Optimal aircraft scheduling and routing at a terminal control area during disturbances

In this paper authors considers the real-time problem of aircraft scheduling and routing. A main task of traffic controllers is to mitigate the effects of severe traffic disturbances on the day of operations in the Terminal Control Area (TCA) of an airport. When managing disturbed take-off and landing operations, they need to minimize the delay propagation and, in addition, to reduce the aircraft travel time and energy consumption. The paper tackles the problem of developing effective decision support tools for air traffic monitoring and control in a busy TCA.

An increasing problem that air traffic controllers have to face is the growth of traffic demand while the availability of new airport resources is very limited. Aviation authorities are thus seeking methods to better use the infrastructure and to better manage aircraft movements in the proximity of airports, improving aircraft punctuality and respecting all safety regulations.

To the purpose of developing effective monitoring tools, centralized and rolling horizon traffic control paradigms are implemented and compared. The mathematical formulation is a detailed model of air traffic flows in the TCA based on alternative graphs, that are generalized disjunctive graphs. As for the aircraft scheduling and (re-)routing approaches, the First In First Out (FIFO) rule, used as a surrogate for the dispatchers behavior, is compared with various optimization-based approaches including a branch and bound algorithm for aircraft scheduling with fixed routes, a tabu search algorithm for aircraft re-routing, and a mixed integer linear programming formulation for simultaneous scheduling and routing. Various hypothetical disturbance scenarios are simulated for a real-world airport case study, Milano Malpensa, and the proposed timing and routing approaches are compared in terms of their performance in the different scenarios. The disturbed traffic situations are generated by simulating multiple delayed landing/departing aircraft and a temporarily disrupted runway. In general, the optimization approaches are found to improve the solutions significantly compared to FIFO, in terms of aircraft delay minimization. However, there are some trade-offs involved in picking the right approach and paradigms for practical implementations.

In this paper, the ATC-TCA problem is modeled as a generalized job shop scheduling problem and is formulated via alternative graphs, that are able to enrich the model of [8] by including additional real-world constraints, such as holding circles, time windows for aircraft travel times, multiple capacities of air segments and single capacity constraints at runways. A single capacity resource is also named a blocking resource, since their must be at most an aircraft at a time processed on this type of resource. This formulation allows accurate modeling of future air traffic flows on the basis of the actual aircraft positions and speeds, and safety constraints. In addition, authors use the alternative graph to obtain a new Mixed Integer Linear Programming (MILP) formulation for the ATC-TCA problem, including all scheduling and routing alternatives. The proposed approach is used to study severely disturbed traffic situations, such as multiple landing and/or departing delayed aircraft and temporarily disrupted runway.

The test bed is the Milan Malpensa terminal control area (MXP). The experiments are executed on processor Intel Core 2 Duo E6550 (2.33 GHz), 2 GB of RAM and Windows XP operative system. The MILP formulation is solved by the IBM LOG CPLEX MIP 12.0 solver.

The models variants are solved by the two frameworks (centralized and rolling horizon) and the four approaches (FIFO, BB for scheduling with default routes, BB +TS for scheduling and re-routing, the MILP formulation for simultaneous scheduling and routing).

Some approaches are not reported for the following reasons. FIFO very often failed to compute a feasible schedule. The MILP approach in the centralized framework was never able to find a feasible schedule. The problem to compute a feasible schedule in presence of a disruption becomes more difficult than for the delay instances, since a runway is disrupted and all aircraft have to be scheduled in the only available runway. Authors next compare the results of the three model variants, the two frameworks and the feasible approaches in terms of the indicators related to optimality, computation time, violations and delay minimization.

This paper investigates the potential of using optimization-based approaches as decision support for air traffic control at a busy TCA, including the management of strong traffic disturbances (such as multiple aircraft delays and a temporarily disrupted runway). Centralized and rolling horizon frameworks are evaluated on a Italian practical case study, i.e. Milano Malpensa (MXP). For both frameworks, authors analyzed the performance of a commonly used rule (i.e. the FIFO rule), a branch and bound algorithm for aircraft scheduling, a tabu search algorithm for iterative aircraft scheduling and re-routing, and a new MILP formulation for simultaneous aircraft scheduling and routing. They also compared the performance of the various approaches for three model variants, with some differences in the objective function and in the set of constraints.

Ongoing research is dedicated to the study of closed-loop decision support systems for traffic control, in which the length of the roll and look-ahead periods changes dynamically and information is updated in real-time. Other research directions are dedicated to the development of more efficient/effective re-ordering and re-routing algorithms, and to the investigation of multi-objective optimization approaches.