

Depeaking – Optimization of Air Traffic Systems

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Abstract

Growing air traffic volume leads to increasing congestion at major European airports. Due to an inhomogeneous traffic flow with several arrival and departure banks throughout the day, demand often exceeds infrastructural capacity. Especially over-demand for runway capacity causes increasing delays which propagate throughout the flight network. With respect to the resulting costs for the affected airlines, the economic optimum is achieved by planning a more continuous traffic flow, a so-called depeaking. In summer 2004, Lufthansa Airlines as the first European airline, implemented depeaking at Frankfurt airport.

Frankfurt International Airport is one of the most congested airports in Europe. More than half of all flights in Frankfurt are conducted by Lufthansa airlines. Lufthansa operates a hub-and-spoke network with hubs in Frankfurt and Munich, which means that at these airports passenger flows are bundled and allocated to connecting flights. For the reliability of transfer connections, arrival punctuality at the hub airports is an important factor. To pre-estimate the delay impact of the depeaking process, Lufthansa used an iterative-stochastic simulation. Furthermore, the new schedule structure was evaluated with respect to aircraft productivity and passenger connectivity to make sure that operational improvements would not be diminished by economic downsides.

Keywords: Airport Congestion, Air Traffic Scheduling, Stochastic Simulation

JEL-Code: C15, L93

1 Introduction

At congested European airports, arrivals and departures are slot¹-coordinated in order to allocate the scarce infrastructure capacity. The maximum number of available slots within a certain time frame, the so-called declared capacity, is set according to the particular infrastructure of the airport. For example available gate or runway capacity can be limiting factors when planning aircraft movements.

Various influences in daily operations such as weather conditions, aircraft maintenance and crew availability lead to a deviation of actual demand for airspace and airport capacity from the slot-coordinated demand.

When the arrival demand exceeds an airport's actual capacity, the European Central Flow Management Unit (CFMU) controls demand through a Ground Delay Program (GDP). Flights which are scheduled to arrive at the constrained airport are held on ground at their origin to ensure that the airport capacity is not exceeded at their estimated time of arrival. GDP produces so-called startup delays ranging from a few minutes to several hours. Furthermore, demand is adjusted in-flight by approach speed regulation, extended approach transitions or holding patterns.

1.1 Infrastructure and Declared Capacity at Frankfurt Airport

Frankfurt airport operates three runways, two parallel runways which are used for both, arrivals and departures and one single runway which is exclusively used for departures (fig.1). Hence the departure capacity exceeds the arrival capacity. In summer 2003, the declared capacity for Frankfurt airport was 43 arrivals and 48 departures per hour before 2 p.m., whereas the maximum overall capacity was 78 movements (43-48-78). After 2 p.m. the declared capacity was 45 arrivals, 48 departures and 80 overall movements (45-48-80).

¹ Slot = Landing or take-off right at a specific time

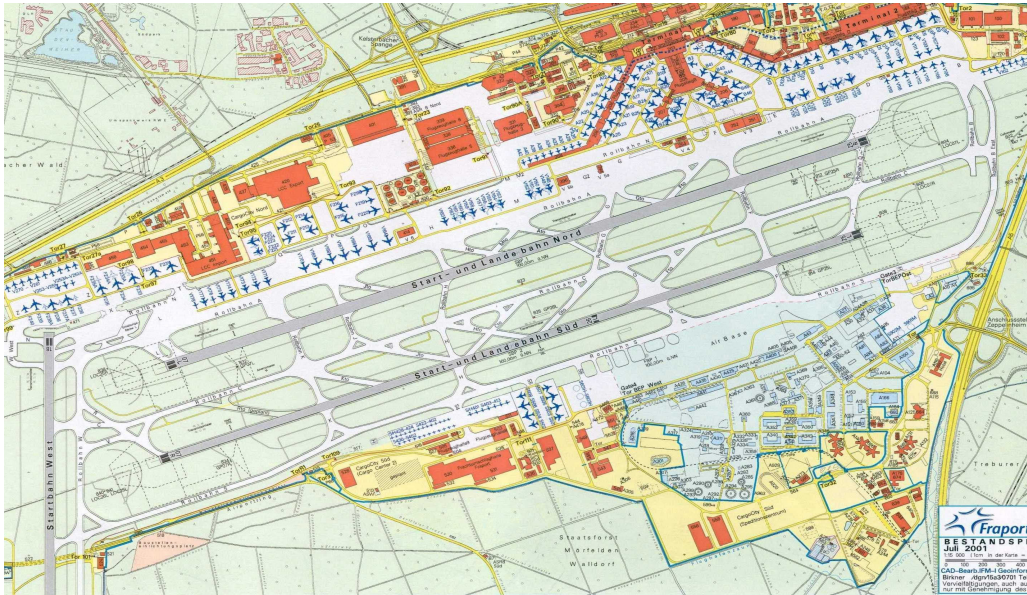


Figure 1 – Frankfurt Airport

1.2 Block Time Determination

Airlines request for take-off and landing slots according to the scheduled block times² of their flight legs. To account for seasonal weather effects, block times are set for summer and winter schedule periods individually. Block time determination for a flight leg is done by statistical analysis of previous years' actual block times of the respective city pair separated by aircraft types.

In order to ensure a certain level of punctuality in operations, the scheduled block time is usually set as the percentile (Lufthansa: 68%) of the empirical distribution of last period's actual block times. This

means that past flight delays are considered when planning new block times.

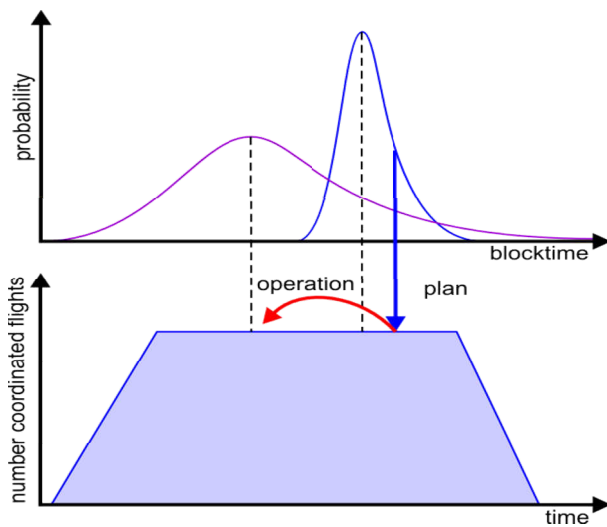


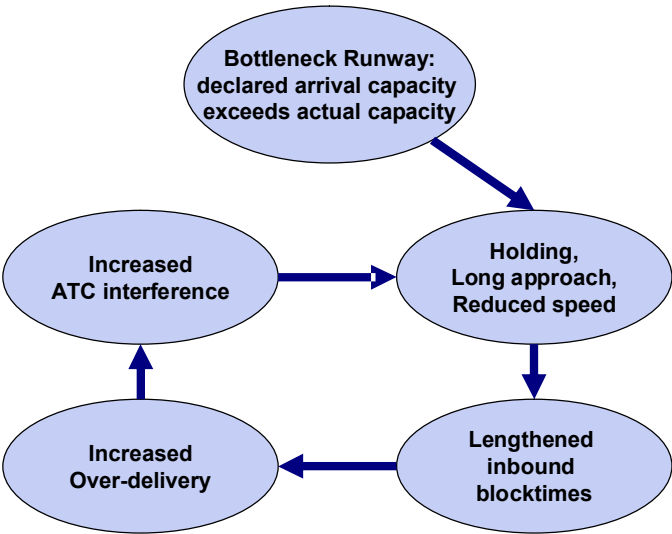
Figure 2 – Block Time Determination

The gap between mode and 68%-percentile increases with data variability, which means that especially for flight legs with a high spread in historical block times the actual block times may differ significantly from the scheduled block times (fig.2). Since this phenomenon affects long

² A block time includes taxi-out time at origin, flight time and taxi-in time at destination, i.e. it is the time between leaving the gate at the originating airport and docking at the gate at the destination airport.

haul flights more than short haul flights, super-positioning of both categories leads to actual demand exceeding declared capacity significantly. In summer 2003, these over-deliveries frequently resulted in demand of up to 60 arrivals per hour at Frankfurt airport instead of the coordinated 43 and 45 respectively.

As mentioned above, this over-demand for arrival runway capacity results in delays caused by air traffic control policies such as startup delays and holding patterns. These delays partially lead to even more variability in actual block times, causing an increasing difference between scheduled and



operationally feasible value in the following period. This vicious circle (fig.3) led to constantly rising block times inbound Frankfurt airport. For example, Lufthansa block times inbound Frankfurt were on average ten minutes longer than outbound. The inhomogeneous traffic flow with high arrival and departure peaks close to the infrastructural limit enforces the circle.

Figure 3 – Vicious Circle of Block Time Determination

2 Depeaking – Preliminary Investigations

In order to break the vicious circle, Lufthansa proposed to “depeak” operations at Frankfurt airport with decreased declared capacity for arrivals and departures and increased overall declared capacity. Lufthansa developed a stochastic simulation model for the runway system at Frankfurt airport to estimate the impact on delay and use this knowledge to reduce scheduled block times proactively. Additionally to this operational evaluation, new schedule structures were analyzed with respect to aircraft productivity and passenger connectivity. Jointly, these models were used to find an economic optimum.

2.1 Stochastic Simulation Model

As mentioned above, numerous stochastic factors influence everyday schedule performance. To account for these effects and resulting demand variability, the stochastic simulation creates random values for aircraft arrival and departure times in every simulation run. These simulated values are based on the scheduled times and probability distributions which describe the average deviation from the schedule. After a sufficient number of runs, the simulation yields average performance values.

Approaching flights have to keep safety distances from each other which certainly depend on aircraft types but also on weather conditions. Therefore, these approach distances also have been modeled by random values based on actual data from Frankfurt airport ([1]). If demand for arrival runways exceeds capacity, flights are queued in a holding pattern. Similarly, departure separation depends on aircraft type, weather and departure routes. If two successive flights use the same departure route, the second flight has to keep larger separation than otherwise.

The simulation tool dynamically assigns flights to the runways. Arrivals use the parallel runways alternately, while departure runway assignment depends on the departure direction. Flights towards north are generally assigned to the parallel runways, while flights to other directions are preferred to use the single runway. Due to the fact that departure runway capacity exceeds arrival runway capacity, arrival flights have priority over departures.

For the simulation of Frankfurt airport one major challenge was modeling the block time effect of delays caused by over-deliveries, i.e. to map the vicious circle which has been described in 1.2. To meet this challenge, an iterative simulation method was developed which is capable of accounting for these complex interactions. In a basic simulation scenario, a small initial deviation from scheduled block times was assumed. This basic scenario delivered an average arrival delay which was considered for block time determination for a further scenario. This second scenario again resulted in arrival delays which were entered into the next scenario. As long as capacity exceeds average demand, after several iterations this method leads to steady values which represent the actual arrival delays in operations.

The model was calibrated using a flight schedule from Frankfurt airport for a typical weekday in summer 2003. The performance of this flight schedule was then compared with simulation results for various depeaked declared capacity values (fig.4), for example 41 arrivals, 43 departures and 80 overall movements (41-43-80) or an even more continuous flow structure of (40-40-80).

For all depeaked simulation scenarios the arrival as well as departure delays decreased significantly compared to summer schedule 2003. The more continuous the schedule structure, the more delay reduction could be observed.

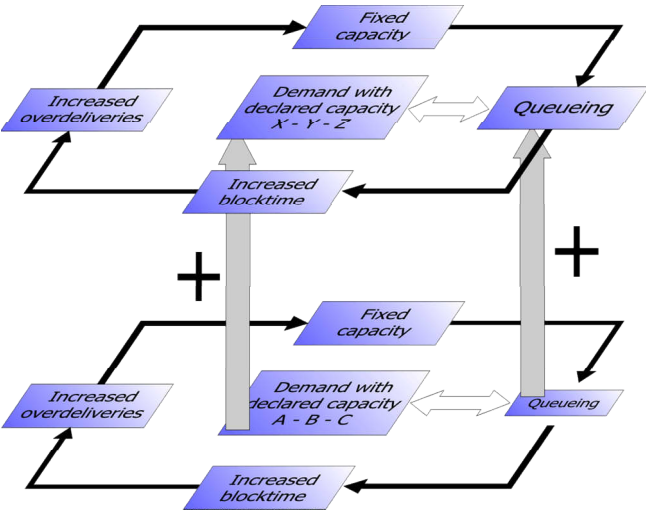


Figure 4 – Iterative Stochastic Simulation

arrivals and departures, which means that with the same number of aircrafts demand reaches the capacity limit more often. Therefore, it is more difficult to find free slots for inbound or outbound legs at preferred times. This can among other things lead to extended ground times when no departure slot is available and finally result in decreased aircraft productivity.

In order to make sure that the operational benefits of depeaking would not be diminished by these downside effects, proposed schedule structures were evaluated with respect to their aircraft productivity and passenger connectivity. Additionally to the declared capacity, fleet structure, initial slot usage and minimum ground

2.2 Evaluation of the Schedule Structure

Flight schedules with several large banks of arrivals followed by banks of departures throughout the day allow for a high number of flight connections in shortest time. In a more continuous schedule structure, this connectivity may be reduced. Furthermore, depeaking reduces the maximum number of

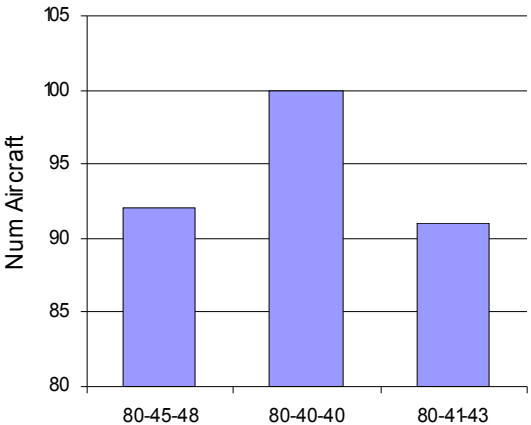


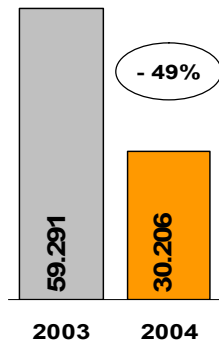
Figure 5 – Productivity of Considered Schedule Structures

times were used to create feasible flight schedules with corresponding aircraft requirements and flight connections.

The flight schedules with declared capacity of (40-40-80) showed decreased aircraft productivity by 9% (fig.5), whereas the structure (41-43-80) even increased schedule productivity and connectivity.

3 Results

In summer schedule 2004, which started on March 28th, declared capacity for Frankfurt airport was changed to (41-43-80) before 2 p.m. and (42-44-81) after 2 p.m.. Within this new schedule structure



the overall travel time for 35 of the 50 most profitable flight connections was decreased. Moreover, startup delays went down by about 50% (fig.6) and flight times inbound Frankfurt decreased due to reduced CFMU interferences. These flight time savings reduced fuel burn by more than 70 000 tons. Nevertheless, it remains to be seen whether the positive effects can also be observed in winter 2004/2005 before reaching a final conclusion.

Figure 6 – Ground Delay Inbound Frankfurt in Minutes (April to September)

References

- [1] IST-Analyse des Flughafen Frankfurt (FRA-IST), Teil 2: Luftseitiger Verkehr, Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Flugführung, Braunschweig, Mai 2001.