Robust and Dynamic Airline Scheduling

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Airline flight and crew scheduling problems, with inherent complexity arising from their large-scale nature and tight coupling of their various elements, are ideal candidates for the application of optimization techniques. Conventional optimization techniques, however, often include simplifying and unrealistic assumptions, such as deterministic model inputs. These simplifications lead to the generation of solutions that lack *robustness,* thereby:

1. creating the need to re-plan at regular intervals when realized operations do not match those for which the plan was developed; and

2. resulting in added costs and increased complexity of operations.

In this research, we develop new models and algorithms aimed at providing *robust* solutions. These robust approaches are designed to provide solutions that: 1) are less fragile to disruption; 2) are easier to repair if needed; and 3) optimize the *realized*, rather than *planned*, problem objective.

There are various approaches to dealing with uncertainties affecting planned routes and schedules. One approach is to allow operating conditions to be realized, and then respond to disruptions by altering the plan when the original plan is rendered non-operational. A more proactive approach is to anticipate potential plan disruptions in the planning stage, either by:

1. **Building *robustness* into the plan**; and/ or

2. **Dynamically altering the plan** to reflect the additional information available as the time of plan operation approaches.

Our research, as detailed below, is organized around these two strategies.

Robust Planning

Airlines typically construct their schedules assuming that every aircraft departure and arrival will occur as planned. Because this optimistic scenario rarely, if ever, occurs, plans are frequently disrupted and airlines incur significant costs to repair and operate the modified plans. To reduce the added costs and operational complexity that results from responding to disruptions, and to reduce the need to repair previously *optimized* plans, we develop optimization approaches aimed at generating *robust* solutions that require fewer repairs and minimize the sum of planned and recovery costs.

In developing our robust planning approaches, we pursue two different modeling directions, namely:

1. **We expand upon the parameterized, robust optimization methods presented by Bertsimas and Sim (2004) and Charnes and Cooper (1963).** In both the Bertsimas and Sim and Charnes and Cooper approaches, the robust optimization models contain *robustness parameters* that can be tuned to reflect the desired trade-off between cost and time. Achieving the desired trade-off can be accomplished by solving the optimization model repeatedly, each time with different values of the robustness parameters. Because we are interested in solving large-scale problems for which achieving multiple solutions can be impractical, we modify the Bertsimas and Sim and the Charnes and Cooper approaches to determine, in a single solution of the models, the most robust solution attainable for a given *robustness budget*. We define a robustness budget as the deviation from the optimal (deterministic) solution value that is allowed to provide a more robust solution. Like Bertsimas and Sim and Cooper and Charnes, we model our budget-constrained robust optimization model as a non-linear, integer program and show that there exists an equivalent linear, integer formulation.

2. **We expand on attribute-driven robust optimization approaches in which robust solutions are generated by identifying attributes of a robust solution.** (For a survey of these approaches in the airline industry, see Ball, et al. 2006). This is achieved through model modifications ensuring that optimal solutions are those for which the presence of these attributes is maximized. Using this attribute-driven robust optimization approach, we define new models for aircraft routing and scheduling.

In our research, we describe how attribute-driven robust optimization models can sometimes be cast equivalently in the framework of parameterized robust optimization models. We then develop algorithms tailored for the solution of these robust optimization models, especially for large-scale problem instances. Finally, we apply all of these parameterized and attribute-driven models and algorithms to a particular routing and scheduling problem arising in the airline industry, and evaluate the relative performance of the corresponding solutions using data obtained from airlines.

Dynamic Planning

A major source of uncertainty that affects plan robustness is, demand stochasticity. Demand stochasticity is a major challenge for carriers in their quest to produce profit maximizing schedules. Even with an *optimized* schedule, many aircraft upon departure have empty seats, while others suffer a lack of seats to accommodate passengers who desire to travel. We approach this challenge, recognizing that demand forecast quality for a particular operating date improves as the date approaches, by developing a dynamic scheduling approach that re-optimizes elements of the plan during the passenger booking process. The goal is to match capacity to demand, given the many operational constraints that restrict possible assignments. We introduce re-timing as a dynamic scheduling mechanism and develop re-optimization models that integrate re-timing and re-fleeting mechanisms. Our re-optimization approach, re-designing the plan at regular intervals, utilizes information from both booking data and forecasts available at the time of re-optimization. Using data provided by airlines, we demonstrate that significant potential profitability improvements are achievable using our approach. Moreover, we evaluate the sensitivity of our approach to the quality of the forecasted demands and show that, even with simplistic approaches to demand forecasting, estimated profit improvements can remain significant.

Finally, we compare and contrast the individual contributions of robust planning and dynamic scheduling techniques, and evaluate whether or not their effects are synergistic.

References

Ball, M., Barnhart, C., Nemhauser, G., and Odoni, A. (2006). "Managing Air Traffic and Airline Operations for Schedule Reliability," to appear in Operations Research Handbook on Transportation, Gilbert Laporte and Cynthia Barnhart (co-editors).

Bertsimas, D., and Sim, M., (2004). "The Price of Robustness", *Operations Research*, Vol. 52 (1) 35-53.

Charnes, A., Cooper, W.W., (1963). "Deterministic Equivalents for Optimizing and Satisficing under Chance Constraints", *Operations Research*, Vol. 11(1), 18-39.