ADAPT - Advanced Prediction Models for Trajectory-Based Operations (TBO)

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Abstract—**Presentation of the concept, data requirements and preliminary results of the ADAPT project.**

Keywords-strategic flight planning; flexibility; metrics; integer programming models; simulation; ELSA; SATURN

I. CONCEPT

The scope of ADAPT is to propose a set of methods and tools (a "solution") at the strategic and/or pre-tactical level of network management that is conducive to trajectory-based operations, which clearly demonstrates the flexibility, information exchange responsibilities, and benefits for all the stakeholders. The aim of the project is to adapt, create and test models and metrics that enable strategic planning (early information sharing), by providing information on flight flexibility (through the assignment of time windows[1] (TWs)) and network hotspots, which can eventually be integrated into the Network Operations Plan and serve as a basis for stakeholder collaboration. The ADAPT project consists of three main activities: (i) Development of the ADAPT strategic solution (ongoing); (ii) Tactical assessment (preparatory tasks), and (iii) Visualisation (still to start).

In turn, the ADAPT strategic solution development consists of three phases: (i) the formulation and implementation of a deterministic model (European Strategic Flight Planning (EFPS) model) to assign flight trajectories and associated time windows at the strategic level, (ii) the assessment of the expected economic loss during disturbances (e.g., flight delays, bad weather), and (iii) the definition of possible actions to mitigate detected expected demand and capacity imbalances, on the day of operations. Phases (i) and (ii) cover the definition of the ADAPT solution, while in phase (iii) the outputs are used to devise mitigation actions in order to improve the situation, if possible.

The ESFP model builds on two deterministic, integer programming models. Considering a busy day in the European network, and the changing sectorisation, the aim of the first model is to assign a minimum cost trajectory for each scheduled flight, in such a way that the nominal capacities of the network are respected. When all flights have a trajectory and departure time assigned, these become inputs of a second integer programming model, the aim of which is to determine the flexibility (in terms of TWs) of all flights and the critical spots in the network [1]. This second model uses departure times as the starting position of TWs, and the objective is to guarantee the largest flexibility by maximising the total duration of all TWs. The output of this second model are the trajectories, assigned TWs and the hotspots in the network.

II. DATA REQUIREMENTS

In order to both develop and validate ADAPT models, extensive amounts of historical data are needed: the network infrastructure, ATM status, traffic (trajectories and sector crossings), flight costs (strategic and tactical), regulations, weather. The main data sources are DDR2 (network infrastructure, traffic), ATFM Network Statistics (for ATFM regulations), a University of Westminster report (for flight and delay costs) [2], and ECMWF, the European Centre for Medium-Range Weather Forecasts (wind ensembles).

III. PRELIMINARY RESULTS

To be able to assess benefits, a baseline is compared with the ADAPT solution scenario (application of ADAPT models). The baseline scenario is obtained by running the first ESFP strategic model, but with unconstrained capacities, which is consistent with the current practice of not considering capacity in the strategic phase. The baseline scenario de facto corresponds to a

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[1] A time window is a time interval describing the flexibility (in time dimension) of a trajectory. A time window indicates how "late" (with respect to declared timing of the trajectory) a flight can be and still not create capacity-demand imbalances in the network.

simple assignment of routes of minimum cost (or minimum duration), disregarding capacities.

In the solution scenario both ESFP models are applied, for the whole day, over the entire European network. The models process 29 535 flights, over 22 862 sector-hours. The optimal solution is found in less than 3 minutes, with the optimality gap less than 0.1%. In the baseline, capacity is breached in a number of sector-hours, while that is not the case in the solution scenario.

Furthermore, we find that a vast majority of flights, apart from not causing capacity imbalance - is flexible - having time windows of 15 minutes. A bit more than 5000 flights have TWs lower than 15 minutes (so called critical flights), out of which only about 600 flights are very constrained (TW of 1 minute), as can be seen in Fig. 1. Fig. 2 depicts a possible use of ADAPT results - a trajectory assigned to a flight from LGAV to LFPO, departing at 08:30, has to be on time, along the entire route as it has a TW of 1 minutes, and there are 3 sectors along the trajectory, the capacity of which is constraining this particular flight.

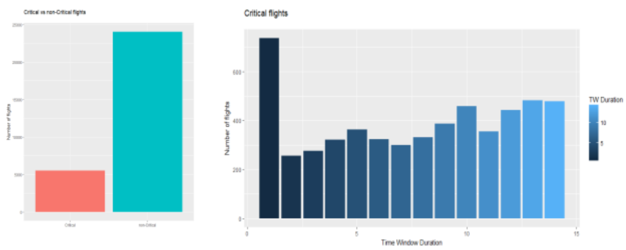

Figure 1. Critical versus non-critical flights and the distribution of flights across TWs of duration <15 minutes.

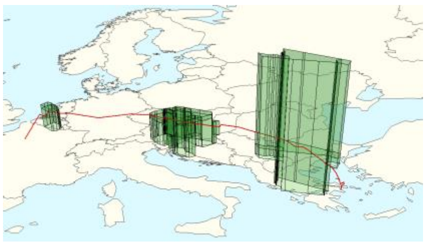

Figure 2. Flight LGAV-LFPO, TW of 1 minute and the constraining sectors (visualisation source: Eurocontrol's NEST).

IV. NEXT STEPS

To assess the ESFP models, the ADAPT project will:

1) Define metrics in support of the development and assessment of the ADAPT solution:

a) A (strategic) measure of the (economic) risk of hotspots, to give information on how likely a hotspot identified strategically can be one on the day of operations, and what consequences it would bring.

b) Statistically robust metrics on sector level to be used in the assessment efforts. In this respect three metrics are being considered:(i) **di-FORK**: to measure the deviations from the original flight plans at the trajectory level, and using it to identify portions of airspace where deviations occurr more or less frequently than expected. (ii) **Complexity metrics**: use of metrics that measure congestion in relation to several operational aspects of air traffic management. (iii) **Percolation**: adaptation of a technique used to investigate congestion at the level of urban mobility to the air traffic management context.

2) Provide a thorough assessment (validation) of the ADAPT solution in the tactical setting, from two points of view:

a) **Network-wide assessment**, where simulations of the entire European network will be performed to understand whether the proposed TWs are meaningful from an operational point of view. This will be done by using the ADAPT strategic solution trajectories as an input to the tactical layer of the ELSA [3] simulator to identify whether the conflict detection and resolution operations can be performed within the assigned TWs, and how frequent are they.

b) **Flight-centric assessment**, where fuel consumption and arrival delay of individual flights are considered. We determine the influence of weather conditions on the punctuality of the flight at sector entry. We consider ensemble wind forecasts, from ECMWF available 1 day in advance of the day of the flight execution. A forecast consists of 50 ensembles which are created by running the forecast with slightly different initial conditions.

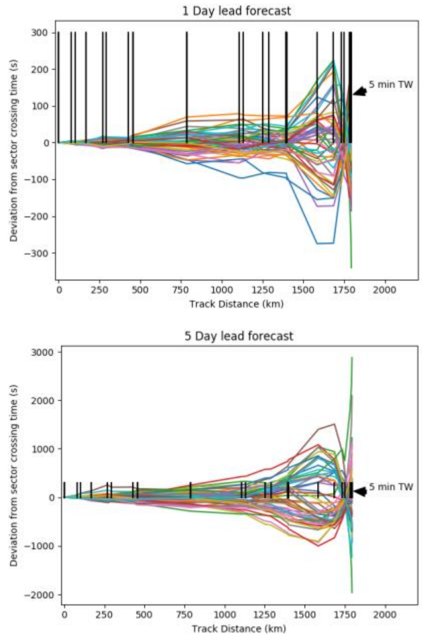

Figure 3. Deviation from sector crossing time in case of 1 day (top) and 5 day lead forecast.

Fig. 3 shows the deviations from the nominal sector entry times as a function of the track length under the influence of uncertainty in the weather, relative to a TW of 5 minutes for each sector entry (vertical, black lines). For a forecast of 1 day before the day of the execution, a TW with width of 5 minutes is sufficient to accommodate the uncertainty associated with the wind forecast.

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