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

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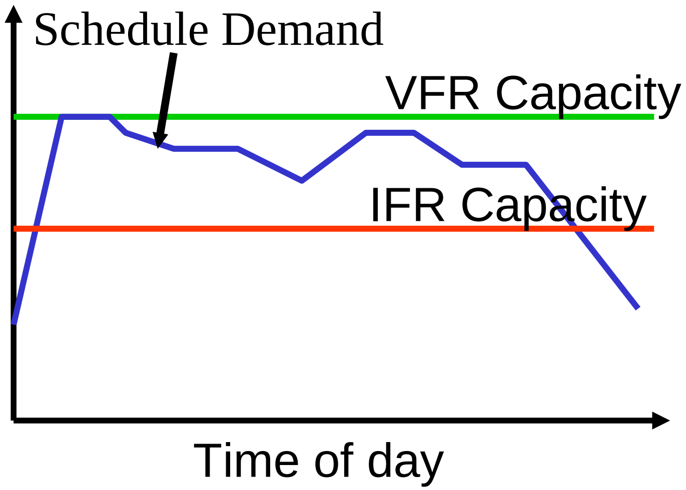
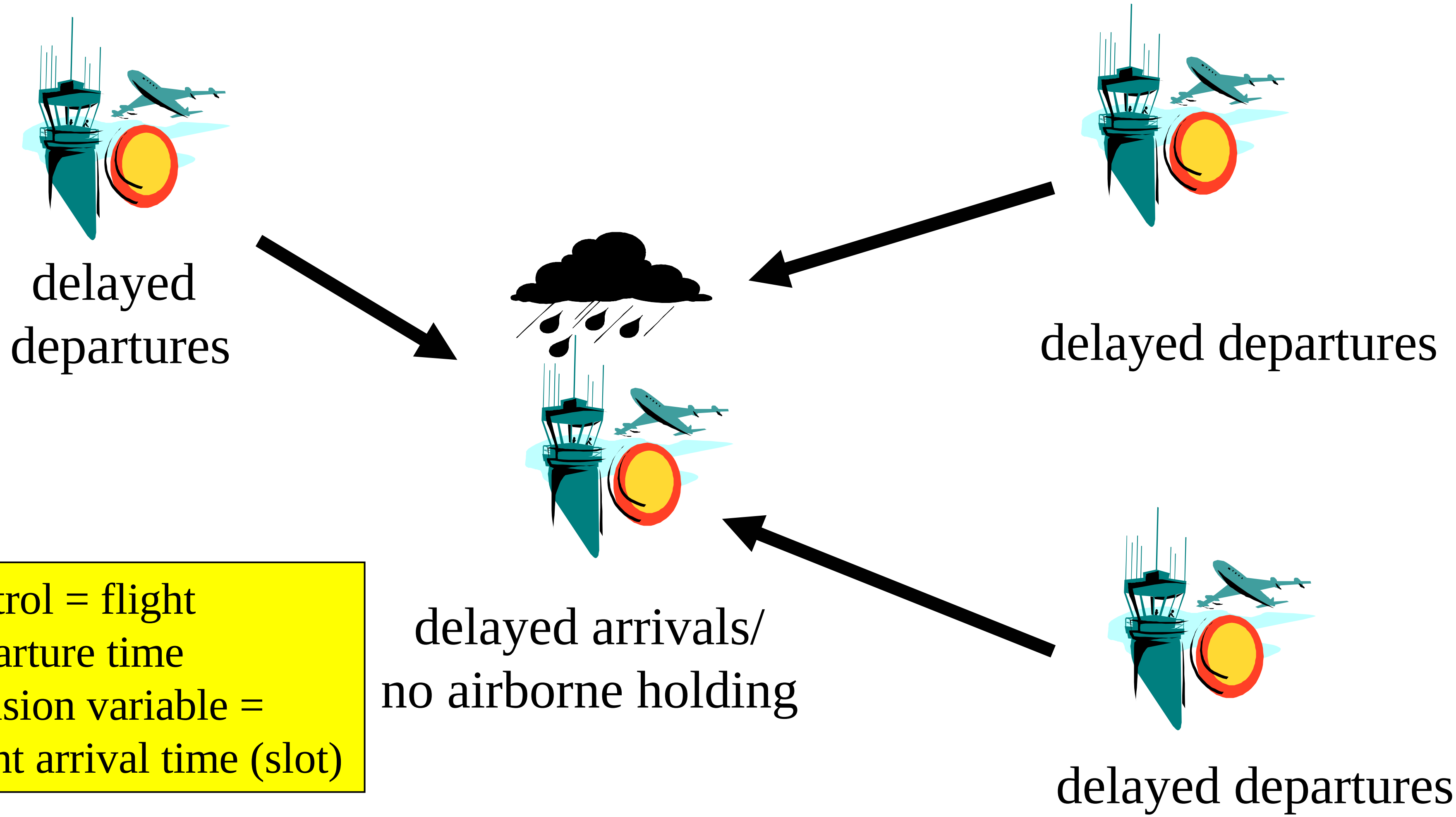
Adverse Weather at an Airport and Ground Delay Program Planning



ISSUES:

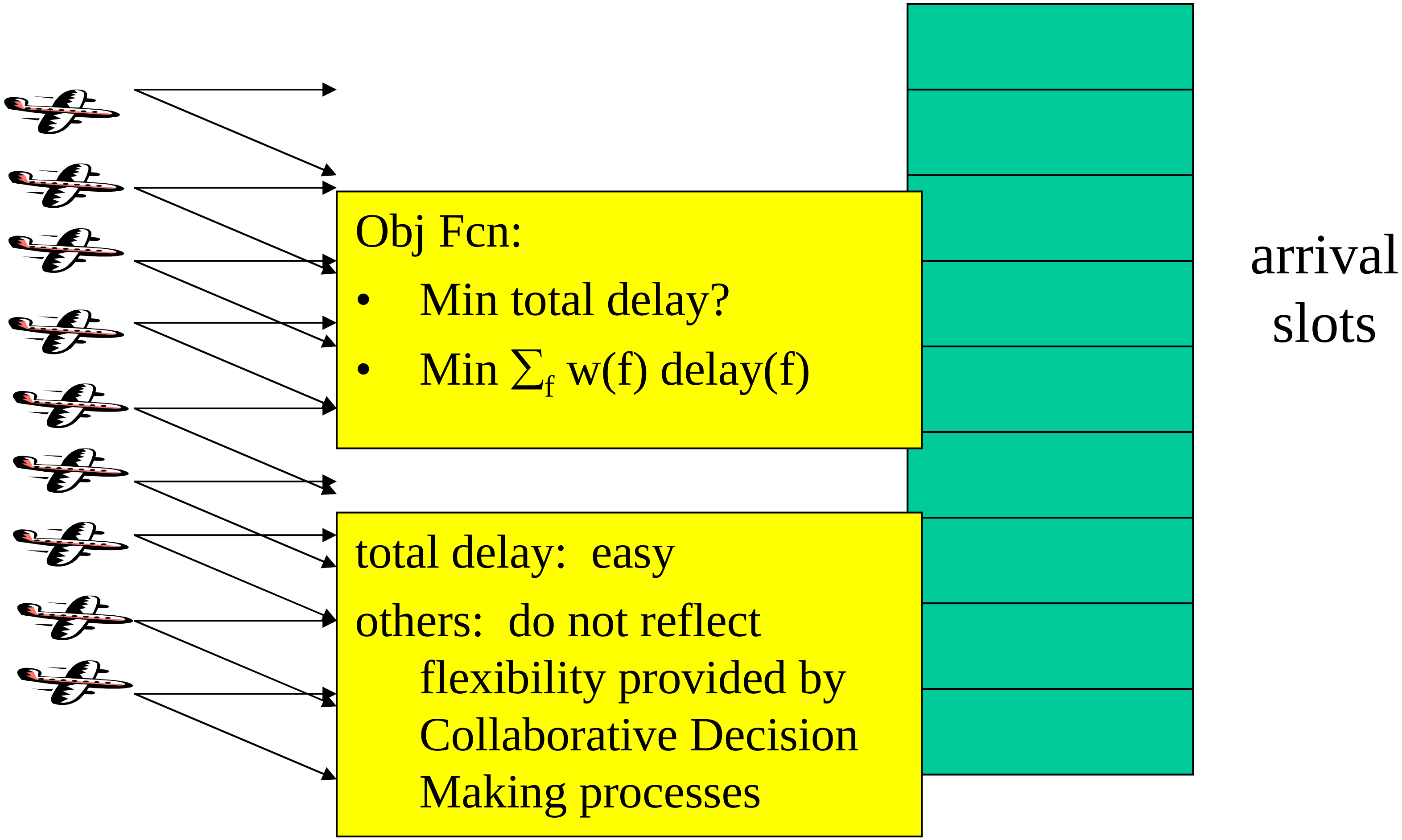
- *How to absorb the necessary delay?*
  - *Delay before aircraft takes-off?*
  - *Delay while airborne?*
- *How to hedge against uncertainty?*
- *Equity*

Ground Delay Programs



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) 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 $= \sum_{s,f} d(f,s)\, x(f,s)$

$= \sum_{s} time(s) - \sum_{f} sched\_time(f)$

➔ total delay only depends on the flights involved and the slots used

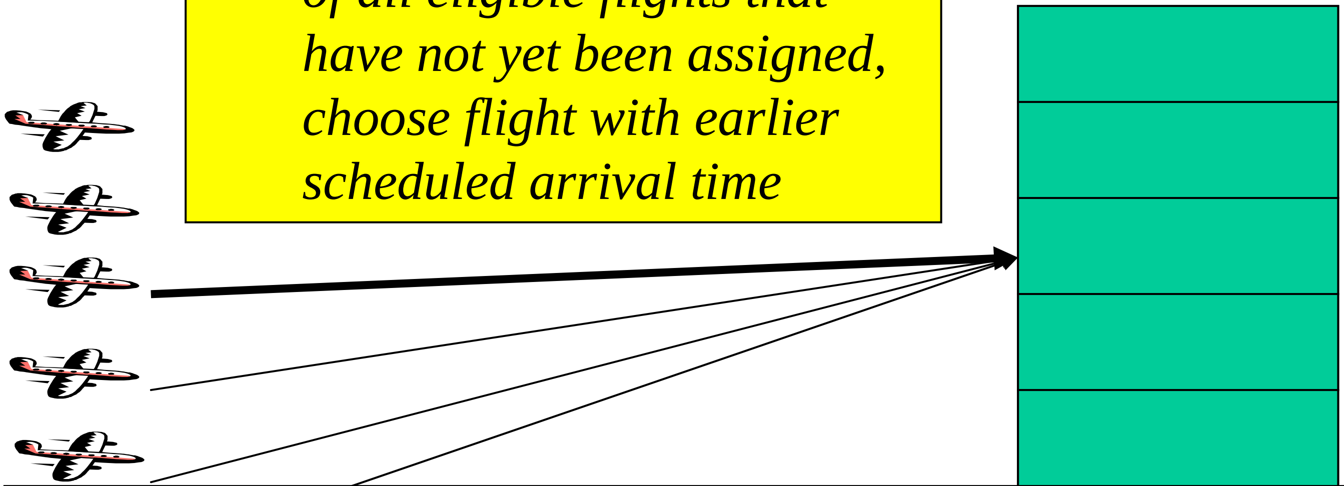
- ➔ "usually" all slots are used but in general there is a unique delay-minimizing set of slots

➔ 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]

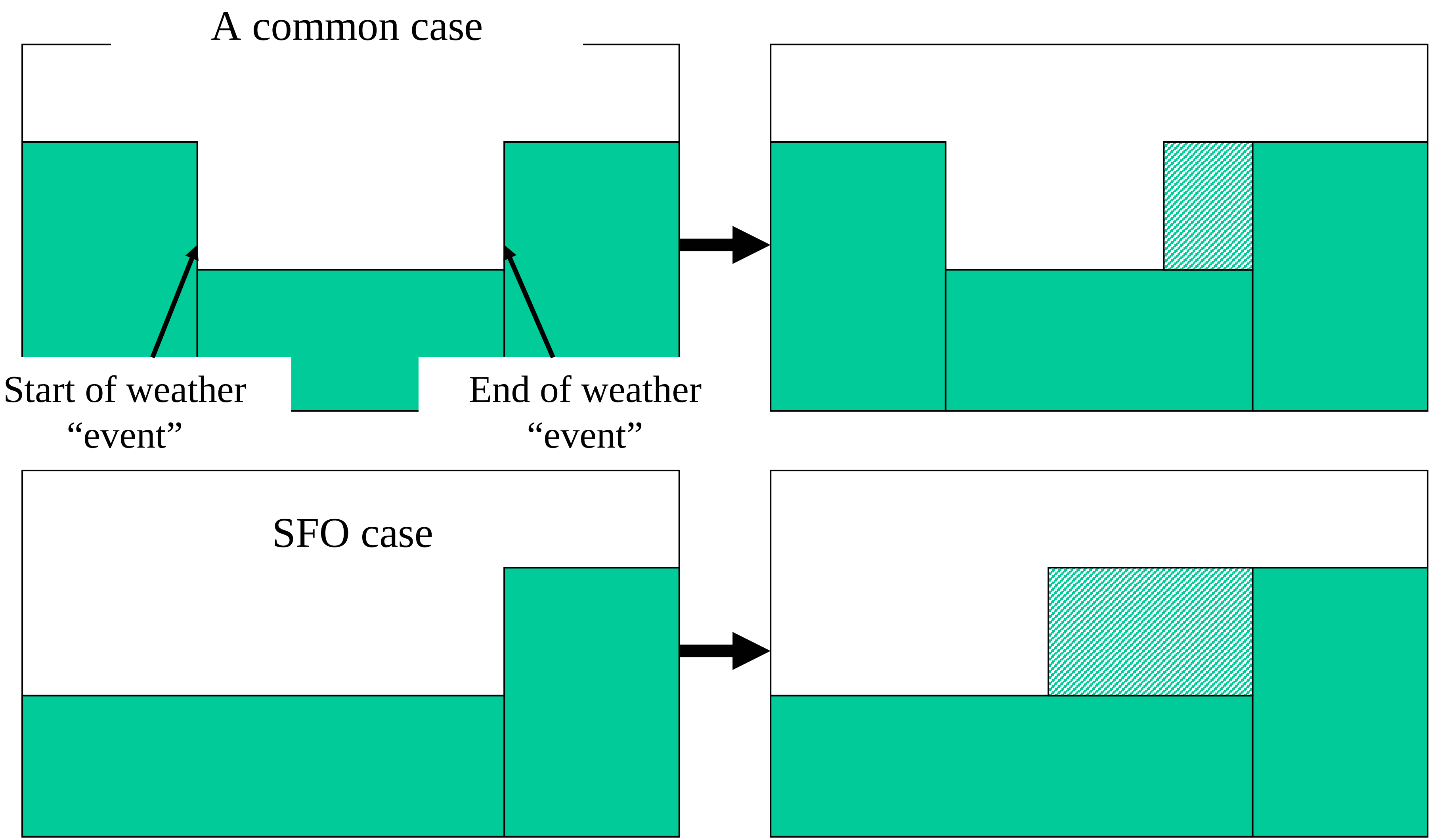
Viewed from a ***deterministic perspective*** the overall process achieves three key objectives:

- **Efficiency:** solution used maximizes 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 an uncertain world.

Typical Weather Events … with uncertainty

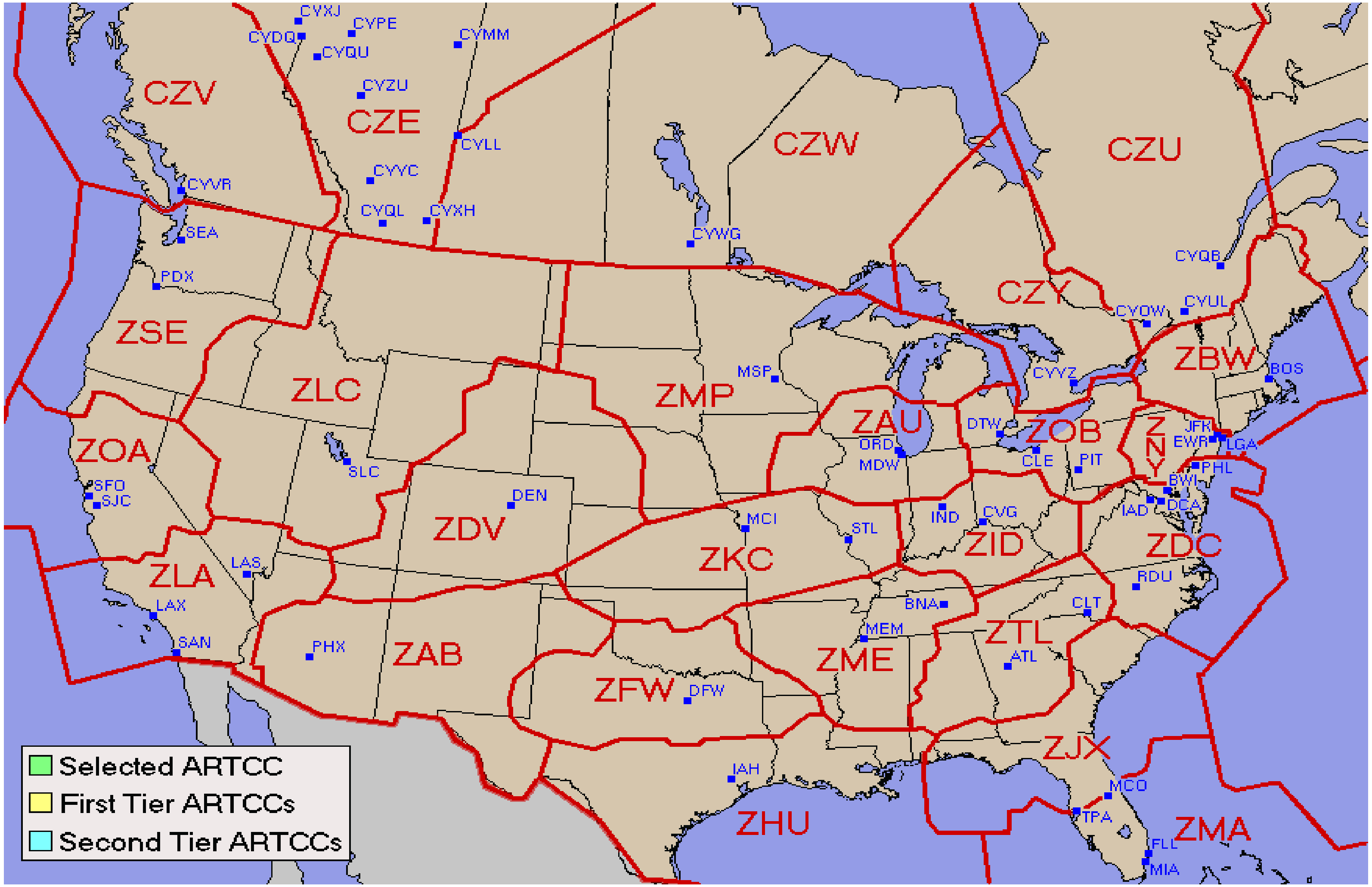


Intuition: assigning delay to short haul flights allows for quicker reaction to changing events

- 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.

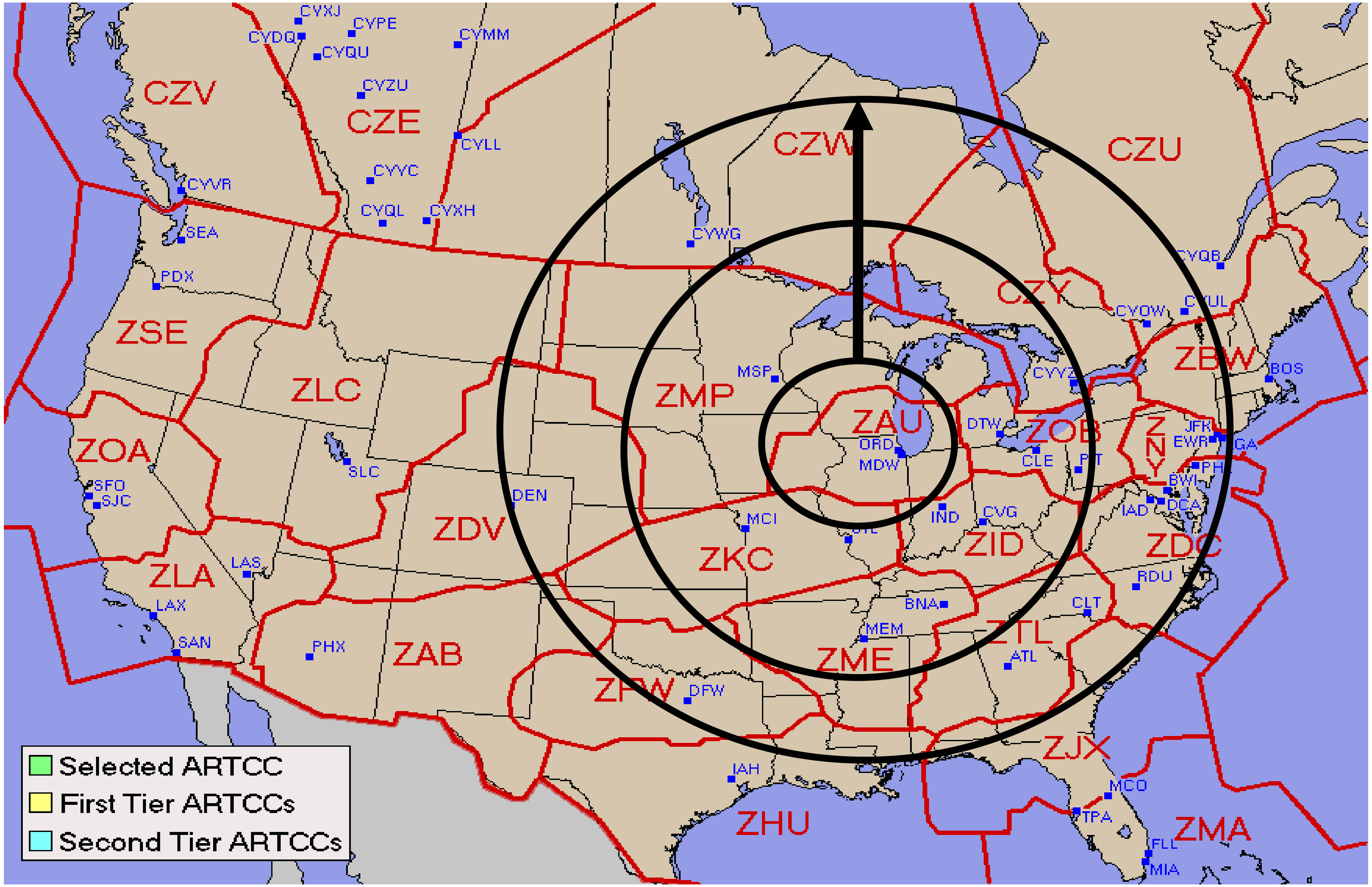
A "blind" application of RBS does not take these considerations into account and it can be shown that "pure" RBS does not in general minimize expected delay.

"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

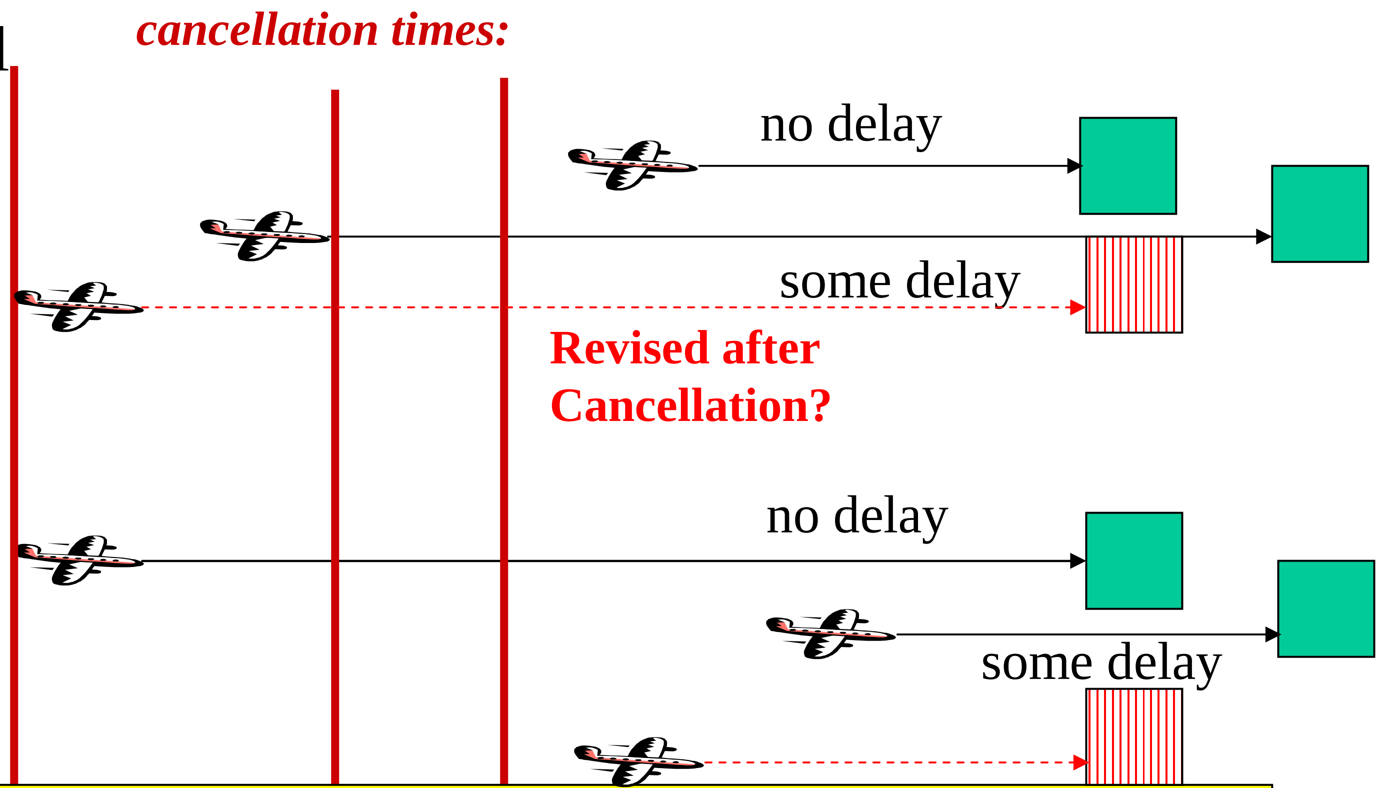


Impact of long-haul priority

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

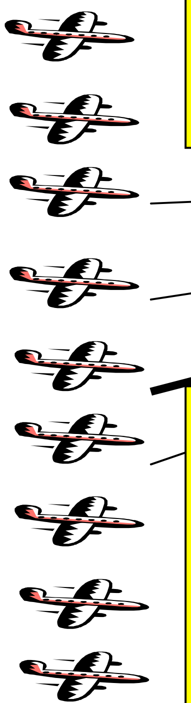


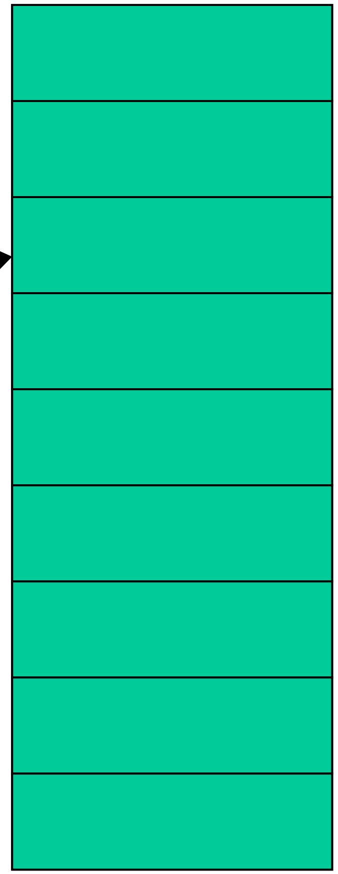
Any cancellation time that allows savings under A also allows savings under B;
Many allow savings only under B

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

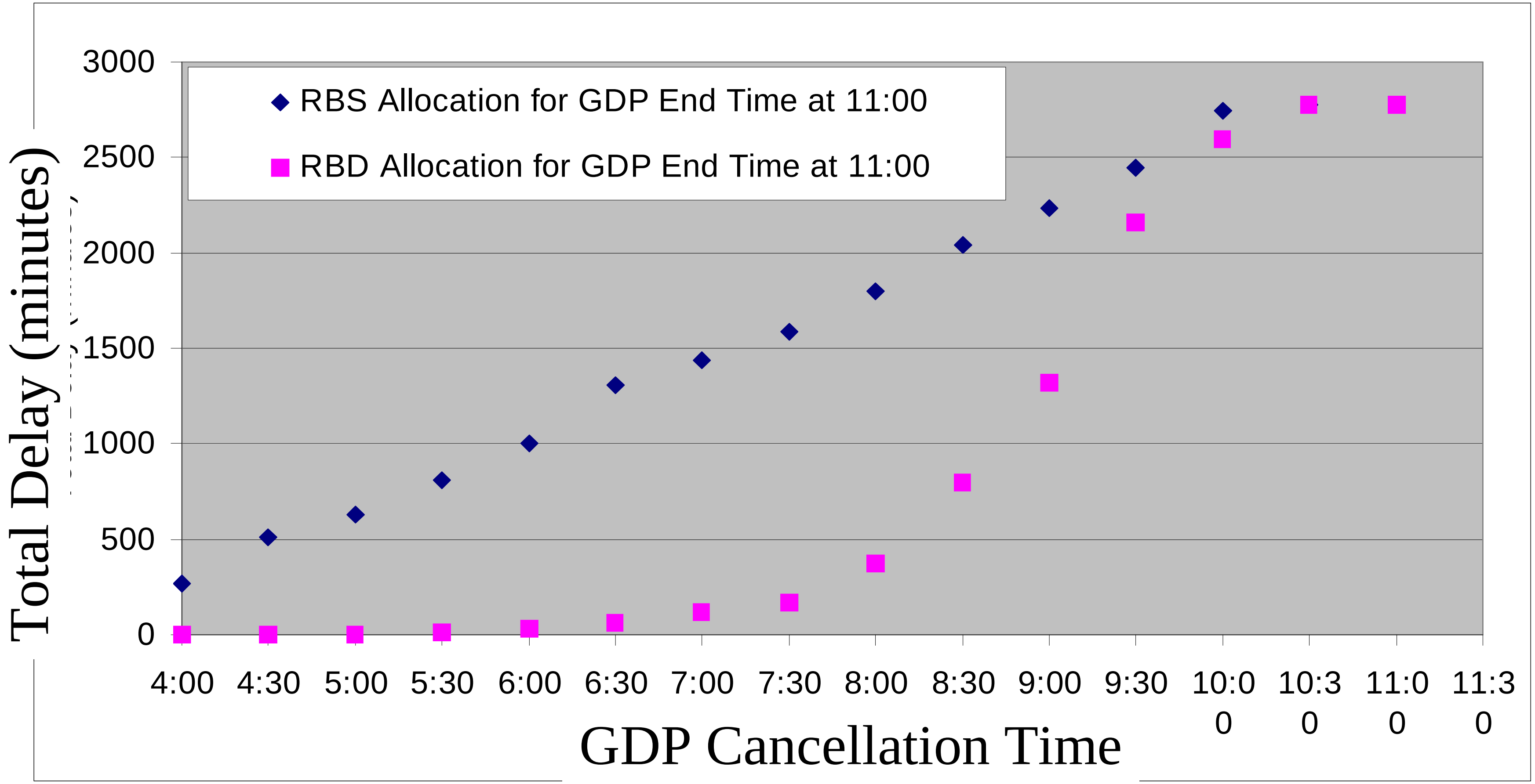




Thm: *For each possible program cancellation time, RBD minimizes total delay.*

➔ RBD minimizes total expected delay

SFO Experiment: RBS vs RBD -- Total Delay for Various GDP cancellation times



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***

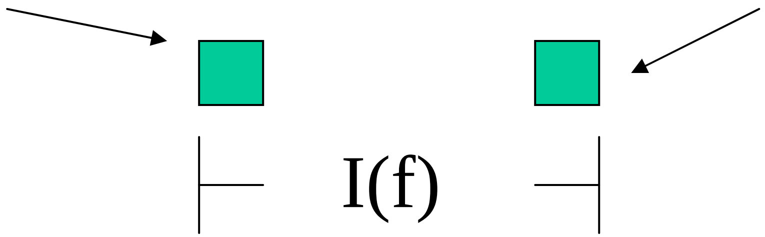
Measuring (and Controlling) Equity

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



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

Equity-Based RBD (E-RBD)

Defn: a_f = sched arrive time for f; L_f = length (time or dist) of f

Step 0. Choose an equity deviation limit I*.

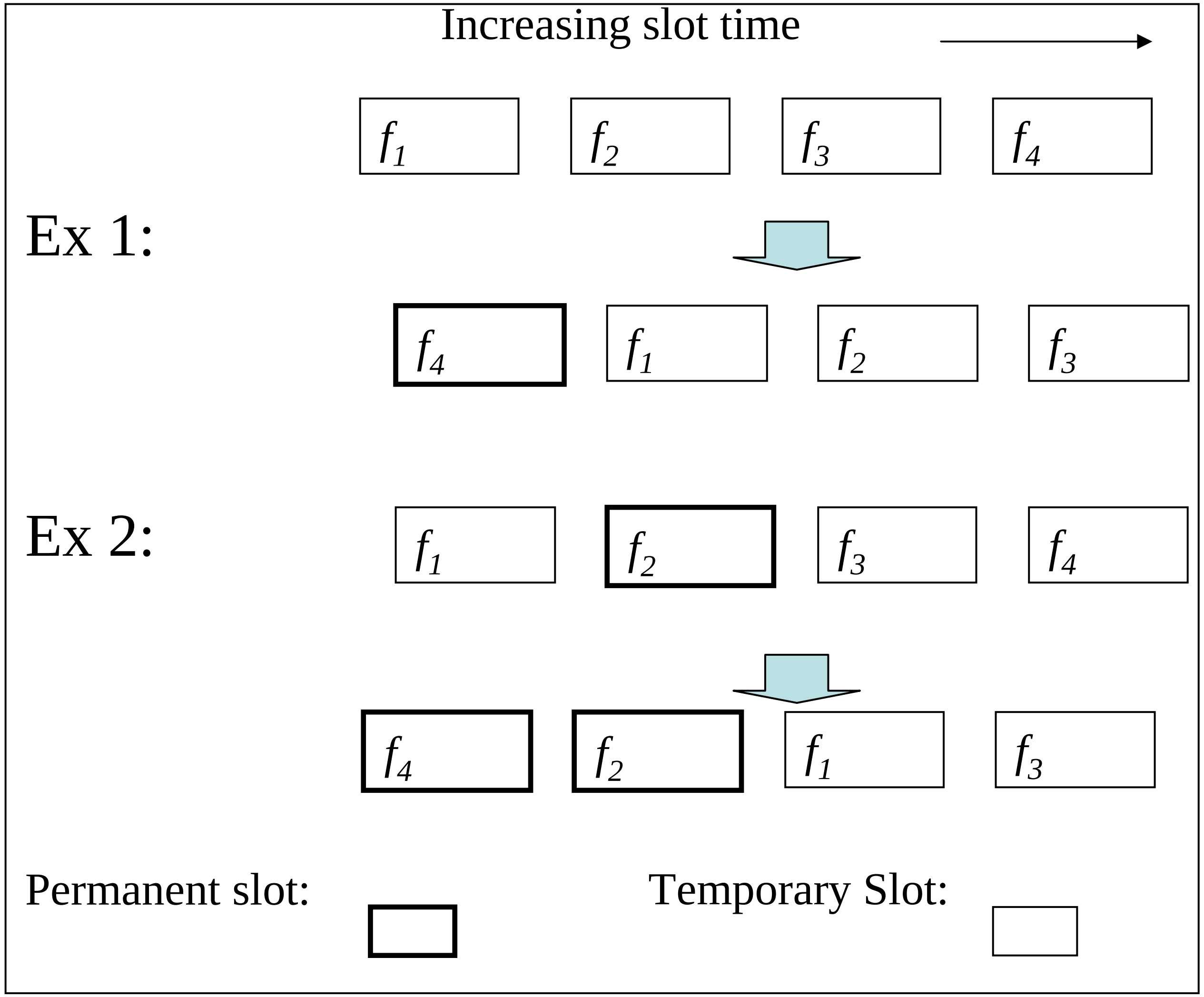
Step 1. Assign each airborne flight, *f*, to the slot closest to a_f and remove these flights and slots from the respective lists. Assign each remaining included flight *f* a temporary slot equal to its (unconstrained) RBS slot. Order the remaining m flights by decreasing value of L_f.

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



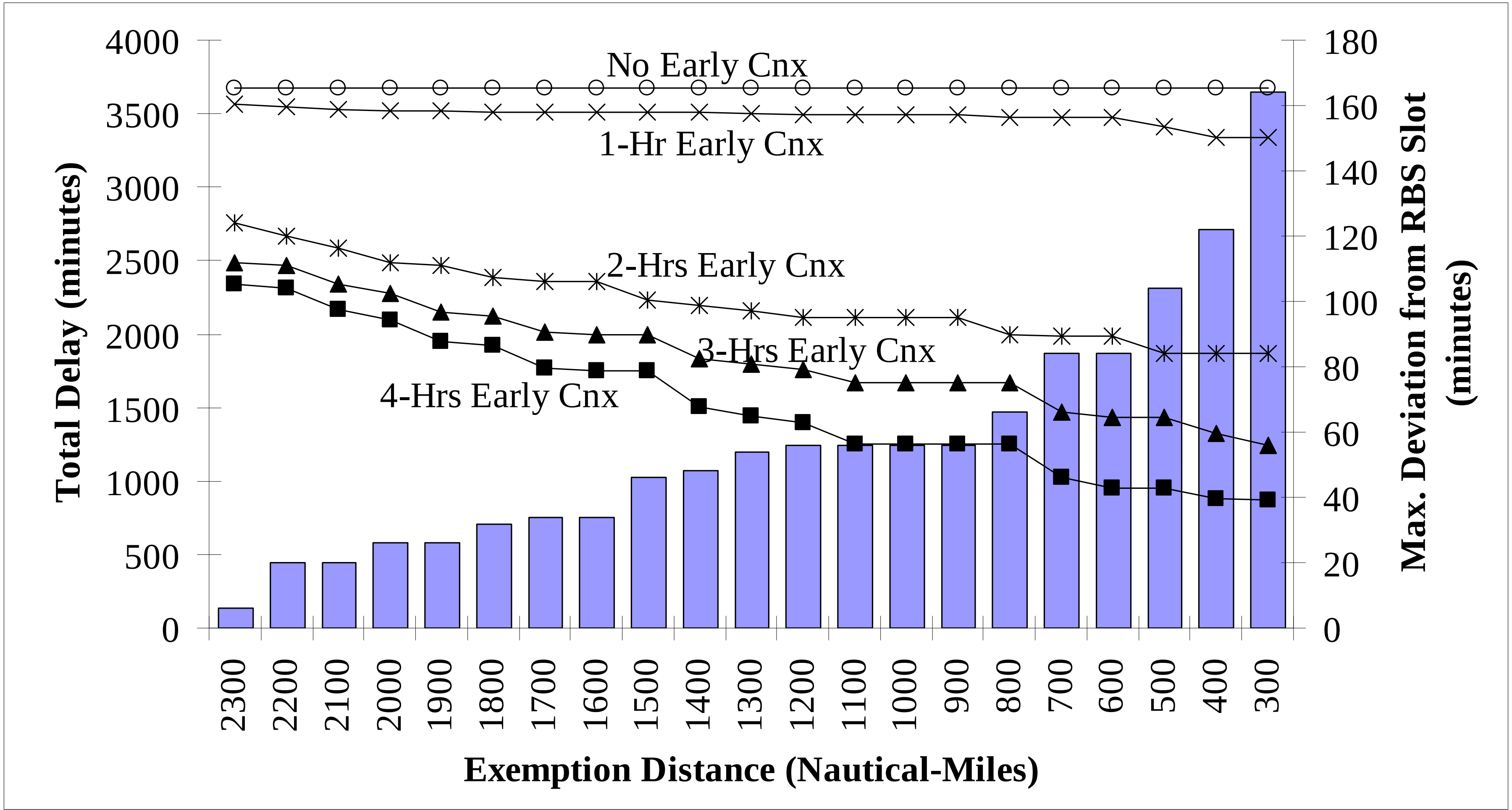
Experimental Setup

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

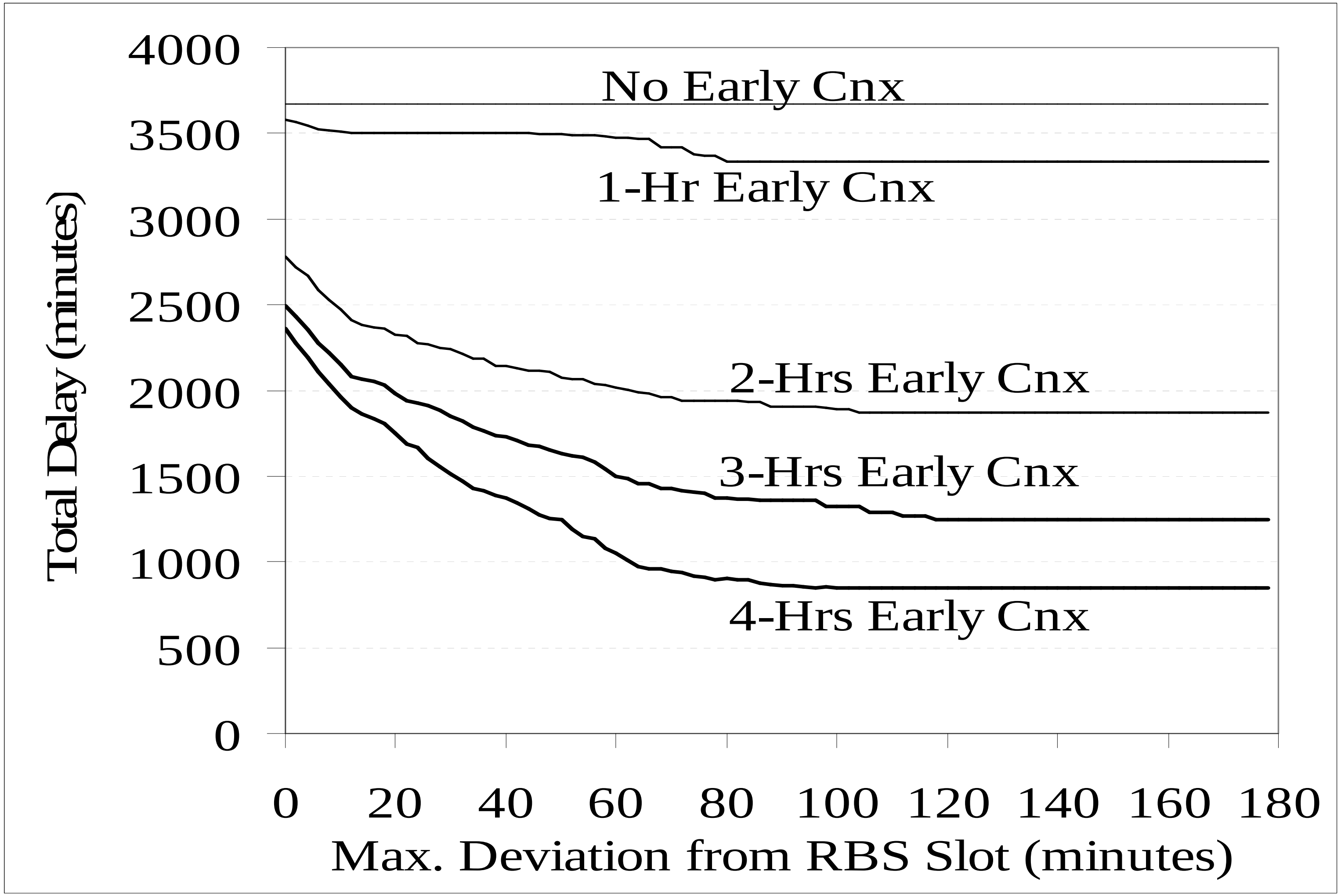
Depicting the "typical" morning fog burn-off case at SFO

- 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)

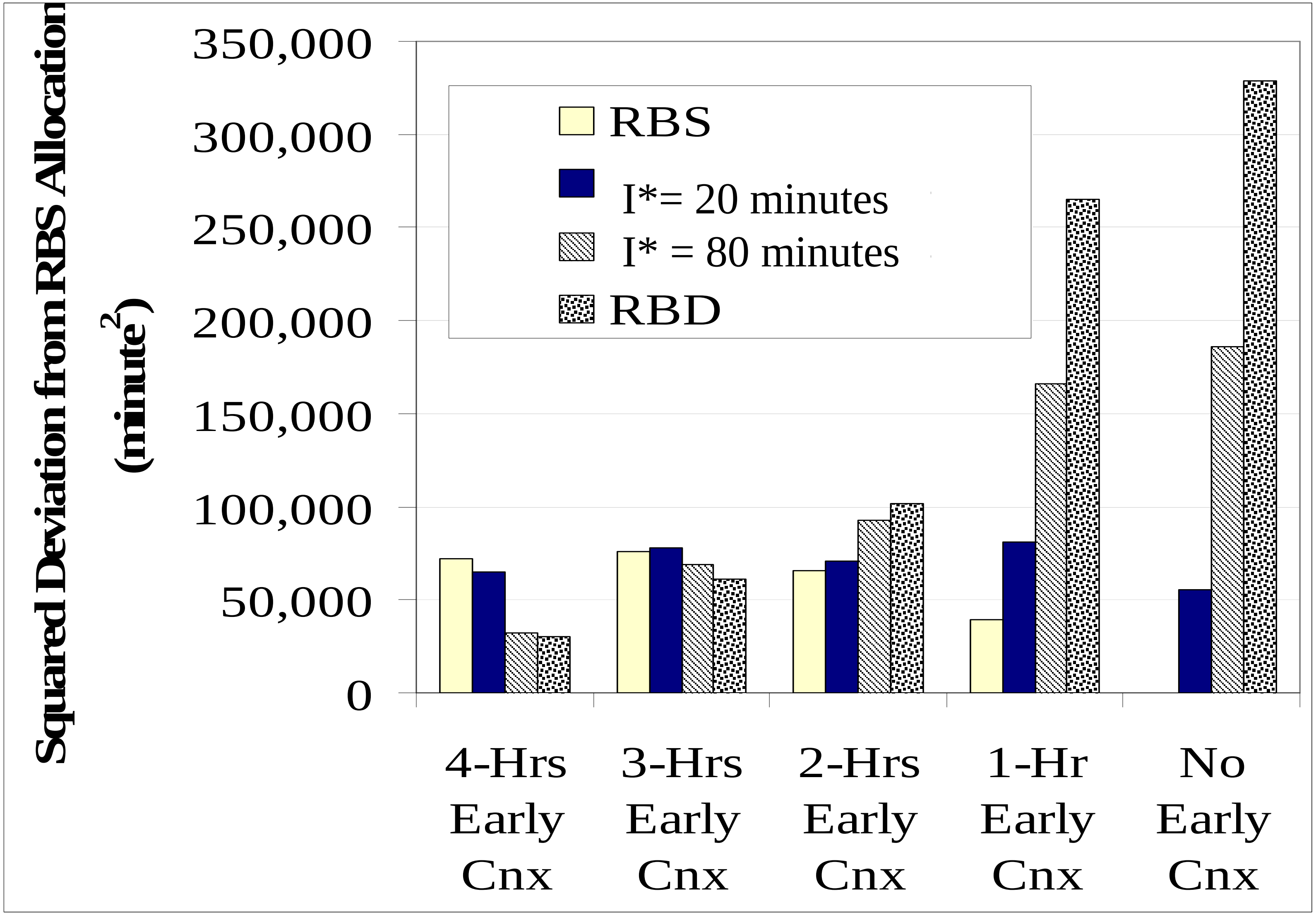
Performance of Distance-Based GDP planning (current approach)



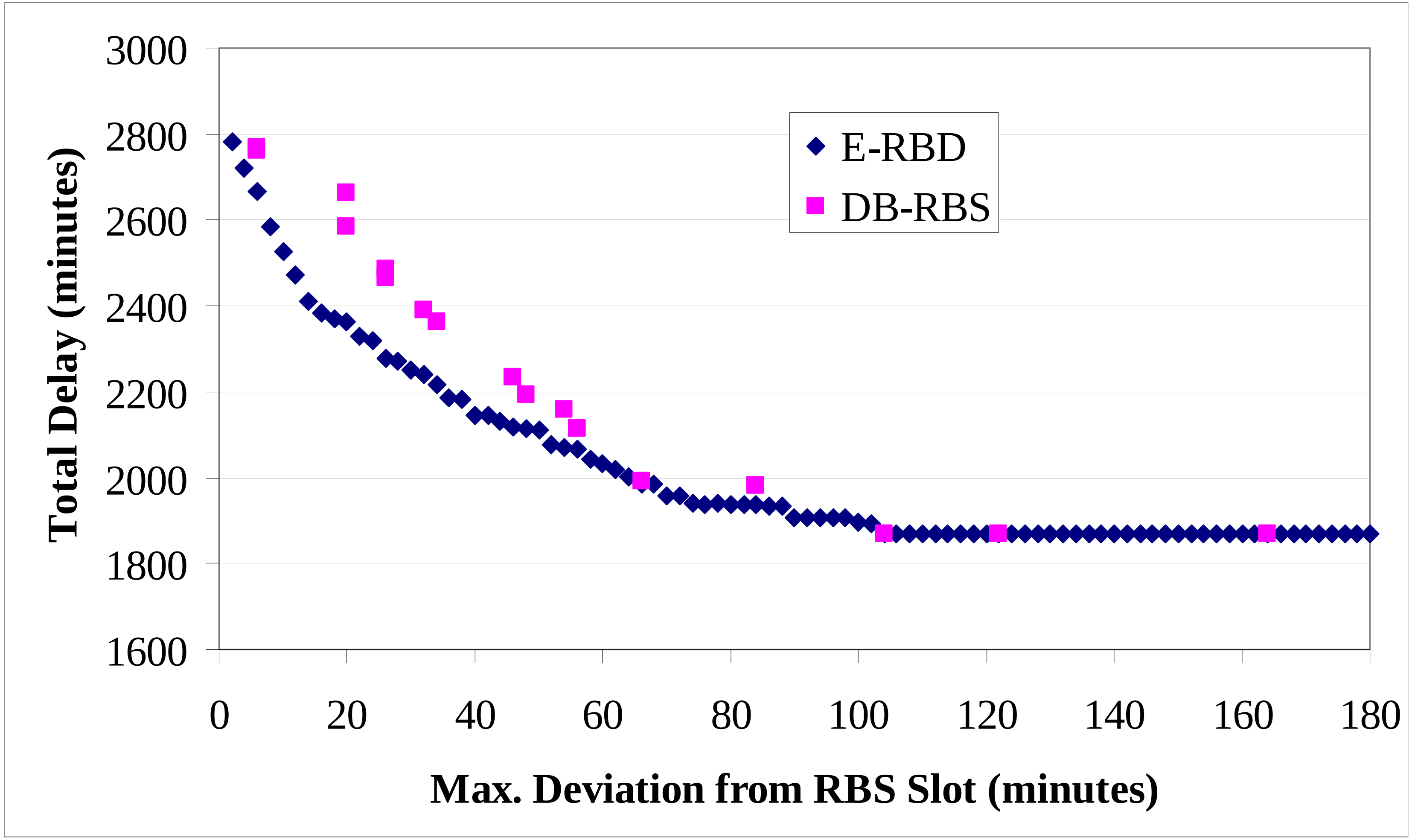
Performance of E-RBD



Equity measures for RBS, RBD, and E-RBD



Efficient Frontiers for E-RBD and Distance-Based GDP Planning Algorithms



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.