majority of airports worldwide have only one runway. There is a number of airports with two runways and some with three runways, but there are only very few with four runways or even more. Therefore, because of small case numbers, we have pooled airports with four runways and more to obtain sound econometric results which are significant and this approach worked well as illustrated by the values of R^2 and the significance levels in Table 6. The step in terms of capacity between two dependent runways and three runways (which are in most cases dependent systems) is almost the same as the step between three runways and four runways, which is about 31 aircraft movements. Thus, for practical annual service volume computations, we have further subdivided the "Four RWYs & more" class: For each runway beyond four runways, we add the difference between three and four runways (+): E.g., ApCApEffOpH for five runways is computed as follows: 105.92 + (105.92 – 79.44) = 132.40 in the case of no slot coordination & IFR. Table 8 displays some example airports. The third column shows annual aircraft movements. The fourth column shows the maximum annual service volume computed by the model. If actual aircraft movements are higher than the computed maximum annual service volume, then the fifth column displays the difference in percentage terms. For London Heathrow, this difference is virtually zero, because the airport has reached the capacity limit. There is a positive difference for Atlanta Hartsfield Jackson

[1] 5% peak hour volume = hourly capacity → ApCapEffOpH = hourly capacity * 0.85 → Maximum annual service volume = ApCapEffOpH * effective operating hours per year

Airport, but it is small. For Frankfurt, the fourth runway which opened in 2011 has already been considered, thus there is a considerably capacity reserve based on 2006 data. However, the situation for Frankfurt with three runways up to the year 2011 is shown too, because the airport was near the capacity limit and therefore we can compare actual vs. computed maximum annual service volume for Frankfurt airport. Beijing airport has an unusual high capacity for an airport with two runways because of the high number of effective operating hours (7928).

Airport (IATA-Code)	# of RWYs	Annual Aircraft Movements 2006 (FESG Data)	Maximum Annual Service Volume (Aircraft Movements)	
LHR	2	446,336	444,035	0.52%
MUC	2	401,842	460,615	
DUS	2, but single RWY Operation only("Angerland-Vergleich")	207,708	231,087	
FRA	3	480,453	535,618	
FRA	4	480,453	714,157	
CDG	4	528,456	669,576	
SAN	1	213,479	243,144	
ATL	5	975,696	940,261	3.63%
MAD	4	432,258	706,550	
PEK	2	371,619	587,786	
ORD	7	933,827	1,421,460	

Table 8: Maximum Annual Service Volume of some example Airports)[2]

8. A first analysis of airports with high and with low capacity utilization

If we want to identify those airports which are operating near capacity levels and are thus likely to be constrained we have to answer the key question before at which degree of capacity utilization the status of being constrained begins. Capacity problems may begin with a few peak hours in a week when traffic volumes reach capacity and airports therefore have to deny additional slot requests of airlines in these hours. And at airports like London-Heathrow (LHR) capacity constraints are prevailing during all operating hours since all available slots within the declared capacity are used by incumbent airlines.

The constraint analyses of airports have shown that at single runway airports with annual volumes of around 70 Thousand ATM's the 5 % peak hour volumes reach levels of about 20 ATM's which corresponds roughly to a 50 % peak hour capacity utilization. Clearly, airports with annual volumes below 70 Thousand ATM's do not have capacity problems today or in the near future; these airports may be regarded as those with substantial capacity reserves.

On the other hand, airports with volumes approaching maximum annual services volumes as described above suffer more or less under a continuous capacity shortage, with all problems associated with a near capacity utilization, in particular increasing delays of flights. London Gatwick (LGW) is a very busy single runway airport which had a traffic volume of around 250 Thousand ATM's in 2014, a value which is already slightly exceeding the calculated maximum annual service volume, depending on the slot coordination regime.

[2]DUS maximum annual service volume with “Angerland-Vergleich (AV)“ is computed as follows: Without AV, DUS maximum annual service volume is 308,116 aircraft movements (ACM). According to the airport, maximum hourly capacity of DUS is 60 ACM, however, AV only allows for 45 ACM. Maximum average capacity utilisation is around 83% and does not depend on capacity levels. Thus AV reduces maximum annual service volume by 25%, resulting in a maximum annual service volume for DUS of 231,087 ACM per year. This number is close to the maximum that has been observed in the past at DUS.

We have therefore decided to include all those single runway airports with annual volumes of over 70 Thousand ATM's in the constraint analysis, airports with more runways were included with comparable threshold volumes, e. g. airports with two dependent parallel runways with more than 100 Thousand ATM's, airports with three runways with volumes of over 150 Thousand ATM'S, etc. Airports with traffic volumes slightly above the lower threshold values can be regarded as airports with a high degree of capacity utilisation, however, they are not capacity restrained.

There is a wide volume range between the lower threshold volume and the maximum service volume, in fact, the latter one is about three times the former one. For this "first step" constraint analysis we have divided the total range into three classes, which stand for different stages of high capacity utilization:

- The lower class "A" includes airports with high capacity utilisation, meaning that the 5 % peak hour volume exceeds 50 % of the hourly capacity, however without capacity constraints; annual volumes are between 30 - 50 % of the maximum annual service volume.
- The middle class "B" includes airports with high capacity utilisation and capacity constraints at peak times; volumes are between 50 – 70 % of the maximum annual service volume.
- The higher class "C" includes airports with high capacity utilisation and severe capacity constraints at significant parts of the operating hours; volumes are exceeding 70 % of the maximum annual service volume.

Airports in world regions with volumes exceeding 70 Thousand ATM's in 2014 have been listed and categorized by runway class and traffic volume, so that the airports belonging to each capacity utilization class as described could be identified. Altogether, 216 airports have been identified with annual volumes of over 70 Thousand ATM's, corresponding to a share of 5.5 % of all 3944 airports with regular services in 2014. These 216 airports had a traffic volume of around 21 Million ATM's, which represents almost two thirds of the total air traffic volume of 33 Million ATM's. However, not all of these airports belong to the class of high capacity utilization, there are 61 airports with more than one runway, the traffic volume of which was over 70 Thousand ATM's, but below the corresponding lower threshold volumes of these higher capacity category airports. This means that only 155 airports have such high traffic volumes so that the capacity utilization in peak hours exceeds 50 % of the hourly capacity. Only these airports may be classified as airports with high levels of capacity utilization.

The other side of the coin is, that almost 95 % of all airports have a traffic share of just one third of the total traffic, with average volumes of 3.200 ATM's a year. Clearly, most of these airports are underutilized in a sense that their peak hour capacity utilization is well below 50 % of the hourly capacity.

The following table lists the airports by capacity utilization class and world region. The capacity utilization class "0" includes all airports with traffic volumes below 70 Thousand ATM's per year and those airports with more than 70 Thousand ATM's, however, with volumes below threshold volumes of the higher capacity classes. The A, B and C class airports belong to the high capacity utilisation class, whereby the B and C class airports face in addition capacity problems either in peak times (class B) or over many hours of the day (class C).

World Region	# of Airports in Capacity Utilisation Class					∑
	0	0	A	B	C	
	with Traffic Volumes					
	<70,000 ATM's per Year	> 70,000 ATM's per Year				
Europe	625	16	24	10	4	**679**
Asia	815	5	22	18	15	**875**
North America	965	24	11	15	7	**1022**
Southwest Pacific	333	1	3	3	0	**340**
Africa	370	4	2	0	0	**376**
South America	509	5	12	3	2	**531**
Middle East	111	6	2	0	2	**121**
World	**3728**	**61**	**76**	**49**	**30**	**3944**
	∑=3789					

Table 9: Airports by Capacity Utilisation Class and World Region (Source: OAG, 2014, DLR)

As can be seen, 30 airports in capacity utilisation class C can be regarded as highly constrained, and these airports are to a great deal the airports with the highest traffic volumes, like Beijing (PEK), Hongkong (HKG), Shanghai (SHA), Istanbul (IST), London Heathrow (LHR), London Gatwick (LGW), München (MUC), Dubai (DXB), Atlanta (ATL), New York LaGuardia (LGA), San Diego (SAN), Mexico City (MEX), and Sao Paulo (GRU), either absolutely or by capacity class. Further 49 airports with high traffic volumes belong to the capacity utilization class B indicating that they have peak hour congestion problems, among them Singapore (SIN), Delhi (DEL), Bangkok (BKK), Amsterdam (AMS), Frankfurt (FRA), Paris Charles de Gaulle (CDG), Chicago O’Hare (ORD), Detroit (DTW), New York J. F. Kennedy (JFK), San Francisco (SFO), Bogota (BOG), and Sydney (SYD). There are thus 79 airports belonging to the top ranking airports worldwide that are both highly utilised and either in peak times or over many hours of the day capacity constrained. Further 76 airports with high traffic volumes have a high capacity utilization as well, they are, however, not yet constrained; they are considered as capacity utilisation class A airports.

The vast majority of airports (3,789) are classified as capacity utilization class “0” airports, of which the greatest part have traffic volumes of less than 70 Thousand ATM’s per year. Because of the low traffic volumes of most of them their capacity utilization is low, too.

The classification of airports into capacity utilization classes is based on airport specific estimates of the degree of capacity utilisation as expressed by the ratio of annual traffic volume and maximum annual service volume. The relationship between capacity utilisation and traffic volume for the 3,944 airports worldwide is shown in Fig. 9.

Fig. 9: Relationship between Capacity Utilisation and Traffic Volume of 3944 Airports in 2014 (Source: OAG, 2014, DLR)

The airport population has been divided into three classes (see Fig. 9): The top 100 airports are those with the highest traffic volume, followed by the 101th to one Thousandth top airports and all other airports with volumes below those of the one Thousand top airports. As can be seen there is a positive relationship between traffic volume and the degree of capacity utilisation, however, with a growing dispersion. Nevertheless, the message if the relationship in Fig. 9 is clear: Small airports have low degrees of capacity utilisation whereas the top airports are those which have the highest levels of capacity utilisation.

9. Results and discussion

Knowing about the global concentration of air traffic the research interest of this paper has been to describe the traffic distribution in detail, on the global scale as well in world regions and selected countries. Since we have to assume a correlation between traffic volumes and capacity utilization we have analysed the degree of capacity utilization by estimating airport capacities and volume-capacity ratios. As a result we show that many of the high volume airports are identical with those that operate in near capacity conditions. On the other side, all airports with low traffic volumes have ample capacity reserves and would welcome additional traffic. In fact the majority of airports worldwide are far away from capacity problems in the near future.

The **total number of airports** with regular scheduled services, which has been subject of the concentration and constraint analysis, has slightly decreased from 4,035 in 2000 to 3,944 in 2014. In contrast, the traffic volume has grown from 27.9 Million flights (corresponding to 55.8 Million ATM’s) in 2000 to 33.0 Million flights. Since the number of airports did not increase the average traffic volume per airports has grown from 6.9 Thousand in 2000 to 8.4 Thousand flights in 2014.

While the total number of airports with regular services has slightly decreased from 2000 to 2014, the **networks in world regions** have developed in different ways. In North America the number of airports has decreased from 1,069 in 2000 to 1,022 in 2014, whereas in Asia networks have grown strongly from 650 to 875 airports. In Europe the number of airports has practically not changed in that time span of 14 years. In the other regions Africa, South America and South West Pacific network density has gone down.

The **global distribution of air traffic** has shown that only about 15 % of all airports have higher than average volumes, which means, on the other hand, that 85 % of all airports worldwide have traffic volumes below 8.4 Thousand flights per year. The cumulative distribution has revealed that traffic share increases sharply over just a small share of all airports, 50 % of total traffic is handled by only 3 % and 90 % is handled by 24 % of all airports. In other words, the biggest 122 airports (3 %) handle half of the total traffic, that is 16.5 Million flights, while the other 3,822 airports handle the same volume of traffic, on average each one 4.3 Thousand flights per year. Furthermore, the biggest 949 airports (24 %) handle almost 30 Million flights, while the other nearly 3,000 airports handle just 3 Million flights, on average thus one Thousand flights per year.

The global airport network consists thus of a small number of airports with high traffic volumes, while on the great number of airports traffic volumes are in the order of just a few flights a day. This latter group of airports does not have capacity problems as airports in the first group may have to struggle with; their main concern is probably to attract more traffic to the airport in order to cover the cost of operations.

Air traffic in world regions has been similarly concentrated as the global traffic. Cumulative distributions are described by similar functions, with high Gini coefficients varying only slightly around the global value of 0.7820. North America is the region with the highest degree of traffic concentration as measured by the Gini coefficient of 0.8240.

The **country specific distribution** functions of the selected countries China, USA, France and Germany are similar to those of the corresponding world regions, their skewedness signals the high degree of traffic concentration on the biggest airports in the country, which form a relatively small part of the overall network, and the great number and share of airports with small traffic volumes. The US for instance concentrate on just 19 % of the 723 airports 90 % of total traffic, while the other 81 % of airports handle just 10 % of total traffic.

Examining the **development of networks and traffic concentration** in the time span since 2000 we have seen that the distribution pattern hardly changed over time: The global air traffic was concentrated in 2000 and has been concentrated since then. A look into the **development of traffic distribution in the four selected countries** shows a similar picture as on the global scale: Traffic has been concentrated on important airports and the level of concentration did not change significantly.

Having proven the high degree of concentration in networks of world regions and selected countries the interesting question is then, whether or not the airports with high traffic volumes are operating at capacity level and are therefore constrained or still have enough capacity reserves for further growth. The combined **concentration and constraint analysis** has shown that there are thus around 80 airports belonging to the top ranking airports worldwide that are both highly utilized and either in peak times or over many hours of the day capacity constrained. Further 76 airports with high traffic volumes have high capacity utilization as well, they are, however, not yet constrained. The vast majority of airports (3,789) are classified as capacity utilization class “0” airports, of which the greatest part have traffic volumes of less than 70 Thousand ATM’s per year. Because of the low traffic volumes of most of them their capacity utilization is low, too.

Due to the hub and spoke concept followed by many scheduled carriers traffic tends to concentrate on hub airports creating thus high traffic volumes at peak times and often also high degrees of capacity utilization. Other airports depend very much on their catchment in the surrounding area whether or not high traffic volumes are achieved. Many regional and peripheral airports do not have a strong catchment area so that they are and will be lacking traffic. In recent years these airports have partly lost traffic because of low growth rates of demand and the change in aircraft size (seats per aircraft). Airlines have in general increased seat capacity per aircraft to be more competitive, at regional airport this has often led to suspending routes with insufficient demand. As a consequence these airports suffer from low traffic volumes, since airports have problems to economically survive because the number of ATM's often is not high enough to cover operating costs. Many airports are thus underutilized. This would mean that air traffic tends to be concentrated in future, too.

10. References

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