Using Absorption Areas to Improve ATFM*

Frédéric Ferchaud *PhD Student at ERC†/LaBRI‡*
Cyril Gavoille *Professor at LaBRI*
Mohamed Mosbah *Professor at LaBRI and ENSEIRB§*
{ferchaud, gavoille, mosbah}@labri.fr
10th December 2003

Introduction

The stochastic nature of ATM[1] comes mainly from the uncertainty associated with flight operational aleas. Examples of these operational aleas include unexpected delays from passengers, technical failures identified through take-off checklists, weather conditions... These aleas jeopardize the initial CFMU[2]'s planning from which consequences of delayed flights are propagated throughout different regulated sectors.

An absorption area is defined as one or several free slots in the CFMU's planning so that the management of aleas is easier. Its aim is to absorb the aircrafts' aleas. The issue is to use the free slots in order to absorb aleas, and so not modify the initial planning.

We developed a little simulatore of Air Traffic Flow Management for the "en-route" control, named SIVOR (SImulateur de VOl en Route-*en-route flight simulator*). With the experimentation, we showed that absorption areas could minimize the delays, while increasing the flow. Then we began to develop a theoretic approach to prove the SIVOR's results.

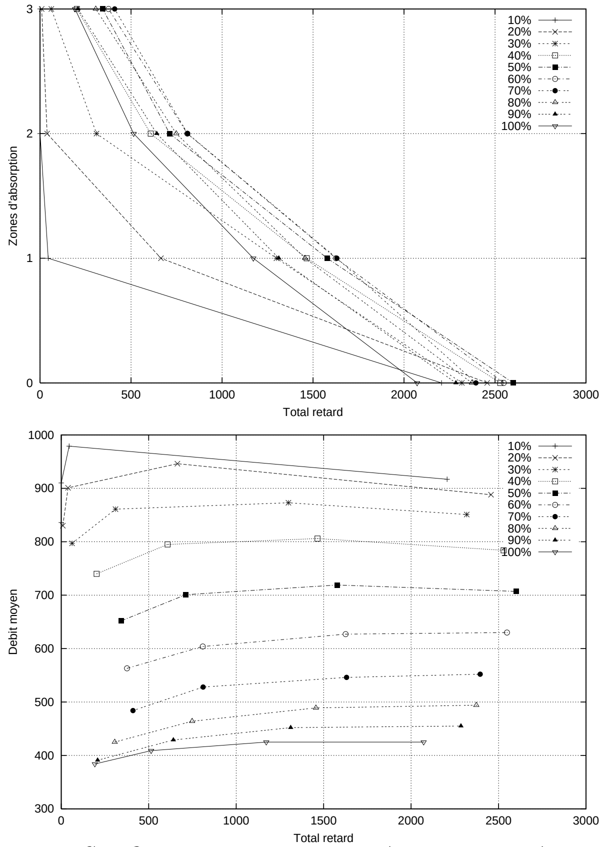

FIG. 1 – *SIVOR's results showing Absorption's Areas Interest, on the X-coordinate, we have the number of times we had to resolve a conflict. The Y-coordinate of the top figure represents the size of the absorption area, and on the bottom figure the flow we have obtained. For Example, the curve with 10% of aleas shows that we reduce the number of conflicts and improve the flow when we put an absorption area, but if we put two, the flow is reduce and not the conflicts, so in this case we will choose the strategy with one absorption area.*

SIVOR's results

With the simulator developed in my MSC placement (DEA), we found that in order to reduce ATC[3] delays, and to increase the flow in a regulated sector, we have to optimise absorption area [1]. In fact, finding the best distribution of absorption areas, in the journey planning, can minimize their size and make the aleas management easier.

On Figure 1, whatever is the rate of aleas, absorption areas always can minimize the ATC delays, and sometimes increase the flow too. The results obtained was for a capacity of 15 aircrafts in the same time in sector for all the tactical planning, and the Y-coordinate 0 correspond to a capacity of 15 for the pretactical planning, 1 to 14, 2 to

*Air Traffic Flow Management
†EUROCONTROL Research centre
‡Laboratoire Bordelais de Recherche en Informatique
§Ecole Nationale Supérieure d'Electronique, Informatique et Radiocommunications de Bordeaux
[1]Air Traffic Management
[2]Central Flow Management Unit
[3]Air Traffic Control

13 and 3 to 12, see Figure 2.

We only put absorption areas in continuous, i.e. the capacities don't evolve during the journey planning. Meanwhile the obtained resluts allow us to show the advantage of using absorption areas. We have tried to put discontinuous areas, but the results were not interesting because we did not consider the sectors' neighbourhood relations.

Indeed, if an aircraft is delayed, we want to give it a free slot, but the free slots of all the regulate sectors must be harmonised, else the aircraft will not take off and the free slots will be lost. It's why we use a model based on Graph Theory. If we arrive to define a good representation, with the known algorithms of the graph, we will probably be able to find the best distribution of free slots during the journey's planning for the pretactical phase.

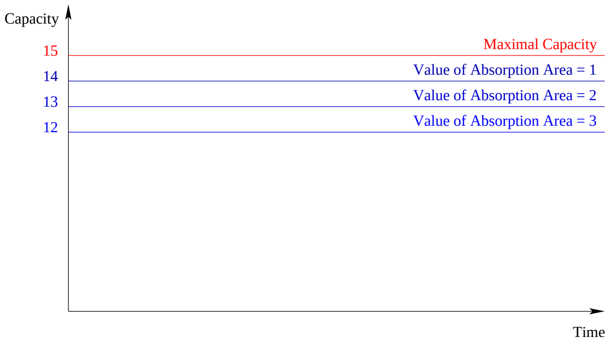

FIG. 2 – *Used capacities on Figure 1*

Model

The model used is a graph whose vertices are the sectors at a given time, and the edges are the temporal relations between them. The graph is evolutive due to the evolution of capacities'sector (properties of the vertices) change in time, used to define the absorption areas.

The benefit of using graph theory is to establish a neighbourhood relationship between all controlled areas, to use the well-known algorithms for graphs, and to control the huge complexity of the problem. This relationship simplifies the establishment of the absorption areas constrained by the problem of harmonization of the flow between sectors. Indeed, absorption areas will not be the same in each sector (distribution, size), but the problem of delays will be globally solved.

Theory

Previously, we had showed that absorption areas are useful only by experimental results.Now we are working on a formal proof. We will demonstrate that we can improve the ATFM with them.

Theorically, we can compare the flow with and without absorption areas.

Let N be the total slots we can allocate. So the maximal flow is equal to N. However, in the reality, some aircrafts are submit to aleas and they can not take theirs slots, so some slots are lost. Let $(1-p)$ the proportion of aleas. Without absorption areas, we obtain a planning where all slots are affected, but when an alea occurs, the concerned aircraft can not take off, and as all the other slots are taken, we consider that they never could take off, its slot is lost and the flow is reduced. Let z the proportion of free slots we have left on the pretactical planning. We consider that as long as it remains free slots, the aleas can be absorbed.

So we obtain :

$$\begin{array}{l} flow_{max} = N \\ flow_{woaa} = pN \\ flow_{waa} = p(1-z)N + min(\underbrace{z, \underbrace{(1-p)(1-z)}_{aleas\ on\ aircraft})N}_{free\ slots\ recovering} \end{array}$$

With $flow_{max}$ the maximal flow (all the slots are taken), $flow_{woaa}$ the flow obtain **w**ith**o**ut **a**bsorption **a**rea, and $flow_{waa}$ the flow **w**ith **a**bsorption **a**reas. For $flow_{waa}$, we have affected only $(1-z)N$ slots, so we only consider $(1-z)N$ aircrafts and the aim is to guarantee that whatever is the rate of aleas, all aircrafts can find a slot to take off. We have to find the best z according to p. This case arrives when all free slots are used and all aircrafts had taken off. It corresponds at :

$$\begin{array}{l} z = (1-p)(1-z) \\ z = \frac{1-p}{2-p} \\ flow_{waa} = \frac{N}{1+(1-p)} \end{array}$$

And we obtain :

$$flow_{waa} - flow_{woaa} = N\frac{(p-1)^2}{1+(1-p)}$$

So $flow_{waa} > flow_{woaa} \forall p \in [0, 1[$. It shows that we can improve the flow with absorption areas when aleas occur, see Figure 3. Moreover, theorically there is no aircraft delayed with the absorption areas, so we can reduce the ATC delays and improve the flow.

Conclusion

Our theoretical as well as experimental work shows that absorption areas improve the ATFM. However, it remains to find the best distribution of free slots on practice to reach the theoretical result. We want to minimize the absorption areas and to reduce the lost slots. Moreover, to reduce again the absorption areas, we can consider a real-time phase which consists of reallocating slots of aircrafts which we know enough time before that they will not take off. Let q this proportion, we prove theorically that in this case :

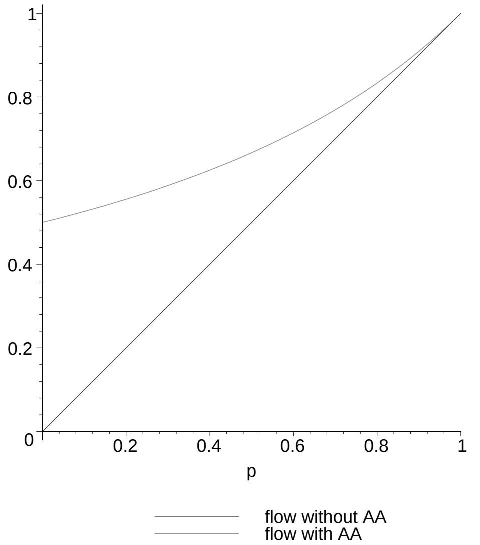

FIG. 3 – *Flow representations with and without Absorption Areas (AA)*

$$z = \frac{(1-p)(1-q)}{1+(1-p)(1-q)} \; flow = \frac{N}{1+(1-p)(1-q)}$$

So we could define the number of absorption areas we need at least, but we must know :

- how to distribute the free slots in the journey planning.
- which function represents the aleas in the journey.
- which function represents the daily traffic.
- which function represents the time knowledge of an alea.
- which function represents the slots we can reaffect.

If we find the best distribution in one sector and model the traffic, the graph theory can help us to find the best distribution in all the controlled airspace.

References

[1] Frédéric Ferchaud. *Gestion de Flux du Trafic Aérien.* Mémoire de DEA, LaBRI, juin 2003.