Congestion and Air Transport: a challenging phenomenon

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This paper deals with the problem of congestion in air transport. The focus is on the congested related delays at airports and en route. One of the solutions in the longer run is additional investment in new infrastructure, but in this article the major attention goes to the short run operational techniques to optimize the use of existing capacity. The pricing mechanism and slot allocation do not constitute a basic part of this article, as many academic publications already exist on these issues. During the years a lot of experience and successful solutions have been adopted in the US by the FAA and in Europe by the European Union and Eurocontrol. Whatever the solutions, constantly new challenges are looming beyond the horizon. Especially the relationship between noise related concerns and congestion is actually becoming a major problem.

Keywords: capacity, congestion, delays, airports, airspace

1. Introduction

Congestion in transportation occurs when demand for infrastructure exceeds capacity, causing delays in travel time as one of the main symptoms. Door-to-door travel time in air transport is subdivided in three parts: the time to travel to and from the airport, the time needed in the passenger terminal before and after the flight, and the airside travel time once boarded. Airside travel time depends on many variables, but in this article only the airport and airspace (en route) related congestion problems and delays will be discussed. The immediate challenge is to decrease congestion but to keep the highest safety levels as traffic increases (FAA, 2005, *Moving America Safely*). The capacity problem in the US and the EU probably will become worse after the implementation of the recent open skies agreement (Turner, 2007a).

Solutions for airport capacity enhancement have extensively been discussed already by air transport economists analysing mainly pricing strategies for congestion costs and airport slot allocation solutions. The focus in this article will be primarily on operational solutions for airport congestion, such as runway occupancy time minimisation, and management of typical airport capacity problems such as caused by heterogeneous traffic, wake turbulence, noise problems and adverse weather. En route congestion is caused by crowded airspace and several solutions will be discussed, such as Reduced Vertical Separation Minima (RVSM), the mandatory use of 8.33 kHz, the Single Sky project of the European Union, and the use of satellite navigation. Most congestion issues as discussed in this paper rely on the vast European and US experience. Many of the available European and US solutions are as well adopted elsewhere in the world or are in the stage of being introduced.

2. Airport congestion

A proxy that that can be used to indicate airport congestion is given by airport departure delays. Congestion indeed causes delays, but not all delays are caused by congestion. The airline companies themselves are by far the main contributors for delays, causing in Europe approximately 50% of late departures (Murillo and Carlier, 2006). Airports are considered to be responsible for delays in 19% of the cases, en route problems account for 11%, adverse weather is a serious factor with 13%, security procedures are responsible for 4% of the delays and a residual 3% for all other problems. Each of these factors on itself can cause major temporary problems, like the terror alert in the UK in August 2006 (Sobie and Field, 2006). The relative share of airport related delays compared to en route delays tends to increase by the years (Murillo and Carlier, 2006).
Most delays (86.8% in July 2005) at European airports were limited to maximum four minutes, but more serious are the delays between 5-15 minutes (6.6%) and those between 16-30 minutes (4.6%). These numbers are averages, and hide substantially bigger problems at many European airports. The twenty worst performers are listed in the following table.

Table 1. Average delay in minutes per movement (July 2005)

1.	Istanbul	21.8	11.	Alicante	16.0
2.	London/Luton	18.7	12.	London H.	16.0
3.	Madrid/Barajas	18.1	13.	Barcelona	15.9
4.	Casablanca	17.1	14.	Rome	15.8
5.	Paris CDG	17.1	15.	Malaga	15.7
6.	London/Gatwick	16.9	16.	Milan/M.	15.6
7.	New York	16.6	17.	Venice	15.4
8.	Belfast	16.6	18.	Prague	15.2
9.	Larnaca	16.5	19.	Newcastle	15.1
10.	Dublin	16.1	20.	Budapest	14.9

Source: CODA (2005)

These highest delay airports however are not consistently the most dense departure airports. From the list of the ten most dense departure airports in Europe (CODA, 2005), only six airports are listed as well in table 1: Paris CDG, London Heathrow, Madrid, Barcelona, Rome, London Gatwick. This refers again to the observation that airport density and congestion is not the only variable that causes delays. Nevertheless airports give the second largest contribution to congestion and delays and airport congestion is predicted to become worse in the period up to 2020 (Goold, 2005). It is consequently an absolute necessity that airport operators focus on sufficient capacity and appropriate operational procedures to use the available capacity as efficiently as possible.

2.1 Capacity

Although a major capacity crunch is expected in the longer run (Communication from the Commission, 2006), still sufficient overall capacity is actually available at most airports if flight departures and arrivals could be distributed evenly over the operational hours of the airport. Most runways can handle up to 30 to 50 movements per hour, which means approximately 250,000 movements per year/runway if the airport is fully operational during 18 hours a day. Operational and legal constraints often reduce airport capacity to lower levels, as is illustrated in table 2.

Table 2. Airport capacity (IFR movements/year x 1000)

Airports	number of runways	capacity*
London Gatwick	1	278
London Heathrow	2	484
Brussels Airport	3	470
Frankfurt Main	3	530
Paris CDG	4	680
Amsterdam Schiphol	5 (6**)	600

* Source: Eurocontrol, 2006, DAP/DIA/STATFOR Doc. 179.
** The Schiphol-East runway 04-22 is less important and primarily used by general aviation (www.schiphol.nl)

The main congestion problems on most major airports are caused by peak hours, which typically cause delays in the morning, around noon and during the evening. Delays during morning peaks can even cause a cascade impact and additional reactionary (Eurocontrol, 2007, *ATFCM*) delays for the full day or even more when international connecting flights are involved (Murillo and Carlier, 2006).
Peak related delays should not be solved primarily by expanding airport infrastructure, but by optimising operational practices, which is the responsibility of airport operators, airlines, and air traffic control (Eurocontrol, 2007, *ACE*, vol. 1).

2.2 Surface management

Runways legally are not allowed to be used for take off and landing as long as the runway is not vacated by another airplane. Consequently aircraft should minimize runway occupancy time (ROT) in order to make the departure or landing of another aircraft possible. Estimates have been made that reducing ROT can increase runway capacity between 5 % for single runway airports up to 15 % in case of multiple-runway airports (Eurocontrol, 2003). For the departure ROT is the average reaction time to take-off clearance 11 seconds at major European airports. By reducing this to 7 seconds, two extra departures per hour are possible (Eurocontrol, 2003). An airport with 18 operational hours could handle 36 extra flights a day, or 13,140 flights per year, or about 1.3 million extra passengers when each aircraft carries on average 100 passengers. A technical constraint is the spool up time that aircraft engines need between idling and take off power. Especially the large turbofan engines of twin wide bodies, such as the Boeing 777 and the Airbus 330, need more spool up time than narrow bodies, such as the Boeing 737 and the Airbus 319/320/321. Priority take off clearance should be given to aircraft with lower spool up times.

Landing ROT refers to the time an aircraft needs between touchdown and vacating the runway via the taxiway system. The configuration of the taxi exits affects airport capacity (Mohleji, 2001). Right angle exit taxiways require slow groundspeeds for safety reasons (Eurocontrol, 2003). A Boeing 747 for instance needs to slow down to 5 – 10 knots to vacate the runway, becoming 5 – 6 knots in wet conditions. A solution for this is offered by the rapid exit taxiways (RETs), with angles of exit between 30 to 60 degrees. Exit speeds are much higher, which reduces landing ROT. A Boeing 747 needs to slow down to only 30 – 40 knots, and to 20 – 30 knots in wet conditions. Most runways on major congested airports in the world are actually already equipped with RETs or are in the process of implementing new ones. Recent examples are the new RETs on the landing runway 33 of Madrid-Barajas and on the runways 07 and 25 of Barcelona El Prat.

Aircraft on the ground can be subject to delays as well caused by numerous non runway factors (Eurocontrol, 2007, *ACE*, vol. 3). Typical delays can happen already at the gate by late gate announcements and gate openings, slow ground handling activities such as cleaning, refuelling, boarding of catering, and late push back clearance received from ATC. Start up and taxi clearance should be given by ATC before push back is terminated. Where multiple push backs are scheduled at the same time, priority should be given to aircraft that can vacate the airport environment in less time, for instance by using shorter runways, intersection take offs, early turns after take off, etc. During taxi, and definitely before reaching the holding point, cockpit crew should have received and copied the IFR (instrument flight rules) clearance, including the SID (standard instrument departure) and the en route clearance.

2.3 Homogeneous traffic and wake turbulence

When aircraft fly at similar speeds in final approach, less spacing between approaching aircraft becomes possible and this increases runway capacity. It is therefore not advisable to mix approaching jet aircraft with slower turboprops and general aviation. Most major hubs have strict limitations on general aircraft activity, and there are even airports that impose restrictions on carriers using turboprops. For each country this information can be found in the national Aeronautical Information Publication (AIP) which is a legal document issued by the national aviation authorities. The principle of sovereignty of individual countries in their own airspace is based on article 1 of the Convention of Chicago, but article 15 excludes discrimination based on the nationality of the carrier. This type of discrimination is not acceptable neither in the European Union.

The flexibility of the airport operator towards heterogeneous traffic increases when multiple runways and intersection take offs are available.
To increase departure and landing capacity, the distribution of aircraft type should be as homogeneous as possible (Mohleji, 2001). An airplane needs aerodynamic lift to become and stay airborne, and this causes some adverse aerodynamic side effects. Vortexes are created at the wing tips, causing a phenomenon which is known as wake turbulence. Airplanes following the flight path of another aircraft at the same altitude or even 1000 feet lower can encounter wake turbulence and in some cases could become uncontrollable. The most dangerous stages are approach and departure. The Airbus A 330 of American Airlines that in 2000 fatally crashed after take off in New York was hit by wake turbulence of a preceding JAL Boeing 747. Consequently strict separation minima should be maintained for approaching and departing aircraft. These minima are higher behind heavy jets such as the Boeing 747 and for aircraft with a typical adverse vortex pattern, such as the Boeing 757. Typical separation minima are in the range between 4 – 6 nautical miles (7.5 to 11 km) for the approach and 2 – 3 minutes time intervals for take-off (FAA, 2005, *AIM*). Research is going on to reclassify these minima, as well because there too many variations between countries (Learmount, 2007c).

2.4 Adverse weather management

Low cloud ceilings and visibility can reduce runway capacity to zero. Landings could more adversely be affected than take offs. Runways can be provided with instrument landing systems (ILS) that allow approaches and landings with specified cloud ceilings and visibility.

Table 3. ILS minima in decision height* and runway visual range**

Categories	DH (feet)	RVR (feet)
I	200	2400
II	100	1200
IIIa	none	700
IIIb	none	150
IIIc	none	none

* Decision height (DH) is “the height at which a decision must be made during an instrument approach to either continue the approach or to execute a missed approach”.
** Runway visual range (RVR) is “the range over which the pilot of an aircraft on the centreline of a runway can see the runway surface markings”.
Source: FAA (2005), *AIM.*

Approaching airplanes only can enjoy the lower minima if they are properly equipped and if the cockpit crew is rated to perform the approach.
Microbursts and wind shear are typical weather phenomena caused by convective activity and happen frequently in the US during the summer season. Approaching airplanes could face sudden changes in wind direction, even up to 180 degrees. Loss of critical minimum airspeed can happen resulting in accidents. When wind shear is reported in the vicinity of airports, approaches can be abandoned or delayed. The worst case is a general wind shear alert around an airport, because this can adversely affect approaches on all runways. If the precise position of a

microburst can be detected, for instance in the axis of a particular runway, the higher the probability that the operations on other runways can continue as usual. By using such a system, safety and capacity are improved on many US airports based on the FAA Integrated Wind Shear and Detection Plan (FAA, 2005, *AIM)*.

2.5 Noise abatement management

Noise abatement is frequently based on restrictions resulting in less available runway capacity. During sensitive periods, operations on some runways can be restricted or prohibited. A relevant example is Schiphol Amsterdam (www.schiphol.nl). Night flight restrictions can even been extended to the entire airport, reducing capacity to zero during these times. Standard arrival routes (STARS) and standard instrument departures (SIDs) can become subject to changes because of noise concerns. The capacity of handling noisy aircraft like those of chapter 2 and hushkitted airplanes has been drastically affected in the European Union by Regulation 925/1999/EC (*Official Journal*, L115) and other noise related operating restrictions at Community airports have been implemented since the introduction of Directive 2002/30/EC (*Official Journal*, L085). Airports that choose for noise quota limitations impose a yearly maximum amount of noise production, and on many airports these noise quota tend to become more restrictive. The only way to keep up sufficient capacity at those airports is the transition by the airline operators to airplanes of the lowest noise category. Airline operators can be encouraged to expedite this transition by being forced to pay higher landing fees on noisier aircraft. The transition to quieter aircraft contributes at the same time to a cleaner environment, as less noisy engines generally produce cleaner exhaust gasses.

3. En route congestion

Congested airspace causes approximately 11 % of delays (Murillo and Carlier, 2006). Airborne airplanes need a minimum horizontal and vertical separation distance for safety reasons. Many solutions have already been initiated to deal with en route congestion.

Separation distance in controlled airspace is managed by air traffic control (ATC). ATC services should be as homogeneous as possible in order to optimize the capacity of airspace. The optimum situation in the EU would be the existence of a very limited number of functional blocs of airspace (Turner, 2007b), controlled by ATC using identical radar and communication equipment, and mandatory standardised English phraseology. Although ATC in the US is outdated and did not change significantly since its design in the 1950s (Air Transport Association of America, 2008), it has the advantage of being a homogeneous system. In the EU however the impact of member states on ATC is still high by tradition, which makes airspace control to be more fragmented than in the US. European airspace is still controlled by many separate national air navigation service providers, causing per year approximately 250,000 hours of flight delay (Learmount, 2007b).

The EU – in cooperation with Eurocontrol - developed during recent years a strategy to set up the Single European Sky project, but still a lot of time will be needed before the final goal will be reached. The practical implementation has been given into the hands of SESAR, the Single European Sky ATM Research Programme (www.sesar-consortium.aero). All major stakeholders of the air transport industry are contributing in this consortium, which is co-financed by the European Union (www.europa.eu). SESAR is actually in its definition phase (2005-2008), which will be followed by the development phase (2008-2013) and finally the deployment phase (2014-2020).

Reduced vertical separation between aircraft at high altitude (FL 290*[1] and higher) has already been introduced by RVSM. These reduced vertical separation minima allow 1,000 feet vertical separation minima instead of the previous 2,000 feet. Airplanes making use of RVSM should have the appropriate cockpit equipment. Non compliance with the new equipment forces these airplanes to fly at altitudes lower than FL 290, which is not compatible with economical fuel burn conditions for turbine aircraft. RVSM is in the process of being implemented on a world wide scale. Vertical and horizontal separation between traffic in European airways is managed by the Control Flow Management Unit (CFMU) of Eurocontrol (www.cfmu.eurocontrol.int). There is close coordination between airport ATC and CFMU. The clearance to join an airway at a specific altitude and time is communicated by CFMU to ATC of the departure airport. The cockpit crew finally gets the consolidated take off and airway clearance from ATC at the airport of departure.

Communication between cockpit crew and ATC is vital to ensure the safe operation of air traffic. The Very High Frequency Band (VHF) is used world wide in the range from 118 to 137 MHz. The available frequencies have been doubled already decades ago by reducing the 50 kHz channel spacing into 25 kHz. Increasing traffic however requires the additional availability new frequencies. VHF communication is only possible on a one to one basis. When VHF communication is going on between an aircraft and ATC, all other airplanes have to wait before transmitting to ATC or receiving ATC messages. In this way a VHF frequency can be overloaded very soon resulting in delays when airplanes are not able to contact ATC. The cost per year of these delays to passengers and airline companies is estimated by Eurocontrol to reach 450 million euro in 2010, up to 6 billion euro in 2020 (Eurocontrol, *8.33 kHz Expansion Programme,* 2006). The solution which will be implemented world wide and in Europe is the use of a narrower channel spacing of 8.33 kHz. The deadline in Europe for implementation above flight level 195 was 15 March 2007, and probably 2010 for the lower altitudes (Eurocontrol, *Europe tunes 8.33 kHz above FL 195*, 2007).

The traditional navigation system used by aircraft relies on ground based VOR (Very High Frequency Omnirange) stations. Airplanes fly from one VOR to another, and this explains why airways have been centered along these VOR stations. Very often airplanes have to use multiple airways before ending up at final destination. Consequently straight line navigation between departure and arrival airport is hardly possible. As airplanes flying between busy hubs have to use the same routings, airway congestion and delays are very common. Straight line navigation would take away the congestion from airways, shorten up flying distances, and reduce fuel consumption and emissions. This solution can be offered by satellite navigation systems, such as the Wide Area Augmentation System (WAAS) in the US (FAA, 2005, *AIM*) and by the plans for

[1] Flight level (FL) indicates 29,000 feet related to the reference datum of 29.92 inches of mercury or 1013.2 hPa.

the European Geostationary Navigation Overlay System (EGNOS) based on the EU Galileo Project (Regulation 876/2002). Galileo has been delayed many times and will probably not be implemented before 2011 (ASD-Network, 2007).
Another new system for the future will be ADS-B. This Automatic Dependent Surveillance-Broadcast system (Learmount, 2007a) will give pilots better traffic situational awareness, and consequently can accept more airplanes in the same blocs of airspace. Shorter and more efficient routes will be become possible in the same airspace (Norris, 2007).

4. Conclusion

Many congestion problems in the air transport sector are caused by airports, ending up with nearly twice as many delays as caused by en route congestion.
Although airport capacity can be increased in the long run by building new infrastructure, short run solutions should be adopted first to optimise the use of existing capacity. The possible solutions are based on a differentiated mix of operational actions. Runway capacity can be increased by minimising runway occupancy time (ROT), by concentrating on homogeneous traffic with similar approach and departure speeds and same wake turbulence category. Adverse weather can be managed by more sophisticated instrument landing systems and microburst detection equipment. Noise congestion can be caused by legally imposed quota per airport, involving maximum yearly amounts of noise production. In this case, more capacity is only possible when airline operators would shift to airplanes producing less noise.
En route congestion enhancement requires primarily an efficient air traffic control (ATC) system. Europe suffered traditionally from a heterogeneous ATC system, but is actually working towards a solution with the implementation of the Single European Sky project. More airplanes can fly safely in the same airspace with the introduction of reduced vertical separation minima (RVSM), and the 8.33 kHz expansion programme will open up more VHF frequencies, allowing more airplanes to communicate with ATC. The development of satellite navigation systems will allow straight line navigation, while in the long run the automatic dependent surveillance-broadcast (ADS-B) system will allow airplanes to fly more direct and efficient routes.

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