The 22nd ATRS World Conference, Seoul, South Korea, July 2-5, 2018

How to measure and describe levels of airport capacity constraint in a global context

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ABSTRACT

Airports suffer from capacity bottlenecks and will so in the future. However, we have to differentiate between occasional and peak hour and severe bottlenecks. The objective of the research is to quantitatively describe different levels of capacity constraint of airports in the global network. So far, a number of studies have shown the airport capacity problem by identifying constrained airports respectively the capacity, forecasts of demand and thus the unaccommodated demand. Capacity constraint, however, is not a black-white problem, but one with a great range of severity. In quantitatively describing this range and establishing capacity utilisation classes we want to contribute to a more rational discussion of the global airport capacity problem.

The empirical part is based on global OAG data of the year 2016. By means of airport volume data, an analysis of hourly volume distribution and the derivation the 5%-peak hourly and average day time hourly volume and capacity utilisation indices (CUI), we identify non-constrained and constrained airports. For the latter ones we can distinguish between degrees of constraint by establishing a relationship between the degree of capacity utilisation and the time duration of that utilisation degree of each airport. The vast majority of airports (ca. 96%) have small traffic volumes and no capacity constraints. However, the remaining constrained airports (ca. 150) carry the bulk of traffic. About 30 of them, among which are the main airports worldwide, are more or less severely constrained, among them London Heathrow, Beijing, Tokio-Haneda, Dubai, Istanbul, New York-Newark and –La Guardia, etc. In the ongoing research we derive capacity utilisation classes (CUC), describing different levels of constraint, by indicating different time shares of near capacity utilization classes.

1. Introduction

It may be a not a straight forward task to quantitatively describe the capacity problem of a given airport, in particular if detailed traffic and delay data are scarce. The task becomes a formidable one if the objective is to describe the global capacity problem of airports worldwide. With capacity problem we mean not only the level of capacity utilization described by both the amount of traffic in terms of aircraft movements and the capacity and the relationship of the demand (number of aircraft movements) and capacity, but also the negative effects of a near capacity utilisation on the performance of the airport. The main effects are certainly the growing complexity of operations and increasing delays of flights when traffic approaches the capacity.

For both tasks questions like how to define and describe airport capacity, how to measure aircraft delays and how to identify capacity influencing factors and to improve the capacity situation arise. For a given airport these methodological and data problems may be solved, for a global analysis there is a high probability that this task is bound to fail. The main reason is that comparable delay data of flights in relation to the degree of capacity utilization are missing for all airports in the global network which may have to struggle with capacity problems. Never the less, our research has a global dimension. The wider objective is to describe the level of capacity constraint in the global airport network; in this study we pursue a methodological objective, the measurement of airport constraint.

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 2 400 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. The main result of that study was that in 2008 only very few airports had been identified as capacity critical airports, and that the vast majority of airports had rather small traffic volumes and no capacity problems. However, when we looked at the largest 100 airports, which handled about 50 % of the global traffic, we found that these important nodes of the network handled the traffic under conditions of high capacity utilization and had in many instances no significant capacity reserve.

In a more recent study (Berster et al. 2015) a first attempt was made to classify capacity constrained airports by the degree of constraint. About 80 airports out of the total number of 3 950 airports worldwide were identified with capacity problems in peak hours or over longer time spans in 2014. The classification approach was based on the ratio of the actual annual traffic volume and a maximum annual service volume, the higher the ratio the more congested is the airport. The annual service volume was derived from the product of a maximum average hourly volume, derived from the 5 % peak hour volume (equivalent to a measure of practical capacity) at a maximum capacity utilization index of 85 %, and the number of operating hours per year.

The approach of relating the actual traffic volume to the maximum annual service volume identifies certainly capacity constrained airports and differentiates between airports with varying degree of capacity constraints, however, gives no information of the time duration, in which the airports operates in constrained conditions. Since delay data were not available and as such not subject of the analysis, also no information could be given on the delay associated with the intensity of constraints. As was mentioned, uniform delay data are still missing on the global scale, so that statements on the degree of constraints based on delay characteristics, which are comparable among airports cannot be made for the time being.

In this study we pursue an approach which describes the intensity of capacity constraint in relation to the relative amount of time, in which aircraft movements at an airport are handled under near capacity conditions. We think that besides the delay statistic the time statistic is a well suited indicator of the constraint problem. The research task is then to determine for airports, which have been identified as airports with capacity problems, the practical capacity and to estimate the number of hours, in which they operate in capacity like or near capacity conditions. The methodological tool to quantify these indicators consists of traffic ranking functions, which have been developed for global airport capacity studies (see e. g. Gelhausen et al, 2013.

2. What do we mean by practical capacity and how do we estimate the capacity?

Basically, we can distinguish between two concepts of capacity, the one aiming at a measure of the maximum number of aircraft being served on a runway without any regard to the level of service, that is a measure of aircraft delays in the take-off or landing phase, and the other reflecting a specified level of service. The first concept mirrors a so called theoretical or ultimate or saturation capacity which indicates the maximum number of aircraft movements within one hour regardless of the delay single aircraft may encounter when they are ready for take-off or landing in conditions of continuous demand. As demand approaches ultimate capacity, delays to aircraft are likely to reach intolerably high levels.

To account for the delay problem the second concept of practical or sustained capacity has found wide application. Movement rates are determined in relation to average delay levels (FAA, 1969). A practical capacity was devised primarily for planning purposes, whereby a tolerable average delay per aircraft movement was the criterion for setting the capacity as a limit to the number of movements per hour for the runway system under day-to-day operating conditions. In contrast to the concept of saturation capacity, the concept of practical or sustained capacity incorporates therefore the quantitative measure (e. g. aircraft movements per hour) with a qualitative criterion, i. e. the average delay of aircraft movements. As has been mentioned comparable delay data of flights at constrained airports worldwide are not yet available, so that we have decided to use a measure of practical capacity in form of the 5 % peak hour volume and relate the traffic in near-capacity conditions with the time duration in order to define a measure of constraint intensity.

When we speak of airport capacity we often mean the runway capacity because the runway system is in many instances the critical component of the airport which determines the overall capacity. Since the airport is a multi-functional entity with many service and infrastructure elements of which each one has its own capacity, airport capacity in a true sense means the component capacity with the lowest partial capacity of all elements.

Since the runway system is crucial for the capability of the airport to handle current and future traffic the throughput of this airport component is of fundamental importance in airport planning. A great amount of research has been devoted to the subject of estimating runway capacity, especially in the US. The FAA has initiated and carried out many capacity related studies, and issued Advisory Circulars on this subject. Three prominent examples of textbooks describing methodological approaches to estimating runway capacity are “Airport

Systems – Planning, Design, and Management" by de Neufville and Odoni (2013), "Planning & Design of Airports" by Horonjeff et al. (2010) and "Airport Engineering – Planning, Design, and Development of 21st-Century Airports" by Ashford et al. (2011). In the global airport constraint analysis we concentrate on the approach which has been developed for and applied in similar studies by the authors (see e. g. Gelhausen et al, 2013). The method is based on traffic volume ranking curves of airports and on the 5 % peak hour volume as a proxy value of the practical capacity for airports operating in capacity-near conditions.

Ranking traffic by hour for all hours of the year allows identifying and determining the traffic in the 5 % peak hour. Airport planners often chose the so called 5 % peak hour as a base for designing facilities and capacity. Based on OAG data (OAG, 2016), traffic volume ranking curves have been derived for all airports with an annual traffic volume of over 70 000 aircraft movements worldwide. 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 for instance in London Heathrow (see Fig. 1), then the highest volume values of the curve are indicative of the capacity of the airport, which in many cases is the capacity of the runway system.

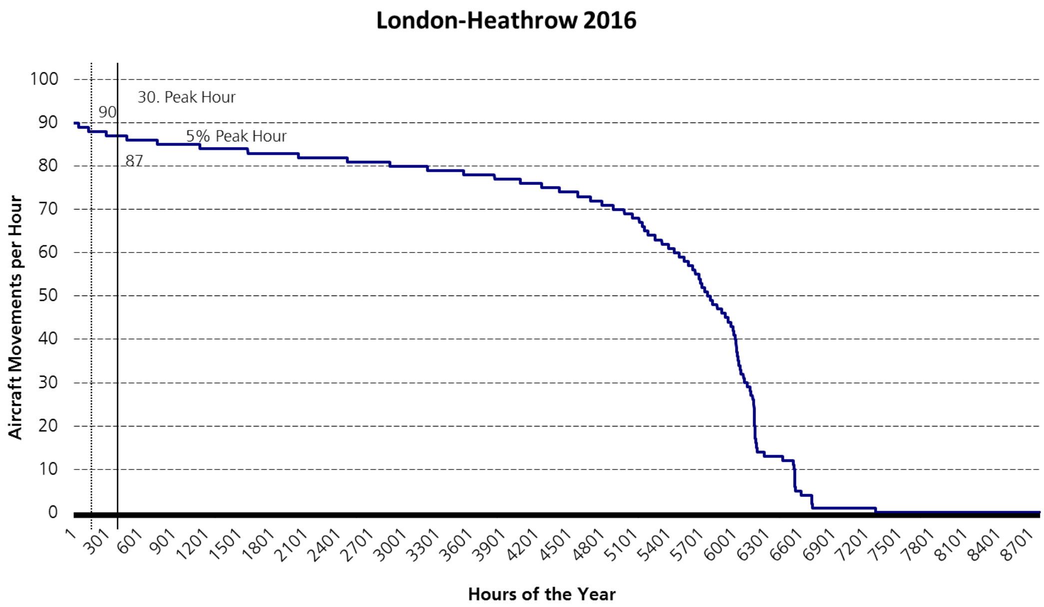

Fig. 1: Traffic Ranking by Hours of Operation of the Year 2016 at London-Heathrow Airport (Source: OAG, DLR)

The traffic ranking curve of London-Heathrow, a major hub airport operating at capacity limit since years, shows a typical belly like form of the traffic volume distribution during all operating hours of the year. The highest hourly volume of the year 2016 was 90 ATMs, and the 5 % peak hour volume was with 87 movements only 3 ATMs lower than the absolute highest volume. The declared capacity of London-Heathrow, which reflects the slot offer in the slot coordination process of airlines at congested airports in Europe and other parts of the world and is equal to the runway capacity, varies between 81 and 88 ATMs in off-peak and peak hours. The 5 % peak hour volume lies within the range of values of the declared capacity, in fact close to the upper limit. It has been found in many cases where airports operate under near capacity conditions that the 5 % peak hour volume is close to the declared capacity and may thus be used in a global comparative assessment of traffic conditions as a reliable indicator of the practical capacity (Wilken et al, 2011).

Traffic ranking curves are a versatile tool of estimating the practical capacity of airports on a global scale in a comparable way. In addition, they allow estimating the time duration within a year in which airports operate in near-capacity conditions.

3. How to identify constrained airports in the global airport network?

Since the method of how to identify constrained airports on a global scale has been described already in former papers of the ATRS world conference, we will for the convenience of the reader repeat here just the main features of the methodological approach (see e. g. Berster et al, 2013, and Gelhausen et al, 2013).

In a first step we have selected those airports with a threshold traffic volume of 70 000 air transport movements (ATMs) in 2016. We could have selected other threshold volumes as well. The decision to choose the volume of 70 000 ATMs was influenced by the fact that single runway airports with a volume in that order have a 5 % peak hour volume of around 20 ATMs which corresponds to about 50 % of the hourly capacity of a runway under IFR conditions. Airports with smaller volumes can be seen as airports of rather regional importance without any capacity problems in the near future. In 2016, there were 230 airports worldwide with traffic volumes exceeding 70 000 ATMs, handling about two thirds of the total flight volume.

In order to identify constrained airports in the sample of 230 airports we have applied an approach which follows a step wise procedure of eliminating airports with low traffic volumes – lower than defined threshold volumes by capacity class of the airport- , then with lower than defined 5 % peak hour volumes, followed with lower than defined capacity utilisation indices (CUI). Based on traffic volume ranking functions, we have calculated for each airport the 5 % peak hour volume and the average daytime hour volume of the year 2016. The ratio of these two volumes has been defined as the capacity utilisation index (CUI). Both the 5 % peak hour volume and the CUI are indicators of whether or not the airport is capacity constrained and if so, to what degree. A high traffic volume in the 5 % peak hour indicates congestion in peak times of the day, whereas a high value of the CUI indicates that congestion occurs also during normal traffic hours of the day. If the values of these indicators exceed certain threshold values – in the case of the 5 % peak hour volume depending on the capacity class of the airport (single runway, two parallel runways, etc.) - then the airport can be regarded as an airport with congestion problems over longer operating hours of the year, the duration depending on the value of the thresholds.

Airport congestion is not a clear cut phenomenon; the term encompasses the whole transition area between constrained flow conditions at some peak hours and at dense traffic conditions with high delays for each aircraft over longer periods of time. For the purpose of differentiating airports with and without capacity problems in this analysis we have defined as threshold values a capacity utilisation of around 85 % in the 5 % peak hour and in addition a CUI of 65 %. In the case of a single runway airport this means that the airport is regarded as constrained if the 5 % peak hour volume exceeds 35 ATMs and the normal day hour utilisation exceeds 65 % of the 5 % peak hour volume, assuming that the 5 % peak hour volume of 35 and more ATMs reflects a near capacity volume.

If the second step analysis – high annual and 5 % peak hour volumes - 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 such an airport may be categorised as non-capacity critical. One could decide otherwise by assuming that an airport starts to be congested if the peak hour volumes cannot be handled without greater delays. An airport which reaches the thresholds of both the annual and hourly volume operates under near-capacity conditions in 5 % of all operating hours; assuming 17 operating hours per day this would mean over 300 hours per year, when aircraft movements have to be handled in delay prone capacity conditions. It could be justified to classify such an airport as congested and assign the airport into the lowest, least severe capacity utilisation class. Since delay data are missing in the global constraint analysis we concentrate in the analysis on the amount of time within a year in which the airport operates at high capacity utilisation. We want to define therefore capacity utilisation classes which describe the relative time with a near capacity peak hour traffic volume.

Given this research interest, we have used as an empirical base the traffic data of the 50 airports with the highest annual traffic volumes. In a second step we would extend the analysis to all constrained airports in order to describe the constraint situation of all airports worldwide. The 50 greatest airports have traffic volumes exceeding 270 000 ATMs in 2016; single runway airports do not belong to this group. In addition, we have selected 11 airports with traffic volumes smaller than 270 000 and higher than 165 000 ATMs which have either a single runway or two runways in operation. The analysis has identified 25 airports in the group of the biggest airports as being constrained (with traffic volumes and a CUI exceeding threshold values) and 6 constrained airports in the second group.

The constraint analysis has shown that the higher the traffic volume the more likely is the airport constrained. If we divide the 50 biggest airports in two groups, the first top 25 and the following 25 airports then we find 17 constrained airports in the first group and only 8 airports with capacity problems in the second group. Similarly we can state that as higher the CUI the higher is the time duration in which the airport operates in near-capacity conditions. This positive correlation is shown in Fig. 2 for the 50 top ranking airports worldwide. The CUI denotes the ratio between the average day time hourly traffic volume and the 5 % peak hour volume and the time share specifies the relative time of the year in which the hourly traffic volumes exceed 80 % of the 5 % peak hour volume. The almost linear function of the time share of high capacity utilization in relation to the CUI shows that in case of a lack of data describing the duration of constrained operational conditions the CUI is a strong indicator of the constraint intensity.

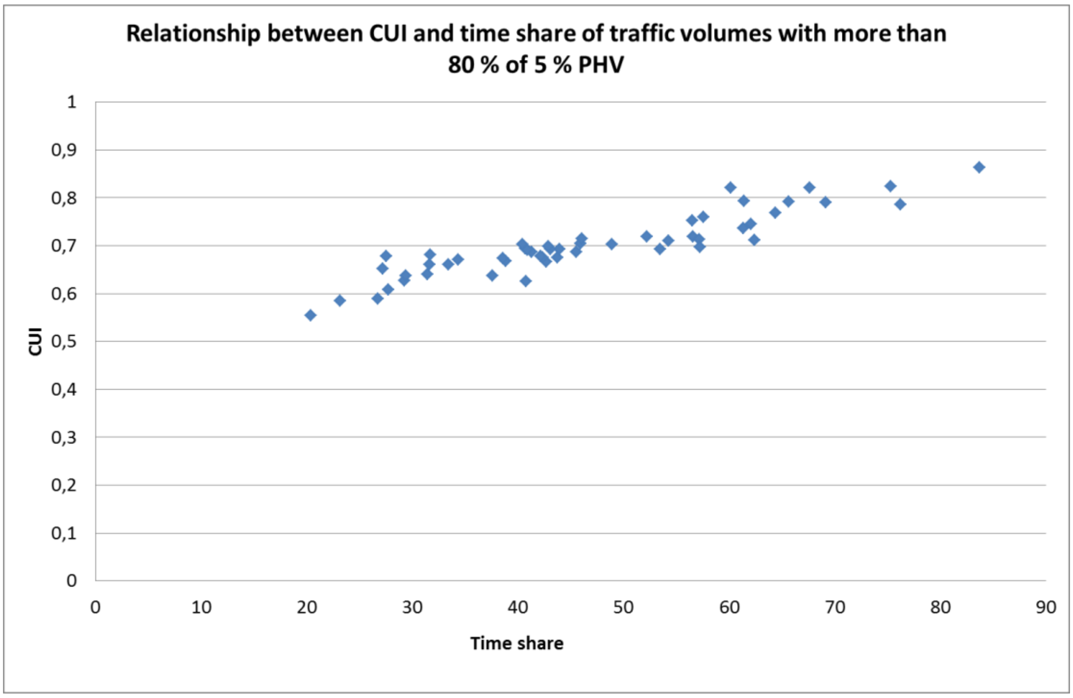

Fig. 2: Relationship between CUI and time share with traffic volumes greater than 80 % of 5 % peak hour volume at the 50 top ranking airports worldwide 2016
Source: OAG, DLR

4. Level of capacity utilization (Capacity utilization classes)

As has been stated traffic volume ranking functions are a useful tool for estimating practical capacity of airports in a comparable way and in addition, for analyzing the constraint situation at airports worldwide. Our research objective is to describe a measure for quantitatively assessing the amount of constraint at airports which have been identified beforehand by means of the criteria annual and peak hour volume and CUI as airports operating near the capacity limit.

Traffic ranking functions like the London-Heathrow one shown in Fig. 1 show the distribution of capacity utilisation within a given year. The function allows determining the number of hours when traffic volumes exceed certain threshold volumes. Such a threshold volume may be defined as a percentile of the practical capacity which can be assumed to be equal or close to the 5 % peak hour volume at capacity constrained airports. We can relate actual volumes to the 5 % peak hour volume and convert the absolute time duration as shown in Fig. 1 into a time share of the total annual operating time and visualize this relationship in a new form of the traffic volume ranking function as shown in Fig. 3 for London-Heathrow.

The traffic volume ranking function in Fig. 3 has the same shape as the one in Fig. 1, however, is not anymore related to the absolute values of the hourly traffic volume and the number of hours of the year, but to the relative traffic volume as a percentage of the 5 % peak hour volume and as a percentage of the total number of operating hours of the year. We are now in a position to read directly the relative time span of a year, in which the airport handles traffic volumes exceeding certain percentages of the practical capacity, for instance more than 80 % of the 5 % peak hour volume.

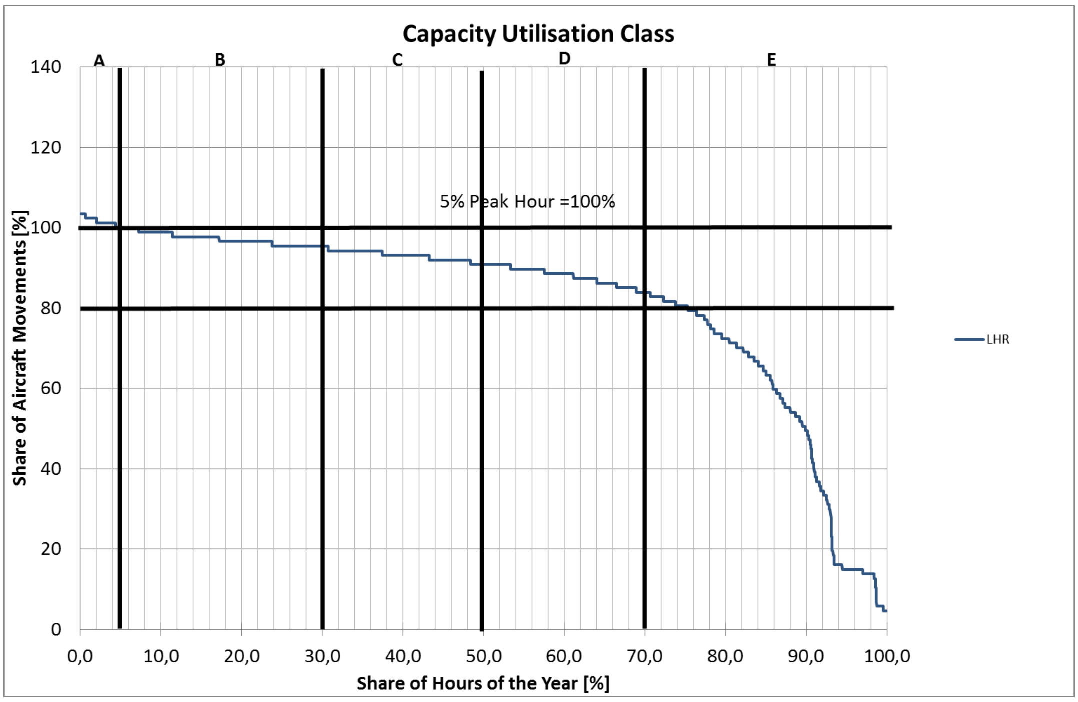

Fig. 3: Traffic Ranking by Hours of Operation (in relative terms) of the Year 2016 at London-Heathrow Airport (Source: OAG, DLR)

In searching for a measure of the constraint intensity we have to ask, at what traffic volume does the airport begin to experience flight delays that grow faster than the number of additional flights? Ideally one would derive this volume from an empirical relationship between flight delay and hourly volume as existed some decades ago and have been described in many sources (e. g. de Neufville and Odoni (2013), Horonjeff et al. (2010)). Lacking these data for today's traffic at high volume airports we have to assume a certain level of traffic in relation to the capacity. We have decided to draw the dividing line between free traffic flow conditions and those when first constraints and delays occur at the airborne or ground side of the runway, at 80 % of the 5 %peak hour volume. For a single runway airport the threshold volume would thus be around 28 aircraft movements per hour.

Further on we are interested to define capacity utilization classes which serve as indicator of the time duration in which the airport operates in near-capacity conditions. After examining the traffic ranking functions of the selected high volume airports we have grouped the airports into five classes, whereby all groups have as a lower volume limit the 80 % of the 5 % peak hour volume and otherwise differ in the relative amount of time when the lower limiting hourly volume is exceeded. The second class limit of groups is set to 5 %, 30 %, 50 % and 70 %, as can be seen in Fig. 3. The **five capacity utilization classes** are thus defined as:

- **Class A**: Airports with traffic volumes exceeding 80 % of the 5 %peak hour volume in less than 5 % of all operating hours of the year.

- **Class B**: Airports with traffic volumes exceeding 80 % of the 5 %peak hour volume in more than 5 % and in less than 30 % of all operating hours of the year.
- **Class C**: Airports with traffic volumes exceeding 80 % of the 5 %peak hour volume in more than 30 % and in less than 50 % of all operating hours of the year.
- **Class D**: Airports with traffic volumes exceeding 80 % of the 5 %peak hour volume in more than 50 % and in less than 70 % of all operating hours of the year.
- **Class E**: Airports with traffic volumes exceeding 80 % of the 5 %peak hour volume in more than 70 % of all operating hours of the year.

As can be seen in Fig. 3, London-Heathrow would be categorized as Class E airport with traffic volumes in about 75 % of all hours exceeding 80 % of the 5 % peak hour volume. The latter one serves in all these cases as a proxy of the practical or declared capacity. In lack of suited delay data we propose this constraint categorization in order to be able to quantitatively describe the degree of capacity constraints of airports worldwide.

In Fig. 4.1 to 4.4 the standardized traffic ranking functions of the constrained 25 biggest airports and the 6 selected smaller airports are shown. If one compares the curves in Fig. 4.1 and 4.3 one can see that the airports with the highest traffic volumes (in Fig. 4.1) are constrained over longer periods than those airports with lower traffic volumes (Fig. 4.3), the former ones thus belonging to a greater part to the higher capacity utilisation classes. The analysis of the constraint situation at the 25 plus 6 airports has led to the following classification:

- Class A airports: None of the selected ones, because only those airports have been analysed which have traffic volumes exceeding the 5 % peak hour volume in up to 5 % of all operating hours.
- Class B airports: DEN, SEA, MUC, MSP, SYD, LGW and ZRH, SAN, GVA, LCY of the second group.
- Class C airports: ATL, DFW, LAX, AMS, FRA, JFK, MEX, PHX, MAD, PHL and CPH, ORY of the second group.
- Class D airports: CLT, IST, HND, CGK, DXB, EWR, LGA.
- Class E airports: LHR and PEK.

Among the 50 biggest airports there are just two airports in the highest constraint class E, Beijing and London-Heathrow. The other constrained airports are fairly evenly distributed among the classes B, C, and D. 10 airports belong to class C with critically high traffic volumes in up to 50 % of all operating hours, 7 airports belong to class D and 6 airports to class B. The 6 selected airports with smaller traffic volumes are to greater part (4) class B airports, two are class C airports, and none belongs to the higher classes D and E. The other non-constrained airports of the 50 biggest airports belong either to class A or to no constraint class at all.

The fact that the constrained airports among the 50 biggest airports are distributed among the classes B to E shows the usefulness of the approach. It is a proof that congestion is not a black-white phenomenon but rather encompasses a wide range of different constraint intensities. The chosen capacity utilization classes help to differentiate between these different levels of constraint; they represent a quantitative measure of constraint intensity.

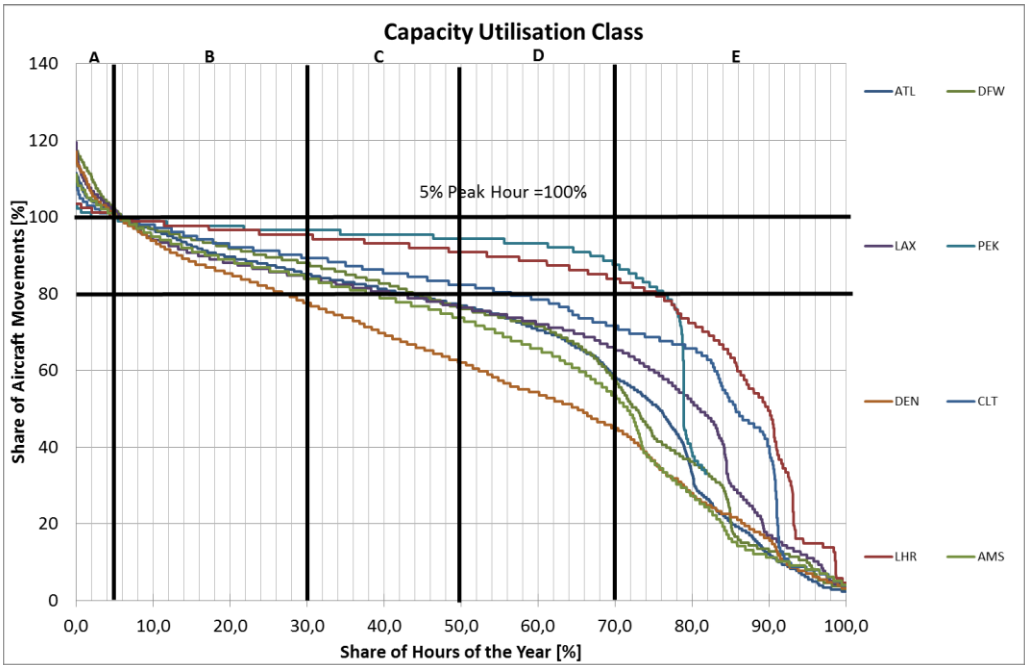

Fig. 4.1: Traffic Ranking by Hours of Operation (in relative terms) of the Year 2016
at the 50 top ranking constrained airports worldwide,
group 1: the 8 top ranking airports
(Source: OAG, DLR)

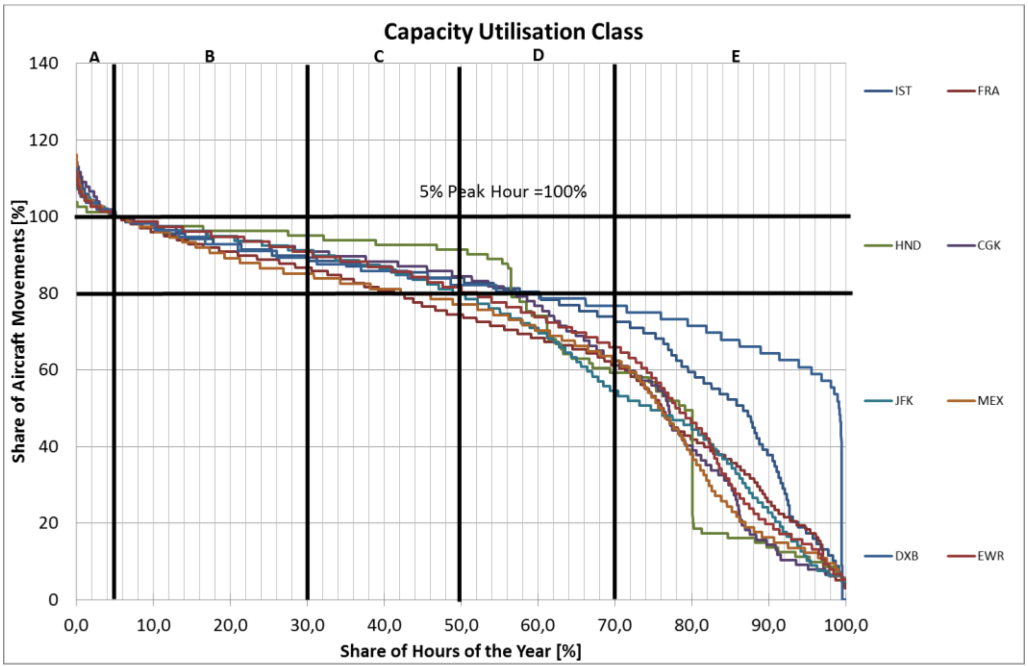

Fig. 4.2: Traffic Ranking by Hours of Operation (in relative terms) of the Year 2016
at the 50 top ranking constrained airports worldwide,
group 2: the 8 top ranking airports following the first group
(Source: OAG, DLR)

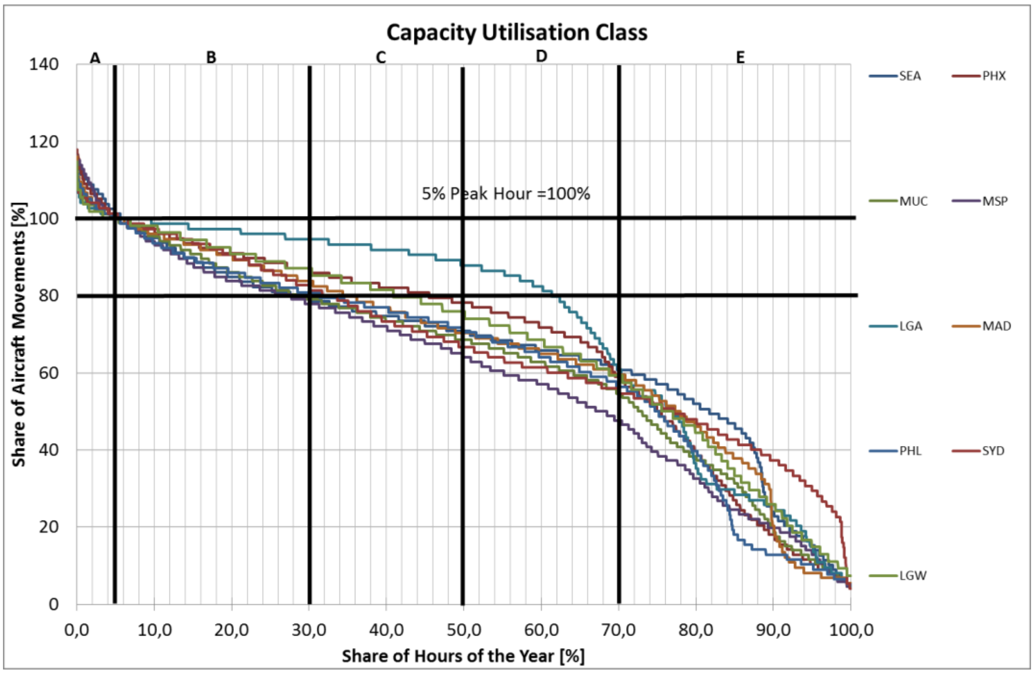

Fig. 4.3: Traffic Ranking by Hours of Operation (in relative terms) of the Year 2016 at the 50 top ranking constrained airports worldwide,
group 3: the 9 top ranking airports following the second group
(Source: OAG, DLR)

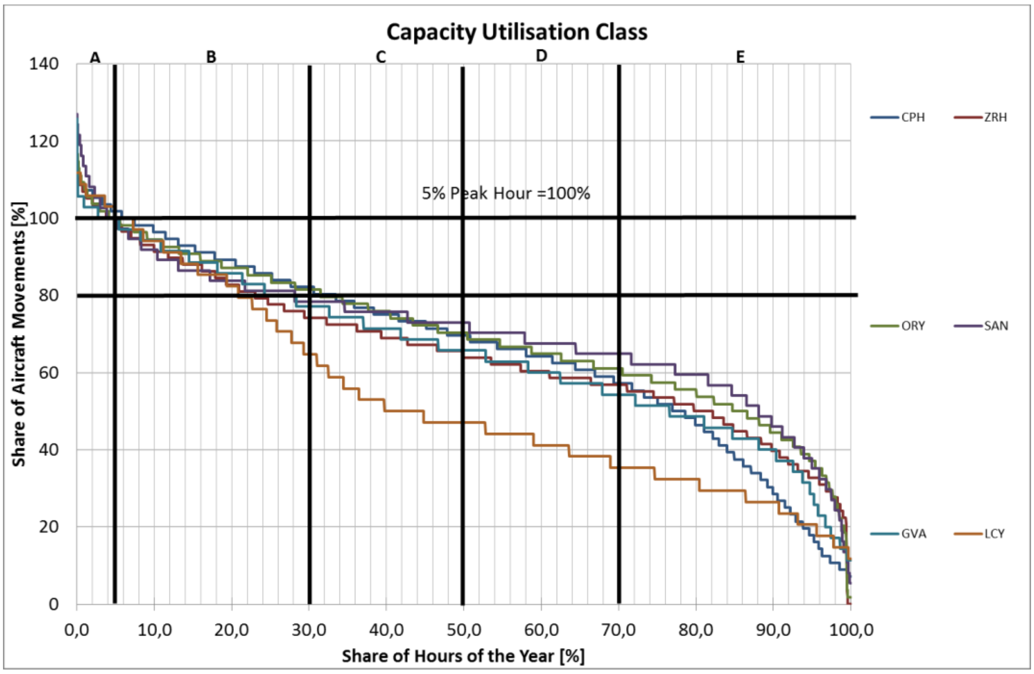

Fig. 4.4: Traffic Ranking by Hours of Operation (in relative terms) of the Year 2016 at 6 additional constrained airports worldwide,
(Source: OAG, DLR)

5. Concluding remarks and recommendations

The objective of the research has been to quantitatively describe different levels of capacity constraint of airports in the global network. Ideally, we would define capacity utilisation classes in relation to the average delay which aircraft encounter when traffic conditions deteriorate and approach capacity. Since comparable delay data of airports worldwide in relation different constraint situations are still missing we have pursued an approach which describes the constraint intensity in relation to the relative time duration in which an airport operates in near-capacity conditions. The methodological tool to quantify indicators of constraint like near-capacity volumes and the time span of near-capacity conditions are standardized traffic volume ranking functions. These functions have been developed for all major airports worldwide.

Five capacity utilization classes A to E have been defined which group airports according to the relative duration of operations with near-capacity volumes. For instance, the group B contains all those airports with traffic volumes exceeding 80 % of the 5 %peak hour volume in more than 5 % and in less than 30 % of all operating hours of the year, and in group E there are those airports with traffic volumes exceeding 80 % of the 5 %peak hour volume in more than 70 % of all operating hours of the year. Among the 50 biggest airports there are just two airports in the highest constraint class E, Beijing and London-Heathrow. The other 23 constrained airports of the 50 airports are fairly evenly distributed among the classes B, C, and D.

The chosen categorization proves that congestion is not a black-white phenomenon but rather encompasses a wide range of different constraint intensities. The capacity utilization classes help to differentiate between these different levels of constraint; they represent a quantitative measure of constraint intensity. We would like to stress, however, that the volume – time dependent classes of capacity utilization are a first proposal of how to measure capacity constraint. The higher objective remains that such classes should be developed in relation to the delay which aircraft encounter in near-capacity operating conditions. The prerequisite for such an approach is the existence and availability of comparable delay data for airports worldwide.

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