RATION-BY-DISTANCE WITH EQUITY GUARANTEES:
A NEW APPROACH TO GROUND DELAY PROGRAM PLANNING AND CONTROL

Michael O. Ball, University of Maryland
Robert Hoffman, Metron Aviation
Avijit Mukherjee, UC Santa Cruz
Adverse Weather at an Airport and Ground Delay Program Planning

**ISSUES:**

- *How to absorb the necessary delay?*
  - Delay before aircraft takes-off?
  - Delay while airborne?
- *How to hedge against uncertainty?*
- *Equity*
Ground Delay Programs

delayed departures

delayed arrivals/
no airborne holding

delayed departures

delayed departures

control = flight departure time
decision variable = flight arrival time (slot)
GDP Planning as Assignment Problem

Obj Fcn:
- Min total delay?
- Min $\sum_{f} w(f) \text{ delay}(f)$

total delay: easy
others: do not reflect flexibility provided by Collaborative Decision Making processes
Many Delay Minimizing Solutions

d(f,s) = delay of assigning flight f to slot s
= time(s) – sched_time(f)

If x(f,s) is assignment variable then:
Tot delay = \sum_{s,f} d(f,s) x(f,s)
= \sum_s \text{time}(s) - \sum_f \text{sched\_time}(f)

➤ total delay only depends on the flights involved and the slots used
  ➤ “usually” all slots are used but in general there is a unique delay-minimizing set of slots
➤ there are many delay-minimizing solutions
Equity Considerations: Ration by Schedule (RBS)

For each slot in order of increasing slot time:

- of all eligible flights that have not yet been assigned,
- choose flight with earlier scheduled arrival time

RBS can be viewed as a priority-based method where priority is based on the published schedule; it was developed and accepted by the FAA and airlines after many “war-gaming” exercises; it has many desirable properties from an equity perspective.
GDPs under Collaborative Decision Making (CDM)

Resource Allocation Process:

• FAA: initial “fair” slot allocation
  [Ration-by-schedule]
• Airlines: flight-slot assignments/reassignments
  [Cancellations and substitutions]
• FAA: periodic reallocation to maximize slot utilization
  [Compression]
Viewed from a *deterministic perspective* the overall process achieves three key objectives:

– **Efficiency**: solution used maximizes throughput/minimizes total delay.

– **Equity**: schedule-based fair-allocation mechanism used; accepted by all parties.

– **CDM**: airlines provided with ability to internally reallocate slots among their own flights.

But ….

things are not quite so rosy when one considers an uncertain world.
Typical Weather Events

— with uncertainty

A common case

Start of weather “event”

End of weather “event”

SFO case
**Intuition:** assigning delay to short haul flights allows for quicker reaction to changing events

- GDP planners hate to give delay to long-haul (3 ½ to 5 hr) flights
  - must ground delay these flights 4 to 6 hours in advance of their arrival ⇔ much uncertainty regarding weather so far in advance

- Practical approach:
  - assign as little delay as possible to long-haul flights ⇔ if necessary can always assign delay (or extra delay) to close-in/short haul flights.

- Another point of view: if short haul flight is assigned a delay and the weather clears then it can launch and quickly get to the airport to take advantage of released capacity.

A “blind” application of RBS does not take these considerations into account and it can be shown that “pure” RBS does not in general minimize expected delay.
“Traditional” Approach: Tier-Based GDPs (flight exempted based on Tiers): local, 1st tier, 2nd tier, all centers
New Options: Distance Based GDPs (flights outside distance band exempted): "optimize" over distance – two objective functions expected delay and equity
Impact of long-haul priority

Scenario: 2 flights have appx same scheduled arrival time; under GDP one must be delayed

A: short haul has priority

B: long haul has priority

Cancellation times:

- No delay
- Some delay

Revised after Cancellation?

Any cancellation time that allows savings under A also allows savings under B;
Many allow savings only under B
Ration by Distance (RBD)

For each slot in order of increasing slot time:
- of all eligible flights that have not yet been assigned,
  choose flight with longest distance (time) from dest airport.

Thm: For each possible program cancellation time, RBD minimizes total delay.
→ RBD minimizes total expected delay.
SFO Experiment: RBS vs RBD -- Total Delay for Various GDP cancellation times

GDP Cancellation Time

Total Delay (minutes)

- RBS Allocation for GDP End Time at 11:00
- RBD Allocation for GDP End Time at 11:00
Is RBD Equitable?

Consider:

– 4 hr GDP
– Flight A: short-haul, e.g. 1 hr, early in program
– Flight A would receive lowest priority and be assigned a slot late in the program ➔ delay of 3+ hrs
– *This would clearly be considered inequitable*
Measuring (and Controlling) Equity

RBS: has been accepted as equity standard

⇒ makes sense to measure degree of inequity as deviation from RBS

Inequity for flight: $I(f)$:

RBS slot

\[ I(f) \]

assigned slot

\[ I(f) \]

\[ \text{Overall inequity } = I^* = \max_f \{I(f)\} \]
Equity-Based RBD (E-RBD)

Defn: $a_f = \text{sched arrive time for } f$; $L_f = \text{length (time or dist) of } f$

Step 0. Choose an equity deviation limit $I^*$.  

Step 1. Assign each airborne flight, $f$, to the slot closest to $a_f$ and remove these flights and slots from the respective lists. Assign each remaining included flight $f$ a temporary slot equal to its (unconstrained) RBS slot. Order the remaining $m$ flights by decreasing value of $L_f$.  

Step 2. For $f=1,2,...,m$: find the earliest slot $s_j$ such that the $f$-to-$s_j$ assignment/exchange is $I^*$-feasible; execute this exchange and permanently assign $f$ to $s_j$.  

E-RBD Illustration

Increasing slot time

<table>
<thead>
<tr>
<th>f_1</th>
<th>f_2</th>
<th>f_3</th>
<th>f_4</th>
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Ex 1:

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<tr>
<th>f_4</th>
<th>f_1</th>
<th>f_2</th>
<th>f_3</th>
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Ex 2:

<table>
<thead>
<tr>
<th>f_1</th>
<th>f_2</th>
<th>f_3</th>
<th>f_4</th>
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</thead>
</table>

Permanent slot: 

Temporary Slot: 

Ex 1: Ex 2:
Experimental Setup

Realistic flight schedule at SFO (data available from FAA’s ASPM database)

Depicting the “typical” morning fog burn-off case at SFO
- GDP implemented to reduce the demand in the morning hours from 9AM to 1 PM
- During the GDP arrival rate (or capacity) drop down to 30 per hour
- When GDP terminates, which can be either at the planned end time or earlier, the rates go up to 60 arrivals per hour
- Five possible GDP cancellation times: 9AM, 10AM, 11AM, noon, and 1PM (originally planned end time)
Performance of Distance-Based GDP planning (current approach)
Performance of E-RBD
Equity measures for RBS, RBD, and E-RBD

![Graph showing equity measures for RBS, RBD, and E-RBD](chart.png)
Efficient Frontiers for E-RBD and Distance-Based GDP Planning Algorithms

![Graph showing comparison between E-RBD and DB-RBS in terms of total delay vs. max. deviation from RBS slot.](image-url)
Summary

- Ration-by-distance (RBD) Algorithm maximizes expected throughput during a GDP (without requiring any explicit probability information).
- RBD “capped” with an inequity parameter (E-RBD) is a simple yet powerful algorithm to assign slots to flights.
- E-RBD functions similar to today’s distance-based flight exemption algorithm, but can produce solutions that are both more efficient and equitable.
- Equity can be much more explicitly controlled under E-RBD than under the current distance-based algorithm.