OPTIMIZATION APPROACHES TO AIRLINE INDUSTRY CHALLENGES:

Airline Schedule Planning and Recovery

Cynthia Barnhart
Lavanya Marla
Massachusetts Institute of Technology

Hai Jiang
Tsinghua University

June 2009

The airline industry has a long history of developing and applying optimization approaches to their myriad of scheduling problems, including designing flight schedules that maximize profitability while satisfying rules related to aircraft maintenance; generating cost-minimizing, feasible work schedules for pilots and flight attendants; and identifying implementable, low-cost changes to aircraft and crew schedules as disruptions render the planned schedule inoperable. The complexities associated with these problems are immense, including long- and short-term planning horizons; and multiple resources including aircraft, crews, and passengers, all operating over shared airspace and airport capacity. Optimization approaches have played an important role in overcoming this complexity and providing effective aircraft and crew schedules.

Historical optimization-based approaches, however, often involve a sequential process, first generating aircraft schedules and then generating crew schedules. Decisions taken in the first steps of the process limit those that are possible in subsequent steps, resulting in overall plans that, while feasible, are typically sub-optimal. To mitigate the myopic effects of sequential solutions, researchers have developed *extended* models that begin to integrate some of the many decisions included in determining aircraft and crew schedules. Examples include Marsten et al. (1996), Lohatepanont and Barnhart (2001), Armacost, Barnhart and Ware (2002), which represent integrated models of flight schedule design and aircraft assignment; Clarke et al. (1996) and Barnhart, Lu and Shenoi (1998), which represent extensions of aircraft assignment models to include some of the downstream effects on crews; Desaulniers et al. (1997) and Barnhart et al. (1998), which are examples of aircraft assignment decisions integrated with considerations of aircraft maintenance requirements; and Klabjan et al. (2002), Cordeau et al. (2000) and Cohn and Barnhart (2003) are examples of approaches to integrate aircraft maintenance and crew assignment decisions.

Additional shortcomings of historical approaches stem from the embedded, simplifying assumption that future demands are known and deterministic. To overcome this issue, recent research on airline schedule optimization has led to new *dynamic scheduling approaches* in which schedules are adjusted during the booking period to reflect increased knowledge of booking patterns and to maximize the achievable total revenue. Dynamic airline scheduling approaches are presented in Etschmaier and Mathaisel [1984], Peterson [1986], Berge and Hopperstad [1993], Bish, Suwandechochai and Bish [2004], Sherali, Bish and Zhu [2005],

Dagstuhl Seminar Proceedings 09261
Models and Algorithms for Optimization in Logistics
http://drops.dagstuhl.de/opus/volltexte/2009/2188

and Jiang and Barnhart [2009]. By developing dynamic scheduling approaches in which flight departure times are slightly altered and aircraft assignments are swapped during the booking period, aircraft seats are provided where needed and schedule revenue capture is maximized.

Another strong assumption included in historical approaches is that aircraft and crew schedules are operated as planned. Recent research on airline schedule optimization has led to a set of new *robust optimization approaches* in which the stochastic nature of airline operations is modeled and *realized* schedule performance is optimized. Although researchers define robustness differently, there is general agreement that a robust solution should reduce the vulnerability of the system. Some researchers define a robust plan as one for which there is a reduced need to re-plan because the plan more frequently remains feasible even as uncertain parameters assume their specific values. Several such metrics exist to measure robustness, with many tailored to the problem under consideration and to reflect its specific vulnerabilities to uncertainty. In the airline industry, crew sickness, mechanical failures and adverse weather result in necessary changes to the planned schedule, often leading to significantly increased costs. In fact, these costs can escalate when the disruptions occur to a finely tuned, optimized schedule with increased utilization levels and less slack to absorb the resulting impacts. To address this, researchers have developed a different planning paradigm, one that considers unplanned, disruptive events and attempts to minimize *realized* (not simply planned) costs. Efforts aimed at this objective include Ageeva (2000), Rosenberger, Johnson and Nemhauser (2004), Schaefer et al. (2005), Chebalov and Klabjan (2001), and Lan, Clarke and Barnhart (2006).

References

Ageeva, Y. 2000. *Approaches to incorporating robustness into airline scheduling.* S.M. thesis, Massachusetts Institute of Technology, Cambridge, MA.

Armacost, A., C. Barnhart, and K. Ware. 2002. Composite Variable Formulations for Express Shipment Service Network Design. *Transportation Science, Focused issue on Freight Transportation* **36** 1-20.

Barnhart, C., F. Lu, and R. Shenoi. 1998. Integrated Airline Scheduling. *Operations Research in the Air Industry*, G. Yu (ed.), International Series in Operations Research and Management Science **9,** Kluwer Academic Publishers, Norwell, MA 384-403.

Barnhart, C., N. Boland, L. Clarke, E. Johnson, G. Nemhauser, and R. Shenoi. 1998. Flight String Models for Aircraft Fleeting and Routing. *Transportation Science* **32** 208-220.

Berge, Matthew E., and C.A. Hopperstad. 1993. Demand Driven Dispatch: A Method for Dynamic Aircraft Capacity Assignment, Models and Algorithms. *Operations Research* **41**, 1, 153-168.

Bish, E.K., R. Suwandechochai, and D.R. Bish. 2004. Strategies for Managing the Flexible Capacity in the Airline Industry. *Naval Research Logistics* **51**, 654-684.

Chebalov, S. and D. Klabjan. 2001. Robust Crew Scheduling: Move-up Crews. *INFORMS Annual Conference presentation, Miami FL.*

Clarke, L., C. Hane, E. Johnson, and G. Nemhauser. 1996. Maintenance and Crew Considerations in Fleet Assignment. Transportation Science **30** 249-260.

Cohn, A. and C. Barnhart. 2003. Improving Crew Scheduling By Incorporating Key Maintenance Routing Decisions. *Operations Research* **51** 387-396.

Cordeau, J., G. Stojkociv, F. Soumis, and J. Desrosiers. 2000. *Benders Decomposition for Simultaneous Aircraft Routing and Crew Scheduling.* Technical Report G-2000-37, GERAD, Ecole Polytechnique de Montreal, Quebec Canada.

Desaulniers, G., J. Desrosiers, M.M. Solomon and F. Soumis. 1997. Daily Aircraft Routing and Scheduling. *Management Science* **43** 841-855.

Etschmaier, M.M. and D.F.X. Mathaisel. 1984. *Airline Scheduling: The State of the Art.* Presentation to AGIFORS Symposium, Strasbourg, France.

Jiang, H. and C. Barnhart. 2009. Dynamic Airline Scheduling. *Transportation Science*, published online before print DOI:10.1287/trsc.1090.0269.

Klabjan, D., E.L. Johnson, G.L. Nemhauser, E. Gelman, and S. Ramaswamy. 2002. Airline Crew Scheduling with Time Windows and Plane Count Constraints. *Transportation Science* **36** 337-348.

Lan, S., J.P. Clarke, and C. Barnhart. 2006. Planning for Robust Airline Operations: Optimizing Aircraft Routings and Flight Departure Times to Minimize Passenger Disruptions. *Transportation Science* **40**, 1, 15-28.

Lohatepanont, M. and C. Barnhart. 2004. Airline Schedule Planning: Integrated Models and Algorithms for Schedule Design and Fleet Assignment. *Transportation Science* **38** 1, 19-32.

Marsten, R.E., R. Subramanian, and L. Gibbons. 1996. *Junior Analyst Extraordinaire (JANE): Route Development at Delta Airlines.* Presentation in AGIFORS Symposium, Atlanta GA.

Peterson, R.M. 1986. *The Penultimate Hub Airplane.* Internal Memo, Boeing Commercial Airplane Group, Seattle, WA.

Rosenberger J., E.L. Johnson, and G.L. Nemhauser (2004). A robust fleet-assignment model with hub isolation and short cycles. *Transportation Science* 38, 357-368.

Schaefer, A. J., E.L. Johnson, A.J. Kleywegt and G. L. Nemhauser (2005). *Airline crew scheduling under uncertainty. Transportation Science* **39** 340-348.

Sherali, H., E.K. Bish, X.Zhu. 2005. Polyhedral Analysis and Algorithms for a Demand-Driven Refleeting Model for Aircraft Assignment. *Transportation Science* **39**, 3, 349-366.