Robust Scheduling

Yana Ageeva
John-Paul Clarke
Massachusetts Institute of Technology
International Center for Air Transportation

Philosophy

- If you like to drive fast, … it doesn't make sense getting a Porsche in Manhattan if the roads aren't freshly paved and the lights aren't correctly synchronized …
- The infrastructure must be in place if an airline schedule is to be robust to disruptions.

Introduction

- **Airline Operations contribute to ATC problems**
  - **Hub Complexes create peaks in the demand for ATC services**
  - **Regional Jets require resources used by larger jets**
- **ATC problems affect airline operations**
  - **Congestion and weather disrupt schedule**
- **Negative interactions between ATC and Airline Operations could be “Achilles’ heel” to growth**
  - **Growing resistance by communities to airport expansion**
  - **Increased demand not being met by increased capacity**
  - **Systems operating at capacity often have large delays**
- **Practical solutions required in the short and long term**

Background

- **Optimality is achieved by maximizing revenue and minimizing cost during schedule planning**
- **Potential irregularities in airline operations are not adequately considered**
  - **Many schedules assume no irregularities (i.e. delays due to severe weather, ATC, crew & equipment failure) occur in actual operations**
- **"Optimal" schedules, once deployed, are affected by irregularities and are far from optimal in practice**
  - **Irregularities result in > $400 million per year in lost revenue for a major U.S domestic carrier**

Solution Approaches

- **Existing Solutions**
  - **Add constant turn-time buffers**
  - **Develop real-time decision-making tools to reschedule flights and crews, and reroute aircraft.**
- **Build robustness into the schedule during the schedule design process**
  - **Sub-Route Switching**
  - **Passenger Flow Redundancy**
  - **Optimized Connection Timing**

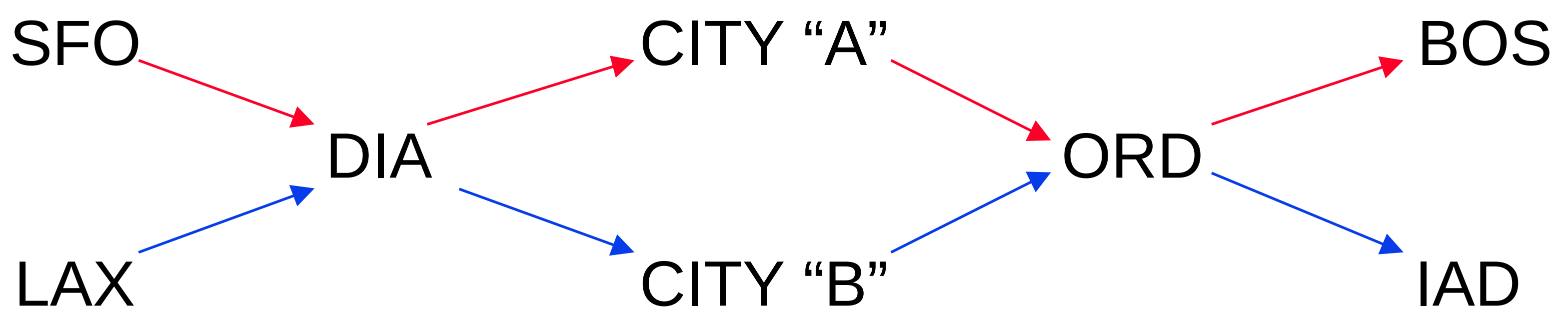
MIT ICAT

Sub-Route Switching

- If two routings overlap at more than one node within a certain time window, an aircraft can be switched from one routing to the other and then returned to its original routing at a subsequent overlapping node
- Thus, if a flight is severely delayed or cancelled and the relative demand for the routing is favorable, route switching can provide robustness by allowing a flight with high demand to be flown when it otherwise would not be flown

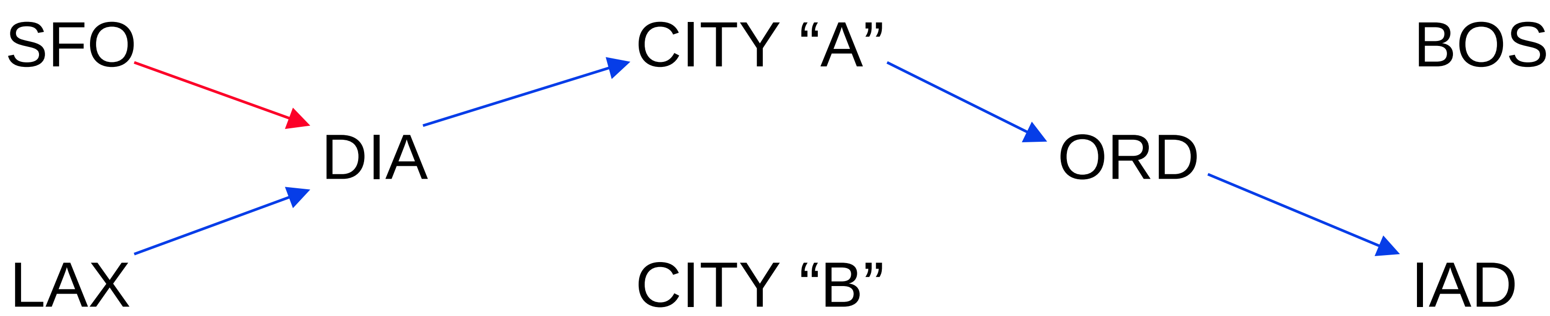
Example Problem

- **Two strings passing through two hubs**



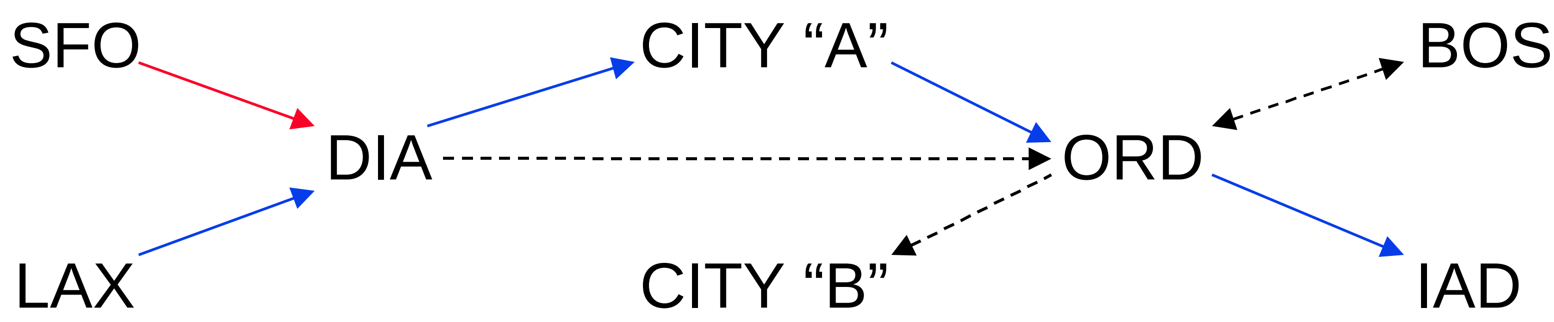
Sub-Route Switching

- **Moved from nominal routing at pre-assigned location**
- **Switched to other sub-routing affected by disruptions**
- **Returned to nominal routing at pre-assigned location**



Passenger Flow Redundancy

- **Incorporate redundant paths for passenger itineraries**
  - **Cancellation of legs does not fatally impact the movement of passengers from origin to destination**
  - **Example: ensure alternative routing for passengers affected by potential flight delays and cancellations**



Optimized Connection Timing

- **Develop optimised aircraft connection times at airline hubs**
  - **Move from FIFO connections to connections that reflect the distribution of expected connection times**
  - **Use historical data to determine probability likelihood and severity of delays during specific hub complexes**
  - **Give flights connection times based on the expected value for delay**

Implementation Phases

- **Aircraft Maintenance Routing**
  - **Mathematically easiest phase**
  - **Limited opportunities to change strings**
- **Aircraft Maintenance Routing + Fleet Assignment**
  - **Mathematically harder phase**
  - **Provides more opportunities to change strings**
- **Aircraft Maintenance Routing + Fleet Assignment + Schedule Generation**
  - **Mathematically challenging (yet to be done)**
  - **Provides the most opportunities to change strings**

Aircraft Maintenance Routing Implementation

- **Add increases in overlap between aircraft routings as an objective in the aircraft routing optimization**
  - **Hard**
- **Add overlap to column generation**
  - **Difficult to implement in OPL Studio**
- **Save multiple solutions and determine robust solution via post-processing**
  - **Optimality curve relatively flat**
  - **Many options to chose from**
  - **Appears to be very promising**

OPL Aircraft Maintenance Routing Model

- **Aircraft maintenance routing(MR) problem normally used to solve 3-day 1-fleet MR**
- **Uses constraint programming as a sub-problem algorithm for linear programming column generation**
- **Each column represents a "routing": a potential set of flights to be flown by an aircraft**
- **Master problem must find a set of routings that covers every flight at a minimum cost, does not use more airplanes than are available, and maintains aircraft flow balance**
- **Particular kind of set partitioning problem**

Sequence Storage

- As new columns (sequences) are generated, they are added to the routeFlt array (Open Flight routeFlt[int+, int+]), which is an open (expandable) array whose first dimension represents sequence numbers, and second dimension represents flights in each sequence
- Thus, Kth flight in sequence i is stored in routeFlt[i,k]; For efficiency and complexity reasons, flight sequences are also stored in an array referenced by flights, i.e. each flight is associated with sequence numbers which contain that flight

Inclusion of Robustness

- After an optimal IP solution is obtained, the OPL Script iterates through the IP model and obtains a number of alternative optimal solutions which have the same cost as the original optimal solution
- Accomplished by incorporating a new constraint into the IP at every iteration:
  - sum_{i \in prev_sol} pair[s_i] < sum{i \in prev_sol} 1,
  - where s_i is column i, prev_sol is the set of columns (i's) which make up the solution at the last iteration, pair[s_k]=1 if column s_k is selected to be in the IP solution, and is 0 otherwise;
- Robustness of alternative optimal solutions generated inside OPL Studio are compared using a C++ program

Inclusion of Robustness (2)

- The idea is to count the number of "overlaps" for each point on every sequence in a solution
  - Point defined as the interval of time that an airplane spends at an airport between arrival and departure
  - Thus, points are defined by time and airport
- P1' > P1 if P1' is later in the sequence than P1, an overlap occurs at point P1 for sequence s1 if there exists a sequence s2 such that s2 meets s1 within a certain interval of time of P1 and also meets s1 at a later point P2 within a certain time interval
- Sequence is "robust" if for every point on the sequence there exists an overlap

Inclusion of Robustness (3)

- **Goal is to minimize P-A**
  - where P=number of potential overlaps, A=number of actual overlaps
- **Complexity of finding pairs avoided by storing sequences by airport and departure time at every point**
  - Each airport is associated with a number of time intervals that cover 24 hours (1440 minutes)
  - For each airport (A)-time_interval(T) combination, there is a linked list of sequences which are present at A at time interval T
- **Every sequence is referenced in the linked lists as many times as there are points on that sequence**
- **Pairs found by looking at the linked list**

MIT ICAT

Results: Network with 22 Flights

	Time Window (mins)				
Solution	20	30	40	50	60
Robust	0.0	0.0	18.0	18.0	18.0
Baseline	0.0	0.0	15.8	15.8	14.2
Improvement	0.0	0.0	2.2	2.2	3.8

Results: Network with 26 Flights

	Time Window (mins)				
Solution	20	30	40	50	60
Robust	12.0	12.0	27.0	27.0	27.0
Baseline	8.2	8.2	16.6	16.6	15.6
Improvement	3.8	3.8	10.4	10.4	11.4

Results: Network with 37 Flights

	Time Window (mins)				
Solution	20	30	40	50	60
Robust	8.0	13.0	19.0	19.0	21.0
Baseline	4.6	10.4	13.8	13.8	14.4
Improvement	3.4	2.6	5.2	5.2	6.6

MIT ICAT

Summary

- **Negative interactions between ATC and Airline Operations could be "Achilles' heel" to growth**
- **Practical solutions required in the short and long term**
- **Robust scheduling offers a means of reducing airline schedule disruption**
- **Improvements in terms of "possibilities to switch aircraft" can be achieved without loss in optimality**
- **May not be a panacea but addresses the interaction between ATC and Airline Operations**