Optimization Models for Off-loading Flow Constrained Areas

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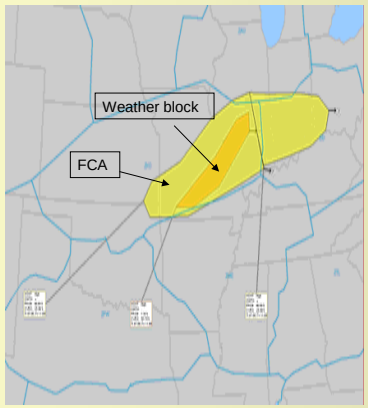
Introduction

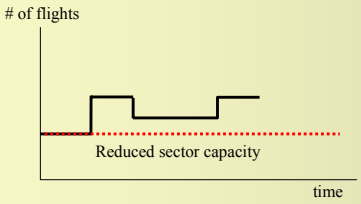
The Federal Aviation Administration (FAA) and the aviation community within the U.S. have recently raised new operational concepts for identifying, implementing and managing Flow Constrained Areas (FCA) based on Collaborative Routing (CR). The main purpose of the study is to determine how the FAA can meet its objectives while giving NAS users as much flexibility as possible when choosing routes.

What is a Flow Constrained Area (FCA)

- 3-dimensional volume of airspace associated with a time interval.
- FCAs are defined in response to
  1) severe weather
  2) capacity/demand imbalance due to excess demand.



Reduced capacity during FCA for a sector



Problem

Given:

- Starting and ending times of FCA
- A set of involved flights *F*
- Entrance and exit times for each flight at each sector
- The reduced sector capacity in this FCA area.

Goal:

Partition the involved flights into two groups:

1) maintain original routes,
2) reroute outside this area

Multi-Objective Integer Programming Model

Given: *P* total number of involved flights.

a_i number of involved flights for airline company *i*.

$$\sum_i a_i = P$$

Decision variables:

x_f = 1, if this flight stays in this area, 0 otherwise.

y_i = number of offloaded flights for airline company *i*.

r_i = target allocated number of flights for airline company *i*.

Objectives: (1) ***Efficiency***: $\text{Max}\sum_f x_f$ or $\text{Min}\sum_f (1 - x_f)$

(2) ***Equity***: $\text{Min} \sum_i | y_i - r_i |$

Main Constraints:

Reduced capacity: $\sum_{f \in U_{j,k}} x_f \le c_k \quad \forall j, \forall k$

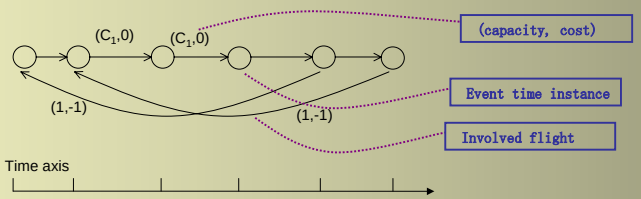
Flight conservation: $\sum_{f \in A_i} x_f + y_i = a_i \quad \forall i$

Target allocation: $r_i = a_i \sum_i y_i / P \quad \forall i$

Alternative Network Flow Model

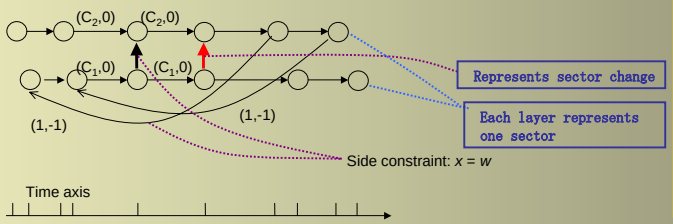
1. Single sector case

The underlying matrix is totally unimodular (TU) **and** problem can be efficiently solved as a pure network flow model.



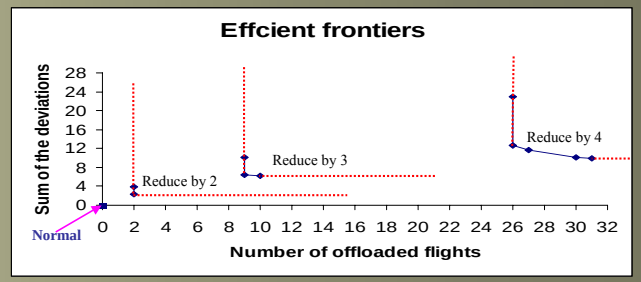
2. Multiple sector case

The underlying matrix is not totally unimodular (TU) **but** problem can be solved as a network flow model with side constraints.



Computational Results

- FCA consists of 31 sectors, involving 45 airline companies/classes associated with 283 flights.
- Data has maximum simultaneous number of flights of 7, and the reduced capacity changes from 3 to 5.



Ongoing Research: Stochastic Model

Goal:

- Give flexibilities to airline companies
- Improve system efficiency and take into account the uncertainty and dynamics of demand on FCAs.

Two-stage decision procedure:

- Flexibility: give tokens to airline companies for some flights in the first stage.
- Utilization: assign the rest time resource to maximize system utilization.

Mathematical model:

Decision variables:

X_f=1 if the flight is pre-allowed to use FCA, 0 otherwise

Y^{ϕ}_f = 1 if the flight is adjusted to pass the FCA under scenario ϕ while X_f=0; 0 no adjustment.

Objectives: (1) ***Predictability***:$\text{Max}\sum_f x_f$

(2) ***Utilization***: $\text{Max}\sum_f w_f x_f + \sum_f \sum_\phi p^\phi y^\phi_f$

Main Constraints:

Reduced capacity

$$\sum_{f \in U_{j,k}} x_f + a^\phi_f y^\phi_f \le c_k \quad \forall k, \forall j, \forall \phi$$