Improving Air Transportation Performance through Collaborative Decision Making

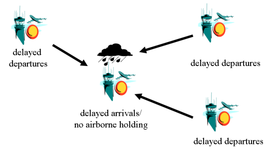
Michael O. Ball

ISR@25 The Institute for Systems Research
A. JAMES CLARK SCHOOL OF ENGINEERING

Slot Trading

Robert Hoffman, David Lovell, Avijit Mukherjee, Thomas Vossen,

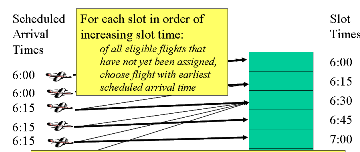
Ground Delay Programs



Collaborative Decision-Making

- Instead of an assignment of flights to slots, the CDM philosophy considers the allocation of capacity to be an allocation of slots to airlines.
- The Ration by Schedule algorithm generates an initial allocation of slots to airlines, based on the recognition that airlines (rather than the actual flight) have claims on the arrival capacity through the original flight schedules.
- Once arrival slots have been allocated, the Compression algorithm performs schedule updates by an inter-airline slot exchange, which aims to provide airlines with an incentive to report cancellations and delays.

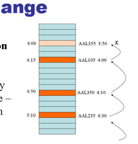
Ration-by-Schedule (RBS)



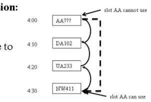
RBS can be viewed as a ***priority-based method*** where priority is based on the ***published schedule***; it was developed and ***accepted by the FAA and airlines*** after many "war-gaming" exercises; it has many desirable properties from an equity perspective.

Slot Exchange

Intra-Airline Slot Exchange -- Cancellation and Substitution Process: *slot-to-flight* allocation viewed as *slot-to-airline* allocation; airlines can reassign slots they "own" to their flights in any way possible – as part of process they may cancel certain flights.

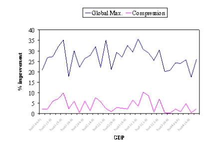


Inter-Airline Slot Exchange -- Compression: implements a type of inter-airline slot exchange in situation where airlines are assigned slots they are otherwise unable to use.



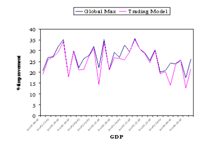
Compression Benefits

- compression executed after flights with excessive delay (>2hrs) are canceled



2-for-2 Trading Model

- proposed offers: all at-least, at-most pairs that improve on-time performance.

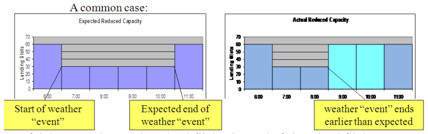


Modeling Uncertainty

Andrew Churchill, Robert Hoffman, David Lovell, Moein Ganji, Charles Glover, Avijit Mukherjee, Thomas Vossen, along with MIT

Uncertainty of Weather

A common case:



If delay was given to long haul flights instead of short haul flights, there may be no flights available to take off and land in the shaded region.

But since the airport can now handle more capacity, it is being under-utilized, and flights are being given UNNECESSARY DELAY!!!!!!!!

$$\text{Min} \sum_{t=1}^{T} (a_t y_t + c_t x_t + \sum_{q=1}^{Q} p_q r_t z_{tq})$$

subject to

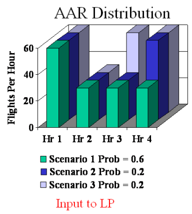
$$x_t + y_t - y_{t-1} = S_t \quad \text{for } t \geq 1, \ (y_0 = 0)$$
$$z_{t-1\,q} + x_t - z_{tq} \leq D_{tq} \quad \text{for } t \geq 1, \ q \geq 1, \ (z_{oq} = 0)$$
$$x_t, \ y_t, \ z_{tq} \geq 0$$

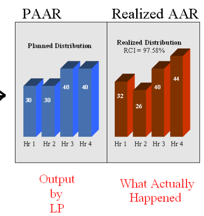
y_t = number of flights held on the ground from period t to $t+1$

x_t = number of flights that arrive during time period t

z_{tq} = number of flights held in the air from period t to $t+1$ under demand scenario q

AAR Distribution





Benefits of this Model

- It Outputs the aggregate number of flights that should be assigned CTAs for each hour.
- This allows for the individual flight CTA assignments to be done through a CDM technique.
- The constraint matrix of the IP is totally unimodular.

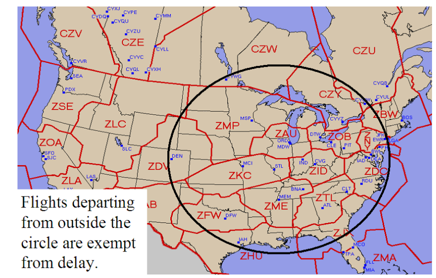
The Good and Bad of Today's Rationing Method (RBS)

Viewed from a ***deterministic perspective*** the overall process achieves three key objectives:

- **Efficiency:** solution used maximizes thru-put/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 the uncertainties associated with weather.



Flights departing from outside the circle are exempt from delay.

- Flights originating farther from the GDP airport must serve their ground delay several hours in advance.
- Overly pessimistic forecasts mean that some ground delay is served unnecessarily.
- By assigning greater proportion to the shorter-haul flights, ground delay decisions can be reactively adjusted, and the overall delays can be reduced, based on near term weather forecasts.

Modeling Equity

Charles Glover, Robert Hoffman, Thomas Vossen

Is RBS Equitable?

- RBS closely relates to well-established equitable allocation concepts:
  - RBS minimizes total delay.
  - RBS lexicographically minimizes the vector giving the distribution of flight delays
  - Also, for any flight k_1, the only way to decrease the amount of delay it receives from RBS is to increase the amount of delay given to another flight k_2 to a value greater than the amount of delay that k_1 receives
- These can be seen as fundamental notions of equity applied within the ATFM context.

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 — assigned slot

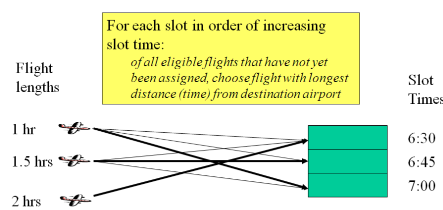
I(f)

Overall inequity = I* = Max$_f$ {I(f)}

or

Overall inequity = I* = $\sum_f$ I(f)

Ration-by-Distance (RBD)



Thm: *For each possible program cancellation time, RBD minimizes total delay.*

➔ ***RBD minimizes total expected delay***

GDPs with Weather Uncertainty

- $\min \sum_{k \in Flights} \sum_{i \in Slots_1} \sum_{j \in Slots_2} \sum_{t \in Scenarios} \left(q_t \left(time(j,t) - arr(k) \right) w_{k,i,j,t} \right)$

Minimize expected cost of reallocation.

$$\sum_{\substack{i \in Slots_1 \\ time(i) \geq arr(k)}} x_{k,i} = 1 \quad \text{for each flight } k$$

$$\sum_{\substack{k \in Flights \\ arr(k) \leq time(i)}} x_{k,i} + x_{s,i} \leq cap_1(i) \quad \text{for each arrival slot } i$$

$$\sum_{i \in Slots_1} x_{s,i} = \sum_{i \in Slots_1} cap_1(i) - |Flights|$$

This is the stage-one transportation problem.

$$\sum_{j \in Feas(k,i,t)} w_{k,i,j,t} + w_{k,i,d_t,t} = 1 \quad \text{for each } k,i,t$$

$$\sum_{k \in Flights} \sum_{\substack{i \in Slots_1 \\ j \in Feas(k,i,t)}} w_{k,i,j,t} + w_{s,i,j,t} \leq cap_2(j,t)$$

for each stage-two slot j and scenario t

$$\sum_{j \in Slots_2} w_{s,j,t} = \sum_{j \in Slots_2} cap_2(j,t) - |Flights| \quad \text{for all scenarios } t$$

$$\sum_{k \in Flights} \sum_{i \in Slots_1} w_{k,i,p,t} = \left| \left\{ (k,i) : \begin{matrix} k \in Flighs, i \in Slots_1 \\ \text{and } time(i) \geq arr(k) \end{matrix} \right\} \right| - |Flights| \quad \text{for all scenarios } t$$

These are the stage-two transportation problems.

$$w_{k,i,d_t,t} + x_{k,i} = 1 \quad \text{for all scenarios } t$$

These constraints link together stage-one and stage-two.

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Theorem: The (integer) output of the RBD Algorithm is an optimal solution to the LP relaxation of this formulation.