

REDUCING DISTURBANCES BY USING ABSORPTION AREAS

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Abstract

The stochastic nature of Air Traffic Management arises mainly from uncertain operational events. This uncertainty may jeopardize the Central Flow Management Unit (CFMU) planning leading to safety problems and sub optimally used capacity.

An absorption area is defined as one or several free slots in the planning so that the management of uncertainty is easier. Its aim is to compensate the aircraft uncertainty. The issue is to use the free slots in order to absorb uncertainty, and so not modify the initial planning. Finding the best configuration of the absorption areas corresponds to balancing optimally their size with the available capacity in order to absorb uncertainty and minimize "load loss" (unused capacity).

This paper presents results showing the absorption areas distribution benefits; one takes into account the slot reallocation time.

Introduction

Airspace congestion was a critical issue the European Air Traffic Management (ATM) had to face. The Air Traffic Control Centres (ATCC) capacities were far exceeded by a constant growth in air traffic demand, resulting in ever increasing flight delays. These time and management costs were such a nuisance for all airlines and passengers that the European Commission had released a special statement acknowledging that current Air Traffic Flow Management (ATFM) system are unable to support high traffic loads.

With more than one flight in three being delayed by over fifteen minutes in 1999, the situation gives cause for serious concern. And even if some of the delays are due to airports operating at the limits of their capacity or to the airlines themselves, more than half are a direct result of Europe's airspace reaching saturation point.

The economic cost was reckoned to be over 5 billion euros (€400M for en route delays in 2003 and €400M for airport ATFM delays [1]), while the impact on passengers, though hard to gauge, is probably of the same order.

The Central Flow Management Unit (CFMU) is in charge of reducing these congestion costs by, among several other strategic or tactical measures, delaying departure slots for the flights involved in overloaded sectors [2].

The principal objectives of the CFMU have always been to protect air traffic services against the overdelivery of aircraft, while at the same time enabling aircraft operators to carry out their flight operation with the minimum of disruption. During 2003 the level of traffic returned to record breaking figures, signalling an end to the depression experienced by the aviation industry following the September 11 attacks and the subsequent SARS. This return to overall growth was matched by record low levels of delays, a clear indication that the effort being undertaken by all concerned are succeeding and a reminder that, with continued growth being forecast, these efforts must continue to succeed.

The EUROCONTROL Provisional Council requested that the average delay per flight during the 2003 summer season (May-October) should not exceed 2.8 minutes per flight. Furthermore, the average delay caused by en-route regulation should not exceed 2.1 minutes.

The traffic forecast for the ECAC area for 2003 predicted a 2.2% increase while the delay forecast, derived from the traffic forecast, predicted 1.1 minutes delay per flight, of which 0.5 minutes would be attributable to en-route delays.

However, the traffic growth could saturate the European air capacities in the next years. Indeed, traffic growth is expected to resume at 3-4% per annum from 2004 onwards, albeit at levels some 15% below those forecast in 2000.

Ground regulations are ineffective in controlling flows when demand is close to capacity,

and yet cause significant delays and reduce aircraft/airport operators' flexibility. More accurate flow control would allow increased effective capacity and reduce unnecessary delays, while preserving safety.

Considering that the gap between capacity and traffic has been almost closed, effective capacity now needs to grow at an annual rate consistent with EUROCONTROL traffic forecast. This requires careful medium term capacity planning:

- Tailored to individual conditions;
- Including flexibility to cope with unexpected events and forecast errors;
- Taking safety and cost-effectiveness objectives into account.

This paper presents an improvement of the second point. For this we introduce the Absorption Areas (AA) corresponding to a safety margin (flexibility) in order to cope with unexpected events and forecast errors like:

- weather conditions;
- technical failure;
- passenger wait;
- flight plan errors...

First, one makes a short presentation of the ATFM and slot allocation in order to show the absorption areas interest. Then one presents the first results obtain and the distribution of the AA in the slot allocation.

Slot Allocation and Uncertainty

The European Airspace is divided into geographical areas call sectors. Each sector is supervised by controllers, one in charge of conflict resolution, and the other of coordination across sectors and conflict detection.

The capacity of the airspace is defined by the maximum workload of the controllers; it depends of controllers' seniority, weathers conditions...

In EUROCONTROL Air Traffic Flow Management (ATFM), the CFMU is in charge of the slot allocation for all flights, elaborates the daily planning of slots. A slot corresponds to a time

window (-5 min, +10 min) during which the aircraft can take-off.

Centralized ATFM is in charge of regulating air traffic demands by, among several other strategic or tactical measures, delaying departure slots of the flights that could overload congested sectors. The purpose of delaying is to respect the "en-route" capacity constraints provided by each Air Traffic Control Centre.

If there were not uncertainty in air traffic, such that all flights could be guaranteed to respect all estimated time of arrival at all route segments, one could envisage a situation in which schedules and routes could be designed to allow gate-to-gate flight without any conflict, and would not be necessary for any active intervention by ATCos.

This ideal situation is not yet reachable today; therefore one major issue with Air Traffic Management (ATM) is to deal with uncertainty. Current ATM is a complex socio technical system organizes to cope with uncertainty: controllers and pilots frequently make important decisions based on uncertain or incomplete information, especially in non nominal and emergency situation.

The culture of eliminating uncertainty therefore seems quite deeply ingrained in ATM, but may not be sustainable or optimal. New concepts and tools, such as those for planning and conflicts detection, tend to increase the amount of data that can be presented and the degree of reliability placed on predicted information.

The research problem described in this paper concerns the reduction of disturbance caused by uncertainty in slot allocation. The goal of slot allocation is to guarantee that the ATCos workload will not be overload. Actually, the disturbance in slot allocation problem corresponds to aircraft not taking theirs slots and requesting new ones. AA is intended to absorb these requests without disturbing the scheduler slots. The issue with AA is that full capacity would not be used in pre-tactical planning. An optional trade-off shall be found in order to maximize capacity while minimizing disturbances.

Absorption Areas Concept and Experimental Validation

When an aircraft lost its slot, it asks for a new one. This demand can delayed other aircraft

because of the “first planned-first served” principle and so forth.

The idea is that aircraft losing their slot use absorption areas. An absorption area is defined as one or several free slots let intentionally unfilled in the slot allocation in order to not disturb the others aircraft.

To valid this idea, one developed a simulator for the “en-route” traffic. The experimentations show the benefits of absorption areas; one can reduce the delays and increase the average throughput of the airspace [3].

First Theoretical Results

Then one developed a theoretical approach in order to find an algorithm for the slot allocation by taking into account the absorption areas. Nowadays, one knows that all the capacity is not declared, but we do not consider it in the slot allocation. One wants to consider it in order to minimize the “loadloss” (unused capacity).

One found the best amount of absorption areas according to the rate of uncertainty [4]. The results obtained are given by Figure 1. The curves represents the number of aircraft taking-off under safety conditions with 1000 slots, with absorption areas (the upper one), and without absorption areas.

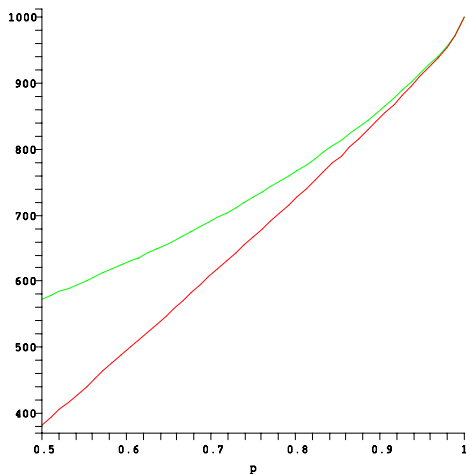


Figure 1: Average throughput obtained with and without absorption areas.

One sees the benefits on the average throughput, but there is another benefit. Without absorption areas, one allocates all the slots. When

an aircraft lost its slot there is no free slots later. So one can not reallocate it, or the safety rules are not respected. With absorption areas, one guarantees that all aircraft allocated will take-off in the number of slots one has.

Absorption Areas Distribution

Presentation

The previous results were obtained without considering the time of slot reallocation. Figure 2 show the strategy adopted to find the results.

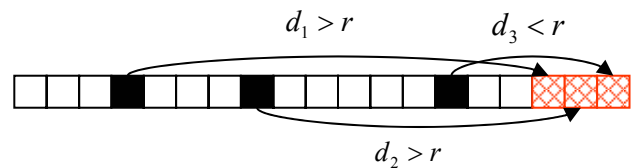


Figure 2: Strategy used to find the amount of Absorption Areas

On Figure 2 one has in red the unfilled slots (absorption areas), in black the aircraft submit to disturbance and having lost theirs slots. The arrows represent the reallocation. Let r be the maximum number of slots we can wait before reallocate these aircraft, it depends of the controller seniority, weather conditions... One considers r equal to 4. Let d_i be the number of slots that the delayed aircraft i before being reallocated. On this example, one has only d_3 which is reallocated under r .

One wants to guarantee that all aircraft will be reallocated in a reasonable time. One considers the distribution of the unfilled slots. A first idea is given by Figure 2. However, one has a big “loadloss” (unused capacity).

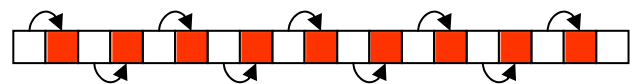


Figure 3: Example of distribution

Figure 3 shows an absorption areas distribution which guarantee that all delayed aircraft will be reallocated without delay. In red one has the unfilled slot, and in white the allocated slots. The arrow represents the reallocation ability. It could be

a good distribution if the rate of uncertainty was greater or equal than 50%.

Model

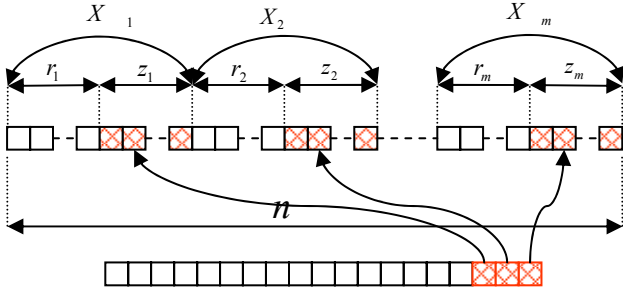


Figure 4: Distribution of Absorption Areas

Figure 4 introduce variables used for next results:

- Let n be the number of slots;
- Let r_i be the maximum of slots one can wait before reallocate an aircrafts during the period i ;
- Let z_i be the number of unfilled slots of the period i ;
- Let X_i be the random variable representing the number of aircraft we could not reallocate during the period i ;
- Let m be the number of period in n slots.

The used strategy is to allocate r_i aircraft in the period i , and then add enough unfilled slot to guarantee that most of delayed aircraft will be reallocate in the unfilled slot. The length of the period i is equal to the sum of r_i and z_i . On Figure 4 one sees how one passes from the strategy used to find the amount of unfilled slots needed (Figure 3) to the distribution of these slots.

Probabilistic Results

$\Pr(X_i = 0)$ corresponds to the case that there are not more delayed aircraft that unfilled slot in the i period. It corresponds to the sum of the combinations of 0 to z_i aircraft in r_i slots. So the probability that $\Pr(X_i = j)$ correspond to the combination of $j + z_i$ delayed aircraft in r_i slots.

$$\Pr(X_i = 0) = \sum_{j=0}^{z_i} \left(C_{r_i}^j (1-p_i)^j p_i^{r_i-j} \right)$$

$$\Pr(X_i = j) = \begin{cases} C_{r_i}^{j+z_i} (1-p_i)^{j+z_i} p_i^{r_i-j-z_i} & \text{if } j+z_i \leq r_i \\ 0 & \text{else} \end{cases}$$

One is interested by:

$$X = \sum_{i=1}^m X_i$$

One obtains:

$$\Pr(X = 0) = \prod_{i=0}^m \left(\sum_{j=0}^{z_i} C_{r_i}^j (1-p_i)^j p_i^{r_i-j} \right)$$

$$\begin{aligned} \Pr(X = 1) &= \Pr(X_1 = 1) \cap \Pr(X_2 = 0) \cap \dots \cap \Pr(X_m = 0) \\ &+ \Pr(X_1 = 0) \cap \Pr(X_2 = 1) \cap \dots \cap \Pr(X_m = 0) \\ &+ \dots \\ &+ \Pr(X_1 = 0) \cap \Pr(X_2 = 0) \cap \dots \cap \Pr(X_m = 1) \end{aligned}$$

$$\Pr(X = 2) = \dots$$

For the moment one is interested by the probability P that all delayed aircraft find an unfilled in its period. So one studies:

$$P = 1 - \Pr(X = 0)$$

Easiest Case Showing Absorption Areas Benefits

To show the benefits on the distribution, one studies P with the same probability of p_i on all the period, and a same amount of z_i in each period.

$$P = 1 - \prod_{i=0}^m \left(\sum_{j=0}^{z_i} C_r^j (1-p)^j p^{r-j} \right)$$

Figure 5 was obtain with $z = r/2$; it corresponds to an amount of 33% of absorption areas.

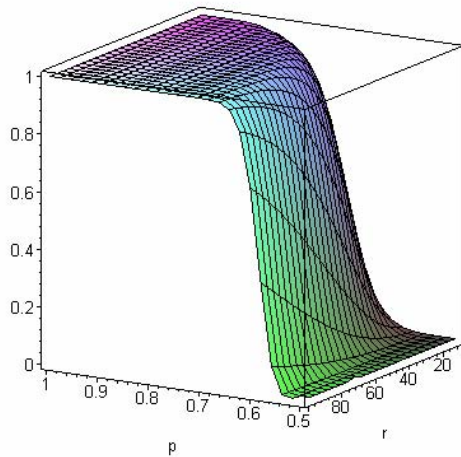


Figure 5: Probability that all delayed aircraft find a slot in a time less than r . r is given in a number of slots, p represents the rate of uncertainty.

One sees on Figure 5 that more r is great, more efficient the absorption areas are. But with 33% of absorption areas and r equal to 80, one can guarantee that one will absorb all delayed aircraft for p greater than 0.7. One needs to distribute this absorption areas more efficiency, in order to reduce the loadloss (unused capacity).

Future Work

One continues to study P without taking into account the variability of p_i . Instead of guarantee that all aircraft will not be delayed than r , one looks of the distribution of the number of period that an aircraft wait before being reallocated.

Then one search to distribute these results in all the regulated system. For this one will use the Graph Theory.

Conclusion

The first results obtained shown the benefits of absorption areas to improve the ATFM. Each new assumption reduces these benefits, because in each case one increases the loadloss. One wants to find an algorithm, according to the probability of the uncertainty, which guarantees that one can improve the slot allocation [5]. The experimental results

shown that such algorithm must exist. Although the absorption areas are already used with the flexibility, they are not yet considered by the CFMU. This safety margin is given according to the ATCos but not according to the uncertainty. It corresponds to a continuous absorption area; each hour, one can add the same number of aircraft. One wants to distribute these unfilled slots more efficiently in the sectors in order to minimize the load loss.

In this paper, one sees that taking into account the reallocation time of delayed aircraft could also improve ATFM.

Another interest of absorption areas is that if one finds an algorithm giving a good distribution of unfilled slots, then its implementation will neither change sectors topologies, nor controller's work nor flight plans submission procedure.

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