Continued traffic growth at predicted rates will soon see the industry run into increased problems relating to airspace and airport congestion. One of the biggest issues is airport congestion. More airports will also suffer from limitations in available slots in the future with continued growth.

The challenge that congestion poses to air traffic growth

Continual exponential traffic growth has been a factor that airline strategy and finance departments have always been able to rely on. Issues are emerging that could prevent or limit continued growth in the future. One is the industry's increasing carbon and CO2 emissions as traffic increases, and the other is airport and airspace congestion.

Growth-limiting issues

CO2 emissions will increase almost in proportion with traffic and passenger numbers, or at least with revenue passenger miles (RPMs) and fleet activity, unless an alternative fuel with a lower net carbon output is developed.

The industry's CO2 emissions reached 332 million tonnes in 2005; 1.3% of all human CO2 emissions. With exponential growth, the industry's emissions are projected to reach 2,700 million tonnes by 2050 without any change in the type of fuel used. The Paris Accord of 2015 agreed the long-term objective of reducing emissions to 50% of the industry's 2005 levels by 2050. The United Nations, however, recognises that commercial aviation will be one of the last industries to find a lower net carbon emission fuel solution. The long-term objective is for emissions to start declining from 2035, after reaching a peak. This will only happen if an alternative fuel comes available.

The second issue that will certainly inhibit continued growth is airspace and airport congestion. Flight delays are caused by multiple factors, but there is no doubt that delays to departures and arrivals, and en route, are steadily worsening, and increasing in length. These flight time delays have become so established that airlines have built them into their timetables and schedules for several decades on routes and city- or airport-pairs in the world's worst affected areas. The long-term effect of this has been to reduce aircraft utilisation and increase flight times beyond what would be optimally required to perform a mission of a particular length. Airlines are therefore required to operate more aircraft to maintain schedules and service a given level of demand.

Airport congestion has also become a bigger problem, and is adding to departure delays. This is caused by terminal space congestion, with larger passenger volumes passing through larger terminals, with the inevitable result that some arrive late at departure lounges and gates.

There is also the issue of runway and consequently aircraft movement capacity. While most of the world's major and smaller airports have implemented terminal expansion plans over the past 30 years, there has been a far smaller increase in the number of new and additional runways built to increase aircraft movement capacity. This increase in system capacity would partly alleviate departure and arrival delays, and will be increasingly needed over the next 20 years.

Another factor in increased airport congestion is the aircraft servicing ramp, aircraft terminal space, and number of aircraft stands or gates. While the number of airline routes and city-pairs has grown over the past 30-40 years, the main factor increasing the number of flights, and therefore the number of departure and arrival operations at airports, is airlines' strategy of increasing service frequencies to optimum levels.

Aircraft movements

The number of overall annual departures globally has continued to climb. In many cases average aircraft sizes have stayed more or less level over extended periods, while in some markets they have even temporarily declined. This is in parallel to increasing passenger volumes, so in many markets sustained passenger growth has been catered for by adding services rather than using increasingly larger types. This strategy has led to fleet growth, which accounts for an increasing portion or most of the available runway movement and airport terminal slots at many major airports. Some growth of service frequencies and air traffic movements (ATMs) is due to low-cost carriers (LCCs), which use a lot of secondary airports in some parts of the world. There has also been high growth rates in ATMs in regions and countries such as China and India *(see table, page 12)*.

The ATM capacity of a runway and each airport is the annual number of take-offs and landings. This is determined by the number of hours per day the airport can operate and the number of take-offs and landings each runway can have per hour. The latter depends on whether an airport uses a runway for both take-offs and landings, or uses separate runways for take-offs and landings.

An indication of a runway's maximum capacity is given by London Gatwick (LGW), which operates with a single runway. It has about 287,000 ATMs per year *(see table, page 12)*. This number has hardly changed since 2007, so LGW's runway capacity is saturated. This suggests an upper limit of ATMs for airports with a

ANNUAL AIR TRAFFIC MOVEMENTS AT GLOBAL MAJOR AIRPORTS

Airport	2017 Annual ATMs	Annual % growth 2007-2017
China		
Guangzhou	451,000	5.7%
Shanghai - Pudong	448,400	7.9%
Kunming	349,000	9.0%
Chengdu	334,800	7.3%
Xian	314,000	10.5%
Chongqing	283,600	11.0%
Shanghai - Sha	258,900	3.6%
Xiamen	181,844	8.8%
Wuhan	180,800	7.4%
Tianjian	158,100	15.0%
Asia Pacific		
Jakarta	447,400	6.0%
Singapore	356,900	5.7%
Hong Kong	356,600	3.8%
Bangkok	341,100	3.2%
Seoul - Incheon	325,000	6.3%
Manila	255,200	5.9%
Tokyo - Narita	223,500	3.1%
Taipei	220,400	7.0%
Jeju	167,300	6.0%
Fukuoka	167,200	9.5%
India		
New Delhi	420,300	7.3%
Mumbai	313,900	3.3%
Bangalore	179,300	4.9%
Madras	150,400	2.9%
Calcutta	144,800	6.6%
Hyderabad	143,100	5.9%
Europe		
Amsterdam	479,000	1.4%
London Heathrow	471,100	Zero
Paris - CDG	445,900	Minus
Frankfurt	443,600	Minus
Munich	380,100	Minus
Madrid	351,600	N/A
Rome FCO	293,700	Minus
Moscow - Sheremet.	289,200	5.9%
London Gatwick	286,000	Zero
Copenhagen	245,600	Zero
Middle East		
Dubai	395,500	7.0%
Doha	202,800	10.1%
Abu Dhabi	136.900	10.8%
North America		
Atlanta	871,700	Minus
Chicago O'Hare	832,400	Minus
Los Angeles	634,100	8.6%
Denver	551,000	Minus
Dallas Fort-Worth	544,300	Minus
Toronto	427,800	1.4%
Houston	421,300	Minus
San Francisco	421,300	2.5%
New York JFK	420,300	Zero
New York Newark	405,700	Zero
Latin America		
Mexico City	403,300	1.7%
Bogota	277,800	7.0%
Sao Paulo GRU	243,300	3.3%
Sao Paulo CGH	183,200	0.7%
Lima	170,900	7.9%
Santiago de Chile	145,700	7.2%

single runway.

Meanwhile, London Stansted and Luton are used as bases by the LCCs Ryanair and easyJet. These two airports had 185,000 and 136,000 ATMs per year in 2017.

Examination of the annual ATMs for the world's major airports over the 10 years from 2007 to 2017 reveals different trends depending on global region *(see table, page this page)*.

In most major North American airports the number of annual ATMs have declined by 5-12% over the period. This is mainly explained by the consolidation of airline networks over the period as airlines have merged. Most of these airports have 500-650 take-offs per day, while Atlanta and Chicago O'Hare have about 1,200 daily take-offs. Despite the decline in ATMs at major airports, they have risen at secondary and tertiary airports.

Intra-North American traffic volumes measured in RPMs or revenue passenger kilometres (RPKs) increased by about 34% from 2007 to 2017; an average rate of about 3% per year. This is reflected by data that shows passengers per ATM rose from 77 to 102 over the 10-year period; 32% increase.

In Europe there has been little change in ATMs at major airports such as Frankfurt, Madrid, London Heathrow (LHR), LGW and Munich *(see table, this page)*. This indicates that these airports were close to maximum ATM capacity in 2007. These have 520-650 take-offs per day.

LHR, with two runways, has one of the highest levels in Europe, at 471,000 ATMs in 2017; 46% more than LGW. Moreover, LHR is capped at 485,000 ATMs per year. This indicates the upper limit for an airport with two parallel runways. While the number of ATMs at LHR has changed little over 10 years, passenger numbers have increased by about 10 million to 78 million in 2017.

Paris CDG has seen a drop of about 13% in ATMs, while Amsterdam has seen an almost equal increase.

Other European airports, such as Brussels, Rome, Hamburg, Manchester and Paris Orly, have seen small declines in the number of annual ATMs.

The only major European airports with significant growth in ATMs are Dublin, St.Petersburg, Istanbul Sabiha Gocken, Istanbul Ataturk, and Moscow Sheremetyevo.

Similar to North America, passenger traffic grew by 55% from 2007 to 2017 in Europe, an average rate of 4.5% per year. Passengers per ATM increased from 93 to 126 over the period.

A different picture is seen in the Asia Pacific. ATMs at Beijing grew by 50%, and Guangzhou grew at a higher rate of 60% over the 10-year period. Average annual growth rates in ATMs in China have been as high as 15% in Tianjian, 11% at Chongqing, 10.5% at Xi'an, 9.7% at Nanchang, and 9.0% at Kunming *(see table, this page)*. This increased the number of ATMs to more than 400,000 per year at China's major airports. Overall, it is typical of route network and service frequency development in fast growing markets.

The rest of the Asia Pacific shows a mixed rate of development. The busiest airports are Jakarta at 447,000 ATMs per year, Singapore at 357,000, Hong Kong at 357,000, and Bangkok at 341,000 *(see table, this page)*. The highest rate in annual

SUMMARY OF CURRENT AND PROJECTED 20-YEAR CAPACITY STATISTICS

MARKET REGION	2017 NO. OF FLIGHTS ('000s)	2017 NO. OF SEATS (million)	2017 AVG NO. OF SEAT	2017 AVG KM	2017 TOTAL ASKs (billions)	20-year GROWTH FACTOR	2036 PROJECTED ASKS (millions)	No. of FLIGHTS 50% INCR ('000s)	AVG SEAT SIZE	No. of FLIGHTS 20% INCR ('000s)	AVG AVG SEAT SIZE
Intra-Europe	7,718	1,133	147	1,093	1,239	1.6	1,982	11,578	157	9,262	196
Intra-Asia	1,476	241	163	1,759	424	3.7	1,569	2,215	403	1,772	503
Intra-China	4,213	683	162	1,177	804	3.6	2,893	6,321	389	5,057	486
Intra-India	1,048	167	160	912	153	5.4	824	1,572	575	1,258	718
Intra-N.America	10,476	1,167	111	1,433	1,672	1.5	2,508	15,714	111	12,571	139
Sub-total	**24,933**	**3,392**	**136**	**1,265**	**4,291**	**2.3**	**9,776**	**37,400**	**207**	**29,920**	**258**
Transatlantic	404	112	276	6,879	768	1.8	1,383	606	332	485	414
Europe-Asia	497	112	226	6,197	695	1.7	1,161	746	251	597	314
Trans-Pacific	219	60	276	9,657	586	1.8	1,077	329	339	263	424
Middle East-Asia	504	124	245	4,278	528	3.4	1,797	757	555	605	694
Europe-Middle East	417	100	239	3,688	368	2.5	919	625	399	500	498
Sub-total	**2,042**	**508**	**249**	**5,800**	**2,945**	**2.1**	**6,336**	**3,063**	**357**	**2,450**	**446**
Other intra- & inter-continental markets	**7,025**	**1,062**	**151**	**1,850**	**1,964**	**2.2**	**4,387**	**10,537**	**225**	**8,430**	**281**
Industry total	**34,000**	**4,961**	**146**	**1,854**	**9,200**	**2.2**	**20,500**	**51,000**	**217**	**40,800**	**271**

growth of ATMs is at Denpasar, Surabaya, Fukuoka, Chiang Mai and Phuket. Many others have seen annual ATMs increase at averages of 4.0-6.5%. These have annual ATMs at 130,000-255,000. A further 10 years' growth at the same rate of increase will see more airports pass the 400,000 ATMs per year level.

ATMs at Tokyo Haneda, which has been increasingly used for international operations, grew by 33% over six years to about 414,000 by 2017. This compares to 223,000 ATMs per year at Tokyo Narita.

Statistics relating to Indian airports show that ATMs increased at some of the highest rates from 2007 to 2017. That is, for all Indian airports there was an increase from 1.3 million ATMs in 2007 to 2.32 million in 2017, an increase of 78%.

Annual rates of increase for domestic operations have been 13-16% in recent years, while international ATMs increased by as much as 9.4% in some years *(see table, page 12)*.

The high rates of growth at Indian airports is illustrated by the fact that New Delhi was rated 50 in the world by Airports Council International (ACI) in 2008, and by 2018 was ranked 12 at 420,000 ATMs. Similarly, Mumbai was ranked 47 in 2008, but had risen to 28 by 2018 at 314,000 ATMs. This clearly indicates the high growth in airline operations during this period.

The other busiest Indian airports had reached 50,000-180,000 ATMs by 2017/18. Annual growth rates have been 2.9-9.1% over the past decade. An average annual growth rate of 7.0% per year will see the number of movements double in a decade.

These ATM rates are reflected by the 2017 annual world air traffic report, which says that the number of aircraft movements increased by 2.7% in 2017, and similarly by 3.3% in 2018. In parallel, passenger numbers increased by 6.5% and 7.5% over the two years. These relative increases reflect that average passengers per ATM will have increased during the 10-year period in most markets.

With respect to runway development, some major airports are building new runways. While these projects can take up to 10 years to complete, and new runways can add up to 270,000 ATMs per year of capacity.

US airports with projects for new runways that will open in 2020 include Chicago O'Hare and Charlotte. Longer-term projects are Denver, which is adding four new runways, and Atlanta, New York JFK and Newark and Washington Dulles which are each adding one.

European airports that are each adding new runways include Dublin, London Heathrow, Munich and Oslo. These will be opened between 2021 and 2030.

While these projects will individually help these airports by relieving some of their congestion issues and helping to cater for traffic growth, they only represent a small percentage of the hundreds of airports around the world and in the five main intra- and inter-continental markets.

Future traffic growth

Air traffic volumes and passenger numbers have always more or less grown at a rate equal to a factor of 2.0 times the annual growth rate of gross domestic product (GDP) of a related market, whether domestic, intercontinental or intracontinental. This implies that passenger numbers will rise exponentially when there is economic growth.

This is illustrated by the industry's historic increase in passenger numbers. Starting from a small base of virtually zero in 1946, it took the industry 41 years to reach an annual volume of one billion enplaned passengers in 1987. It took 18 years for it to reach two billion enplaned passengers in 2005, just seven years for it to reach three billion annual passengers in 2012, and an even shorter period of another five years for it to reach four billion annual enplaned passengers in 2017. Thus the period for the industry's annual passenger volume to increase by another billion has steadily got shorter. This trend will continue with continued exponential traffic growth.

Recent world traffic forecasts indicate that this growth is expected to be sustained in-line with economic growth. A 20-year forecast indicates that annual enplaned passenger volumes will reach between 7.6 billion and 9.1 billion by 2036. That is equal to an increase of one billion annual passengers on average once every four years, although each successive increase of one billion passengers will be achieved in a progressively shorter timespan.

How this growth should be accommodated raises several questions, including how airline capacity will develop. At the simplest level, the options airlines have for absorbing larger passenger numbers include adding services, increasing aircraft size, or a combination of the two. There are other detailed issues to consider in this context, however, such as the fact that larger aircraft do not provide a proportionate increase in capacity. This is

London Heathrow operates with two parallel runways, and has its annual ATMs capped at 485,000. This is the highest level of ATM activity in the world for a dual-runway airport.

because larger types can increase congestion on the ground, and also due to wake turbulence can result in fewer ATMs at airports than smaller types. Large and ultra-large types can therefore often result in a less than a proportionate increase in capacity.

Airlines will prefer to optimise service frequencies on each route, before increasing aircraft size in many cases. Not only have service frequencies already reached optimum levels in the case of many routes, increased airspace and airport congestion is making it harder for airlines to raise service levels and frequencies.

Raising service levels on existing and new routes is affected by airspace and airport congestion. Clearly if congestion cannot be relieved, and it increasingly becomes a limiting factor, then aircraft size would have to rise at a faster rate.

The amount or level by which total capacity, and therefore service frequencies and aircraft size, has to be increased is also dictated by a third factor. Average passenger load factor has already increased over the past 20-25 years from the historic levels of 65-70% to a global average of 80.4% in 2017. Data from the International Air Transport Association (IATA) shows that the load factor for the industry overall increased from just under 80% in 2014 to almost 82% in 2018.

This increase has been made by airlines mainly for the purposes of revenue management, and partly due to increased competition imposed by LCCs resulting in diluted passenger yields. Load factors have therefore been increased to offset this effect, so airlines have had to accept passenger spill as a consequence.

A further increase in load factor will have to be accepted by airlines, partly due to environmental pressure to reduce the CO_2 emissions per passenger flown. It is unlikely, however, that load factors will increase by the same number of percentage points as already seen. They may increase to about 85%, but are unlikely to get beyond 90%.

Global capacity

The total capacity on individual routes, and for a market, is measured in available seat-miles (ASMs) or available seat-kilometres (ASKs); a measure of the product of total aircraft seats and distance flown on each route. The number of ASMs/ASKs provided will clearly only increase on a route if the number of seats provided increases, since route length will be unchanged. An increase in total seats provided is either through an increase in number of services, an increase in average aircraft size, or a combination of the two.

An increase in total ASK/ASM capacity for a group of routes, an airline's network or an entire market can indicate that average distance flown has increased, in addition to seats being added. This will be because longer routes have been opened or there has been a larger increase in the number of seats on the longer routes.

Analysis of capacity statistics, average aircraft size and total capacity for the world's major markets in 2017 shows the size of the industry. It is also a starting point for forecasting the amount of capacity that will be required in each market after 20 years of projected growth. This is summarised *(see table, page 14)*.

Capacity statistics for 2017 show a global total of 9.2 billion ASKs, 4.96 billion seats, about 34 million flights, and an average route length of 1,787 kilometres (km) *(see table, page 14)*.

The five main intracontinental markets are Europe, North America, the Asia Pacific, China and India. The total capacity for 2017 for these five was about 4.29 billion ASKs, 25 million flights, and 3.4 billion seats. Average aircraft size was therefore 136 seats *(see table, page 14)*. This is clearly in parallel with narrowbody aircraft dominating services in four of five of these markets.

The Asia Pacific and China also have a high portion of services being operated by widebodies, partly explaining larger average sizes of 160-163 seats.

Meanwhile, average aircraft size in Europe and North America is smaller at 147 and 111 seats, with some operations being performed by regional aircraft. The US has the largest regional fleet, with E-Jets and members of the CRJ family accounting for a high portion of major airline regional services.

The five main inter-continental markets are the Transatlantic, Europe-Asia, Transpacific, Middle East-Europe, and the Middle East-Asia Pacific. These had a total capacity of 2.95 billion ASKs, 2.04 million flights, and 508 million seats. Average aircraft size was thus 249 seats *(see table, page 14)*. This average aircraft size corresponds to the trend over the past 10-15 years of adopting members of the A330, A340, 787, and 777 families to provide most of the capacity on long-haul routes.

Other intra- and intercontinental markets around the world provided a further 7.02 million flights, 1.06 billion seats, and generated another 1,964 billion ASKs *(see table, page 14)*.

Projections for 20-year traffic and capacity growth show different rates of increase in overall ASK capacity for each market. These range from the smallest growth factor of 1.5 for the intra-North American market, up to 5.4 for the intra-Indian market. The total global capacity in 2036 is forecast to reach 20.5 billion ASKs *(see table, page 14)*, an overall growth factor of 2.3. This takes into consideration a small likely increase in average airline load factor.

Capacity growth options

The issue is how will this increase in capacity be provided? One broad assumption that can be made is that average route length around the world will

Airport terminal piers in close proximity result in crowded ramp areas. Aircraft have to be pushed back one at a time in many cases and so airlines have to build long total ground times (TGT) into their schedules for particular routes.

not increase, or will only increase by a small percentage. This is because while there may be more ultra-long-distance routes opened for the first time over the next 20 years, the opening of regional routes over the same period would offset the effect. A large number of regional routes being opened over the next 20 years is possible in intra-continental and regional markets such as India and Africa.

There are three scenarios that can be analysed to illustrate by how much the number of flights and services, and the average aircraft size would have to increase to generate the additional ASKs required.

Doubling flight numbers

In the first scenario, analysis shows that if average aircraft size and seat numbers were to remain the same in all markets, then the number of annual flights would have to increase to 78,300; an increase by a factor of 2.3. This is unlikely to happen, since more than doubling the number of services could probably not be catered for on a global level.

Airport congestion is a bigger limiting factor than airspace capacity. Doubling the number of flights would now require at least an increase of 50% in the number of runways at a large number of major airports in the busiest markets, given the current levels of runway utilisation. This would be in addition to a doubling of terminal capacity in many cases. Adding runways tends to be a longer and more difficult process than increasing terminal capacity.

While a large number of airports have substantially increased terminal capacity over the past 20-30 years, doubling capacity over the next 20 years is less likely to be possible for all airports. New technologies can be used, however, to improve existing airport terminal utilisation, and so achieve an appreciable increase in aircraft movements.

50% more flights

A second scenario therefore considers by how much aircraft size would have to increase if the number of flight services and frequencies increased by 50% *(see table, page 14)*.

For the intra-continental markets, it indicates that aircraft size would only have to increase by about 20 seats in Europe, and would not need to increase at all in North America *(see table, page 14)*. These two markets are the most mature, so growth rates are expected to be modest. Narrowbodies and regional aircraft would continue to be the dominant types.

Because of high growth factors for the other three markets of the Asia Pacific, China and India, aircraft sizes would have to increase by 230-310 seats to average sizes of 389, 403 and 575 seats. This does not consider the issue of on-ground congestion caused by larger types.

These large aircraft sizes clearly indicate that a 50% increase in the number of services is not enough to absorb projected passenger growth. The number of services and frequencies on most routes in these markets will be able to grow by a larger factor, given that there are still many small and medium airports in these three markets that are under-utilised, and many new routes have yet to be opened.

The high number of ATMs at the major airports probably means that they need more runways to be built, in addition to a large increase in average aircraft size. This factor will stimulate the opening of new routes serving alternative airports.

In this scenario, the size of aircraft in the intercontinental markets would see a modest increase of 25-60 seats in the Transatlantic, Transpacific, and Europe-Asia Pacific routes. Larger increases in aircraft size would result in the Europe-Middle East, and Middle East-Asia Pacific markets averaging 400 and 555 seats. A larger increase in the number of flights will therefore be required to offset this requirement. While major Middle Eastern airports are busy, all except Dubai have sufficient runway capacity for ATMs to double. Dubai will require more runway capacity.

20% more flights

A third scenario considers how much average aircraft size would have to increase by if the number of flights could only increase by about 20%. That is, if airport and airspace constraints prohibit significant growth in the number of flights and services for an extended period.

This scenario is less likely to occur at major airports in some markets when the calculated average aircraft sizes in each market are examined. The intra-European and North American markets would see aircraft sizes increase to 193 and 139 seats *(see table, page 14)*. This would still not cause any difficulties at most airports on both continents. Although LHR is at ATM saturation, a third runway should open from 2025, and allow a 50% increase in ATMs.

Due to high projected long-term growth, the average aircraft sizes in the intra Indian, China and Asia Pacific markets would, however, need to increase to 486-718 seats *(see table, page 14)*. As with the second scenario, an increase in the number of services is unlikely to be as small as 20%, and can be far higher given that most airports still have a lot of ATM runway capacity. There are also a larger number of routes that have not yet been opened in these regions. Nevertheless, the busiest airports in India and China will need to use new technologies to increase the number of aircraft operations.

In the case of inter-continental markets, the Transatlantic, Transpacific and Europe-Asia Pacific markets would require an increase in average aircraft size to 314-424 seats *(see table, page 14)*. This is close to the scenario of the number of services and

FEBRUARY 2019 GLOBAL AIRPORT DELAY STATISTICS

Airport	Flights February 2019	Percentage flights delayed (+15 minutes)	Average delay minutes
North America			
Toronto	15,990	38.6	61.4
Chicago	6,032	34.7	54.8
Calcary	7,325	33.9	60.7
Vancouver	9,283	31.6	53.0
Dallas Love-Field	5,688	29.0	50.9
Houston	4,770	28.5	56.1
Las Vegas	13,263	28.1	67.4
Montreal	7,726	27.4	64.6
Chicago	31,931	26.9	71.4
San Francisco	15,289	26.4	69.4
Denver	21,032	25.9	67.6
Oakland	4,029	25.7	53.9
Asia Pacific			
Manila	10,432	38.3	49.7
Nanjing	8,591	35.7	96.9
Xiamen	7,621	34.9	65
Mumbai	11,550	28.9	40
Hangzhou	10,637	27.8	59.7
Seoul	14,219	23.9	39.8
Delhi	17,311	23.6	65.2
Bangkok BKK	15,136	21.8	40
Hong Kong	14,303	21.5	46.8
Sapporo	6,019	20.8	35
Jeju	6,466	20.2	33.4
Tokyo	8,895	20.0	54.8
Europe			
London Gatwick	9,670	28.4	45.7
Stockholm	8,148	24.9	46.9
Paris	16,389	23.1	37.8
Munich	14,545	22.9	44.8
Amsterdam	16,977	22.8	39.0
Berlin	7,138	21.2	37.4
Brussels	6,958	21,2	41.7
Zurich	8,726	20.0	33.0
Oslo	8,789	20.0	38.3
London Heathrow	17,662	17.4	41
Frankfurt	17,272	17.4	32.9
Barcelona	10,755	17.3	38.3

flights increasing by 50%.

A 20% increase in the number of flights may not be sufficient in the Europe-Middle East and Middle East-Asia Pacific markets, since average aircraft size would have to increase to 500 and 700 seats *(see table, page 14)*. These flights would be operated almost solely by ultra-large aircraft.

Congestion levels

These scenarios raise the issue of what is the current state of affairs with respect to airspace congestion, airport congestion, as well as the development of additional airport capacity.

One indication of airport congestion is the percentage of flights delayed by more than 15 minutes, and the average length of the delay in minutes. The worst offending airports for North America, Europe and the Asia Pacific in February 2019 are summarised *(see table, this page)*.

In Europe the worst offending airport is LGW, which operates with a single runway, has almost 29% of its flights classified as delayed and an average delay of 46 minutes *(see table, this page)*. This is followed by Stockholm, Paris CDG, Munich, Amsterdam, Berlin, Brussels, Zurich, Oslo and LHR. The other worst airports in Europe's top 10 are all major hubs.

An interesting point is that LGW operates 286,000 flights per year with a single runway, while Stockholm operates 234,000 flights per year with three runways - yet the two airports have similar levels of delay *(see table, this page)*. A similar issue applies to Rome Fiumicino (FCO) airport, which also has three runways, when compared to LGW. Historical data shows that most delays are up to 60 minutes and, and a minority are 120 minutes or more. Moreover, historical data also shows that the average delay per departure gradually increases each year, it being four to nine minutes longer in 2018 compared to 2014, for example. The same trend applies to arrival delays. These trends follow the general trend in the long-term increase in ATMs.

Delays can also be expressed in particular airport- and city-pairs. The percentage of departures delayed are 75% for Lisbon-Porto, 64% for Barcelona-LGW, 70% for LHR-Frankfurt, 62% for LHR-Munich, 60.4% for LHR-Geneva, 63.4% for Frankfurt-Paris CDG, and 64.4% for Frankfurt-Hamburg. These delayed flights have delay times of 22-45 minutes. The portion of flights delayed and the size of the delays indicate the extent of congestion in Europe.

The European Commission compiles annual statistics on delays, and categorises their causes. The main groups of delays are reactionary, airline, air traffic flow and capacity management (ATFCM), and airport.

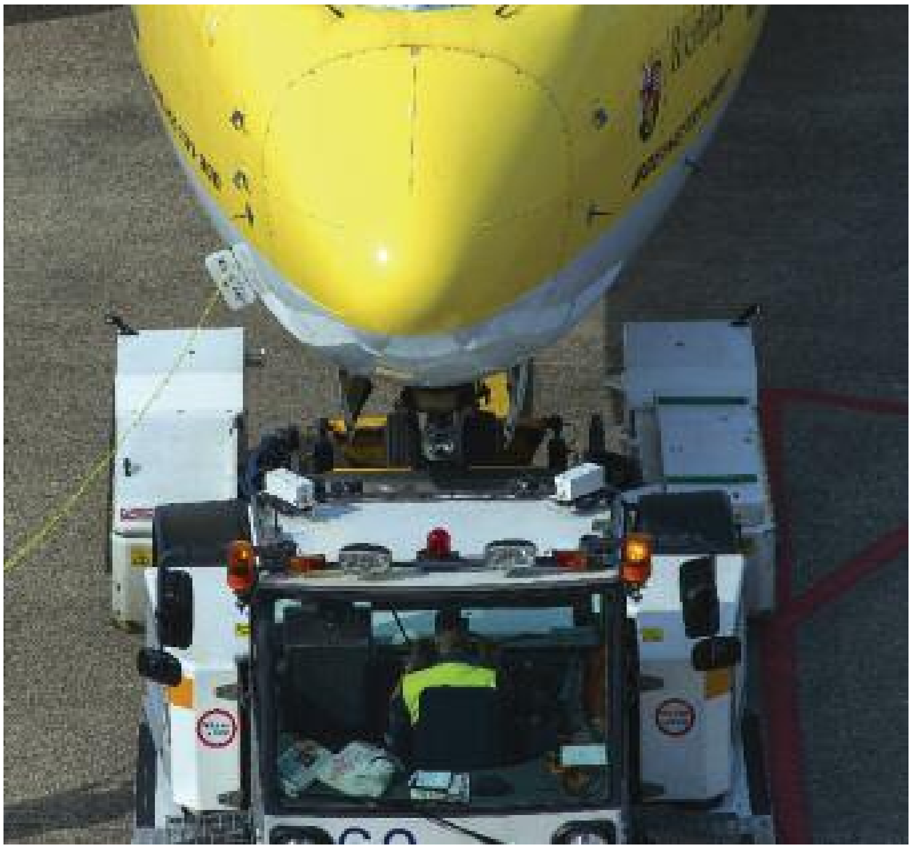
Reactionary delays are those caused by a previous flight or flights being delayed and having a knock-on effect on the schedule. Airline delays are those caused by operational problems within the airline, such as crews and aircraft preparation.

ATFCM delays fall into several categories. The first group are those relating to air traffic control (ATC) issues, and are types of en-route delays. The second group are delays that relate to ATC arrival and departure delays at airports, and involve pre-arrival stacking and holding, and airport runway and taxiway congestion prior to departures. These are therefore delays that are not caused by ground or airline operations, but are a result of airport and airspace congestion.

Delay data for North America perhaps surprisingly shows that Toronto Pearson has the highest percentage of flights that are delayed by more than 15 minutes at 38.6% and an average delay of 61.4 minutes *(see table, this page)*. The third and fourth highest airports are also Canadian: Calgary and Vancouver.

The US airport with the worst performance is Chicago Midway, at 34.7% and 54.8 minutes. Houston, Chicago O'Hare, Denver, Minneapolis St Paul, Seattle and Dallas Fort Worth are the six major US hub airports in the top 20 airports with the highest level of delays *(see table, this page)*. Newark, Boston, Washington DC, Detroit and Atlanta are in the next 20.

In the Asia Pacific, Manila is the worst ranked airport for delays, with 38.3% of 10,432 annual flights delayed by an average of 59.7 minutes. It is followed by Nanjing, Xiamen, and Hangzhou in China;



The conventional pushback & engine start process averages about eight minutes and up to 13 minutes for most twin-engined aircraft.

as well as Mumbai, Seoul, Delhi, Bangkok, Hong Kong and Sapporo in the top 10, worst airports *(see table, page 18)*.

While other airports have a smaller percentage of flights that are delayed, of the next 24 worst offending airports there are seven that have average delays that are longer than 60 minutes. These include Wuhan, Shenzen, Xian, Kunming, Chongqing, Guangzhou and Shanghai Hongqiao (SHA).

Relieving congestion

The three main elements that influence congestion are the number of aircraft stands and gates at terminals, the turnaround time (TAT) of aircraft between flights, and the space available for manoeuvrering and taxiing aircraft, and the number of available take-off and landing slots.

These ultimately affect the two main parameters of total ground time (TGT) and TAT. TAT is the time between on and off blocks while the aircraft is parked, while TGT is TAT plus aircraft taxi in and out time. TAT is affected by all the tasks that have to be performed during the turnaround process. Both TAT and taxi time are affected by on-ground congestion, and ultimately determine TGT.

Most major European airports have been using remote stands for the past 10-20 years, since all terminal gates with airbridges are fully used for at least the busiest parts of the day. This is an indication of terminal building congestion. Remote stands require passengers to be transported by bus between the aircraft and the terminal building, and so inevitably lead to longer TATs than flights using terminal gates.

It is clear is that congestion on the ramp is affected by the layout of terminals, terminal piers, the size and width of gates for aircraft, and the relative positioning of aircraft. There are many older terminal designs that result in high levels of ramp congestion, and delay aircraft pushback times. These issues are the main cause of limiting airport through capacity, rather than the number of runways and potential ATMs.

Data from flightradar24 clearly shows that TATs between short- and medium-haul flights are 10-20 minutes longer in Europe and North America compared to airlines in the Asia Pacific. TAT and TGT both affect aircraft utilisation, with aircraft being able to complete fewer flights per day, and so a smaller number of flight hours (FH) and flight cycles (FC) per year. With aircraft financing costs being a high percentage of total direct operating costs, aircraft utilisation has a large influence on airline unit cost efficiency.

Analysis of the elements of the aircraft turnaround and the processes performed during taxi and taxi-out clearly show that there are several elements where time savings can be achieved. If all consistently reduced, airlines can re-adjust their schedules for shorter turn times and so achieve more FC per day and reach higher levels of aircraft utilisation.

Two of the main elements of taxi time and TAT are aircraft pushback, engine start and the commencement of taxiing, and the servicing of the aircraft on the ground.

Pushback & taxi time

Total taxi time includes the time the aircraft taxis into the gate. A small amount of time can be gained by the aircraft promptly arriving at the gate, and shutting down engines. ADB Safegate has offered its visual docking guidance system (VDGS) for several years. This is based on light detection and ranging (LiDAR) technology. VDGS presents a screen on the outer terminal wall that provides visual signals to the flight crew taxiing towards the parking position at the gate to inform them to turn right or left, and how far they have left to manoeuvre before coming to a halt.

The main issue regarding taxi time, however, is taxi-out. Aircraft pushback and engine start accounts for a large portion of taxi-out time. The traditional system has been for aircraft to be reversed using a ground tug, with a ground marshal walking alongside the tug, while talking to the flightcrew via a connected headset, and guiding them through the procedure of starting all engines.

This process has several disadvantages and inherent inefficiencies. The first is that the flightcrew needs to request the flight operations department or flight dispatcher to arrange for the ground handling department to send a pushback tug and crew to the gate, and connect the tug to the aircraft so as not to miss the pushback time.

When ready for pushback, the procedure can take up to 12-13 minutes, and averages about eight minutes for most twin-engined aircraft. One of the main reasons for this amount of time is flightcrews going through engine start checklists. The pushback and engine start process, however, comprises a large number of elements.

Other disadvantages are that a lot of time is required while the ground crew checks that ground equipment and other aircraft are clear before the pushback. A lot of space is required for the procedure, since there is the blast from the engines as they are started. Aircraft often have to wait for pushback because of other aircraft being pushed back and starting engines in another part of the ramp area. All these issues mean airlines have to build in a lot of spare time for taxi-out into their schedules, with the negative consequences for aircraft utilisation.

A conventional pushback first incurs the direct cost of the use of the pushback tug and groundcrew, and also means the aircraft uses fuel from the beginning of engine start.

In addition, the TAT has to be long enough for passengers to disembark at the end of the previous flight, and a new complement of passengers to embark for the next flight all via a single entry door at the front of the aircraft. This is because of the convention of the aircraft being parked in a nose-in position at the terminal. Passenger disembarkation and embarkation using this method increase TATs compared to using two entry doors for the same process.

A solution to overcome the inherent inefficiency of conventional aircraft pushback and engine start has been the development of self-taxi systems. A prominent system for this is the WheelTug system. This works with the use of an electric motor in the nosewheel of the aircraft, and has been developed for 737 and A320 family narrowbodies, as well as regional jets.

The powered nosewheel gives the flightcrew the freedom to reverse from the terminal gate, after receiving clearance from ATC, and turn the aircraft to bring the fuselage parallel with the terminal building, as is the case with a conventional pushback. The pilot has a small control box to the side of their seat, including a forward and reverse control. The standard WheelTug procedure requires the use of a ground marshal to visually check for other aircraft and ground equipment.

The absence of a pushback tug and many other elements of a conventional pushback, means that this reverse procedure can be achieved in one to two minutes. With ATC clearance, the crew can then taxi the aircraft forward, using the electrical power of the nosewheel electric motor. Engines can therefore be started after the aircraft has left the ramp area during taxi-out, which is where one of the time savings of the system is realised. WheelTug claims this can reduce taxi-out time by an average of four minutes overall.

A single engine taxi for a twin-engined aircraft can be used for most of the taxi-out time; a useful feature at congested airports where taxi-out time is long at peak departure periods. This thus has the second benefit of saving fuel, as well as minimising the ingestion of grit and small stones in the engine, which impact engine maintenance costs. In addition, airlines will realise savings from not using pushback tugs and the associated ground crews.

The main benefit of WheelTug is a more predictable time for pushback, which means the airline schedule requires less buffer time for taxi-out to be added to the flight time. This should allow a higher rate of FC utilisation.

The original WheelTug system has been enhanced with several features. The first of these is WheelTug Vision. This is the addition of cameras to provide the flightcrew with clear visibility for all external points on the aircraft including the underbelly, wingtips and tail.

This can be viewed on a screen in the flightdeck, or on the pilot's electronic flightbag (EFB) device. This is optional to the basic system, which works with ATC clearance via the control tower. Thanks to the cameras and all-round vision, a ground marshal is not required. This system is being developed together with Fokker Services and Dresden Aerospace/FTI Group.

A second enhancement to the system is a cooperation between WheelTug and ADB Safegate, called WheelTug Guide. There are already VDGS screens used at about 200 airports around the world. The system will feature an upgrade to the VDGS that provides the visual guidance for pilots to park the aircraft parallel to the airport terminal buildings instead of the standard nose-in parking. This is possible because of the ability to drive the aircraft in and reverse it out of the parking position, if required. Parallel parking allows the use of two airbridges to disembark and embark passengers, and so can reduce TATs.

ATC at airports will be able to use data from WheelTug and the VDGS to monitor aircraft movement at gates. This will be based around the time used for pushback and engine start. The overall improvement in airport efficiency is a reduction in TATs of 7-12 minutes. The airports will pay

Self-taxi systems such as WheelTug allow aircraft to leave the terminal building and ramp area in about two minutes, start engines on the taxiway, and so effect a large reduction in an aircraft's total ground time (TGT). The system will also allow parallel aircraft parking at terminals, reducing passenger disembarking and embarking times, further reducing TGT.

ADB Safegate to upgrade the VDGS screens, and the airports will benefit from increased throughput. This means that airlines will not have to pay for this feature. Airlines will agree a rate that they pay for WheelTug, and this will be based on the savings realised by reduced turn times. An extra fee will be paid for the WheelTug Vision product.

The WheelTug Guide system should save up to 16 minutes in TGT. Four minutes will be saved in taxi-out time, and another 12 minutes in TAT. The saving could be even larger at crowded airport terminals when the reduction in taxi-out time is considered.

Aircraft servicing

The other issue with the potential to improve aircraft utilisation, is better management of the turnaround process on the ramp.

There are several elements to the entire process. Many of these either have to be completed in a sequence or in parallel. The main issue affecting turnaround is that the process has traditionally been managed manually, and with paper and conventional communications that include direct voice and via short-range radio, or telephone.

Lufthansa Systems has generated the concept of a digitised ramp turnaround process for the future. All relevant information will be fed into a turnaround management system, and used by the turnaround coordinator or ramp manager via a handheld device.

The first main processes of an aircraft turnaround are connecting the airbridge or stairs, connecting electrical power to the aircraft, opening lower hold doors and docking baggage-handling equipment to offload baggage and freight, and bringing servicing vehicles for the various elements of ground servicing.

In between passenger disembarkation and the loading of the next complement of passengers, the aircraft cabin has to be cleaned, technical issues in the cabin have to be dealt with and fixed if required, and new passenger servicing items such as cushions, blankets, newspapers, and on-board sales carts loaded and re-stocked.

All these processes can be organised to occur in the most efficient time possible. The ramp manager, however, has a large number of tasks to monitor simultaneously. Being out on the ramp area where there is lots of noise and activity makes it difficult to be aware of the progress of all these items. "The failure or absence of all the relevant vehicles or staff to arrive on time and when required will mean a loss of precious time," says Michael Muzik, senior product manager and consultant, at Lufthansa Systems Airline Consulting. "Dealing with these issues is still being managed at many airlines' by simply watching, what happens and phone calls, if something "by feeling" seems to go wrong. Digitising the turnaround process will create transparency for the turnaround coordinator. This has the potential to get a lot more flights to depart on time, and so then reduce the number of reactionary arrival and departure delays throughout the rest of the day.

A digitised turnaround management system will give the ramp manager / turnaround coordinator several items of vital information to manage the process. With the real-time turnaround information, the turnaround management system will alert the user if any relevant vehicles or personnel being used to perform their tasks are overdue, as well as indicate via user-friendly graphics the progress of all the different tasks. Such a system provides visibility with respect to all the tasks and sub-tasks. The system can also be used by the ramp manager to communicate via a chat functionality with relevant parties so that requests for assistance or additional help can be made.

"Such a digitised system would be enhanced by the use of predictives to provide accurate information with respect to aircraft positions on the ramp, and their effect on ground congestion," says Muzik. "Predictives can also be used to allocate aircraft to airport terminal gates and stands. An example would be placing an aircraft at a stand close to the runway to minimise the effect of reactionary delays."

Over time such a digitised system can be used to gauge the infrastructure and amount of ground equipment and staff required at peak times to reduce the effects of delays and achieve a reduction in TATs. "Another functionality will allow the ramp manager to request help, staff and equipment as required," says Muzik.

The main pieces of information being fed into the system are from the aircraft itself, airports systems and or service providers, partially still manually.

"To overcome the manual input of turnaround timestamps, the newest trend in turnaround management is the use of artifical intelligence. This translates video streams from cameras on the apron area into data," continues Muzik.

"This will be fed into the digital turnaround management system omitting finally any manual input by any stakeholder. One company developing this is Zero G, which is a subsidiary of Lufthansa Systems."

Summary

Clearly some of the main issues that could have a negative impact on global growth relate to airport capacity. This can partially be alleviated by new runways and airport terminals. There are also new technologies under development to ease the already established problems of congestion. There are still other issues to overcome for the industry to continue its growth path, and these include CO2 emissions. AC