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Options to mitigate negative effects of airport capacity constraints – A discussion of potential mitigation effects -

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ABSTRACT

Capacity problems do exist on an increasing number of airports, while air traffic demand continues to grow. Questions of how to mitigate these problems become more important in airport planning and operations. However, they are typically dealt with for each airport separately, due to the diversity of applicable options. This paper undertakes to categorize measures of mitigation to draw generally valid conclusions.

While the spectrum of applicable mitigation measures varies from airport to airport, due to different local, regional and state wide framework conditions, the objective of this research is to generalize such measures for a global perspective and analyse their potential effects on mitigating capacity constraints. The first part of the paper describes the attempt of a typology of mitigation measures, which is not necessarily all-comprising, however, concentrating on applicable and relevant options, such as investment and non-investment options and further on direct and indirect measures and on organizational, regulatory and pricing options. The second part analyses the potential capacity enhancement and /or traffic flow optimizing effects of measures identified. Concluding remarks discuss problems of realizing mitigation measures. The analysis has shown that direct investments measures, i. e. into new runways, yield the highest effects of capacity increase. They are, however, the most difficult measures to realize, at least in most Western states. Increasing seat capacity of flights has been a widely applied measure of airlines in capacity constrained situations, with good results in increasing passenger volumes. It seems that the potential effects of the other measures discussed are less pronounced.

1. Introduction

Global air traffic is very concentrated on a relatively small number of important airports the majority of which are facing capacity problems at present or in the near future (Gelhausen et al, 2013). Global air traffic is expected to continue to grow in the long run, however, with a pace that differs greatly between Asia and the Middle East on the one hand, and Europe and North America on the other. While in Asia the demand has only begun to grow during the last few decades, and is growing rapidly, demand in North America is more mature at a high level of propensity to fly, and demand development shows signs of saturation with a relatively low growth tendency compared to other markets. Demand in Europe will still be growing, however, with decreasing growth rates.

These differing traffic growth expectations imply that future capacity problems will be less severe at major airports in North American than at Asian airports such as Delhi, Jakarta, Mumbai and others. Due to further demand growth on the one hand and political difficulties with the population living in the vicinity of airports and opposing the development of new airport capacity on the other, problems of overcoming airport constraints will mostly likely aggravate in the future, primarily in Europe.

2. Overview: Typology of mitigation measures

Solutions to the capacity problem will vary from airport to airport and from region to region, depending on the severity and type of the capacity bottleneck, the financial situation of the airport owner and region or state and the regulatory framework governing in the region or state of the airport. A whole range of technological, investment and non-investment options does theoretically exist, furthermore, a spectrum of demand and supply management measures may be applied, ranging from pure administrative measures, i.e. regulations, over hybrid measures, like slot coordination with secondary slot trading, to market based options, like congestion pricing schemes and primary slot trading. Management measures in particular are thereby not aiming first of all at increasing the capacity but rather at optimising traffic flows or increasing traffic volumes within given capacities, thus improving the utilisation of the existing infrastructure.

In Table 1 a typology of options for mitigating negative effects of airport capacity constraints is shown. With this typology we do not pretend to propose an all-comprising structure of potential measures but rather state and describe relevant options which are applied or may be practical candidates for future application. Some of the options listed have not yet been commonly applied, like congestion pricing of aircraft movements since landing fees are regulated in many countries on grounds of non-discrimination of airport users and preventing the abuse of market power of airports operators.

Broadly we can distinguish investment and non-investment options, which may be subdivided again into options of investing directly into airport infrastructure like runways in particular and indirectly into airport related infrastructure like rail terminals at airports, connecting thus the air side with the regional and/or the intercity rail system. Connecting the airport with the regional train network would change the modal split of passengers from their true journey origin to the airport and from the airport to the final destination, while a direct access to intercity trains would both enlarge the catchment area of airports and reduce the demand for short distance flights.

Mitigation measures

infrastructure investment options		non-investment options		
direct investment	indirect investment	organisational options	regulatory options	pricing options
- additional airport infrastructure: - runways - taxiways - ramps - terminals - ATC infrastructure - etc	- additional airport related infrastructure, i.e. rail terminal - high speed rail system	- stronger use of off-peak times - diversion to less congested airports - use of bigger aircraft - raising of load factors	- IATA slot coordination - exclusion of traffic segments - perimeter rule	- congestion pricing - differential pricing of congested and non-congested airports - primary and secondary slot trading
		- changing ATC-rules i.e. reduction of separation minima in take-off and landing procedures		

Tab. 1: Options to mitigate negative effects of airport capacity constraints

Typically, for airports with up to two or three runways, the option of directly investing into runway systems would clearly bring the greatest capacity gains of all options, in some regions of the world, however, such as in the London area, no enlargement of airport capacity has been realised in the last decades, in spite of many political propositions, whereas other regions, such as China or the Middle East, have experienced rapid extensions of runway systems or the construction of new airports. In many other instances, in particular in Europe, new facilities, especially runways, have been added only with great delays, caused by strong opposition of the population living in the vicinity of airports. These delays have been in the order of up to 20 and more years, a time span in which air traffic may have doubled. In such situations public authorities, airport operators, airlines and Air Navigation Service Providers (ANSP) have to look for measures which optimise the throughput of facilities rather than increase the capacity, by applying in broad terms non-investment options, like operational, regulatory or pricing options.

Operational measures aim at better using the airport infrastructure available and affect the planning and operations of aircraft services at airports. Examples are diverting flight movements to off-peak times and/or to nearby airports with less congestion, the deployment of aircraft with higher seat capacity in order to increase the number of passengers without having to raise flight frequency, and raising load factors of flights.

Regulatory measures have been introduced by public authorities to optimise traffic flows in capacity constrained conditions or to allow or prioritise certain types of traffic like scheduled flights, and exclude others, like for instance general aviation at main airports. A famous example of air traffic regulation at constrained airports is the widely applied IATA slot coordination, by which flight requests of airlines are allocated to slots (points in time for a complete take-off or landing procedure) following administrative priority rules, in particular the so called "grandfather right" (IATA, 2018). Another example is the perimeter rule, applied at some airports, which excludes certain traffic segments like international flights, with the aim to direct traffic segments to certain airports.

The IATA slot coordination deals as a regulatory measure with capacity scarcity without applying market based measures, although slots at constrained airports have a high market value and are traded, wherever allowed, at high prices among airlines, after they have been allocated in the first place ("secondary slot trading"). Pricing options are in contrast aiming at optimising and maximising traffic flows by allowing airlines to trade with slots and airport operators to charge for aircraft operations different prices depending on the degree of constraint. Primary slot trading (without any preceding slot coordination regulation) and congestion pricing are, however, still theoretical options and not yet applied in air transportation.

Airports charge airlines with weight- and passenger-related landing fees per flight; since these fees have to be cost-related and adopted by government agencies in many countries, especially in Europe, airports often have no means to raise fees in relation to capacity scarcity. In any case, regulatory and pricing options are not measures directly increasing airport capacity but rather optimise traffic flows in constrained situations, however, with one exception, and that are possibly future regulations in air traffic control permitting reduced separation minima of aircraft in the take-off and landing procedure. Such regulations would rely on technological progress of surveying aircraft more accurately in the controlled airspace, e .g. by satellite navigation. Since new ATC rules of shorter separation minima do not yet exist and are not foreseen to be introduced in the near future the existing rules are supposed to stay on for some time and will as such influence traffic flow capacity in the same way as in the past.

3. Investment options: New runways

In an environment of continued air traffic growth, airport operators have an inherent interest in meeting the demand by providing sufficient capacity of all functional elements of the airport. While capacity enlargements of ground side facilities, terminals and airside facilities like ramps, aprons, and buildings and areas for servicing aircraft belong more or less to the normal business of managing airports, adding new runways is on the other hand a rare event which often requires lengthy planning procedures with a strong involvement of the public. Even if national politics may be favoring the provision of sufficient airport capacity, regional politics and the population living in the vicinity of airports are likely to oppose – in Western states more than in Asia - plans of increasing airport capacity since they fear more gaseous emissions and noise caused by the additional traffic, which a new runway would attract.

An investment into new runways brings normally the highest capacity gain, compared to all other options listed in Table 1. The costs of building a new runway are also much higher than those of the non-investment options; however, building a new rail terminal near the air terminal of an airport may easily exceed the costs of a new runway. Nevertheless, the long delays in realising a new runway, which typically accompany the expansion process of airports in Europe and other countries, are often not caused by a lack of financial means, but by political and public resistance to endorse the capacity enhancement. In addition to public investment, in particular in the USA, private investment has been available to mitigate the infrastructure gap at many airports around the world.

A predominant example of such a problem of delaying investments into airport infrastructure is the project of increasing the capacity of airports in the London area. Although London Heathrow airport has been operating at capacity limit since decades it was only in 2018 that the UK Government has come to a decision to back a third runway at that airport. The opening of the runway is foreseen for the year 2027; there is, however a likelihood that the population of the communities surrounding the airport and other interest groups will oppose the project and fight in courts against the realisation, with the result, that the runway might be opening at a later date. If built, the airport would increase the capacity by 260,000 aircraft movements (Airports Commission, 2015) per year, so that the traffic volume could reach a level of about 740,000 movements per year. The number of passengers could grow to 130 million from about 76 million in 2017. The hourly capacity gain of the new runway would thus be in the order of 40 to 50 aircraft movements, from a coordinated capacity of 80 to 90 movements in 2018.

The London Heathrow case may be not a typical example, however, long delays in realising new runway projects are common in Europe; they are in contrast rather short and thus of lesser importance in Asian countries, where a great number of new airports and airport extensions have been built in recent years. Based on official data sources of airport lay-out plans, like the digital aeronautical flight information files of the US Government (DAFIF, 2018), unofficial data like "ourairports" (http://ourairports.com/airports) and various internal data sources we have looked into the development of new runways worldwide and in major world regions in the years of 2008 to 2016 (see Table 2). Some of the original data of airports in world regions had to be complemented and corrected since the data sources have listed series of airports, in particular in Asia, without information regarding the number of runways.

All airports

Region	Number of aiports			Number of flights			Number of runways		
	2008	2016	Δ in %	2008	2016	Δ in %	2008	2016	Δ in %
Africa	359	388	8.1	905,039	1,206,038	33.3	448	479	6.9
Asia	749	921	23.0	5,677,855	10,149,228	78.8	832	1,024	23.1
Europe	677	685	1.2	7,771,604	8,234,691	6.0	922	931	1.0
Middle East	113	111	-1.8	694,164	1,239,500	78.6	152	144	-5.3
North America	971	1,018	4.8	11,480,093	10,181,932	-11.3	1,614	1,773	9.9
South America	522	530	1.5	2,664,643	3,312,908	24.3	598	606	1.3
Southwest Pacific	399	401	0.5	1,081,085	1,129,757	4.5	542	556	2.6
World	**3,790**	**4,054**	**7.0**	**30,274,483**	**35,454,054**	**17.1**	**5,108**	**5,513**	**7.9**

100 top ranking airports

Region	Number of aiports			Number of flights			Number of runways		
	2008	2016	Δ in %	2008	2016	Δ in %	2008	2016	Δ in %
Africa	1	1	0.0	100,183	104,098	3.9	2	2	0.0
Asia	18	29	61.1	2,147,244	4,497,591	109.5	32	59	84.4
Europe	31	26	-16.1	3,887,681	3,658,637	-5.9	80	71	-11.3
Middle East	1	4	300.0	113,283	514,973	354.6	2	8	300.0
North America	41	33	-19.5	7,189,299	6,179,896	-14.0	155	136	-12.3
South America	5	4	-20.0	489,677	550,290	12.4	10	8	-20.0
Southwest Pacific	3	3	0.0	320,781	372,995	16.3	7	7	0.0
World	**100**	**100**	**0.0**	**14,248,148**	**15,878,480**	**11.4**	**288**	**291**	**1.0**

other airports

Region	Number of aiports			Number of flights			Number of runways		
	2008	2016	Δ in %	2008	2016	Δ in %	2008	2016	Δ in %
Africa	358	387	8.1	804,856	1,101,940	36.9	446	477	7.0
Asia	731	892	22.0	3,530,611	5,651,637	60.1	800	965	20.6
Europe	646	659	2.0	3,883,923	4,576,054	17.8	842	860	2.1
Middle East	112	107	-4.5	580,881	724,527	24.7	150	136	-9.3
North America	930	985	5.9	4,290,794	4,002,036	-6.7	1,459	1,637	12.2
South America	517	526	1.7	2,174,966	2,762,618	27.0	588	598	1.7
Southwest Pacific	396	398	0.5	760,304	756,762	-0.5	535	549	2.6
World	**3,690**	**3,954**	**7.2**	**16,026,335**	**19,575,574**	**22.1**	**4,820**	**5,222**	**8.3**

Tab. 2: Runway extensions at airports of the global network 2008 – 2016
(OAG, Dafif, ourairports.com, 2008, 2016)

According to the data available the 4,054 airports of the global air traffic network, for which scheduled traffic data of the Official Airline Guide (OAG 2008 - 2016) exist, provide a capacity of around 5,515 runways in 2016, with the great majority of airports equipped with a single runway. The overall average number of runways per airports is just 1.36. Since 2008, when the global network counted 3790 airports, 264 airports have been added to the network until 2016. In the same time span, network capacity was enlarged by around 405 runways, either at new airports or as airport extensions, most of them in Asia (almost 190) and North America (almost 160). The data available reveal, that the number of runways in the Middle East has slightly decreased from 2008 to 2016 although traffic in that region has gone up by almost 80% and thus significantly more than the total traffic (17%). The reason is that some airports were listed in 2008, however, not anymore in 2016, when other airports entered the list instead. Europe, the Middle East, South America and Southwest Pacific are the world regions that have seen hardly any capacity growth in terms additional runways, quite in contrast to Asia and North America.

An interesting question is which category of airports has gained most of the new runway capacity. Have the major airports added more capacity than the secondary airports or did the latter ones and new airports add more runways? We have seen that traffic has been concentrated on a relatively small number of important airports while the great majority of airports handle rather small traffic volumes. In fact, in the year 2016 about 45% of the global air traffic was concentrated on the 100 top ranking airports, which represent just 2.5% of all airports (Gelhausen et al, 2019). We have therefore checked the runway extensions of the two groups of airports separately. The result is rather surprising insofar as the top 100 airports have increased their runway capacity only marginally by adding just three new runways whereas the other 3,954 smaller airports have extended the capacity by about 400 new runways, whereby this group includes new airports as well. It should be added that the top 100 airports in 2016 are not identical with those in 2008; some airports of the 2008 list, the traffic of which grew well below average, were not anymore among the top 100 airports in 2016, while others with a stronger traffic growth entered the 2016 list. The traffic concentration was such that each runway of the top 100 airports handled on average about 55,000 flights in 2016, whereas on the other 3,954 airports the equivalent traffic volume was less than 4,000 flights.

Comparing the traffic growth between the two airport groups, we see that traffic on the top 100 airports grew by 11% between 2008 and 2016, while the traffic on all other airports increased twice as much by 22%. One would perhaps assume that traffic grew similarly in the two groups. The reason for the relatively low growth at the major 100 airports is that a capacity shortage at a great part of these airports hindered them from offering free slots, so that they were unable to participate in the general air traffic growth. We have identified 30 of the top 100 airports, which are more or less severely capacity constrained. They handled a traffic volume of over 6.2 million flights, which represent nearly 40% of the traffic of the top 100 airports. In addition, there are more airports with capacity bottlenecks at peak times. We estimate therefore that on about 40 of the top 100 airports the traffic - making up nearly half of the total traffic at the top 100 airports - cannot be enhanced due to lack of capacity. For further accommodating traffic at these airports, additional runways would be needed. The small number of new runways added at the major 100 airports is indicative of the difficult circumstances at these airports to enlarge the capacity by means of new airside infrastructure.

4. Rerouting traffic to underutilized airports and/or using more off-peak times

The option to reroute traffic from constrained to non-constrained airports seems to be at first glance a relief measure easy to realise. A look at some important airports shows, however, that this measure has not been applied to a great deal. Major airports do often not only serve the traffic originating in the catchment area of these airports but are also used as points of transfer traffic, in particular by those air carriers which are concentrating operations there, like full service network carriers. The hubbing function of these airports inter-relates feeder services with other flights, especially long distance and intercontinental flights. Because of this interrelationship schedules of both types of flights are coordinated and airlines have no interest to negatively affect the arrival and departure structure by taking out flights as they would immediately lose market segments. Rerouting traffic from hub airports to secondary airports is therefore more a theoretical than a practiced measure.

In case, major airports with congestion problems serve primarily origin-destination traffic like of low-cost carriers, incoming and outgoing flights do not depend on each other, and some of them may be diverted to other airports nearby. Experience has shown, however, that in particular guest airlines are not willing to divert operations, since they want to serve as much as possible the demand from or into the catchment area of such airports. This may be less so with airports having a smaller catchment area, but then the probability that the airport serving this area is congested becomes less likely.

Even if rerouting of flights to less congested airports may be regarded as a solution to mitigating constraint problems the question is which institution would be in charge to ask airlines to reduce frequencies at congested airports and divert flights to other airports. Airlines could of course voluntarily renounce from serving an airport as planned, for instance in case of terminating flights on non-sustainable markets. Otherwise this would be a very unlikely event, since an abandonment of flights would be equal to discontinue serving lucrative markets. Anyway, there is no regulatory institution which could hinder airlines from continuing services if they have performed in the past according to prevailing regulations.

On the contrary, whenever the IATA type slot coordination is applied as an official procedure at congested airports, like for instance in Europe according to EU-Regulation 95/93 (EU, 2004) at Level 3 airports, then incumbent airlines have a “grandfather right” to plan the same number and type of services for the next season as are operated in the present season. A diversion to less congested airports would only be feasible in case of a coordinated airport system in a metropolitan area, where the slot coordinator might ask airlines applying for new services to offer them at a secondary airport. Those airlines would, however, have the choice to deny such requests. Most likely they would opt for another measure that is offering flights with more seats. Altogether, there have been in 2016 almost 200 Level 3 airports worldwide, which have been by definition of the IATA Worldwide Slot Guidelines congested, either in peak times or over longer time periods. A part of these airports are rather small airports with mainly touristic traffic in summer time, where typically the terminal capacity is insufficient for handling waiting and incoming passengers in some peak periods per week. The greater part, however, are major airports with often important hubbing functions, where demand over longer periods exceeds the capacity, i.e. runway capacity. With the exception of the US airports – the USA do not apply the IATA type slot coordination – all top ranking airports with capacity problems are slot coordinated.

We may conclude that the option to divert flights from congested to non-congested airports nearby may be seen as a “nolens-volens measure” which requires some kind of compulsory action from the regulatory side; it is typically not a voluntary airline option. Of similar nature is the temporal diversion of flights to off-peak periods at partly congested airports. Only in exceptional cases airlines have an interest to accept shifting flights from their originally scheduled time; especially at hub airports they need coordinated slots because of the interdependency of flight arrivals and departures.

At Level 3 airports, however, slot coordinators have most likely applied the measure of filling up off-peak periods with flights by allocating new slot requests for unavailable peak time slots at off-peak times. It may well be that some airlines did not accept the diverted slot offer and withdrew, however, looking at hourly traffic patterns at congested airports we can observe that formerly off-peak periods with capacity reserves have been filled with flights over time, when traffic demand was growing and airlines were in need for additional slots. We cannot prove whether slot coordinators shifted arrival or departure times of slot requests for peak times to off-peak times, however, since at Level 3 airports off-peak times were filled with additional flights, there is a strong indication that slot coordination has been responsible for the new flight schedules. We have selected two examples of traffic patterns at London Gatwick and Frankfurt airport in different years, to illustrate these schedule changes over time.

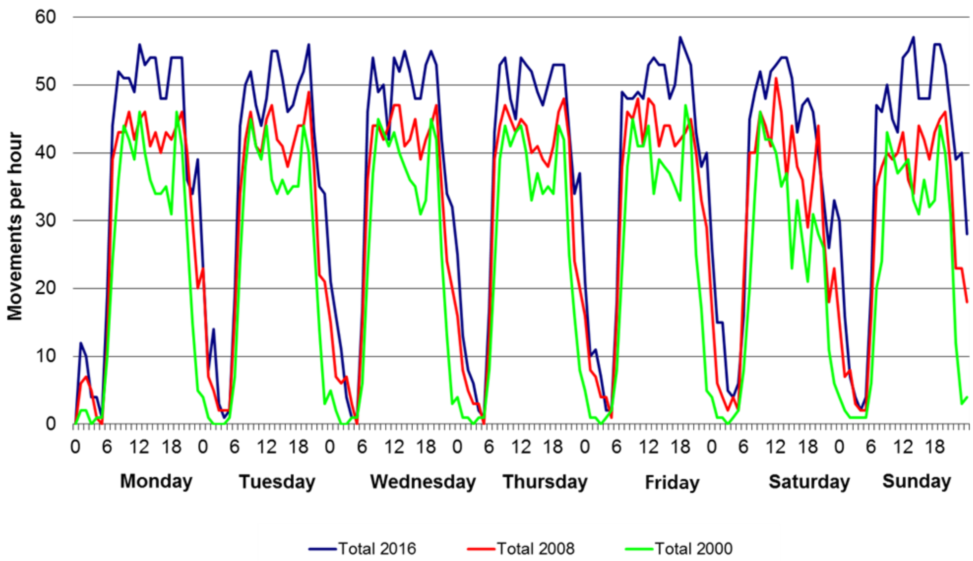

Fig. 1: Daily traffic pattern at London-Gatwick (LGW) airport during a peak week in 2000, 2008 and 2016 (OAG, 2000 - 2016)

Figure 1 shows the daily traffic distribution at London Gatwick (LGW) during a peak week of the years 2000, 2008 and 2016. The annual traffic volume has grown from 200,600 flight movements in 2000 to 233,300 in 2008 and further to 273,700 movements in 2016. The annual traffic growth is mirrored in the change of the daily traffic pattern from 2000 to 2016; while in 2000 the hourly traffic varied around 40 flight movements, with a longer off-peak period in the afternoon, hourly traffic increased to about 40 to 45 movements in 2008, again with a pronounced variation, and then further on to around 50 movements in 2016, with three peak times and traffic reaching values of 55 movements. Three off-peak times can be seen which are shorter and less pronounced than in former years; along with the traffic growth slots in off-peak periods have been used more and more. Since the demand for slots in London Gatwick has exceeded capacity of the single runway since years, the airport is slot coordinated; there are only a few airports worldwide that reach hourly volumes on one runway as high as 50 flight movements and more in slot coordinated conditions.

Frankfurt (FRA) airport is more than London Gatwick a major hub airport with a dominant home carrier (Lufthansa); due to the hubbing the daily traffic pattern shows typical peaks during the day when either feeder flights or intercontinental and other flights with corresponding passengers arrive and depart in banks in order to keep the transfer time as short as possible. FRA has been equipped with three runways in 2000 and 2008 and got an additional runway in 2011, which is used mainly for landings. Traffic grew from 423,400 flight movements in 2000 to 469,300 in 2008 and went down slightly to 454,600 movements in 2016.

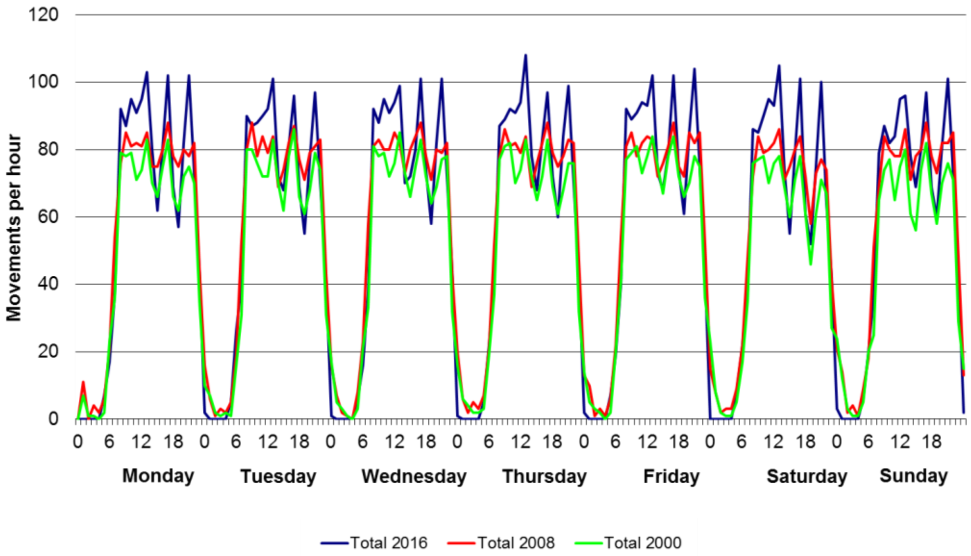

Fig. 2: Daily traffic pattern at Frankfurt (FRA) airport during a peak week in 2000, 2008 and 2016 (OAG, 2000 - 2016)

Figure 5.2 shows the development of hourly traffic distribution at FRA airport during a peak week from 2000 to 2008 and to 2016. The airport operated in 2008 more at the capacity limit than in 2000, and again less in 2016 when the declared capacity had gone up with the new runway from about 80 to 100 flight movements per hour, however, at a price of a strict night curfew. Thanks to the capacity increase the airport was able to build up a long peak in the morning and two additional peak periods in the afternoon. Whereas the peak traffic volumes could not go up further from 2000 to 2008, due to capacity limits, the off-peak periods were partly filled with additional flights resulting from traffic growth in that time span. In the following period to 2016 annual traffic slightly decreased, however, hourly traffic in peak times increased, whereas traffic in two off-peak times in the afternoon decreased sharply, thus allowing for a hub-based banking of flight arrivals and departures during the day.

5. Raising seat capacity and load factor per flight

If on the one hand the overall demand for air transport grows, but airport capacity is on the other hand not anymore available at congested airports we would assume that airlines offer flights with more seats in order to cope with the demand. Analysis of developments of frequencies and average seat capacity at congested and not yet congested airports has shown that the hypothesis of bigger aircraft in congested situations is valid in most instances, however, not at all airports. Using bigger aircraft and aircraft with higher seat density are measures that airlines use to varying degrees depending on factors like level of airport congestion, airline fleet, network structure, competition with other airlines, etc.

We would assume that airlines in liberalised markets wanting to serve a growing market increase their capacity by offering more seats on existing as well as new routes. At congested airports airlines would do so by deploying bigger aircraft and at uncongested airports by increasing first of all the number of flights. Capacity constraints would hinder airlines from increasing frequencies, whereas at airports with capacity surplus airlines would rather prefer to offer more flights in order to better comply with the needs of travelers, in particular business travelers. Our analysis of the development of average seat capacity of flights offered should then differentiate between more and less congested and uncongested airports respectively. We have therefore subdivided the total population of airports (4,054 in 2016) into the 100 top ranking and other airports, as has been done already in Section 3 for examining runway extensions of airports worldwide, and derived average values of seat capacity per flight, the number of passengers per flight and of the load factor per flight for the years 2008 to 2016 (see Table 3).

All airports

	Seats per flight			Pass per flight			Load factor		
Region	2008	2016	Δ in %	2008	2016	Δ in %	2008	2016	Δ in %
Africa	117	120	2.6	79	89	12.6	67	74	9.7
Asia	159	163	2.6	110	133	20.7	69	82	17.6
Europe	126	147	17.0	91	119	31.1	72	81	12.1
Middle East	167	192	15.3	122	138	13.1	73	72	-1.9
North America	94	109	16.4	67	89	32.8	72	82	14.1
South America	104	120	15.5	75	98	29.9	72	81	12.4
Southwest Pacific	105	124	17.4	79	97	23.9	75	79	5.5
World	**118**	**138**	**17.2**	**84**	**111**	**32.6**	**71**	**81**	**13.1**

100 top ranking airports

	Seats per flight			Pass per flight			Load factor		
Region	2008	2016	Δ in %	2008	2016	Δ in %	2008	2016	Δ in %
Africa	131	141	7.7	86	109	27.4	66	78	18.3
Asia	190	183	-3.6	133	149	12.4	70	81	16.6
Europe	140	164	17.2	100	133	32.8	71	81	13.3
Middle East	213	231	8.4	161	177	10.2	75	77	1.6
North America	109	126	15.4	79	105	32.2	73	83	14.6
South America	119	146	22.2	86	118	37.0	72	81	12.2
Southwest Pacific	156	169	8.1	120	133	10.4	77	79	2.2
World	**132**	**156**	**18.2**	**95**	**127**	**34.2**	**72**	**82**	**13.6**

other airports

	Seats per flight			Pass per flight			Load factor		
Region	2008	2016	Δ in %	2008	2016	Δ in %	2008	2016	Δ in %
Africa	116	118	2.4	78	87	11.3	68	74	8.7
Asia	139	146	4.9	96	119	24.4	69	82	18.5
Europe	112	134	19.7	81	108	32.5	73	81	10.7
Middle East	158	165	4.4	115	111	-3.5	73	67	-7.5
North America	68	83	22.3	47	66	38.9	69	79	13.6
South America	100	115	14.4	73	94	28.7	72	81	12.5
Southwest Pacific	84	102	21.0	61	80	31.0	73	79	8.2
World	**105**	**123**	**17.4**	**74**	**98**	**32.3**	**71**	**80**	**12.7**

Tab. 3: Average numbers of seats and passengers per flight and load factors of global air traffic 2008 to 2016 (OAG, Sabre MI, 2008, 2016)

The values of seats and passengers per flight as shown in Table 3 are lower by a small margin than the true values, since the number of flights (see Table 2) includes in addition to passenger also cargo flights, which should be if possible excluded when the number of passengers and seats are related to the number of flights. Cargo flights, however, form only a fraction of a few percent of all flights, and the OAG data base does not even include all cargo flights, in particular not ad-hoc cargo flights, so that the calculated values are roughly correct, however, not exactly. Since we are more interested in the development of seat capacity and load factor, the lack of accuracy is of minor importance.

The average number of seats per flight has globally grown from 105 seats in 2000 to 118 seats in 2008 and continued to rise to 138 seats per flight in 2016, in 16 years by 33 seats or by 31% in relative terms. This development proves that airlines have deployed in general bigger aircraft into the market in order to satisfy the growing demand. As can be seen in Table 3 and Figure 3, this option has been chosen at the 100 major airports as well at all other airports. Average seat capacity at the 100 top ranking airports has risen from 132 in 2008 to 156 seats in 2016 and at all other airports from 105 to 123 seats per flight. At the 100 top ranking airports, of which about 40 airports have been more or less capacity constrained, flights offered in 2016 had thus 33 seats more than at all other airports. In terms of passenger throughput efficiency this means that at the major airports 127 passengers were transported per flight, whereas at the great number of all other airports 98 passengers and thus 29 passengers less were on average on board of a flight. Nevertheless, at both classes of airports, at the 100 top ranking airports with high traffic volumes and more or less severe capacity problems, and at all other airports with many of them without capacity constraints, the average number of seats per flight has increased by 20 seats or by 2.5 seats per year in eight years' time span. And there is no sign of saturation in this development as can be seen in Figure 3.

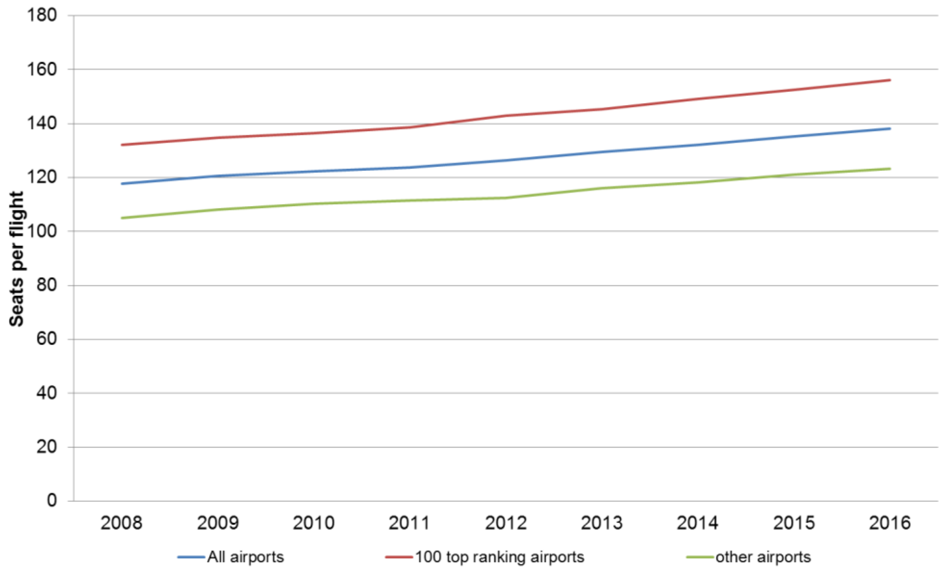

Fig. 3: Development of average seat capacity per flight in the global network of airports, of the 100 top ranking airports and of all other airports from 2008 to 2016 (OAG, 2008 - 2016)

As may be expected the absolute value of seat capacity and the development over time vary with the region and airport. The smallest aircraft in terms of seats per flight are operated in North America; in 2008 only 94 seats and 109 seats in 2016 have been offered, whereas in the Middle East flights with the highest seat capacity can be found, 167 seats in 2008 and 192 seats in 2016. If we look at the 8 airports in the Middle East belonging to the 100 top ranking airports then the average seat capacity rises to 231 seats, 75 seats more than on average on all 100 top ranking airports. The growth in seat capacity has been quite different in world regions as well. While on average the number of seats offered per flight has gone up by 17.2% from 2008 to 2016, Africa and Asia have experienced almost no growth. At the same time, the traffic in Asia has grown by almost 80%, much more than the total traffic, which has increased by just 17.1%.

Based on the linear growth of average seat capacity per flight over the period from 2008 to 2016 as shown in Figure 3, we could assume a continuation of this trend into the future. The overall development hides, however, the variation in regions and at individual airports. As there are some regions without growth of average seat capacity and other regions with stronger than average growth, there are airports where flights have been operated with rather constant aircraft size, while at most airports average seat capacity of flights has increased over time. A former study on the development of flight seat capacity (Berster et al, 2015) has shown that in almost 80% of constrained airports as well as of unconstrained airports airlines have increased seat capacity of flights. Other reasons than airport congestion played a decisive role for increasing average seat capacity at unconstrained airports.

If sustainable levels of load factor and frequency are achieved and demand continues to grow airlines have an economic interest to schedule aircraft with higher seat capacity at lower unit costs rather than to increase frequency, in constrained airport conditions even more than in unconstrained conditions. There has been a clear tendency of employing bigger aircraft types on longer routes. We have seen that average flight distances have gone up at both congested and uncongested airports. An increase in average flight distance may therefore be regarded as a factor describing the tendency of employing aircraft with higher seat capacity at lower unit cost. Other factors may cause airlines to schedule otherwise, depending for instance on local conditions, aircraft availability and airspace and airline regulation.

Table 3 shows a third passenger throughput efficiency indicator, average load factors. Increasing load factors to a possible maximum is a general objective of airlines' fleet, route and frequency planning, regardless of airport constraints. We have shown this efficiency indicator in connection with the two other indicators to demonstrate that the past development of load factors has lead already to values exceeding 80% on average at all airports worldwide and at the 100 top ranking airports and reaching 80% at all other airports (see Figure 4). We can see that average load factors are rather similar in the two groups of airports, that is the 100 top ranking airports and the many other airports with smaller traffic volumes. Figure 4 shows as well that the development of average network wide load factors follows a linear trend with no indication of approaching a saturation value. Because of the absolute limit of 100%, an extrapolation of the trend must, however, approach at some point of time saturation, which we would assume near values of around 90 to 95%.

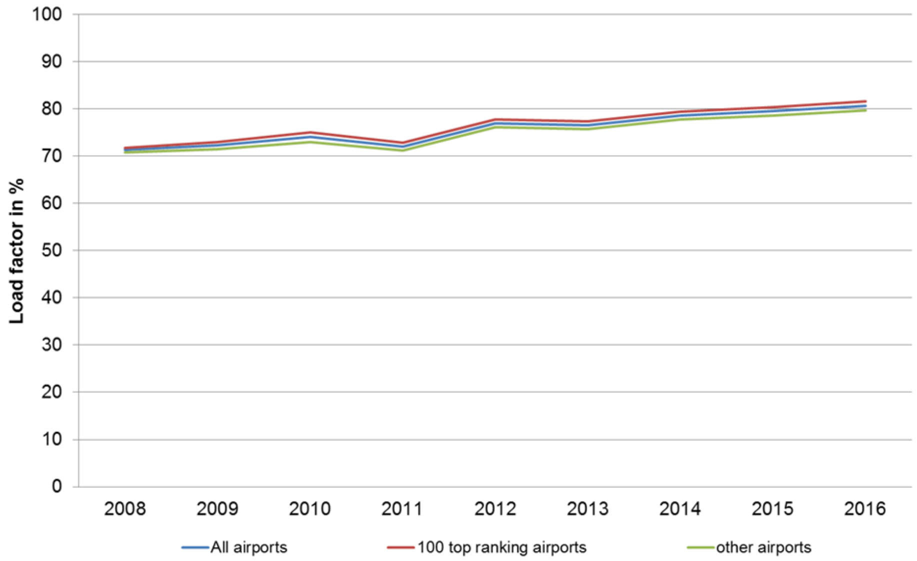

Fig. 4: Development of average load factors in the global network of airports, of the 100 top ranking airports and of all other airports from 2008 to 2016 (OAG, 2008 - 2016)

Low-cost carriers have been achieving average load factors of more than 80%, some airlines in peak months of almost 90%, thus reaching values which cannot be raised much higher, since load factors vary during days, weeks and seasons. If top load factors of 100% are reached in peak periods without denying too many passengers then average load factors can hardly exceed values of 90% to 95%. This means that the capacity reserve of free seats in flights has been exhausted to a great deal already; nevertheless, full service network carriers in particular have still some possibilities to raise load factors by some percentage points.

6. Case study: Development of mitigation measures at three example airports: San Diego (SAN), London Heathrow (LHR) and Beijing (PEK)

After having looked at the diverse optional measures of mitigating capacity constraints at airports on a global scale we concentrate in this section on three example airports, namely San Diego (SAN) in the USA, London Heathrow (LHR) in the United Kingdom and Beijing (PEK), the capital airport of China.

The three airports differ in runway capacity; SAN is a single runway airport with an hourly capacity varying between 48 aircraft movements in IFR conditions and 57 in optimum conditions. LHR has two independent parallel runways which are used for environmental reasons in a segregated mode, one runway for take-offs and the other for landings. Since LHR is slot coordinated, the declared capacity determines the maximum slot offer. In 2016 the declared capacity reached values of up to 88 movements in some peak hours; traffic demand has been using the slot offer to a full degree during most hours of the day. PEK airport is the only airport among the three which had a substantial capacity growth by means of a new runway, which has been added to the two existing runways in October of 2007. With three independent parallel runways PEK has a theoretical capacity about three times as high as

SAN and about 50 to 70 % higher than LHR. This capacity, however, cannot be used to the full degree, since limitations exist in using all three runways simultaneously and in the controlled airspace in the Beijing area so that the practical capacity – equal to the declared capacity – reaches values of up to 88 aircraft movements per hour according to the Air Traffic Management Bureau of Civil Aviation Administration of China (ATMB of CAAC). The capacity utilisation of the example airports can be seen in Figures 5, 6 and 7.

As has been described in Section 4, slot coordinators have applied the measure of diverting slot requests to off-peak periods and thus filling up these time spans with traffic at Level 3 airports. SAN airport does not belong to the slot coordinated airports, and as we can see in Figure 5, the traffic pattern at SAN airport is characterised by high peaks reaching with 45 aircraft movements near capacity levels, however, also by off-peak periods with lower traffic volumes following the peaks. The hourly traffic in the peak week has slightly increased from 2000 to 2016; however, the annual traffic has not grown during that 16 years period. A limiting movement cap, like a declared capacity would be, seems not to be reached yet in most operating hours, on the contrary, SAN has still a capacity reserve of up to ten aircraft movements per hour until the airport would reach the technical capacity of 58 movements in optimum conditions.

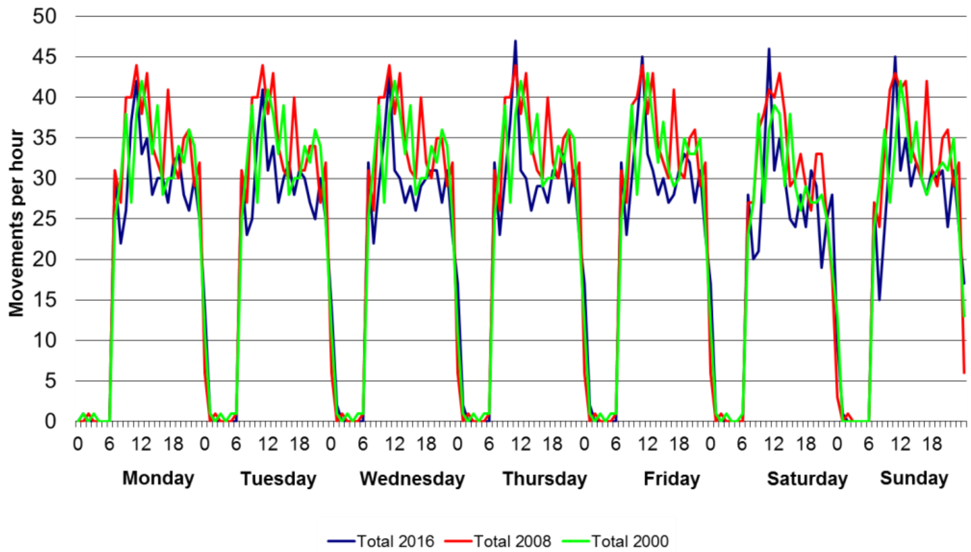

Fig. 5: Hourly traffic pattern at San Diego (SAN) airport during a peak week in 2000, 2008 and 2016 (OAG, 2000 - 2016)

Such a movement cap in form of a declared capacity exists since many years at LHR airport. Figure 6 shows the hourly traffic pattern of LHR during a peak week in 2000, 2008 and 2016; as can be seen, traffic volumes reach over many day time hours the limit of declared capacity of up to 88 movements. Traffic variation is much smaller than at SAN airport since the declared capacity has almost been fully used during the day, at least in 2008 and 2016. The off-peak periods which existed still in 2000 were filled up with new flights, some of which were certainly requested for nearby peak periods.

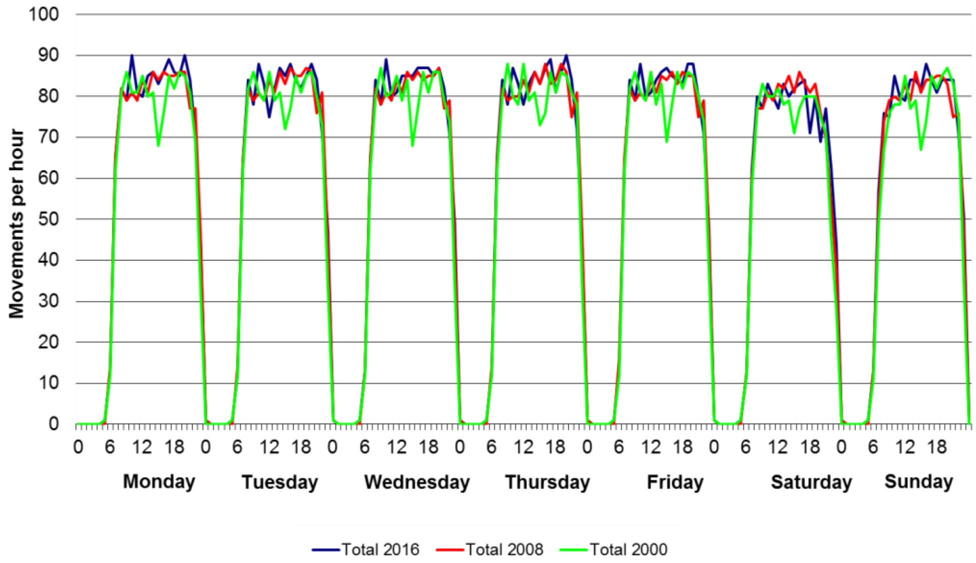

Fig. 6: Hourly traffic pattern at London-Heathrow (LHR) airport during a peak week in 2000, 2008 and 2016 (OAG, 2000 - 2016)

PEK airport has experienced a different development of traffic as is shown in Figure 7. Due to the strong traffic growth from less than 200,000 aircraft movements in 2000 to over 400,000 in 2008, hourly peak volumes during a peak week went up from around 40 movements to 80 movements. The new runway – opened in 2008 – allowed the peak hour traffic to double from 2000 to 2008, however, not so in the following period to 2016, when the annual traffic continued to grow to over 600,000 movements without any further capacity growth. Peak hour volumes increased slightly to almost 90 movements and hourly traffic variation decreased, an indication that off-peak periods were filled by slot coordination with additional flights in a similar way as was the case in LHR.

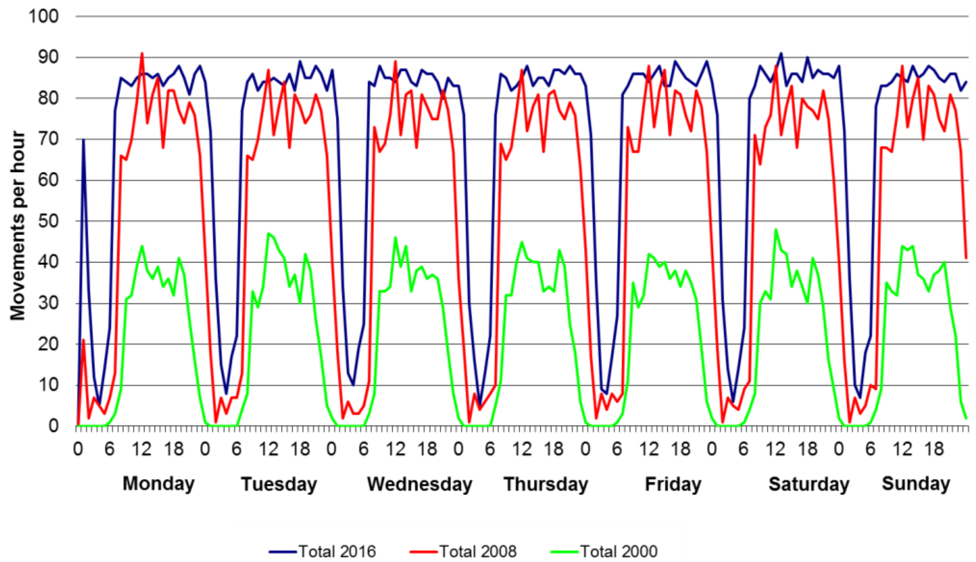

Fig. 7: Hourly traffic pattern at Beijing (PEK) airport during a peak week in 2000, 2008 and 2016 (OAG, 2000 - 2016)

The global analysis has shown that airlines use the option of deploying aircraft with more seats widely in order to cope with growing passenger numbers at both constrained and unconstrained airports. As we have seen there are next to the fact that at constrained airports the possibilities for increasing frequencies are limited or not anymore existing economic reasons for offering flights with higher seat capacities. The trend of increasing seat capacity has been linear over more than 15 years; we may assume therefore that with further demand growth airlines will continue to mitigate the negative effects of capacity constraints with bigger aircraft.

Here we will look at the developments at the example airports. As Figure 8 shows, seat capacity per flight has been rising more or less linearly from 2008 to 2016 at SAN and PEK airports, at SAN from 123 to 145 and at PEK from 183 to 195 seats per flight. LHR airport had already in 2008 an average seat capacity of 193 seats, which grew to 199 seats in 2012 and remained constant until 2016. It seems that at LHR a seat capacity of around 200 seats per flight forms an upper threshold, given the fleet composition at that airport. It might, however, well be that the further development will not stop there, and flights with more seats will be offered to and from LHR, depending on the demand growth and the duration of the status-quo of airport capacity.

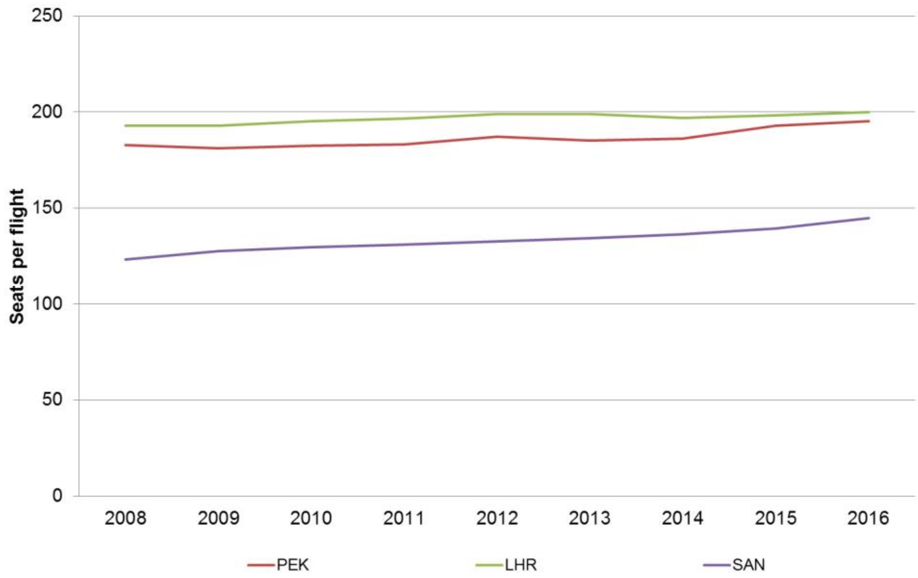

Fig. 8: Development of average seat capacity per flight at SAN, PEK and LHR airports from 2008 to 2016 (OAG, 2008 - 2016)

With a greater uncertainty regarding LHR we may conclude that also at the three example airports average seat capacity per flight will continue to rise; reaching saturation levels in the near future is rather unlikely if economics of flight operation and capacity constraints will also in future positively influence seat capacity. Load factors as a further measure of increasing passenger throughput without raising flight frequency have already reached rather high levels of more than 80% at all airports and major airports worldwide. This is true as well for PEK and SAN airport as can be seen in Figure 9. Average load factor of flights at LHR has also risen in the past and has reached a level of 80% in 2016, while SAN and PEK airports have surpassed the 80% already in the year 2012. As has been discussed earlier, these values may still increase in the future; however, there seems to be a natural limit at around 90 to 95%, depending on the type of market. Short haul business traveller routes for instance have a higher demand variation during a day than typical touristic routes, with the consequence that maximum average load factors may be lower in the first instance than in the second.

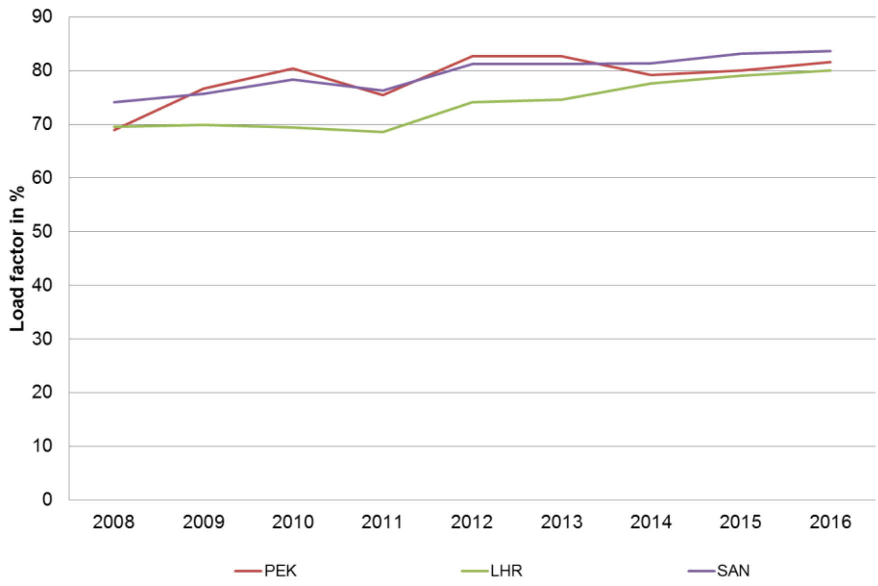

Fig. 9: Development of average load factor per flight at SAN, PEK and LHR airports from 2008 to 2016 (OAG, 2008 – 2016)

7. Conclusions

Solutions to specific capacity problems vary from airport to airport, depending on the actual situation and capacity constraint. In general we may distinguish between investment and non-investment measures, whereby the first category encompasses direct investment options like new runways or terminals, and indirect investments like new rail terminals near airports, and the latter group demand and supply management options, ranging from administrative or regulatory over hybrid to pure market based options. The typology of options to mitigate negative effects of airport capacity constraints as given in Table 1 includes a selection of measures which are practiced or may be candidates for future application. We have discussed in particular:

- Adding new runways as investment option
- Rerouting flights to less utilised airports nearby
- Diverting flights to off-peak hours
- Raising seat capacity of flights
- Raising load factors of flights

Enlarging airport capacity by means of a new runway or even by building a new airport is the most effective way of creating new capacity for additional flights. This measure is on the other side the most controversial one to realise since the neighbouring population and regional politics are often – at least in Western type states – opposing such projects on ground of environmental reasons. The most famous example of this kind is the long planning process of adding new runway capacity in the London area. After decades of proposing various capacity extensions a political decision has been reached in favour of a new runway at London Heathrow airport. Until the year 2018 this runway has not been realised.

We have seen that the global network of 4,054 airports in 2016 has been enlarged by about 400 runways since 2008, the majority of them, however, in the network of 3,954 secondary airports. The top 100 airports in terms of traffic volume have seen almost no runway capacity extension, although these airports handle about 45% of the total traffic, in many instances in severe capacity constraint circumstances. The fact that these airports were not in a position – with a few exceptions – to add capacity is indicative of the difficult transport political situation of airports in many states.

We have discussed the measure of rerouting flights to secondary airports nearby and concluded, that this option is not widely used, in particular not at hub airports because of the interrelationship of incoming and outgoing flights. Operators of touristic services might choose such bypass routes, however, only as secondary choice.

Of similar nature is the temporal diversion of flights to off-peak periods at partly congested airports. Only in exceptional cases airlines have an interest to accept shifting flights from their originally scheduled time. This measure has been applied by slot coordinators at Level 3 airports when airlines requested slots at peak times, these slots, however, were not available, because incumbents held them and slot coordinators proposed alternative slots at off-peak times. The filling-up option will be used in future as well whenever slot coordinated airports have still off-peak periods with free slots for new entrant and incumbent airlines.

In contrast to the flight rerouting and diverting options, raising seat capacity per flight has been the most effective measure among the non-investment options to keep pace with growing bottlenecks at airports. The average number of seats per flight has globally grown from 105 seats in 2000 to 138 seats per flight in 2016, in 16 years by 33 seats or by 31% in relative terms. This option has been chosen at the 100 major airports as well at all other airports. At the 100 top ranking airports, of which about 40 airports have been more or less capacity constrained, flights offered in 2016 had 33 seats more than at all other airports. In terms of passenger throughput efficiency this means that at the major airports 127 passengers were transported per flight, whereas at the great number of all other airports 98 passengers and thus 29 passengers less were on average on board of a flight.

As can be seen in Figure 3, there is no sign of saturation in the growth development of the number of seats offered per flight. Besides the fact that a lack of available slots hinders airlines from increasing frequencies at congested airports, it is an economic interest which leads airlines to operate bigger aircraft with lower unit costs, both at constrained and unconstrained airports. Airlines have equally an economic interest to raise load factors of flights; in fact they have achieved already with average values of 80% and more rather high levels of passenger occupancy rates. Average load factors have risen in the past rather linearly without approximating a saturation level. Because of the absolute limit of 100%, however, they will approach in future saturation, which we assume to be in the order of 90 to 95%. This means that average load factors will still rise, however, not more than by 10 to 15%. Low-cost carriers will reach maximum levels probably earlier than full service network carriers, because the latter ones serve less homogeneous passenger markets with greater variation of daily traffic patterns.

The analysis of mitigation measures has shown that two measures – new runways as investment option and raising seat capacity per flight as operational option – have proven to be more effective than the other measures. In discussing future mitigation measures one should put emphasis on these options rather than on rerouting flights to less congested airports and diverting flights to off-periods at the same airport.

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