The 2011 World Conference of Air Transport Research Society (ATRS)
In Sydney, Australia, June 29- July 2, 2011

# DO AIRPORT CAPACITY CONSTRAINTS HAVE A SERIOUS IMPACT ON THE FUTURE DEVELOPMENT OF GLOBAL AIR TRAFFIC?

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 air transport industry is one characterised by a long term growth, at least on the demand side. The question is whether or not the airport infrastructure side will be suited to accommodate the future air traffic, given the fact that there are already now important hub airports that suffer from capacity bottlenecks. The objective of the paper is to give some statistical insight into the general capacity constraint situation by comparing traffic with capacity for the largest 1000 airports of the global network. We concentrate on air transport movements (ATMs) and runway capacity, since runways form in many instances the airport component most critical for expansion, due to environmental constraints. Based on OAG data, the paper informs first that air traffic is very concentrated on a relative small number of airports: 50 % of total traffic is handled by just 4 % of all airports. In order to show the capacity utilisation of each airport we have calculated the ratio of average annual hourly volume and the 5 % peak hour volume as an indicator of capacity. These two characteristic values have been derived from “traffic ranking functions”, which show the distribution of the number of hours at each volume level over all hours of operation within a year. By identifying airports with both high traffic and high capacity utilisation levels we are able to demonstrate the degree of traffic concentration on airports which have important traffic functions, however, face capacity problems already now or in the near future.

KEYWORDS

Airport capacity; capacity utilisation; peak hour volume; future air traffic growth; capacity constrained airports; peak hour – annual traffic volume and capacity utilisation index – annual traffic volume relationships.

## 1. Introduction

While we have seen a strong growth of air traffic world wide in the past, and can expect a continuation of growth for the long term future we have to take note of the fact that some important airports are faced with capacity constraints so that airlines have problems in scheduling the planned traffic in the preferred way. There are many airports with traffic volumes that reach capacity only in certain peak times, for instance in some morning and evening hours, however, there are also airports with high traffic loadings which experience near capacity utilisation during many hours of the day every day, like London-Heathrow, Frankfurt, R. Reagan Washington National, or New York LaGuardia, and others. On the other hand, there are many airports, in fact the great majority, with low traffic volumes and no capacity problems. The question is whether or not airport capacity constraints become such a problem in the global air transport network as to form a barrier to future growth of demand. The objective of this contribution is to give some statistical insight into the global capacity constraint situation and discuss in a more abstract way potential measures of remedying capacity shortages and describe options of how to incorporate these measures in long term forecasting of air transport demand and supply.

Since so far no publicly available airport specific forecasts of global air traffic exist we have analysed the capacity constraint situation in the global airport network for the year 2008. Air traffic data may be retrieved either from airport statistics of flights that have been carried out at each airport or from airline schedule data that are provided for about 3500 airports by the Official Airline Guide (OAG). If the latter ones are taken one has to be aware of the fact that these data bases contain first of all airline schedule data, however, not data of other flights like ad hoc charter and transfer flights and other commercial or non-commercial flights. A comparison of traffic at all German airports in 2008 as given by official German statistics and by OAG has shown that the OAG traffic volume captures almost 90 % of the total volume. The difference between airline traffic (based on OAG data) and total traffic becomes smaller with growing importance of airports, since they concentrate on airline traffic while airports with less traffic are more frequented by non- and other commercial traffic. If we take only the five busiest airports of Germany, which handle about two thirds of total German air traffic, the difference between OAG and total traffic narrows down to 3 %. In the following, we base our analysis on OAG data since they form the only basis available which offer data from airports around the world.

In analysing the capacity utilisation at airports world wide we pursue a double interest in first applying a new methodological approach incorporating annual traffic volumes, peak hour volumes and capacity utilisation indices, derived from traffic ranking curves, and secondly in finding out about the already existing significance of airport capacity constraints. The research interest stems among others from the fact that some important airports suffer already from capacity bottlenecks and on the other side the general view that air traffic demand will continue to grow further in future.

## 2. Global Demand Growth – Local Constraints to Growth

As can be seen in Fig. 1, global air traffic has grown substantially in the past, the pace of growth was only interrupted by oil and financial crises, terrorism and wars. The number of passengers transported world wide in air transportation has reached a volume of almost 2,500 millions in 2010, since 1994 this volume has almost doubled with an average annual growth rate of 4,3 %. The strong growth since 2003 has been influenced mainly by the upcoming of low cost carriers in the US and Europe.

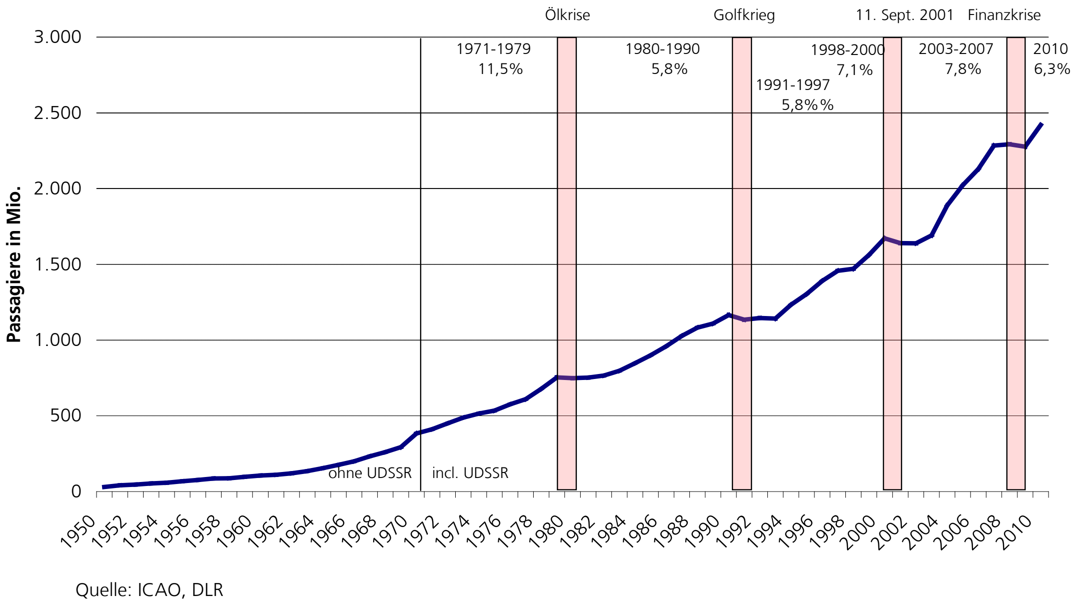



Fig. 1: Development of Global Air Passenger Travel since 1950

Air transport demand forecasts of the aircraft industry and institutions like ICAO use as a unit of demand the number of pass-kms, counted as revenue passenger kilometres (RPK's). As can be seen in Fig. 2, the demand as measured in RPK's grew even stronger than the number of passengers, in the sixteen year period from 1994 to 2010 the demand more than doubled and increased with an average growth rate of 5 %.

The long term forecasts of Boeing and Airbus as well as of ICAO have in common a continuation of the past development over the next 20 years. They differ only marginally in their growth expectations. According to the Current Market Outlook of Boeing (Boeing 2010) global airline traffic (RPK) will grow from 2010 to 2030 with an average growth rate of 4,9 %. Airbus foresees a growth of annually 4,8 % for the period of 2009 to 2029, according to the Global Market Forecast of 2010 (Airbus, 2010). ICAO differentiates between three scenarios in their long term forecast of 2010 (Teyssier, 2010), a low, most likely and a high scenario, with growth rates of 3,7 %, 4,7 % and 5,2 % for the period from 2010 to 2030. In Fig. 2 we show a linear extrapolation of the past development with an average growth rate of 4,9 % over the period of 2010 to 2030. The annual RPK-volume will then reach a level of 9 billion pass-kms, corresponding to a growth of 80 % of the volume of 2010, which was 5 billion pass-kms

There is growing concern about the implicit hypothesis of these forecasts that system capacity will be such that the strong growth of air traffic can be handled. Even if we assume that air traffic control capacity will suffice in future to handle the growing traffic, can we assume alike of airports, knowing that some important airports have already problems in peak traffic times or during most of the day to cope with the demand for free slots? And do these airports still participate in the general growth?

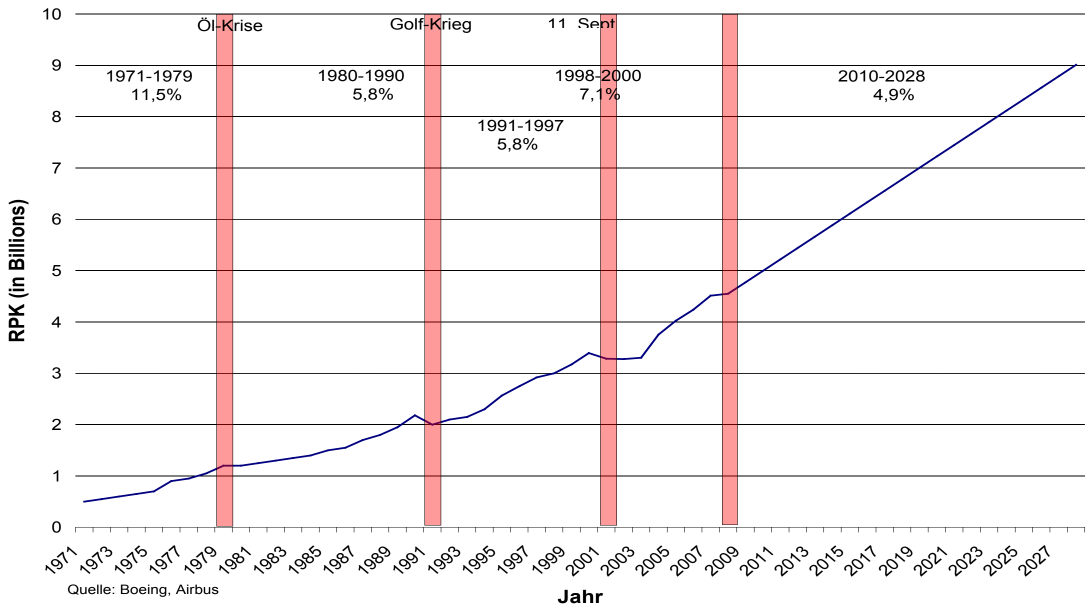



Fig. 2: Development and Forecast of Global Air Transport Demand (RPK)

If traffic reaches levels which are close to the maximum throughput of the runway system then the airport encounters not only problems of maintaining good quality of operations but is faced with the fact that future traffic growth cannot any more be accomplished. Airlines are forced to serve the growing demand without increasing the frequency of services or reschedule flights by choosing other airports. As mentioned, some important airports, partly being main hub airports, struggle already since years with capacity constraints, among them London Heathrow and Frankfurt in Europe, and R. Reagan Washington National and New York LaGuardia in the US. As can be seen in Fig. 3, the European airports didn't participate in the traffic growth in the same way as the "average" airport in Europe, as expressed by the total growth of European traffic. The flight volume at Frankfurt and London Heathrow stayed more or less constant from 2006 to 2010, while the total traffic volume of Europe grew by 16 % in the same period.

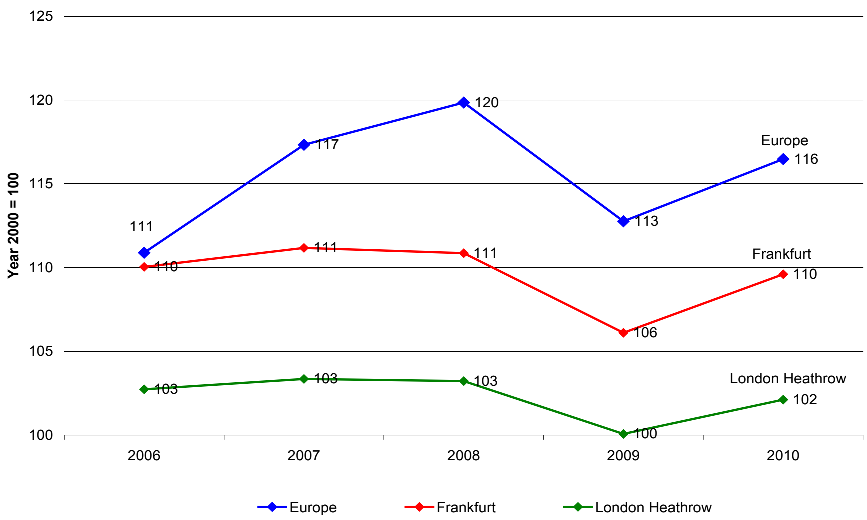



Fig.3: Air Traffic Development in Europe and in London Heathrow and Frankfurt Airport 2006 – 2010; (2000 = 100); (Source: OAG, DLR)

As can be seen in Fig. 3 as well is the fact that in the recession year of 2009 traffic declined overall stronger than at the two constrained airports. Frankfurt airport will open a new runway in 2011 and thus add capacity so as to be in a position to again participate in the general growth, however, London Heathrow will not be able to augment capacity substantially. Conditions in the US have been different, since the overall traffic in the US didn't grow, but rather declined by almost 20 % between 2000 and 2009. On the other hand, main airports with no capacity constraints may grow more dynamically than the overall traffic, depending on airlines' strategies and market conditions; examples are Peking airport (PEK), which grew by 185 %, and Dubai airport (DXB), which grew by more than 120 % between 2000 and 2009.

Given these two developments, on the one hand the growing scarcity of free capacity at some airports and on the other hand the long term continuation of growth in demand for air transport services, there is a need to analyse globally the constraint situation. Only in the case of sufficient capacity at airports we can assume that the forecasts of the aircraft industry and of institutions like ICAO are realistic. In the other case, these forecasts are just theoretical in nature, since they indicate the demand growth without regard to the basic condition of sufficient capacity.

## 3. Assessing the Constraint Situation at Airports

Airports are multifunctional and complex traffic nodes the capacity of which may be determined by the weakest system element. We concentrate here on runway capacity, since in many cases the most critical element of capacity enhancement measures is the runway system. Planning procedures of runway extensions often require an involvement of the public, which is more or less opposed to the realisation of new runways on grounds of protecting the airport environment against further noise immissions.

In order to assess the constraint situation at airports we have to therefore compare traffic volumes, as given by the number of air transport movements (ATMs), with the runway capacity. For the comparison, both the volume and capacity have to have the same definition, that is the number of aircraft movements (take offs and landings) per time unit. Demand and flight movements are normally given and forecast on an annual basis, while the capacity as a measure of the true through-put of the system is calculated or estimated for a short time period, typically for one hour or even shorter intervals. Annual "capacities" are used for long term planning purposes as a measure of available service volume as well, however, not for measuring the maximum through-put of a runway in a comparable way.

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.

Given the present or forecast annual traffic volumes (ATMs) on the one hand and hourly capacities to be compared with on the other we have to convert annual movements into some kind of peak hour movements. **Peak hour volumes** are taken for the constraint analysis, since we want to guarantee that traffic can be handled even in peak hour conditions, although not necessarily in the absolute peak hour of the year. Airports must provide sufficient capacity for most traffic situations within a year, however, may take into account some delays of traffic in peak hours occurring only occasionally. Airport planners often chose the so called 5 % peak hour as a base for designing facilities and capacity. After having demonstrated the peak hour characteristics by means of ranking curves of many airports (Berster et al, 2010) we have adopted this concept and take the 5 % peak hour as the typical peak hour chosen for estimating capacity reserves and utilisation. In a network or global analysis, the ranking curves as developed on the basis of OAG data allow determining the 5 % peak hour of airports in a consistent way. An additional advantage is given by the fact that peak hour volumes are comparable between airports.

Ranking traffic by hour for all hours of the year allows us to identify and determine the traffic in the 5 % peak hour. Based on OAG data, **traffic ranking curves** have been derived for around 3500 airports world wide. In the case of comparing peak hour traffic with capacity for a future year, they form the empirical base for establishing a functional relationship between peak hour traffic and annual traffic. In addition, traffic ranking curves are a tool well suited for analysing and estimating hourly capacity of those airports that are already working under near capacity conditions. The question whether or not an airport has reached almost capacity in daily operation can be seen easily by regarding the slope of the ranking curve over all hours of the day (excluding night hours). If the slope is such that the variation of hourly traffic is rather small, as is the case in Frankfurt or London Heathrow for instance, then the highest volume values of the curve are indicative of the capacity of the airport, which in such cases is typically the capacity of the runway system.

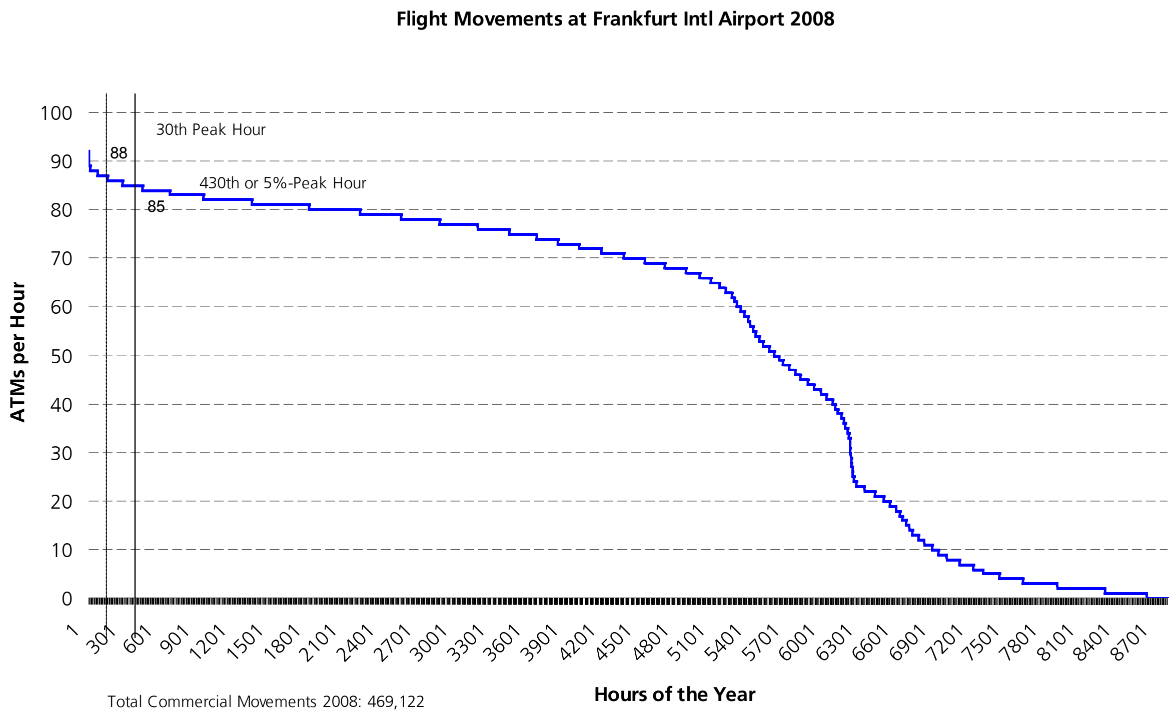



Fig. 4: Traffic Ranking by Hours of Operation of the Year 2008 at Frankfurt Airport (Source: OAG, DLR)

As an example the ranking curve of Frankfurt airport is shown in Fig. 4. The highest hourly volume of the year was in 2008 almost 90 ATMs, and the 5 % peak hour volume was with 85 movements only 5 ATMs lower than the absolute highest volume. The declared capacity of

Frankfurt, which reflects the slot offer in the scheduling process of airlines and is equal to the runway capacity of Frankfurt airport, has been set to 85 ATMs. As can be seen the highest volumes including the 5 % peak hour volume exceed in the case of Frankfurt the declared capacity. It should be noted in this context that the number of movements according to OAG data corresponds to the on-block and off-block occurrences, whereas the capacity refers to the number of movements on the runway. London Heathrow (see Fig. 5) is another example airport which stands for a congested airport with high traffic volume (ca. 480,000 ATMs in 2008). The capacity reaches a maximum value of 90 movements per hour for some hours of the day, and the 5 % peak hour volume in 2008 has been found to 86 ATMs, which is close to capacity.

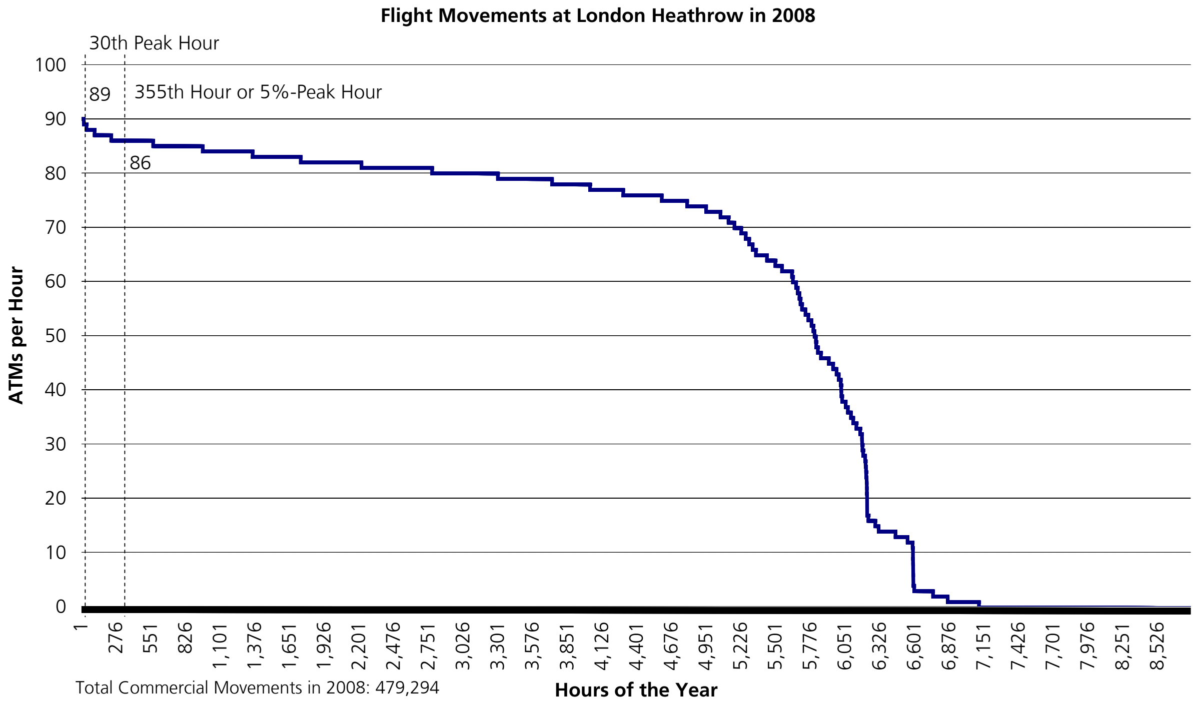



Fig. 5: Traffic Ranking by Hours of Operation of the Year 2008 at London Heathrow (Source: OAG, DLR)

It has been found in other cases where airports operate under near capacity situations that the 5 % peak hour volume is close to the capacity of the runway system and may thus be used in a global comparative assessment of traffic conditions as a reliable indicator of the true capacity (Berster et al, 2010). In the case of airports operating at low traffic volumes during a typical day, the 5 % peak hour volume is also rather small and by no means indicative of the capacity. This may be seen in the ranking curves of Fig. 6, in which we depicted out of a sample of airports with an annual traffic volume of more than 70,000 ATMs in 2008 those five single runway airports with the highest and the lowest volumes. Those airports with high annual volumes have equally high peak hour volumes which are close to capacity, and also rather high volumes during day hours (until about the 5,000$^{th}$ hour), whereas the airports with lower annual volumes, however, more than 70,000 ATMs, reach lower peak hour and lower day time volumes, with ranking curves which are more inclined already in the upper part of the function.

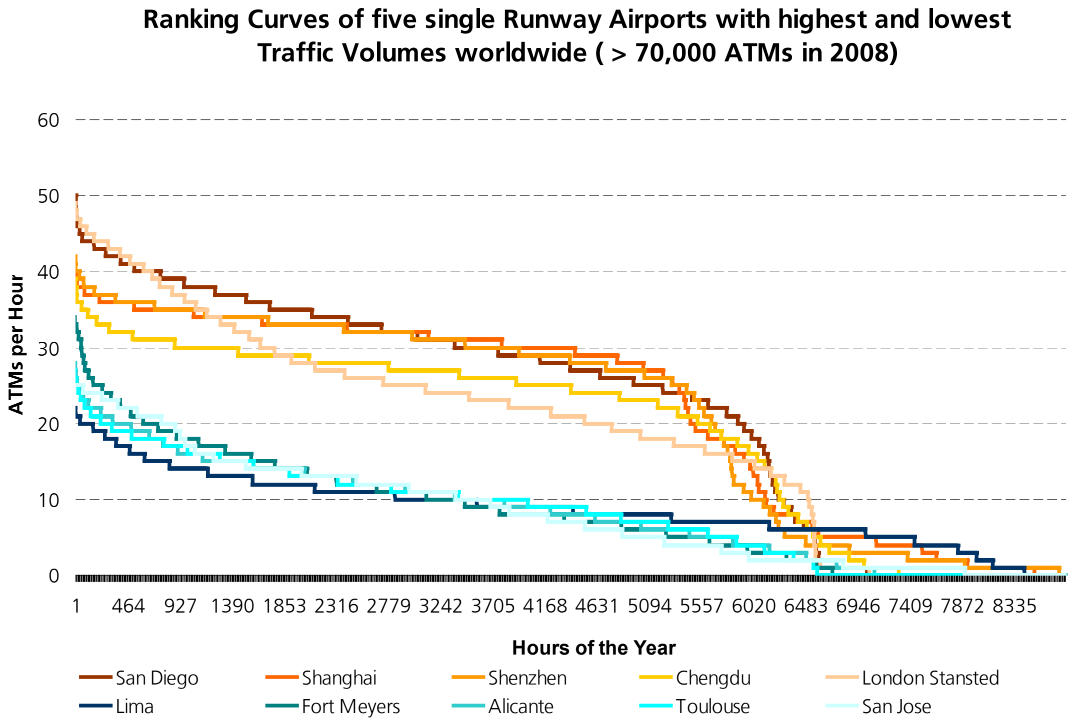



Fig. 6: Traffic Ranking by Hours of Operation of the Year 2008 at the five Single Runway Airports with the highest and lowest Traffic Volumes of all Airports with more than 70,000 ATMs (Source: OAG, DLR)

In addition, the average hour volume of an airport operating at near capacity conditions like London Heathrow is not much smaller than the peak hour volume. In the case of London Heathrow the average hour is characterised by volumes in the order of 73 ATMs in 2008. If we relate the average hour volume with the 5 % peak hour volume we will get an **index of the capacity utilisation (CUI)**. Airports with high traffic volumes as related to capacity have typically high utilisation indices while airports with ample capacity reserves have somewhat lower values of capacity utilisation. In the case of London Heathrow the ratio of the average hour to the 5 % peak hour volume is 0.85, a value that can hardly be exceeded, given the tight capacity situation in London Heathrow. In fact, no other airport world wide reaches that level of capacity utilisation. The capacity utilisation index of Frankfurt is 0.74, of San Diego, the airport with the highest traffic volume in the category of single runway airports, has a value of 0.72.

With the annual traffic volume, the 5 %peak hour volume and the capacity utilisation index we have three criteria to assess the degree to which traffic is approaching capacity of an airport. 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:

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

It should be noted that the runway capacity varies less between airports in the first two classes than in the following classes, since the exact runway configuration may vary more in the latter classes. These classes have been retained in order to have enough airports in each class specific sample for estimating a function between the 5 % peak hour volume and the annual volume that is applied in case of analysing the capacity utilisation for future years when only the annual volume are forecasted (Berster et al 2010). In more specific capacity utilisation analyses it may be helpful to subdivide the classes further according to the runway layout.

## 5. Selection of Airports with High Traffic Volumes, Global Air Traffic Concentration

Traffic in general and air traffic in particular is characterised by concentration in time and space. Concentration in time is primarily caused by activity patterns of people, like active living during the day and being inactive during night, and spatial concentration of traffic is caused by the fact that more and more people live in conurbations, especially those who participate in air travel. In addition, the way how air traffic is organized contributes to concentration of routes and airports as well: Hub and spoke networks have been developed as to optimise transport by concentrating flights on a relative small number of trunk and feeder route.

The global air traffic network consists of several thousand airports; flight data on the basis of the Official Airline Guide (OAG) are available for about 3800 airports. We have selected those airports which are equipped with infrastructure sufficient to handle regular scheduled and charter traffic and are part of the international air traffic network. Their number is about 2400. If we want to look at the traffic concentration in this network we have to rank airports according to traffic volume and draw a so called Lorenz curve. In Fig. 7 we see the traffic concentration for the year 2008, the year with the highest traffic so far. The airport traffic volumes are shown as market shares of the total number of flights, which was in 2008 about 55 million flight movements (OAG). The number of airports is equally shown as a relative portion of the total number.

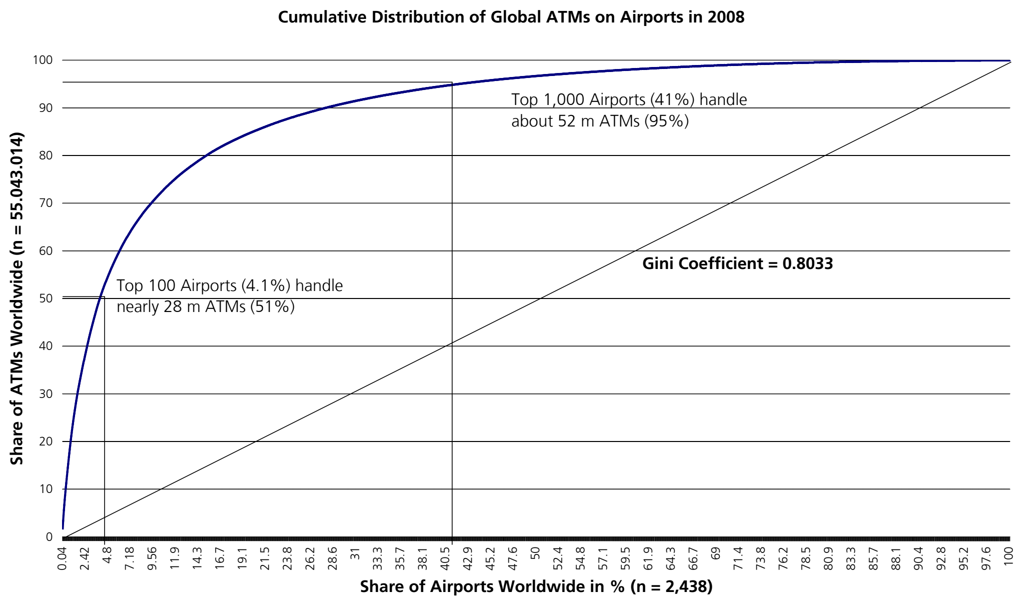



Fig. 7: Cumulative Distribution of Airport Traffic in the Year 2008
(Source: OAG, DLR)

As indicated by the Gini Coefficient (0.8033), air traffic is indeed very concentrated on a relative small number of airports: 50 % of the total traffic is handled by just 4 % of all airports, equal to the top 100 airports world wide, and 95 % of the total traffic is concentrated on the top 1000 airports (41 %). Correspondingly, there are 1400 airports with traffic volumes as low as to account for just 5 % of the total. As a result, there are a relative small number of airports with high traffic volumes contributing significantly to the total traffic, and on the other side a great number of airports with low traffic forming thus – at least theoretically – an important reservoir of airport capacity. The interesting question is then: Do the high volume airports have sufficient capacity reserves in order to deal with the traffic of today and in the future? And what is the degree of capacity utilisation at airports?

For the top 1000 airports world wide, Fig. 8 shows the cumulative distribution of the capacity utilisation index in the year 2008. Here again we see a concentration of traffic, in this case on those airports which have already a relatively high value of CUI. 57 % of total traffic (of the 1000 top airports) is handled by airports which have already a relatively high degree of capacity utilisation; with a CUI above 0.7. The highest of all values of CUI is given with 0.85, which belongs to London Heathrow. The constraint analysis has shown, however, that the CUI criterion alone is not a measure to describe the constraint situation in a satisfactory way at an airport. The reason is that airports with volumes well below their capacity may have already relatively high CUI values in the order of 0.5 to 0.6. The CUI is thus meaningful only in relation with the annual and peak hour volume. Therefore we base our constraint analysis on this threefold approach.

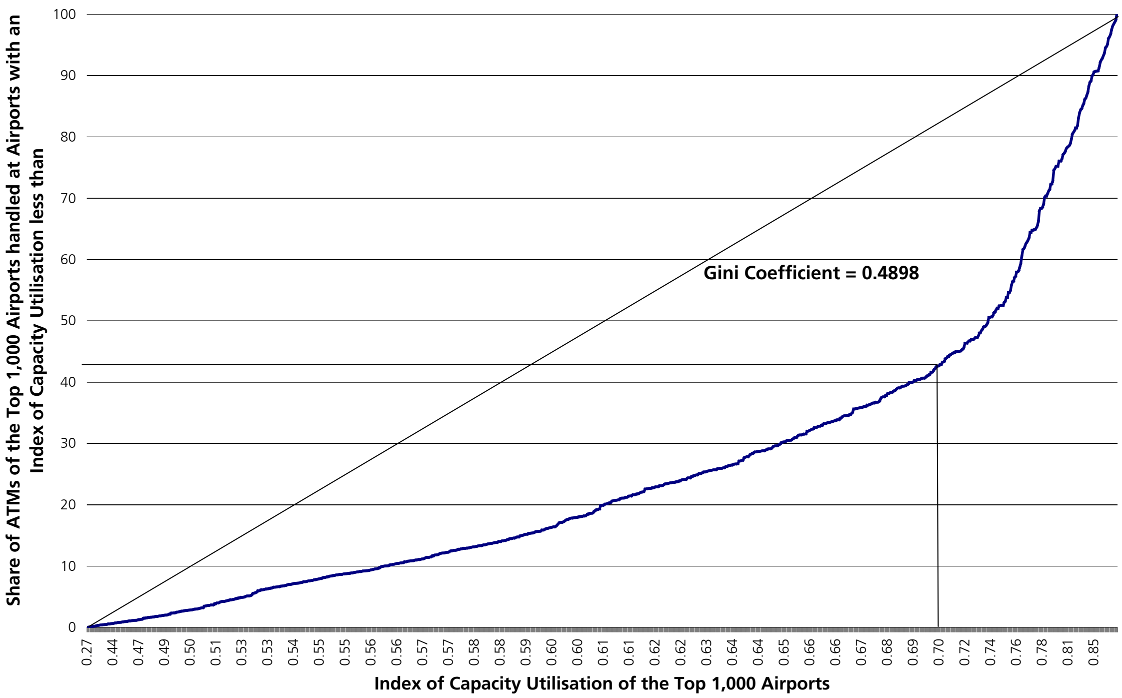



Fig. 8: Cumulative Distribution of Capacity Utilisation (CUI) in 2008 of the 1000 Top Airports (Source: OAG, DLR)

Given the degree of traffic concentration on a relatively small number of airports there is no need to extend the constraint analysis to all airports, on the contrary, we have to select those airports above a threshold value of aircraft movements, for which we can assume that traffic bottlenecks may occur already now or in the near future. The airport capacity class with the lowest capacity is the single runway airport; all other airports are able to handle more traffic. The analysis of annual volumes and peak hour volumes of airports has shown that if annual volumes are around 70,000 ATMs the 5 % peak hour volume is around 20 ATMs. This value corresponds roughly to 50 % of the hourly capacity of a runway in IFR conditions as are the rule in Europe, or less than 50 % in VFR conditions as are practised in the US. We have therefore decided to carry out the constraint analysis of airports world wide only for those airports which exceed a minimum annual traffic volume of 70,000 ATMs. Of all other airports we can assume that they do not have capacity problems now or in the near future.

Applying the threshold volume of 70,000 ATMs reduces the number of airports to 177. Due to the concentration of traffic these 177 airports, corresponding to 7.2 % of all airports, handle around two thirds of total traffic. Correspondingly, more than 2000 airports with traffic volumes of less than 70,000 ATMs annually handle not more than one third of total air traffic of around 55 million flight movements in 2008.

## 6. Approach Used in Constraint Analysis

Potential capacity constraints of the top 177 airports with more than 70,000 ATMs in 2008 have been analysed by a combined approach, which includes the three criteria annual service volume, 5 % peak hour volume as proxy value of hourly capacity, and capacity utilisation index (CUI). These criteria are applied in an interdependent and hierarchical way.

The first step of evaluating constraints is to assess yearly aircraft movements of an airport. For this, we define lower bounds of yearly aircraft movements by runway system class from our airport sample (see Fig. 9). If the yearly aircraft movements of an airport are below the lower bound – e.g. in the single runway class 70,000 ATMs -, the airport is not critical with regard to capacity constraints and the analysis needs not be conducted further. If on the other hand, yearly aircraft movements of an airport exceed the lower bound – e.g. in the single runway class 70,000 ATMs -, the airport is subject to the constraint analysis.

| Runway Configuration | Min. ATMs | Min. 5% Peak Hour | Min. CUI |
|---|---|---|---|
| 1. Single Runway | 70,000 | 35 | 0.7 |
| 2. Two independent parallel Runways (Distance >= 1.5 km) | 140,000 | 70 | 0.7 |
| 3. Two dependent parallel Runways (Distance < 1.5 km) | 100,000 | 50 | 0.7 |
| 4. Two crossing Runways | 100,000 | 50 | 0.7 |
| 5. Three Runways | 150,000 | 75 | 0.7 |
| 6. Four and more Runways | 200,000 | 100 | 0.7 |

Fig. 9: Bounds of Annual Volume, 5 % Peak Hour Volume and Capacity Utilisation Index Used in Constraint Analysis

In a second step, 5 % peak hour and average hour volumes and capacity utilisation index (CUI) are analysed, if appropriate: Airports which have at least a moderate degree of capacity utilisation, the 5% peak hour is a reliable indicator of the runway capacity of an airport, as stated above. A comparison of the 5 % peak hour with the average hour yields a picture of capacity saturation of an airport: As written above, the more the value of the average hour approaches the value of the 5 % peak hour, the more the airport is capacity saturated. Thus, the capacity utilisation index serves as an index of capacity saturation. As demonstrated in

Fig. 4 and 5, Frankfurt and London are good examples of airport the capacities of which are saturated. The 5 % peak hour values which have been retained as critical values for classifying airports as being saturated or not have been set in analogy to those values that have been found at airports with the highest volumes in each runway system class (see Fig. 9). The critical value of the 5 % peak hour volume of a single runway airport, for example, has been set to 35 ATMs, indicating a utilisation in the peak hour of around 75 to 90 % of the capacity. The second step consists thus of an examination of the 5 % peak hour value; if this value is below the critical value then we can assume that the airport has still some capacity surplus and is not yet congested, if on the other hand the 5 % peak hour value exceeds the critical value we must assume that the airport is operating near or at capacity level, unless the third step of the analysis yields a CUI value which is below the threshold value of CUI.

From the statistical analysis of the 177 airports, we have found CUI values of 0.7 and higher for all runway systems as a necessary condition, however, not sufficient condition, for airports struggling with capacity problems (see Fig. 9). Nevertheless, we have found some examples of airports with high CUI values, which are not yet congested and have substantial capacity reserves. These airports are well under-utilised and the 5% peak hour volume is rather low and is not a true description of airport capacity. Therefore, a high CUI value alone is not a sufficient criterion for airport capacity constraints. In such cases, high CUI values correspond with a rather small number of aircraft movements, which are below the lower bound of annual movements or of the 5 % peak hour volume and thus, not subject to further constraint analysis. If on the other hand annual volume and 5 % peak hour volume exceed the critical value (second step analysis) and the CUI value is higher than 0.7 (third step analysis), then we have almost certainly a situation of congested traffic conditions at the airport. If the second step analysis yields a near capacity traffic condition, however, the CUI value is not critical, we assume that the airport has some problems only during peak hours, but still some capacity reserves during non peak hours, and we categorise this airport as non critical. It should be noted here, that in such a situation one could decide otherwise by assuming that an airport starts to be congested if the peak hour volumes cannot be handled without greater delays. Since delay data are missing in this constraint analysis we cannot judge better in such a case. If this analysis needs any refinement then an accompanying delay analysis would certainly improve the significance of the approach.

To summarise, we have a set of three indicators to identify capacity constraints at airport: Yearly flight movements serve as a KO criterion in a first round in which some airports are identified as either capacity constrained or not. In a second phase, 5% peak hour are used to identify capacity constrained airports among those, which survived round one. In a third phase we check the CUI value and in case the value is not critical then the airport is regarded as not critical in terms of shortage of capacity. This three-step process is necessary because it is generally not possible to tie upper and lower bounds of yearly flights movements tight enough (see also discussion of hourly vs. yearly capacity concept).

The constraint analysis has been carried out separately by runway system class. In Fig. 10 – 15 in the Annex we show the relationships between annual volume and 5 % peak hour volume on the one hand and capacity utilisation index on the other hand for the airports in each runway system class within the sample of the top 177 airports world wide. As can be seen there is a positive correlation between the variables annual and peak hourly volume. Never the less, for a given peak hour volume the annual volume might vary substantially, depending on the distribution of hourly traffic utilisation and night hour regulation. Given for example the threshold value of 35 ATMs as critical 5 % peak hour volume, there are four airports – San Diego, Shanghai, Shenzhen and London Stansted - with higher values and one airport –

London City – with exactly this value, however at a much lower annual volume due to a night curfew, that could be classified as airports operating under near capacity conditions.

As can be seen in Fig. 10 – 15 there is no strong relationship between annual volume and the capacity utilisation index, high CUI values can be found at airports with both high and low traffic volumes, however, airports with critical hourly volumes have in general high CUI values as well. All selected airports (with volumes above 70,000 ATMs per year) have CUI values greater than 0.5. As can be seen of the four critical airports identified on grounds of high 5 % peak hour volumes in the single runway class three have high CUI values, too, except London City and Stansted, which have a relatively low CUI of 0.58 and 0.59 respectively, indicating capacity reserves in normal traffic hours during the day. (London City airport serves a niche market of short haul business travel, characterised by morning and evening peaks.) Concluding for the single runway class we would therefore classify the top three airports as airports operating under near capacity conditions or as already congested airports. This global comparative analysis of constraints does not allow specifying the congestion at each airport exactly, the method can only yield a rough measure of capacity problems. The main advantage of the approach is the treatment of all airports in a comparable way.

## 7. Results and Discussion

The main result of the capacity constraint analysis is that in 2008 only a very few airports have been identified as capacity critical airports; in fact 10 airports have both high annual and peak hour volumes and a high capacity utilisation index (above 0.7). These airports are:

- San Diego (SAN),
- Shanghai (SHA),
- Shenzhen (SZX),
- Mexico City (MEX),
- New York La Guardia (LGA),
- Barcelona (BCN),
- London Heathrow (LHR),
- Frankfurt/Main (FRA),
- Charlotte (CLT), and
- Paris Charles de Gaulle (CDG).

Three of these airports (SAN, SHA, SZX) belong to the single runway airport class, MEX to the class with two dependent parallel runways, LGA and BCN to the class with two crossing runways, LHR, FRA and CLT to the class with three runways and CDG to the class with four and more runways. Related to the sample of the top 177 airports these ten airports handle about 10 % of the traffic, and related to the total network, the share is 6 %. In 2008, only 6 % of all flights were restrained by airport capacity at ten airports world wide, in other words, the great majority of flights were operated under unconstrained conditions. This seems to be a positive result, although the amelioration of capacity conditions at some of the constrained airports may be a difficult task.

We have identified more airports with high annual volumes and peak hour volumes, where capacity problems might occur during peak hours, however, not yet in off-peak hours. And we have identified more airports with high capacity utilisation indices that have not high peak hour volumes, and thus, no substantial capacity problems. These circumstances highlight the fact that capacity constraints are not a clear-cut phenomenon: It is rather a smooth transition from airports which are able to participate fully in traffic growth and those which are increasingly not: Beyond a certain threshold capacity constraints are becoming more and more important and the ability to fully accommodate future traffic growth declines with increasing airport utilisation. It can be assumed that such a threshold is somewhere in the range of 75 % traffic utilisation of capacity and of 0.7 capacity utilisation index. There are in reality no clear-cut lines between unrestrained and restrained traffic conditions, whereas in our method we had to draw such lines in the first place. Since there is in many "boundary" cases room for interpretation it may be useful to enlarge the approach in future to areas in which airports can be classified according to unconstrained, near capacity and at capacity traffic conditions. If one studies the Fig. 10 to 15, it can be seen that there are a number of airports with high volumes and capacity utilisation which have not yet reached critical levels but are close to them, especially in runway system class one (single runway airport), three (two dependent parallel runways) and six (four runways and more). If we lower for instance the threshold value of the CUI from 0.7 to 0.65, and leave the annual and 5 % peak hour volume unchanged, we would classify 11 more airports as critical, and more than one quarter of all flights to and from the 177 top airports would then be operated under capacity constrained conditions, related to the total network, around 15 % of all flights would be critical.

Given the long term growth of air traffic as discussed in Chapter 2 we have to assume that the situation, still favourable in the year 2008 will change fairly soon and will include more network links and airports with capacity problems. A first test application of the constraint analysis approach to a data set of ICAO/CAEP, which includes an airport specific forecast for the year 2016, by which the traffic will have grown by about 40 % as compared with 2006, has shown that about 70 % of all flights to and from the 177 top airports world wide will be operated in capacity constrained conditions, be it near capacity or at capacity level. This shows clearly that although capacity conditions at most airports are still such that traffic growth is not yet impeded by constraints, the capacity problem will soon gain in importance. This result, however, has to be seen against a do-nothing-development of airport capacity, which is probably the worst scenario of potential investments. This leads to the questions of remedies of upcoming bottleneck situations at airports.

The actors within the air transport system, like airlines, airports, air traffic control agencies and institutions have several options to react to existing or upcoming bottlenecks. They are in general terms:

- increase in capacity by adding new runways (investment),
- re-organisation of traffic operations by using more intensively off-peak times,
- re-organisation of traffic operation by diverting traffic to less congested airports,
- re-organisation of traffic operations by using aircraft with higher seat capacity.

A do-nothing measure would be to leave the demand unaccommodated and let the market react; as a consequence prices of air transport services would go up to balance the market. The investment option is in some Western countries and regions more and more difficult to realize, on grounds of resistance of the neighbouring population. People are often opposing enlargement plans since they fear a more intense exposure to aircraft noise. And in many cases airports are surrounded by urbanized areas so that an extension of the site is more or less excluded.

Traffic re-organisation becomes more and more important since it is an endogenous measure of the air line industry. Flight schedules may be rearranged so that off-peak hours are frequented more than before and neighbouring airports with more capacity reserves will be integrated in the airline network. And airlines have typically the option to operate more aircraft with higher seat capacity so that the growing demand can be satisfied without increasing the frequency. Naturally, the measures have weaker effects than an investment in a new runway. In the light of growing problems of increasing capacity through new runways, at least in Europe and the US, however, the traffic re-organisation measures gain in importance.

**References**

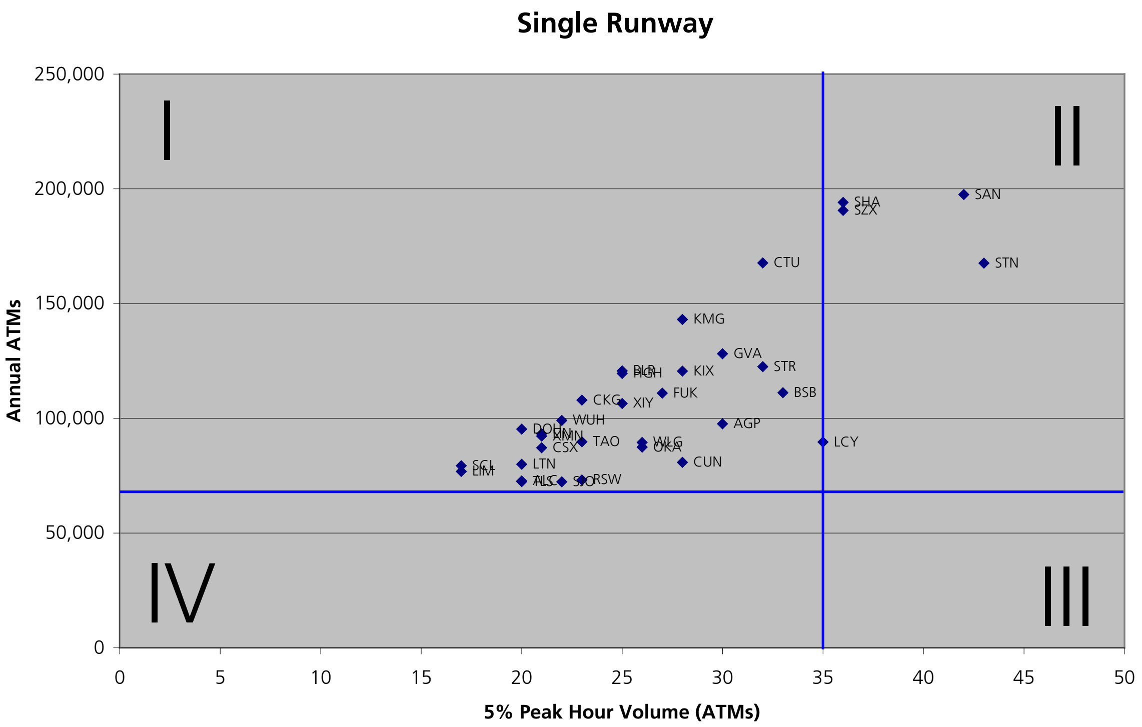
Boeing (2010), Current Market Outlook 2010-2029, Seattle, Washington, 2010.

Airbus (2010), Global Market Forecast 2010-2029, Toulouse, France, 2010.

Teyssier N. (2010), "Aviation Statistics & Data: A Vital Tool for the Decision Making Process", ICAO, Montreal 2010.

Berster, P., Gelhausen, M., Wilken, D., „New Empirical Evidence on Airport Capacity Utilisation: Relationships between Hourly and Annual Air Traffic Volumes", Paper Presented at the 2010 World Conference of Air Transport Research Society (ATRS) in Porto, Portugal, 2010

## Annex



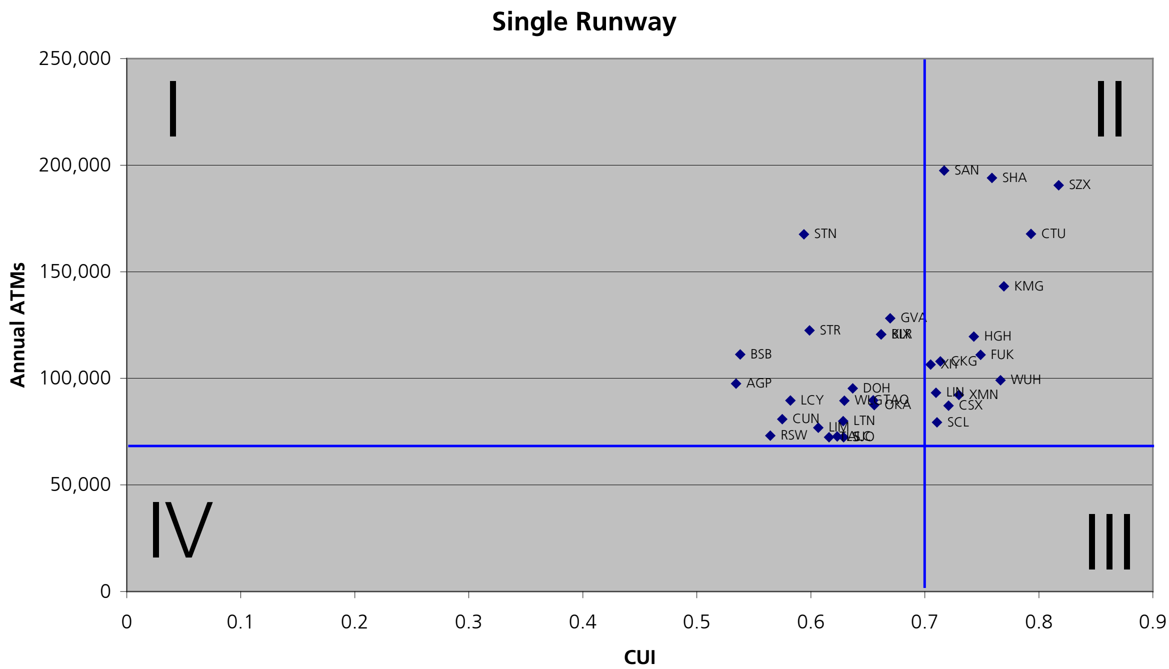
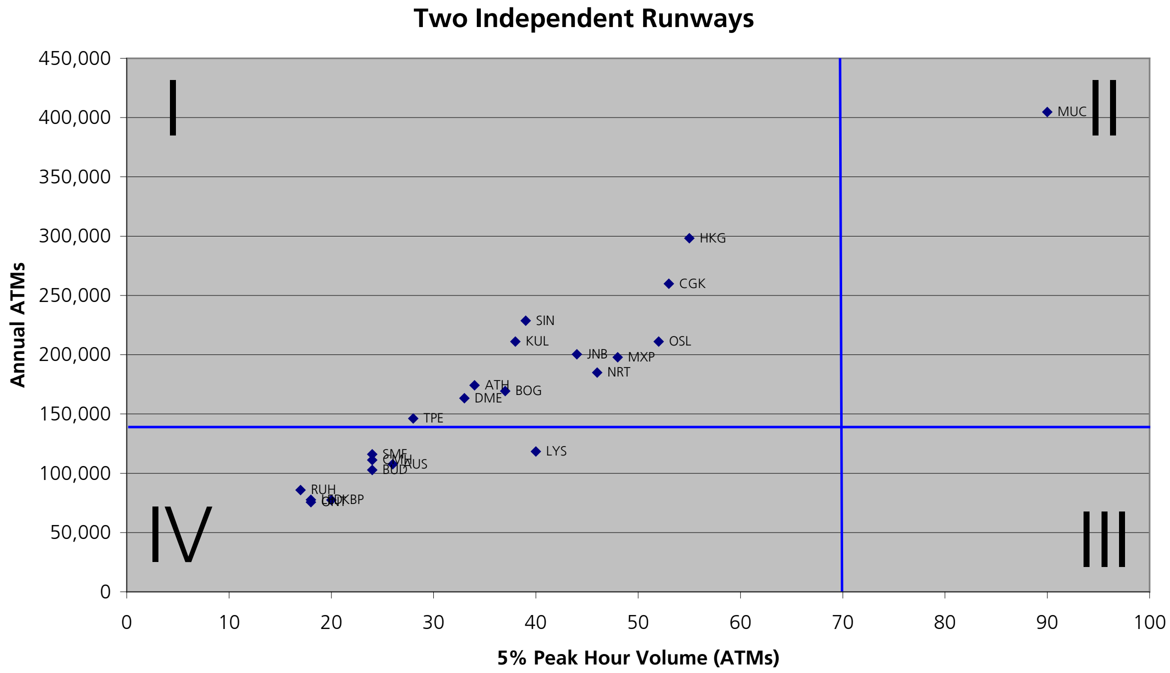




Fig. 10: Relationship between Annual ATMs, 5 % Peak Hour Volume and Capacity Utilisation Index (CUI) for Airports with a Single Runway



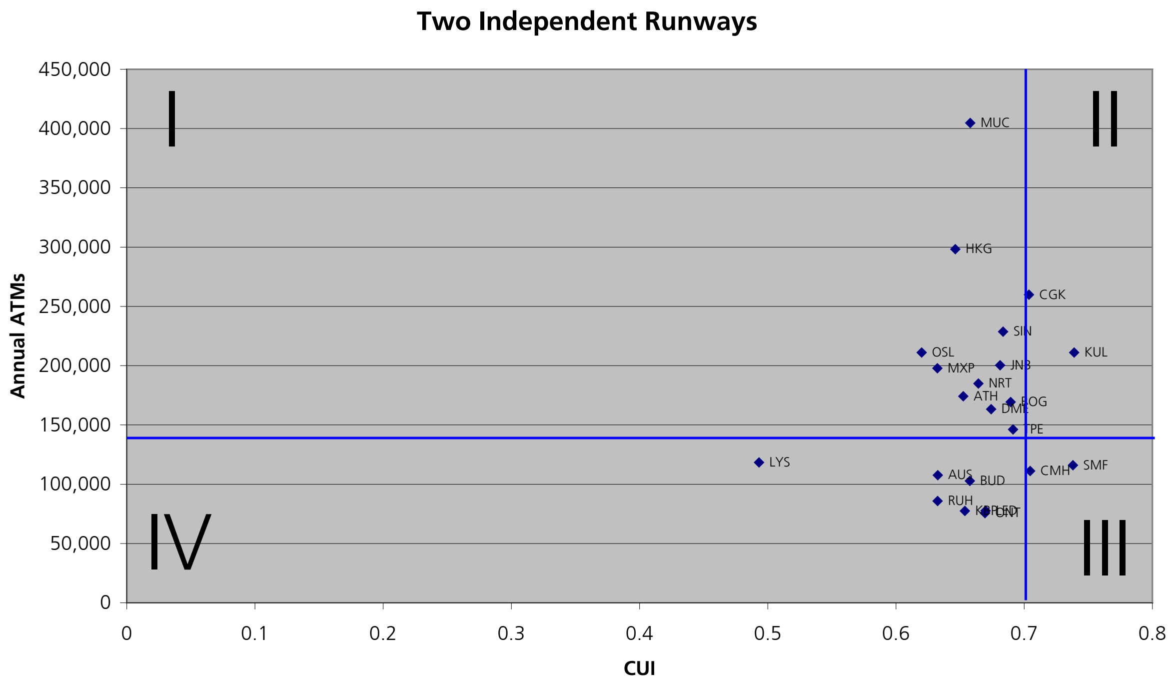
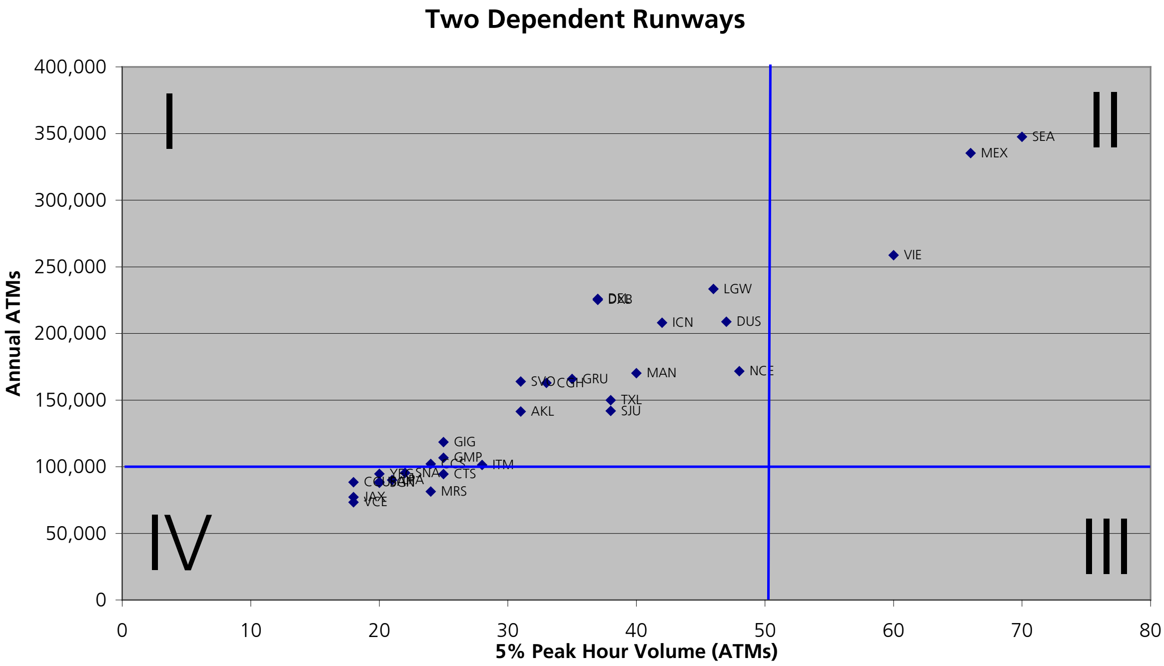




Fig. 11: Relationship between Annual ATMs, 5 % Peak Hour Volume and Capacity Utilisation Index (CUI) for Airports with Two Independent Runways



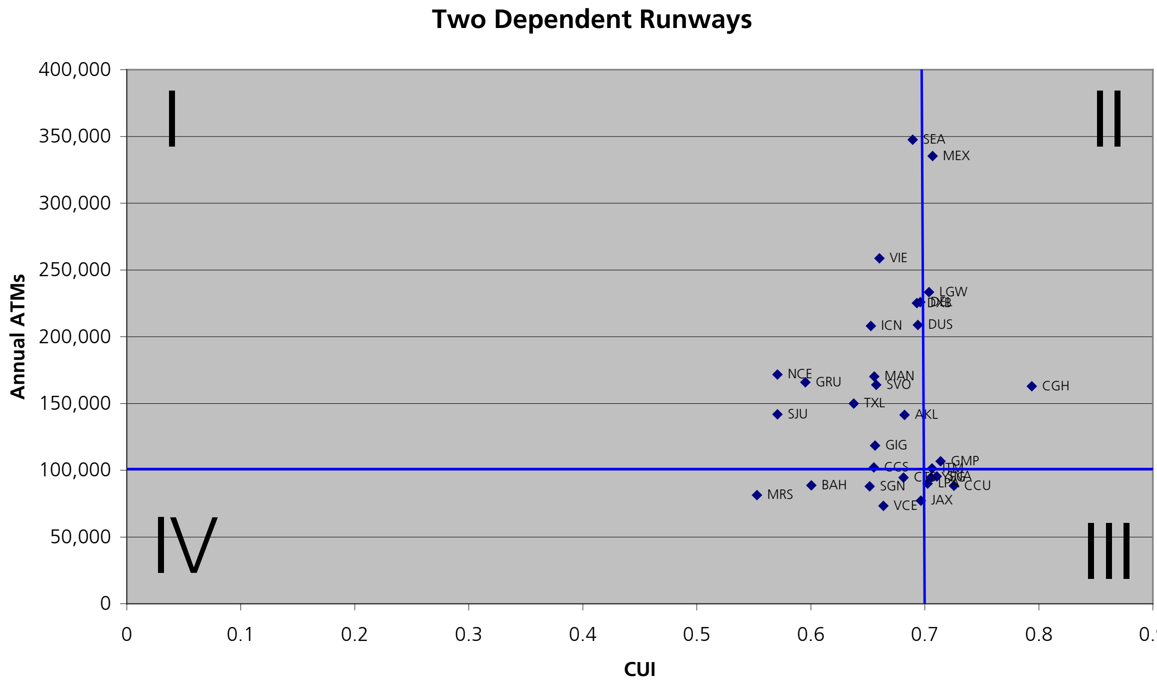
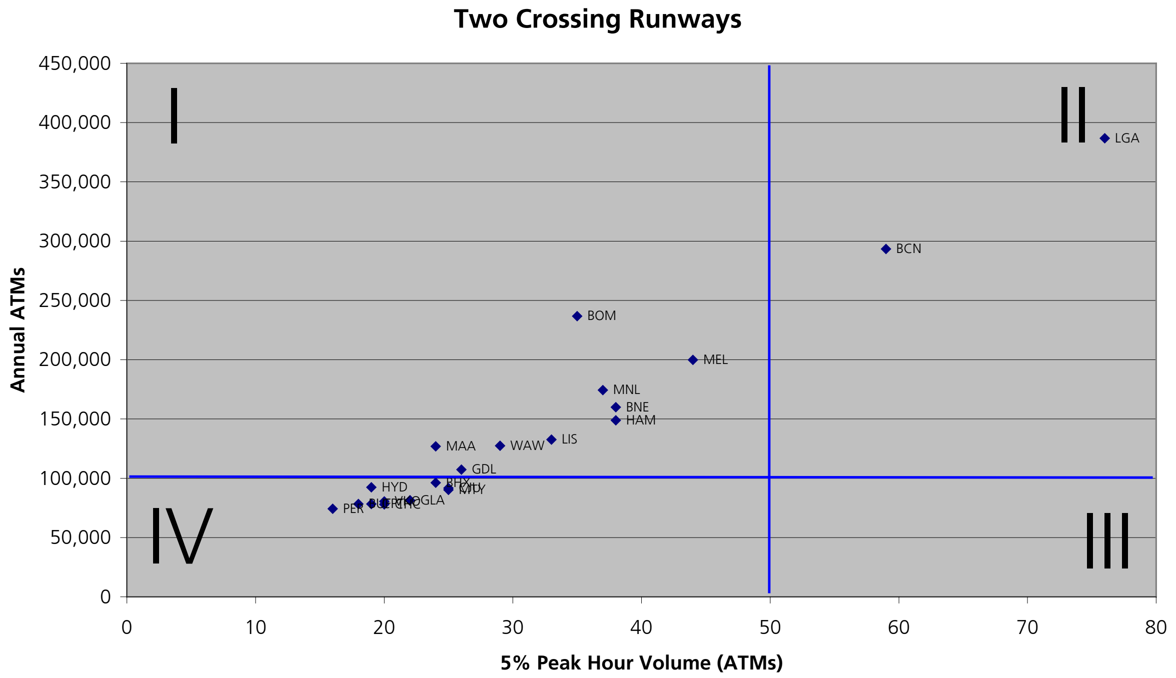




Fig. 12: Relationship between Annual ATMs, 5 % Peak Hour Volume and Capacity Utilisation Index (CUI) for Airports with Two Dependent Runways



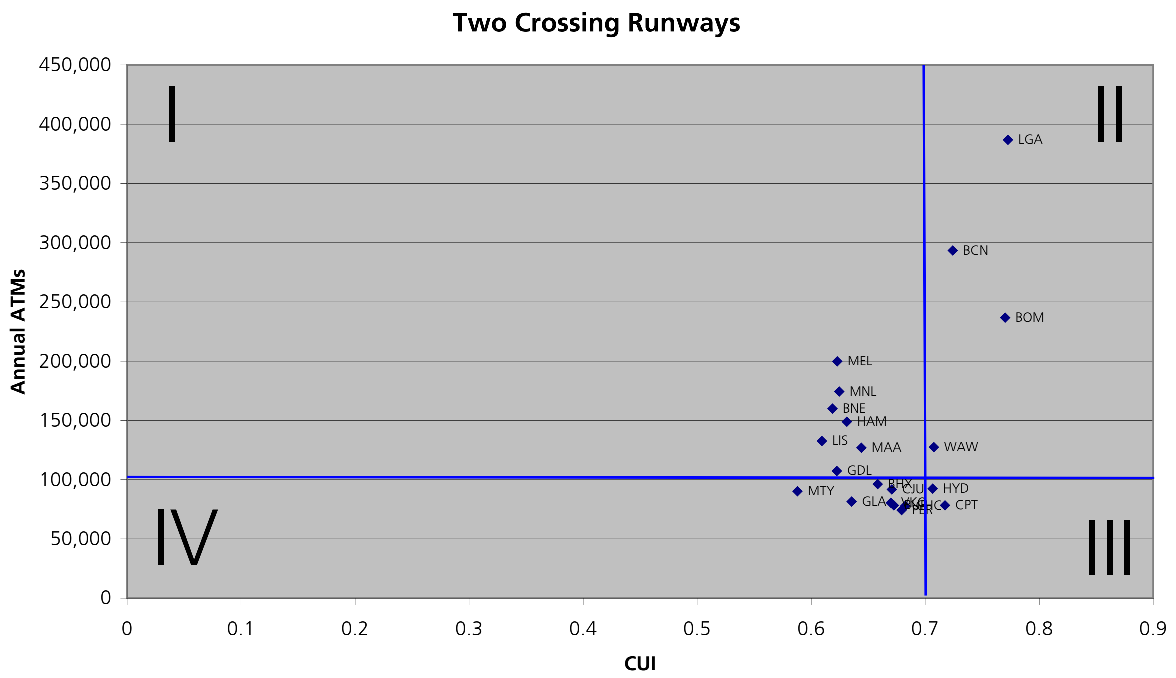
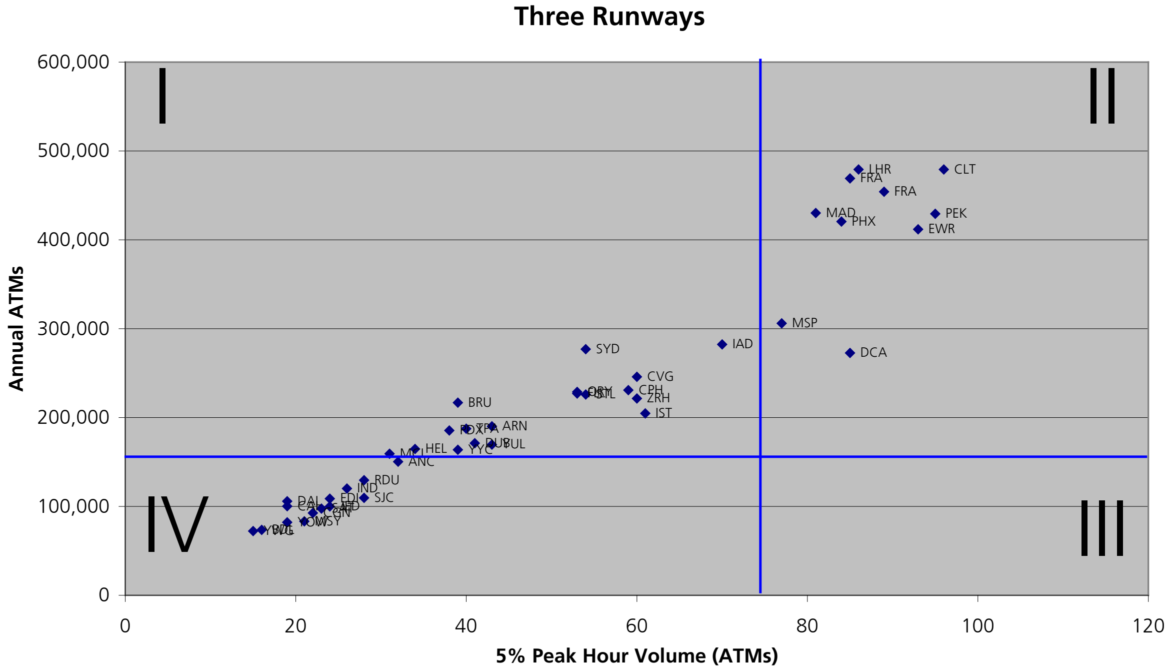




Fig. 13: Relationship between Annual ATMs, 5 % Peak Hour Volume and Capacity Utilisation Index (CUI) for Airports with Two Crossing Runways



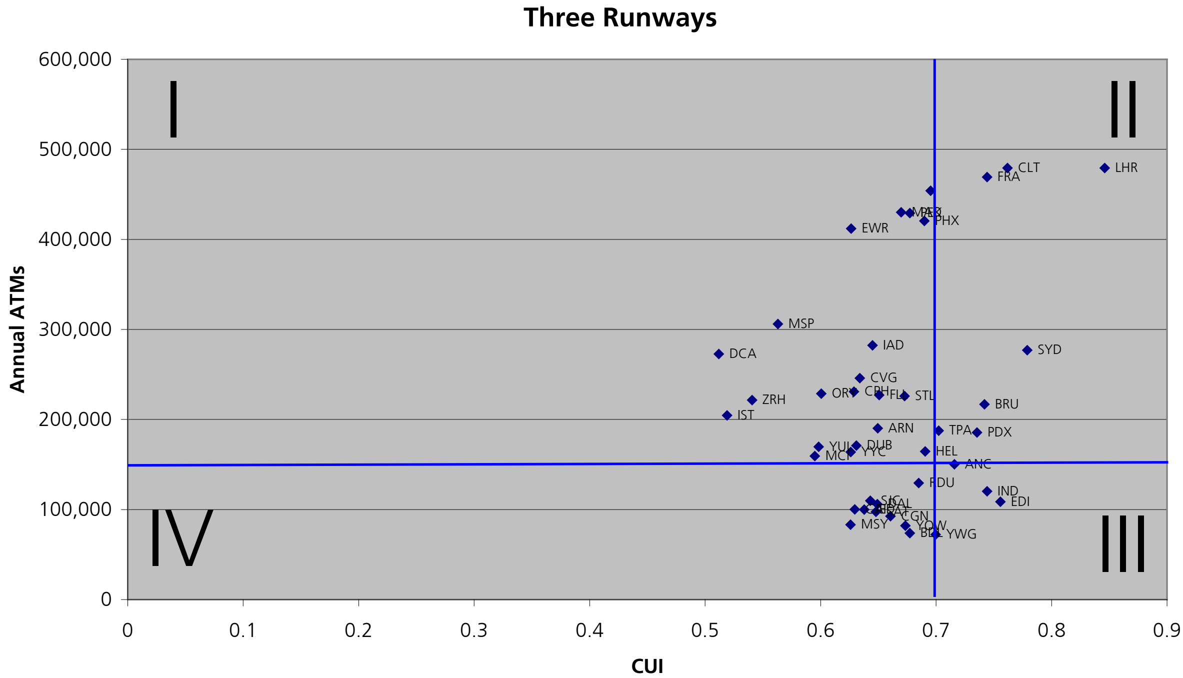
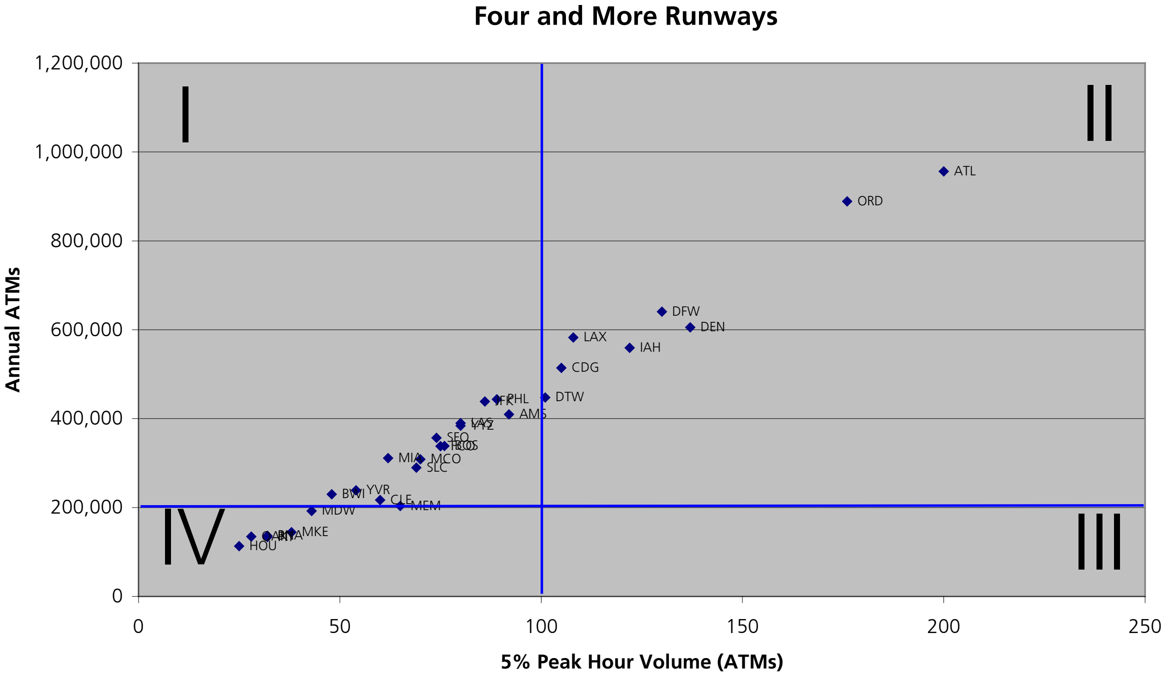




Fig. 14: Relationship between Annual ATMs, 5 % Peak Hour Volume and Capacity Utilisation Index (CUI) for Airports with Three Runways



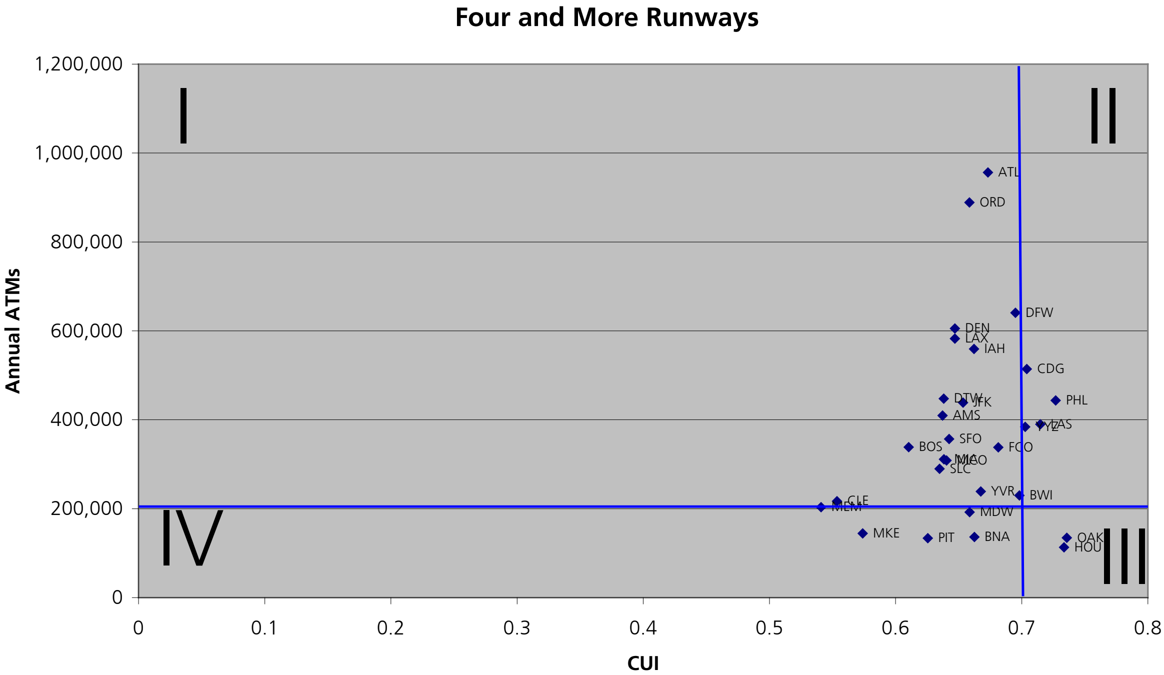




Fig. 15: Relationship between Annual ATMs, 5 % Peak Hour Volume and Capacity Utilisation Index (CUI) for Airports with Four and More Runways