Multiobjective Optimization for Reducing Delays and Congestion in Air Traffic Management

Gaétan Marceau[1,3]
[1]Thales Air Systems
Rungis, France
gaetan.marceaucaron@thalesgroup.com

Pierre Savéant[2]
[2]Thales Research & Technology
Palaiseau, France
pierre.saveant@thalesgroup.com

Marc Schoenauer[3]
[3]TAO project-team, INRIA Saclay Ile-de-France
Université Paris Sud, Orsay, France
marc.schoenauer@inria.fr

ABSTRACT

Nowadays, with the increasing traffic density of the European airspace, air traffic management includes the planning and monitoring of the capacity of the network as a way to facilitate the work of the air traffic controllers. This article presents the use of an evolutionary multiobjective algorithm for optimizing a schedule on the time of overflight of the waypoints. The evaluation function is defined as a probabilistic model, which reports the expected delays and the expected congestion giving the schedule. We believe that the robustness of such decision-support tool can only arise from a precise modeling of the uncertainty at a trajectory level and to propagate it to the sector level, allowing us to compute the probability of congestion. This paper gives the outline of the probabilistic model and the way it is used with an evolutionary algorithm in order to optimize the schedule. The proposed approach is tested against two artificial instances where one consists of 300 aircraft and 16 sectors.

Categories and Subject Descriptors

J.2 [**Applied Computing**]: Physical Sciences and Engineering—*Aerospace*

General Terms

Design, Algorithms, Experimentation, Performance.

Keywords

Air Traffic Control; Trajectory Prediction;
Evolutionary Computation; Multiobjective Optimization.

1. MOTIVATION

In air traffic flow and capacity management [3], the main goal is to ensure that the demand on the network will not exceed the capacity. Today, multiple entities work together at different scales to construct and monitor a global plan, which must be adapted when unexpected events occur, like hazardous weather phenomenon. Therefore, we model the airspace situation as a large geographical area including several control sectors, each under the responsibility of an air traffic controller. The action is determined at a network level and then, communicated to the air traffic controllers who only have a local scope, as it is well-accepted that those who own the most comprehensive, up-to-date and accurate information shall choose the actions. Consequently, a controller can see his workload increased by an action, but for the decreasing of the workload of another controller in the need. Moreover, the action shall be proportionate to the perturbation of the plan. This is very important since different scenarios are created beforehand in function of anticipated perturbations. Some scenarios will require important actions from different actors and will potentially decrease the network performances. In this work, we propose to do small local changes to the trajectories in order to solve the capacity and delay problem and therefore, to avoid the use of scenarios. These local changes correspond to objectives associated to estimated time over some waypoints. The evolutionary algorithm is responsible to find the values of these objectives. In terms of benefits, the minimization of the delays can generate consequent savings for the airlines, but also for all the passengers. The minimization of the congestion will contribute to maintain the safety level without impacting directly on the conflict avoidance task. In effect, the proposed solution ensures that controllers will not face a traffic that will exceed their capacity to manage it. We believe that multiobjective optimization will help to find actions that are proportionate to the perturbation.

GECCO'13 Companion, July 6–10, 2013, Amsterdam, The Netherlands.
ACM 978-1-4503-1964-5/13/07.

2. MODEL

Our model is a probabilistic model, which propagates the uncertainty from the trajectory level to the sector level. First, we define the markovian trajectory model:

$$p^f_{1:N}(t_{1:N}) \quad = \quad \prod_{i=2}^{N} p^f_{i|i-1}(t_i|t_{i-1})p^f_1(t_1) \tag{1}$$

where $p^f_{1:N}$ is the joint density function giving the probability for the flight f to be at each waypoint at a given time. $p^f_{i|i-1}$ and p^f_1 are conditional and marginal density functions respectively. On the one hand, the expected delay for a flight is the product of the delay cost function and the marginal density function associated to the last point, here N, along the time. On the other hand, we can easily obtain the probability for a flight to be in a sector, which is a Poisson Binomial distribution. Finally, the two objective functions are defined with the mean aggregation over all the flights and all the sectors respectively.For the decision variables, these are the estimated times over significant points. Here, we only consider boundary points of the control sectors. Therefore, the optimization problem consists in minimizing the expected cost of congestion and the expected cost of delays by controlling the time of departure, but also the time of coordination between air traffic controllers. Clearly, the two cost functions are antagonist, because the flights use the orthodromic distances between the waypoints and also, use a target speed, which can not be increased significantly. Consequently, the action required to decrease congestion will imply delays on some flights. We justify the use of a probabilistic model in this study with robustness. As a matter of fact, we want to introduce safety margins between the instant when a flight exits a sector and another one enters. These safety margins should reflect the degree of confidence in the trajectory prediction of the system and defined in function of uncertainty given by our model. [6] gives further details on the problem and the chosen model.

3. METHODOLOGY AND RESULTS

Simulations were done with a Bayesian Network with decision nodes. It was implemented in C++ with the algorithm proposed by [5] to compute the probability distribution of the Poisson Binomial. It requires the use of a Fast Fourier Transform and we used the library FFTW [4]. Also, we use the evolutionary multiobjective algorithm called Non-dominated Sorting Genetic Algorithm-II [2] with SBX crossover and polynomial mutations in order to deal with the box constraints. We used its implementation in the Paradiseo framework [1] with the default parameters. The experiments were done on a on a 2.2 GHz Intel Core i7 without the parallelization over the sectors. This could enhance greatly the performance, i.e. the computation of the congestion is independent from one sector to another.

In order to get an insight on the interaction between the evolutionary multiobjective algorithm and the probabilistic model, used here as a black-box model, experiments were done on two artificial instances. The first one is a toy instance with 10 flights and 5 sectors with a central sector, which becomes congested. There are already 60 dimensions in the decision space, each associated to a box constraint. On average, the evaluation function takes 113ms with the direct method of evaluation of the probability of a Binomial Poisson. We used an initial population of 100 individuals and a maximum number of 400 generations. The main result is that there are potentially many local optimums in the region where the congestion cost has low values. In effect, we observed, with 11 runs, that the obtained pareto fronts converge to the same points when minimizing the delays, but cover a large region when minimizing the congestion. This is not due to a premature stop since the hypervolume indicator stabilizes around the generation 100 for all runs. In order to investigate further this problem, parameter tuning will be done on many instances.

The second instance consists of 300 aircraft and 16 sectors. The sectors are organized as a 4x4 grid where 10 flows of 30 flights enter from north and east, including the diagonals from northwest and northeast, at a pace of 1 flight per 2 minutes. In this problem of the size of a real instance, we have 1500 decision variables with their associated box constraints. Within the decision variables, we have 300 departure variables and 1200 en-route variables. The former have a larger feasible domain than the latter; this simply reflects that it is easier to delay a flight on ground than when it is airborne, because of the difference in fuel consumption. The chosen time horizon is 250 minutes in order that the last flight leaves the airspace with probability 1 beyond the last timestamp. In order to obtain an instance where the actions modeled here are sufficient to resolve the problem, we impose that each sector has a probability to be congested around 0.5 except for one where its capacity is decreased of 2. This results in a probability to be congested of 1. This instance is complicated because the situation cannot be solved solely by applying an action on a flow since it will impact the neighbor sectors and thus, reduce the overall network performance. An evaluation function takes around 3 seconds with the characteristic function method. At this point of the research, we know that the mean fitness of the population increases along the generations. This is not surprising at all since the initialization of the population is totally random and so, there is a huge probability to impact flights that are not contributing to the local problem. Further research concentrates on determining the subset of flights that are effectively impacted by the capacity degradation. The major difficulty is that optimizing only on this subset will provoke potentially capacity problems in other sectors and then, we will add the new impacted flights in the subset, but still new sectors will potentially be impacted. Nevertheless, we believe that the proposed approach will be able to solve this problem.

4. ACKNOWLEDGMENTS

Gaétan Marceau is funded by the CIFRE 710/2012 scholarship established between Thales Air Systems and the TAO project-team at INRIA Saclay Ile-de-France, and the scholarship 167544/2012-2013 from the *Fonds de Recherche du Québec - Nature et Technologies*.

5. REFERENCES

[1] S. Cahon, N. Melab, and E.-G. Talbi. Paradiseo: A framework for the reusable design of parallel and distributed metaheuristics. *J. Heuristics*, 10(3):357–380, 2004.

[2] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan. A Fast Elitist Multi-Objective Genetic Algorithm: NSGA-II. *IEEE Transactions on Evolutionary Computation*, 6:182–197, 2000.

[3] Eurocontrol. ATFCM Operating Procedures For Flow Management Position, 2013.

[4] M. Frigo, Steven, and G. Johnson. The design and implementation of FFTW3. In *Proceedings of the IEEE*, pages 216–231, 2005.

[5] Y. Hong. On Computing the Distribution Function for the Sum of Independent and Non-identical Random Indicators, 2011.

[6] G. Marceau, P. Savéant, and M. Schoenauer. Multiobjective Tactical Planning under Uncertainty for Air Traffic Flow and Capacity Management. In *Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013)*, 2013.