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NATIONAL CENTER OF EXCELLENCE FOR NEXTOR AVIATION OPERATIONS RESEARCH

An Analysis of Resource Rationing Methods for Collaborative Decision Making

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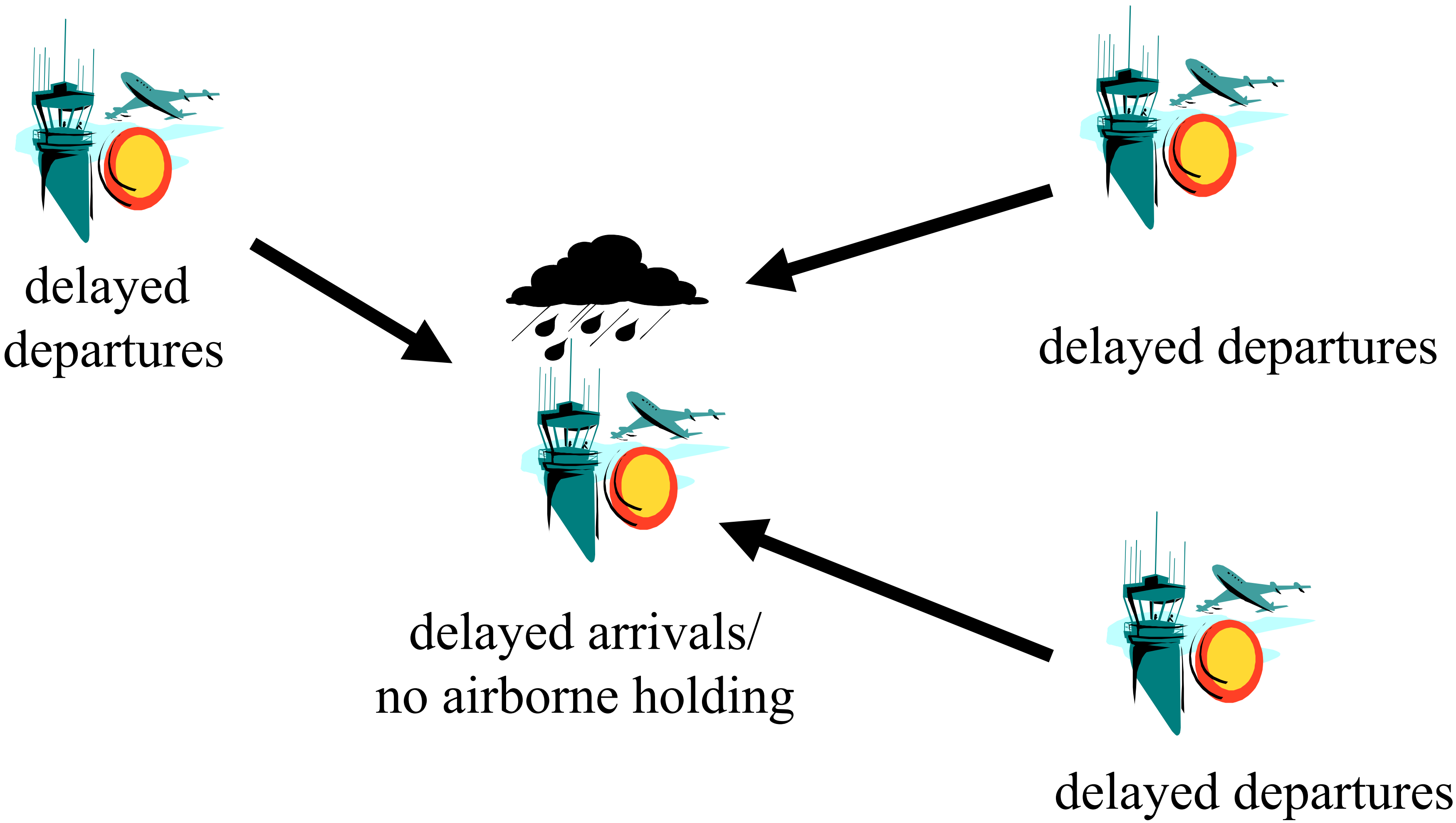
Ground Delay Programs



GDPs under 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]

Note:

- reduced capacity is partitioned into sequence of arrival slots

- ground delays are derived from delays in arrival time

Allocating Slots under CDM

Ration-By-Schedule:

Step 1: Order flights by their *original scheduled time of arrival*

Step 2: Select the first flight that has not been assigned an arrival slot.

- assign the selected flight to the earliest unassigned slot
- repeat step 2.

The resulting allocation is independent of current status of flights and is not affected by status information given by airlines!!

Slot Reallocation under CDM

Need for Inter-airline slot exchange:

slots made available through flight cancellations and delays

Compression Algorithm

Initial

AAL1:1200 →	S1200
AAL2:1201	S1202 *CNX*
UAL1:1202 →	S1204
USA1:1203 →	S1206
UAL2:1204 →	S1208
COA1:1205 →	S1210
USA2:1206 →	S1212
AAL3:1207 →	S1214

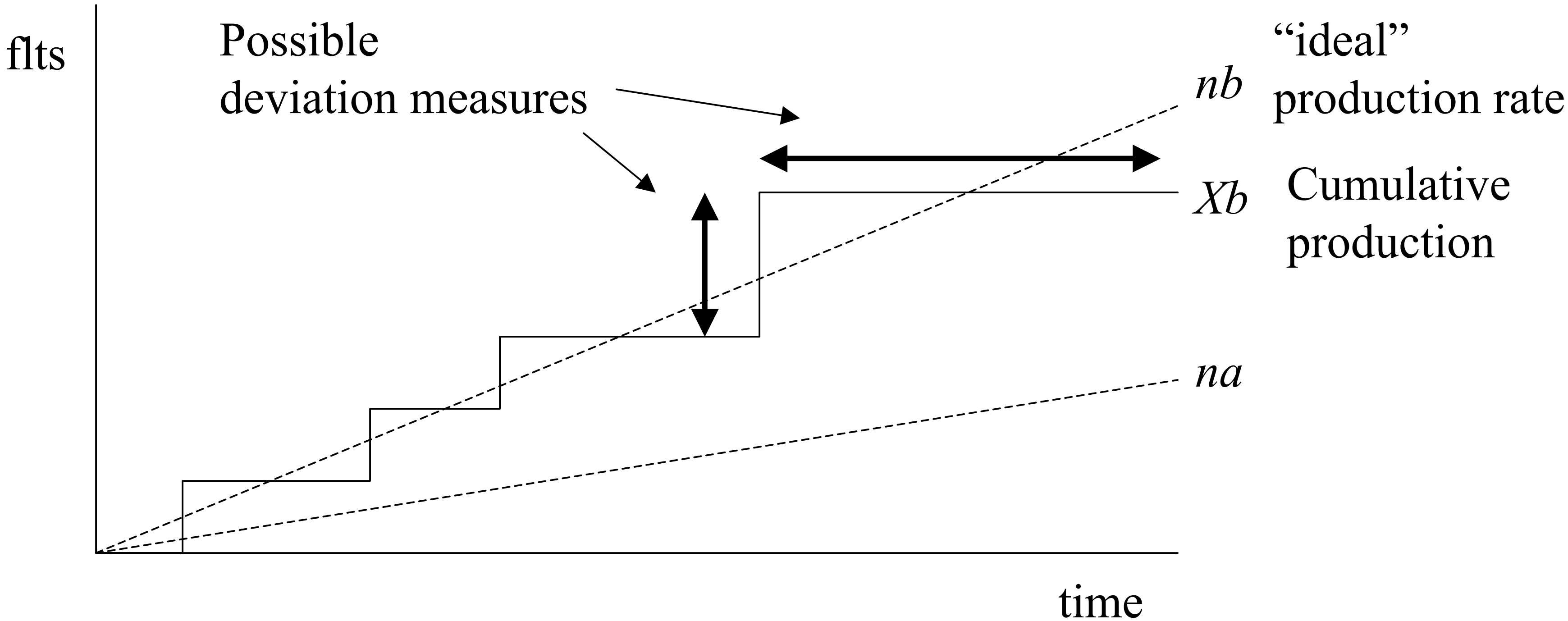
Final

AAL1:1200	S1200
AAL2:1201	S1202
UAL1:1202	S1204
USA1:1203	S1206
UAL2:1204	S1208
COA1:1205	S1210
USA2:1206	S1212
AAL3:1207	S1214

Generalizations and Extensions of CDM Procedures

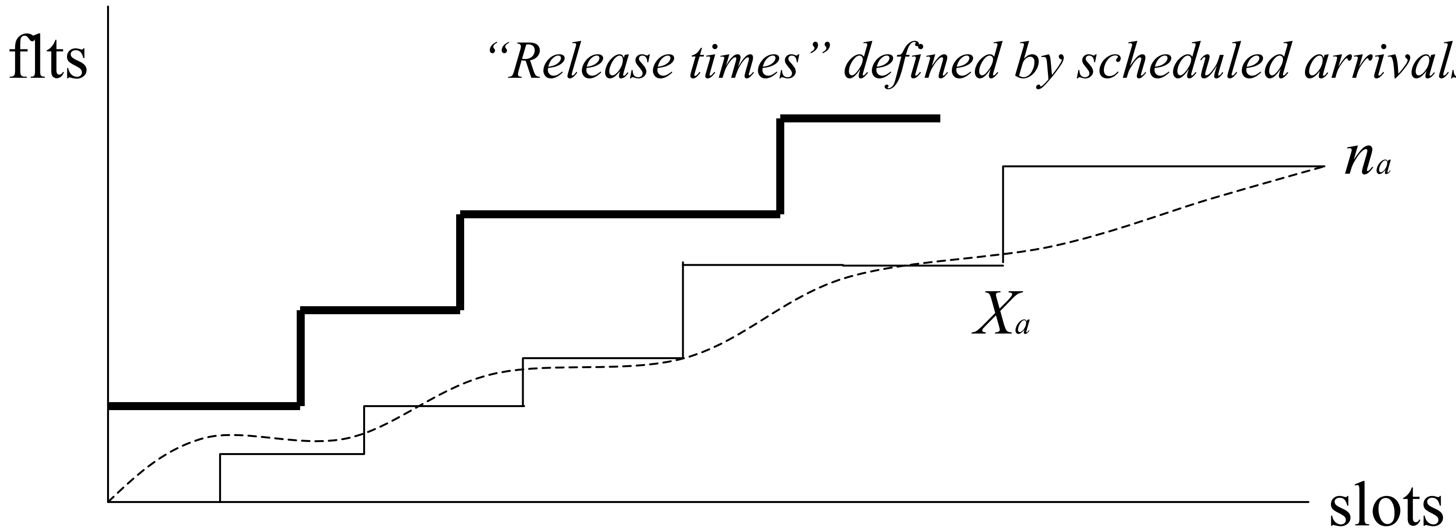
- View RBS as Process for Achieving Equitable Allocation of Time Slots – extend to insure better equity during dynamic GDP operation
- Extension of RBS to Enroute Airspace: Priority based on accrued delay
- Interpret Compression as slot trading process: extend from 1-for-1 trades to 2-for-2 trades

#1. GDPs as Balanced Just-in-Time Scheduling Problem



- Airlines = products, flights = product quantities
- Minimize deviation between "ideal" rate and actual production

GDP Situation



Questions:

- What are appropriate "production rates" ?
- How to minimize deviations ?
- Managing program dynamics

What is an appropriate production rate/ideal allocation??

Answer: RBS!!

It can be shown that RBS lexicographically minimizes the maximum delay assigned to each flight.

General Principles of equity applied to a set of claimants; equity defined relative to pair-wise comparisons:

in an equitable solution it should not be possible to improve the allocation to a claimant at performance level p without moving another claimant to a performance level of p or worse.

For the mini-max (RBS) solution:

if flight f has been assigned t* units of delay, it is impossible to reduce the delay assigned to f without increasing the delay assigned to another flight a value of t* or higher.

It can be shown that RBS satisfies some very fundamental axioms for consistent, fair allocation process (there are other alternatives that we are now investigating)

Models and Algorithms for Minimizing Deviation from Ideal Allocation

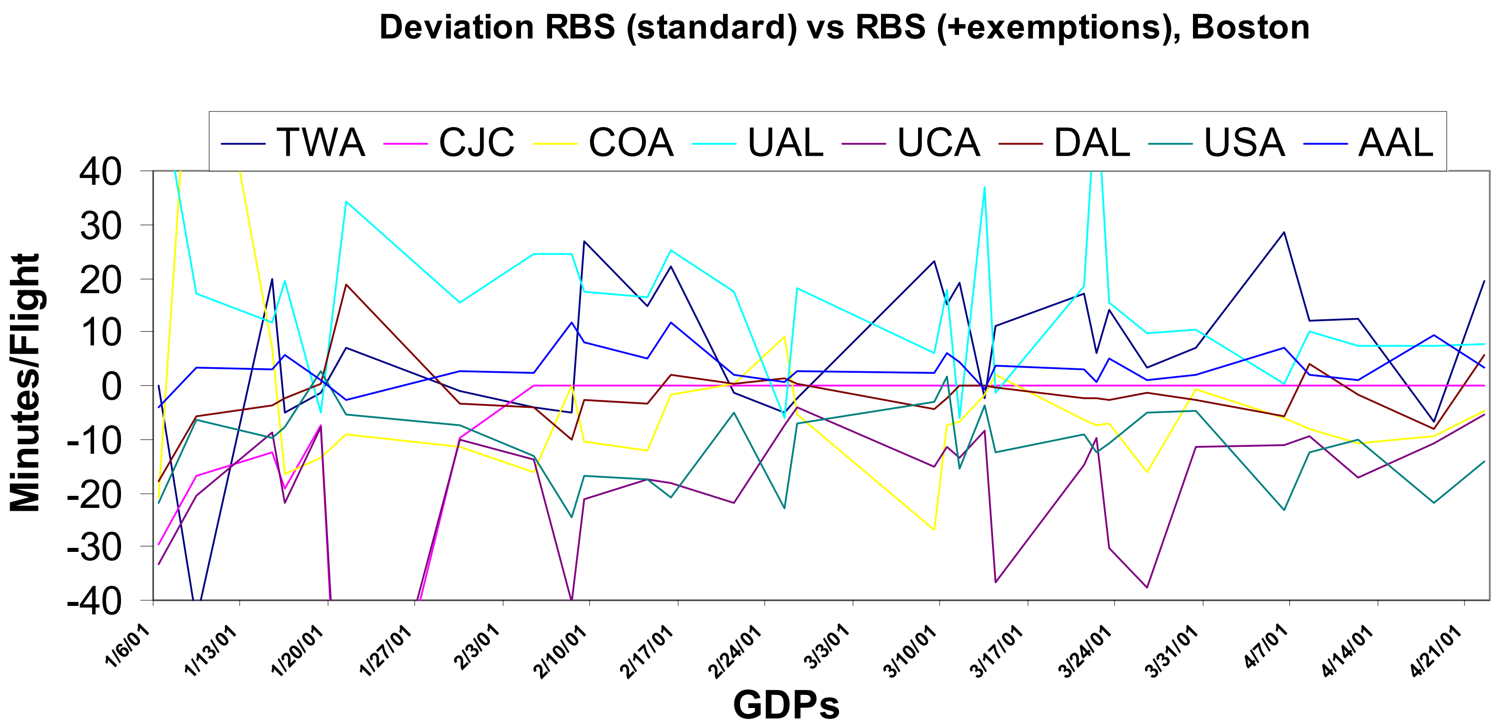
- General class of problems: minimize deviation between actual slot allocation and ideal slot allocation

  Variants based on:
  - Objective function (deviation measures)
  - Constraints on feasible allocations
- Minimize cumulative/maximum deviation:
  - complex network flow model (based on JIT scheduling models) can solve most variants
- Minimize sum of deviations between jth slot allocated to airline *a* and ideal location for airline *a*'s jth slot:
  - Assignment model
  - Greedy algorithm for several cases

GDPs and Flight Exemptions

- GDPs are applied to an "included set" of flights
- Two significant classes of flights destined for the airport during the GDP time period are exempted:
  - Flights in the air
  - Flights originating at airports greater than a certain distance away from the GDP airport
- Question: Do exemptions induce a systematic bias in the relative treatment of airlines during a GDP??

Analysis of Flight Exemptions (Logan Airport)



Flight exemptions introduce systematic biases:

- USA (11m/flt), UCA (18m/flt) “lose” under exemptions

Reducing Exemption Bias

Objective :

- Use deviation model to mitigate exemption bias
  - i.e. “inverse” compression

Approach:

- RBS applied to all flights whose arrival times fall within GDP time window ➔ ideal allocation
- Set of exempted flights are defined as before (there are good reasons they are exempted)
- Time slots given to exempted flights “count against” allocation
- Delays allocated to non-exempted flights so as to minimize overall deviation from ideal allocation

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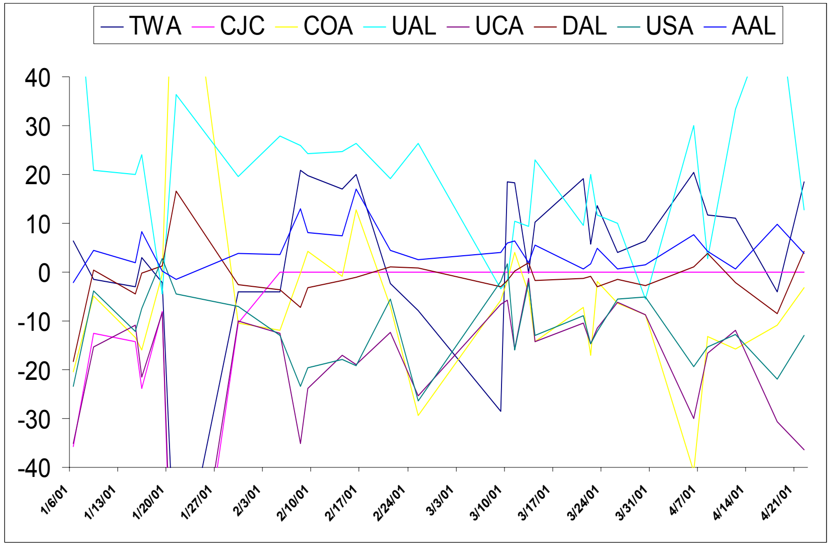
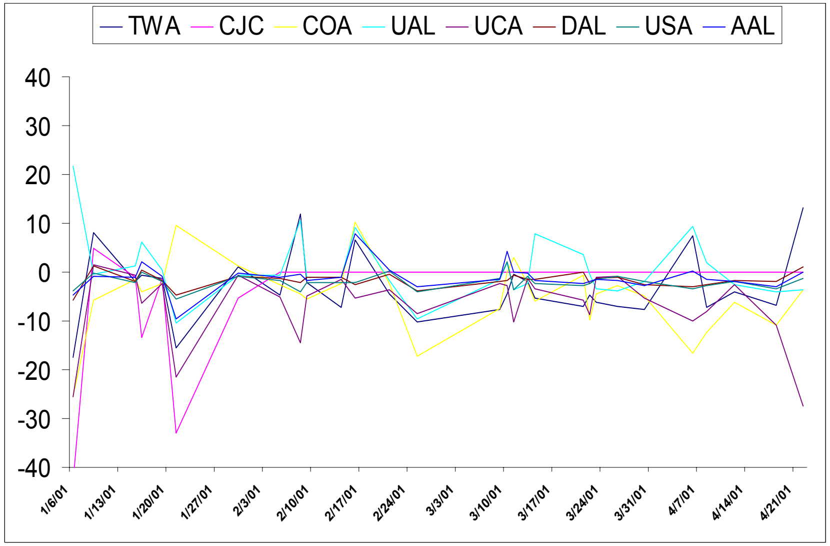
Flight Exemptions

Deviation RBS ideal-RBS actual



Deviation RBS ideal-Opt. model



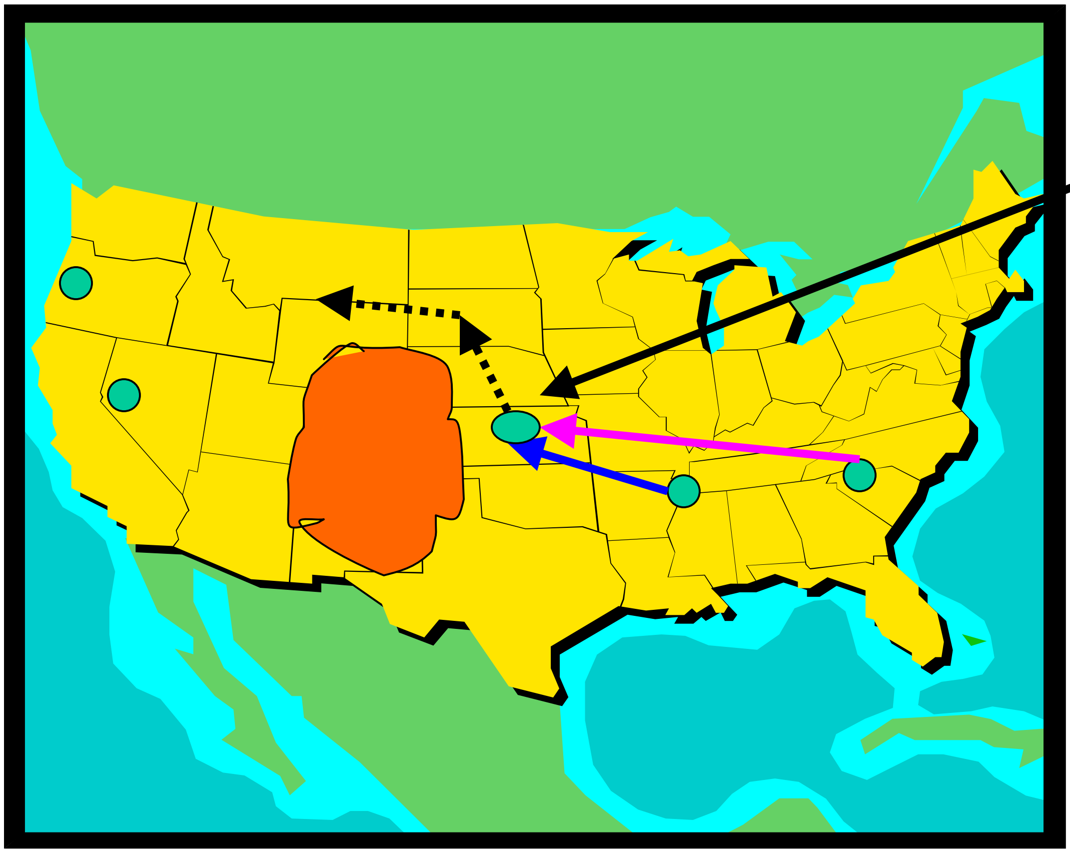
- Minimize deviations using optimization model that incorporates exemptions
- reduces systematic biases, e.g. USA from 11m/flt to 2m/flt, UCA from 18m/flt to 5m/flt

Discussion

Approach yields system where:

- airlines are assigned priority *lists*
  - based on sched. arr. times, constant during GDP
- dynamic changes (capacity, airline data) initiate (re)rationing
  - ration according to *airline* priorities (compression)
- priority scheme cannot (completely) be maintained with flight exemptions
  - deviation model shows potential to reduce exemption bias

#2. Extension of RBS to Enroute Airspace: Priority Based on Accrued Delay



Priority given to flight with largest accrued delay; *accrued delay (downstream) defined as difference between ETA and scheduled arrival time.*

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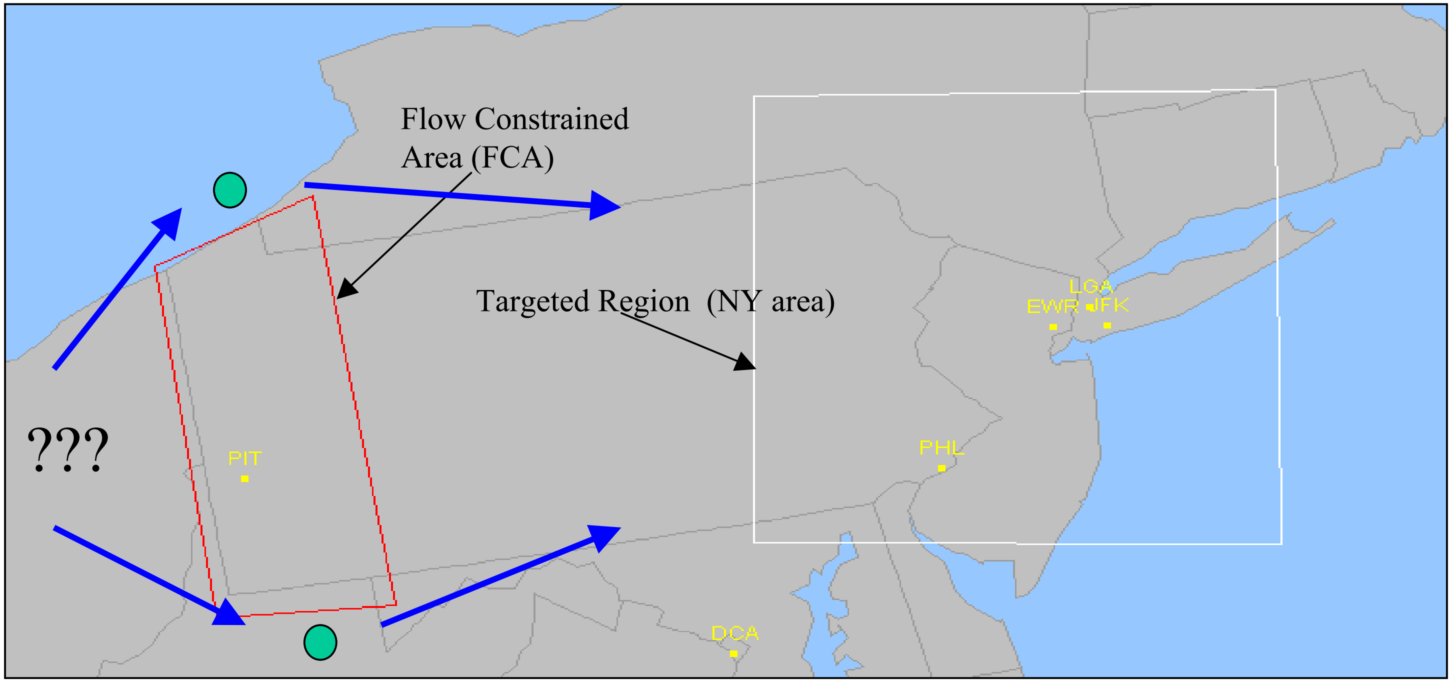
Scenario

Scenario: flights in air and on the ground; need to reroute flights around flow constrained area:

Which flights are rerouted?? Which flights are delayed on ground??



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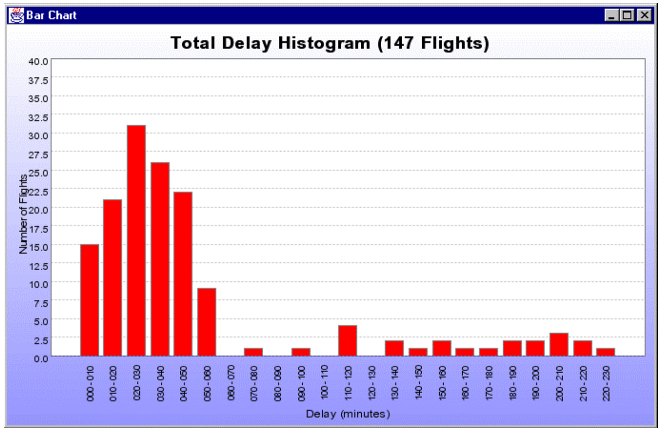
Impact on Allocated Delay

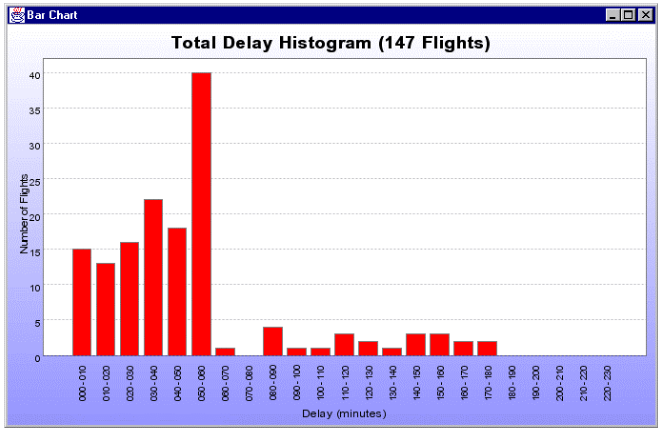
Motivation for Priority Based on Accrued Delay:

- Generalization of RBS – equivalent relative to equity principles
- Implicitly coordinates multiple initiatives since previously delayed flights are given priority.

1^{st} come/ 1^{st} served



Priority Based on Accrued Delay



Implementation Alternatives

F-Based

Step 1: For each unassigned flight, calculate its total accrued delay assuming it is assigned to the earliest available slot for which it is eligible.

Step 2: **Choose the flight with the maximum accrued delay** that has not been assigned to a slot.

- assign the selected flight to the earliest unassigned slot for which it is eligible
- if there are remaining unassigned flights, go to step 1; otherwise stop

S-Based

Step 1: **Choose the earliest available slot, *s*.**

Step 2:

Find the set of flights, *F*, that can be assigned to *s*.

For each flight in *F*, calculate the total accrued delay assuming the flight is assigned to *s*.

Choose the flight in *F* with the maximum calculated accrued delay and assign it to *s*.

If there are remaining unassigned flights go to step 1; otherwise stop.

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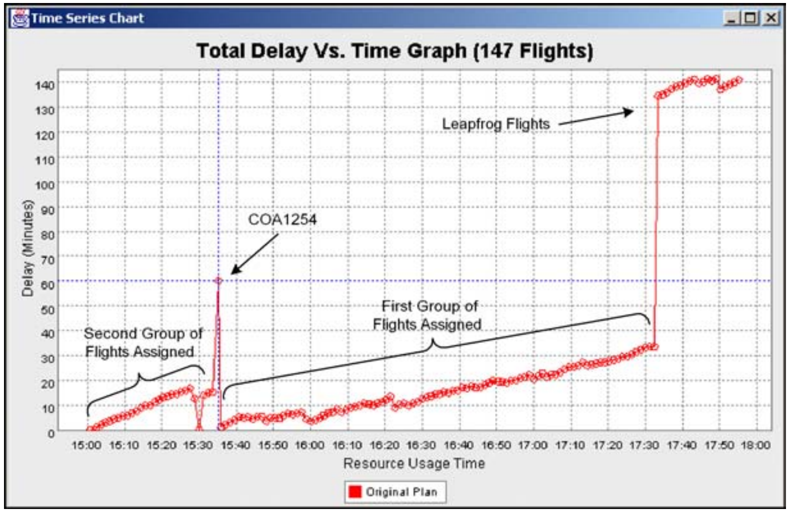
F-Based vs S-Based: The Leap Frog Principle

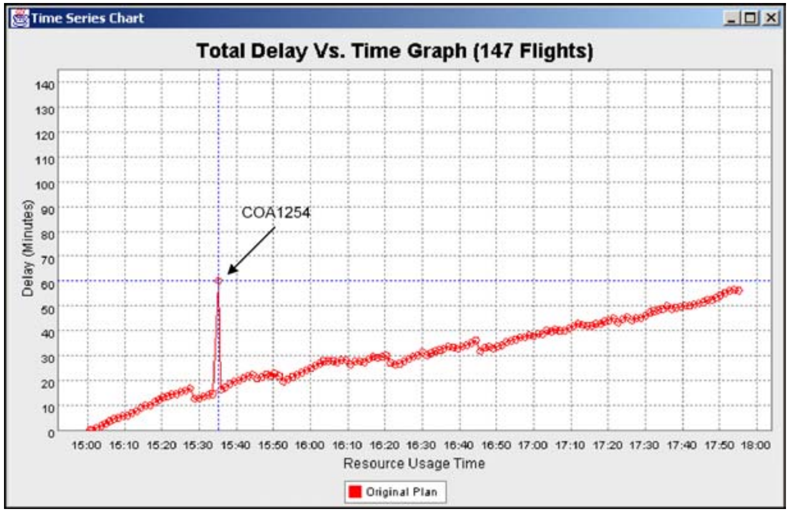
F-Based:

- Utilization = 100%
- Avg. delay = 30 min
- Avg. of top 20% = 103 min
- Std. Dev. = 43 min.



S-Based:

- Utilization = 100%
- Avg. total delay = 30 min
- Avg. of top 20% = 50 min
- Std. Dev = 14 min.

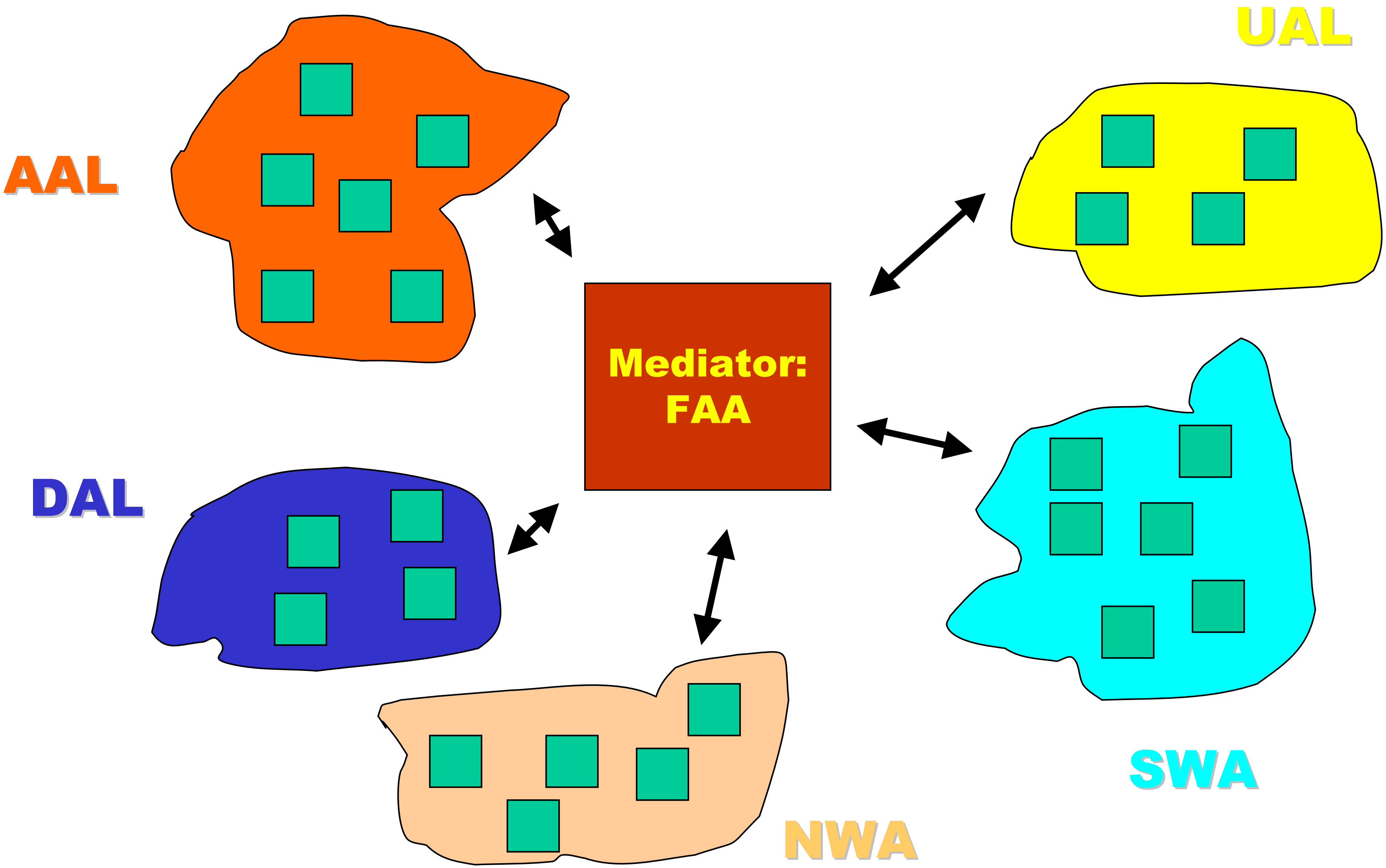


#3. Compression vs Trading

RBS allocates slots to airlines during a GDP

Compression provides a mechanism whereby an airline gives up a slot it cannot use and get one (from another airline) that it can use …

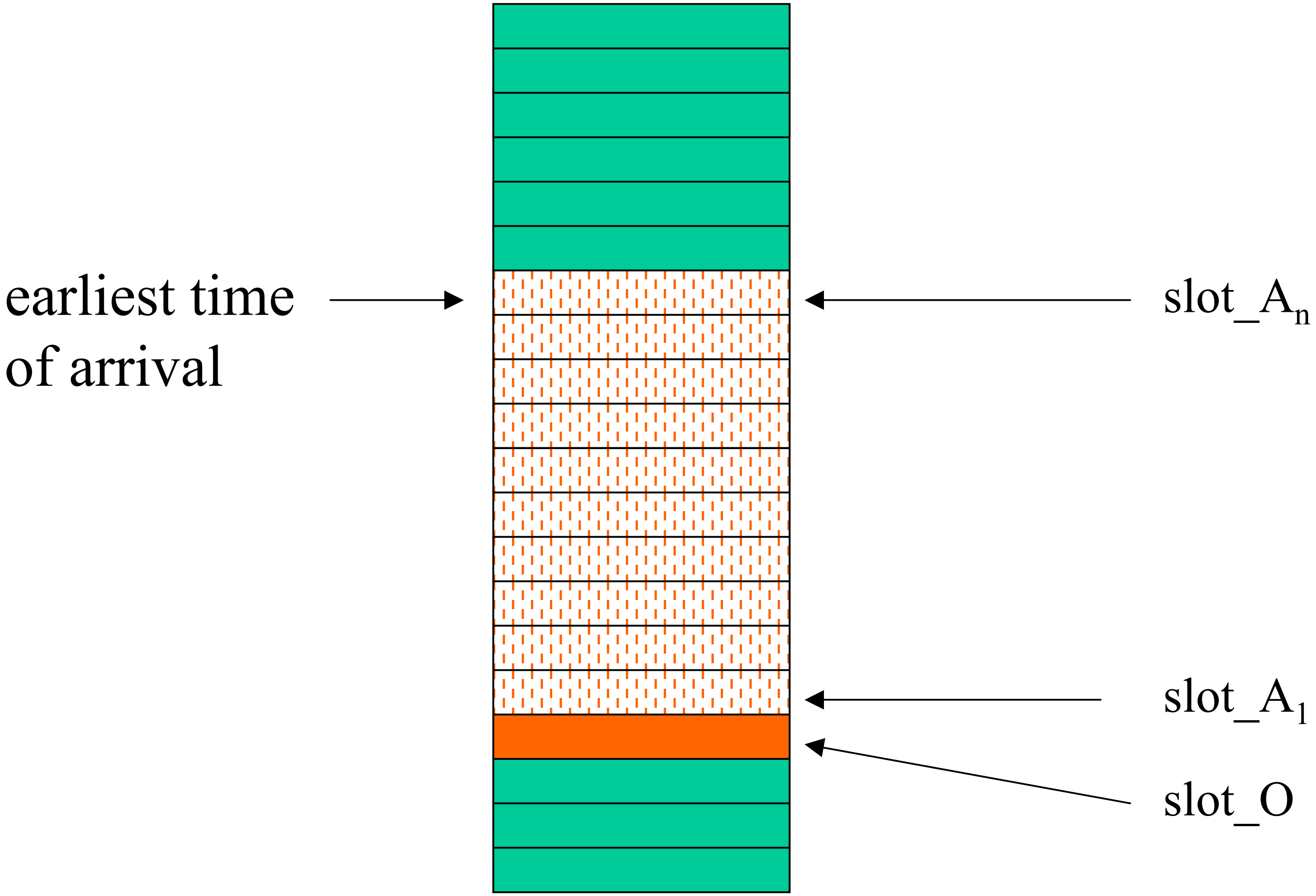
An Alternate View of Compression: Inter-Airline Bartering



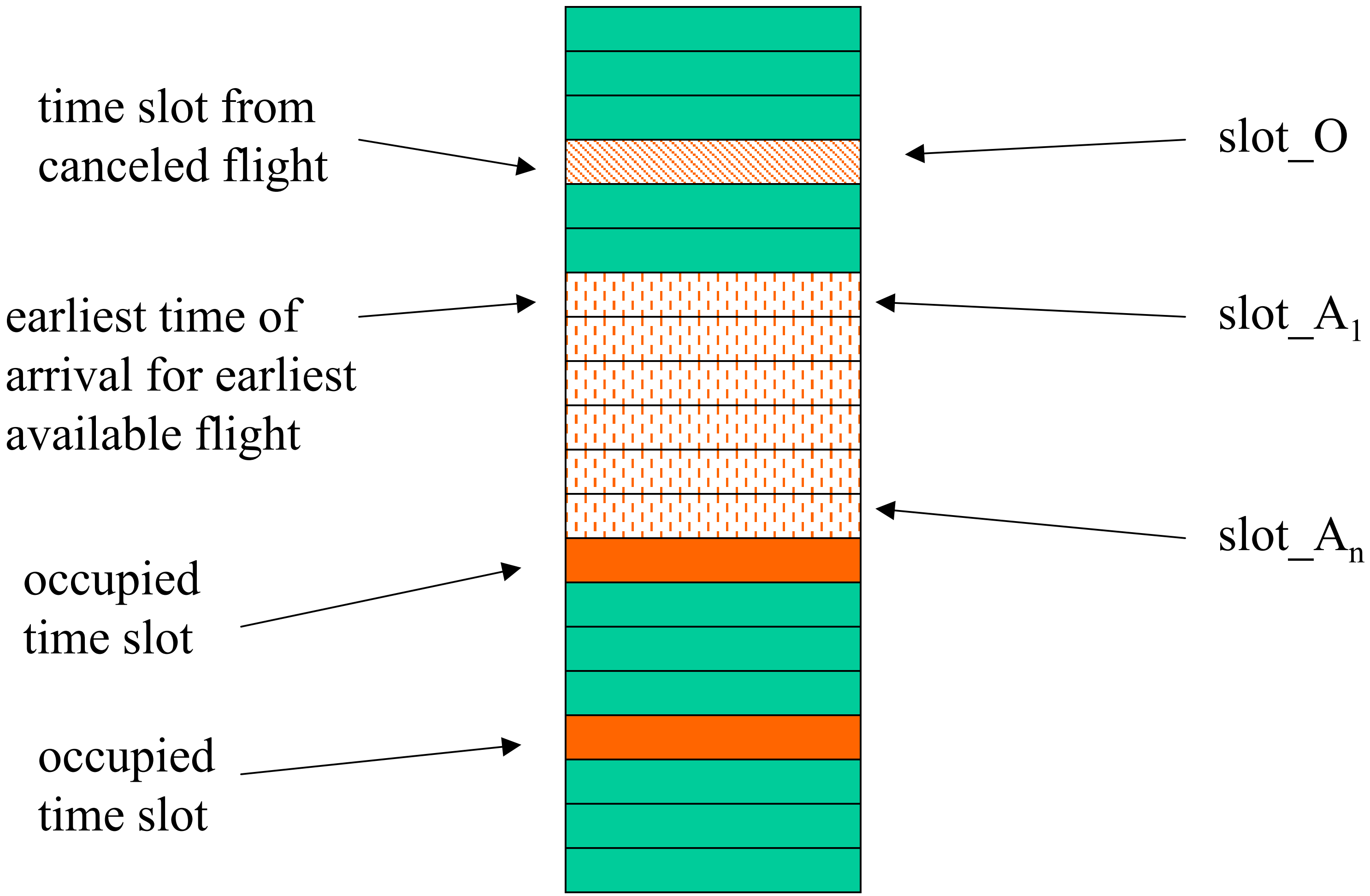
Mediated Slot Exchange

- Offer:
  - slot_O: slot willing to give up
  - slot_A_1,…, slot_A_n: slots willing to accept in return
- Each airline submits a set of offers
- Mediator determines set of offers to accept and for each accepted offer, the returned slot

Default Offers

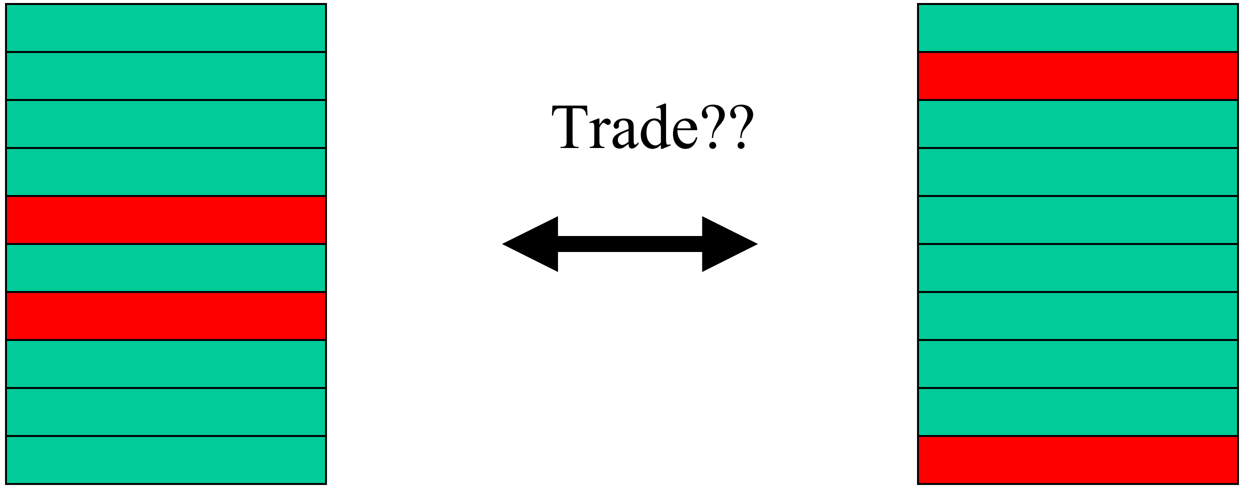


Offer Associated with Canceled or Delayed Flights



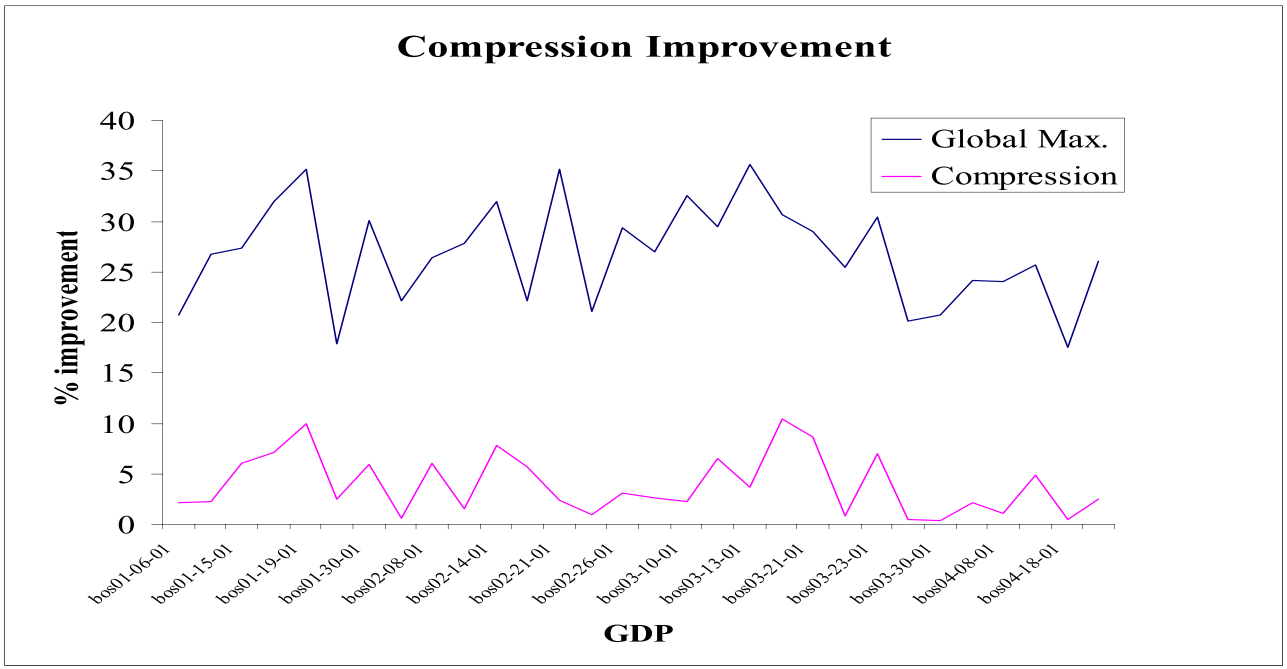
1-for-1 trades to 2-for-2 trades

- Compression ⇔ 1-for-1 trading system, i.e. offers involve giving up one slot and getting one in return (many offers processed simultaneously)
- What about k-for-k or k-for-n offers, e.g. 2-for-2:



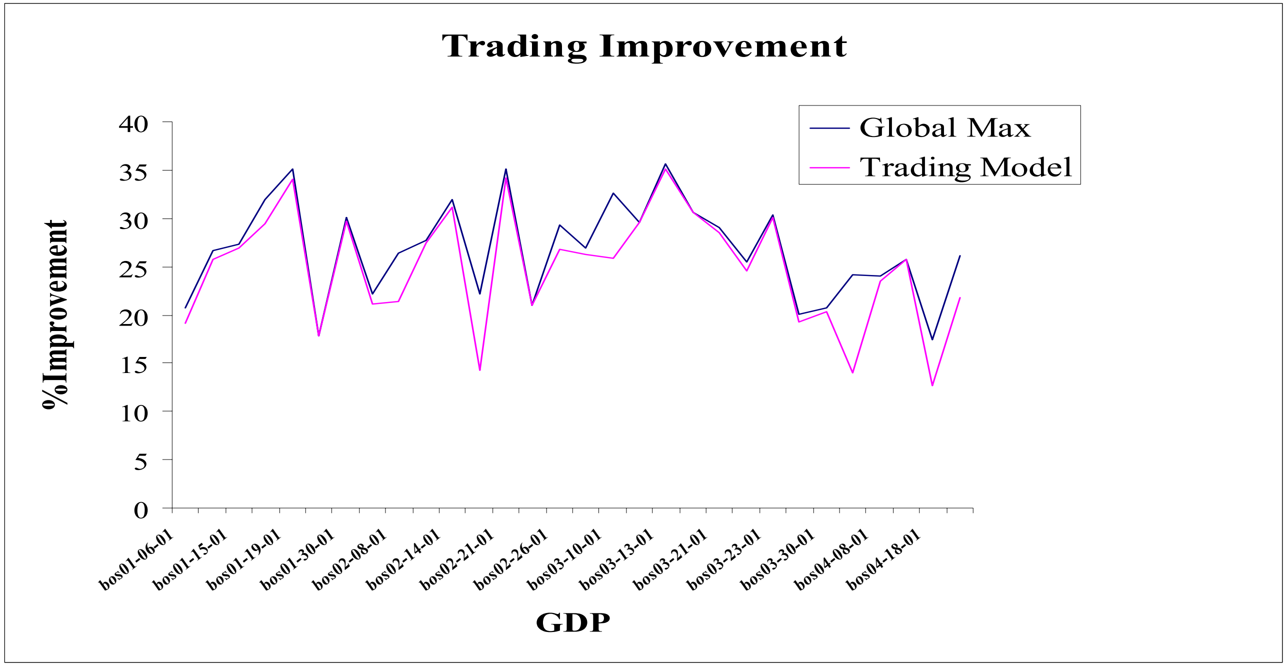
Initial Results

- Compression Benefits
  - performance improvement if compression executed after flts with excessive delay (>2hrs) are canceled



Initial Results

- 2-for-2 Trading Model:
  - proposed offers: all at-least, at-most pairs that improve on-time performance



Computational Efficiency:
- 13sec avg.
- 67% solved by LP relaxation

Generic View of CDM GDP Procedures

- Equitable allocation among airlines
- Intra-airline maximization of economic efficiency
- Inter-airline resource exchange