



Dynamic Slot Exchange Mechanisms in Air Traffic Management

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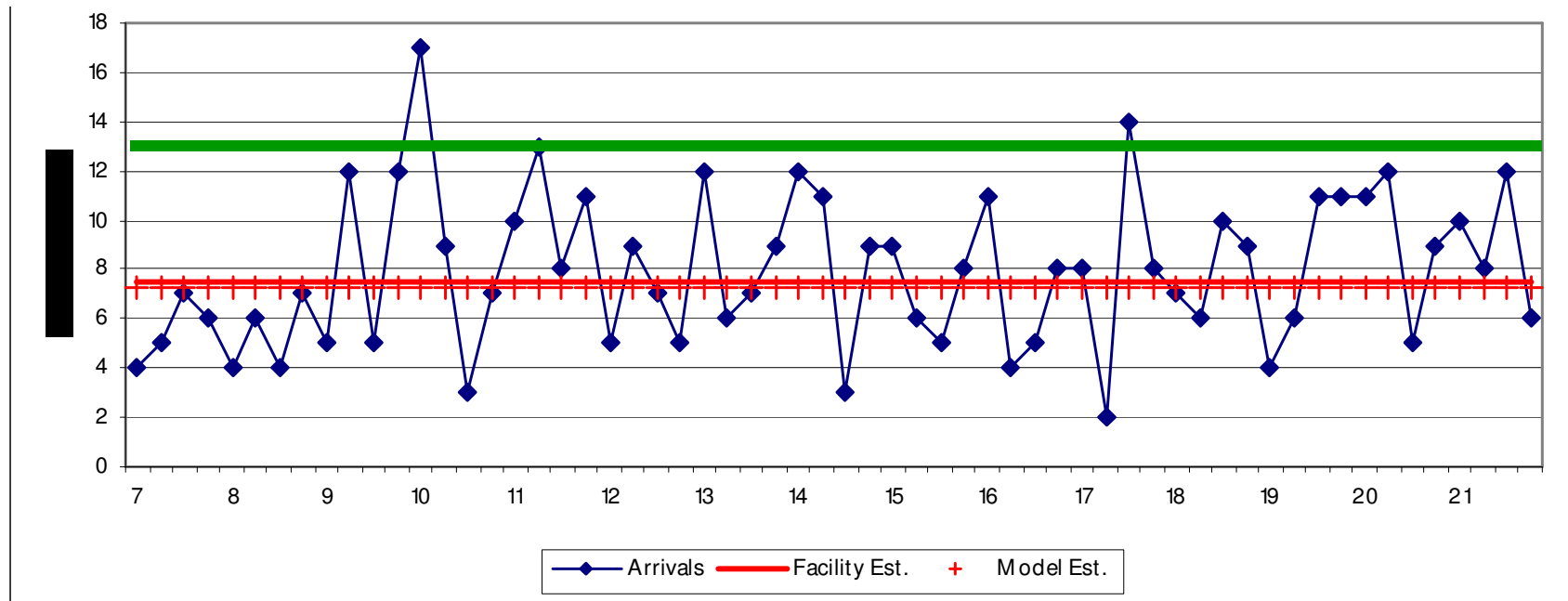
University of Maryland

College Park, MD

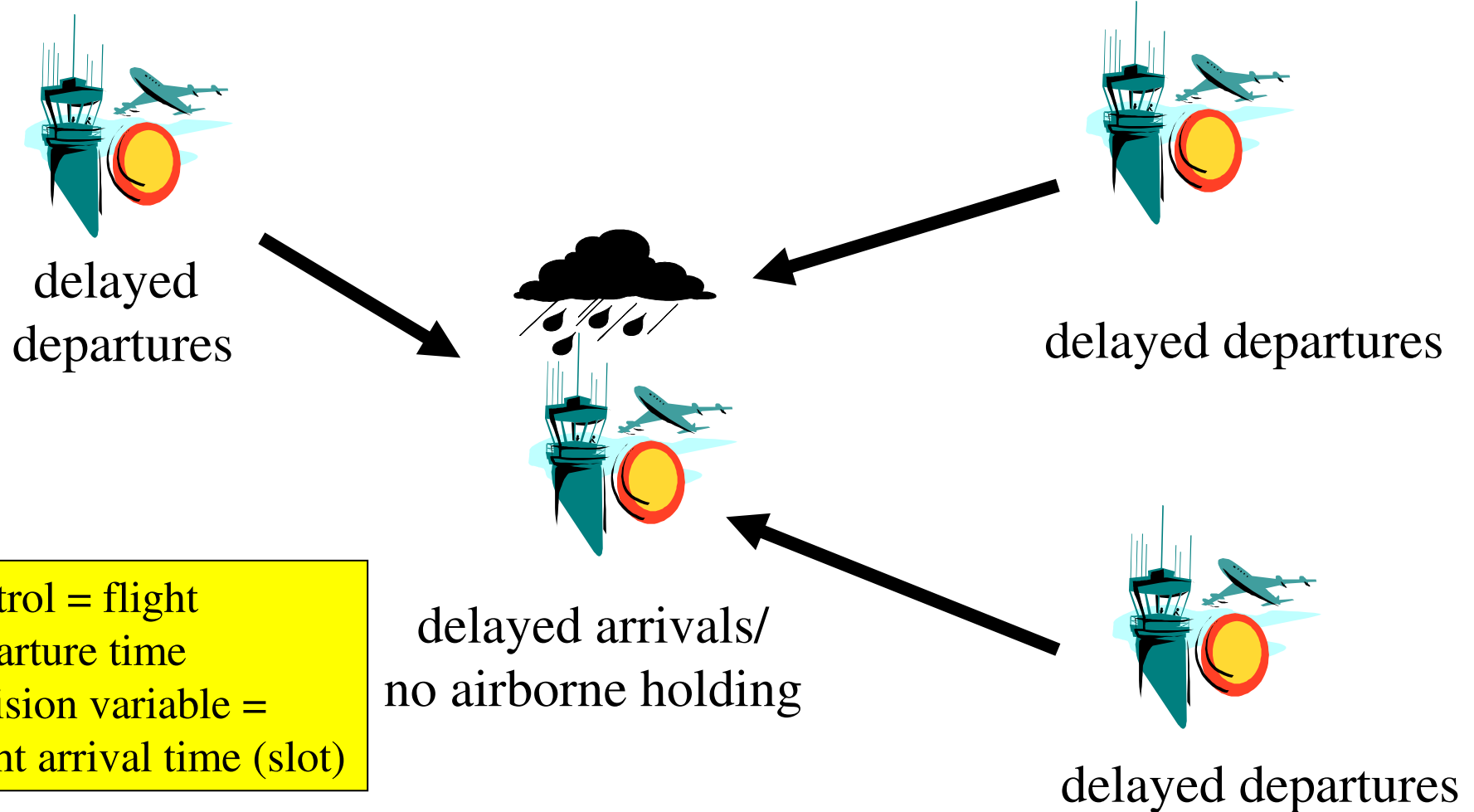
joint work with Thomas Vossen & Philippe Montebello

Motivation for Ground Delay Programs: airline schedules “assume” good weather

SFO: scheduled arrivals: 
VMC airport acceptance rate: 
IMC airport acceptance rate: 



Ground Delay Programs



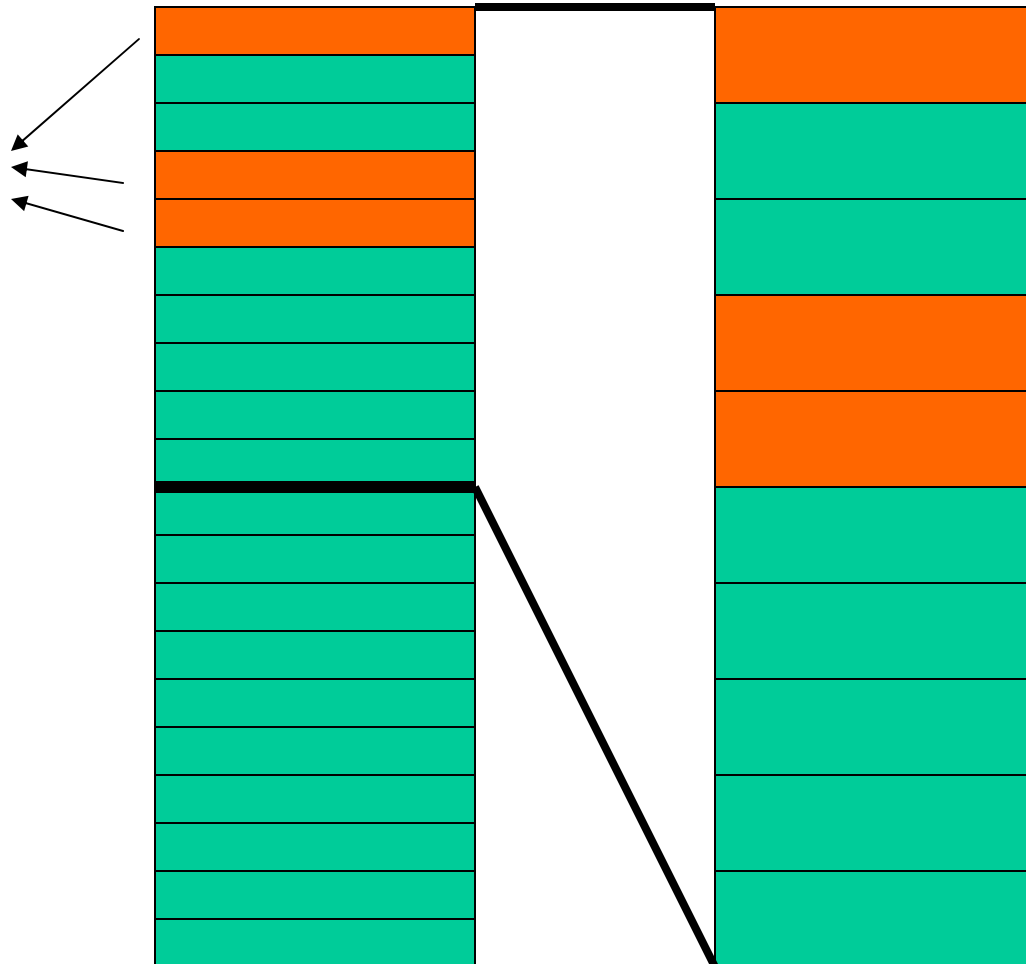
control = flight
departure time
decision variable =
flight arrival time (slot)

Rationing Arrival Slots

Normal arrival rate = 60/hr

Degraded arrival rate = 30/hr

AAL has
3 slots in
1st 10 min



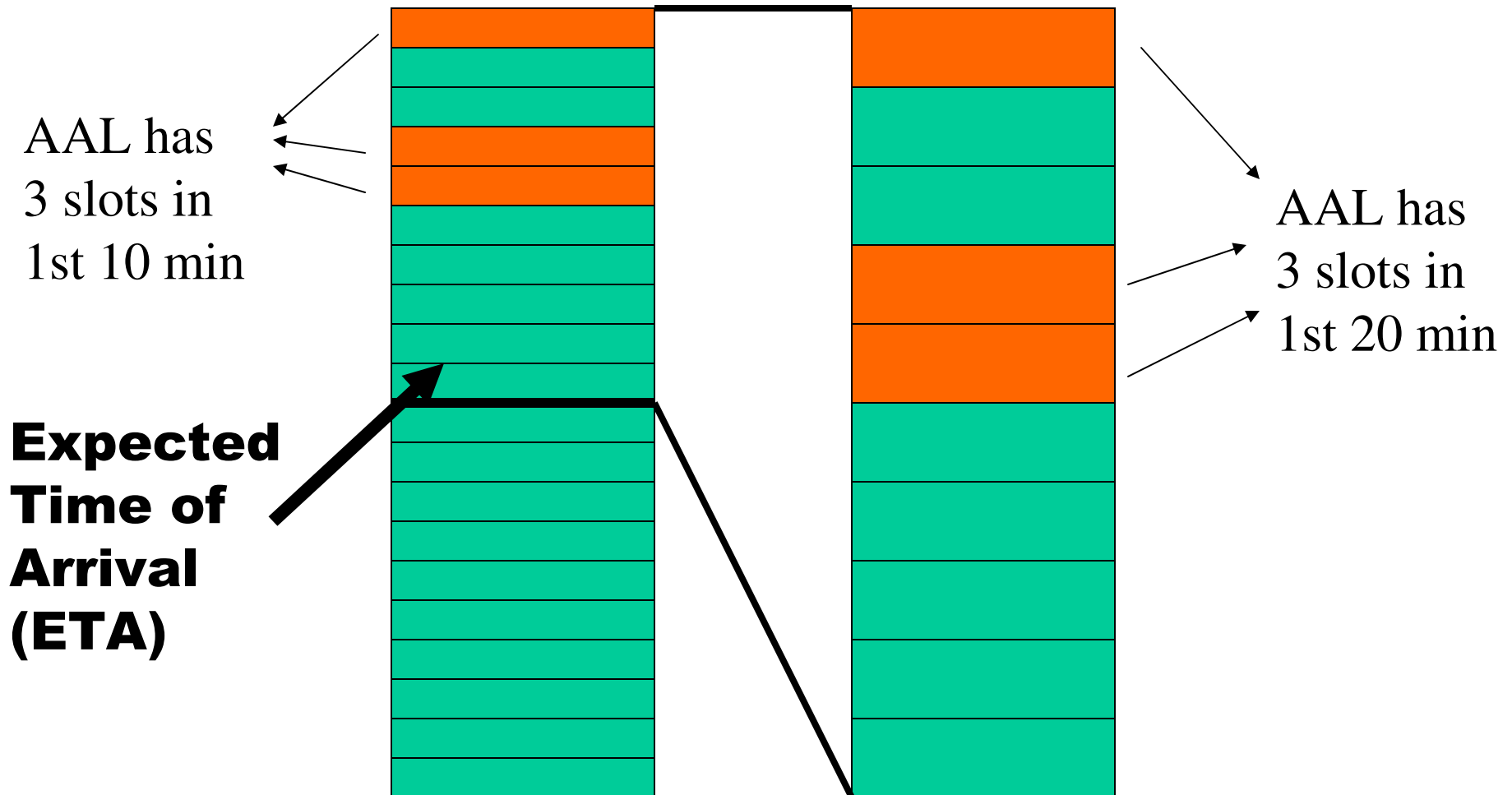
AAL has
3 slots in
1st 20 min



Old Way (before Collaborative Decision Making – CDM)

Normal arrival rate = 60/hr

Degraded arrival rate = 30/hr

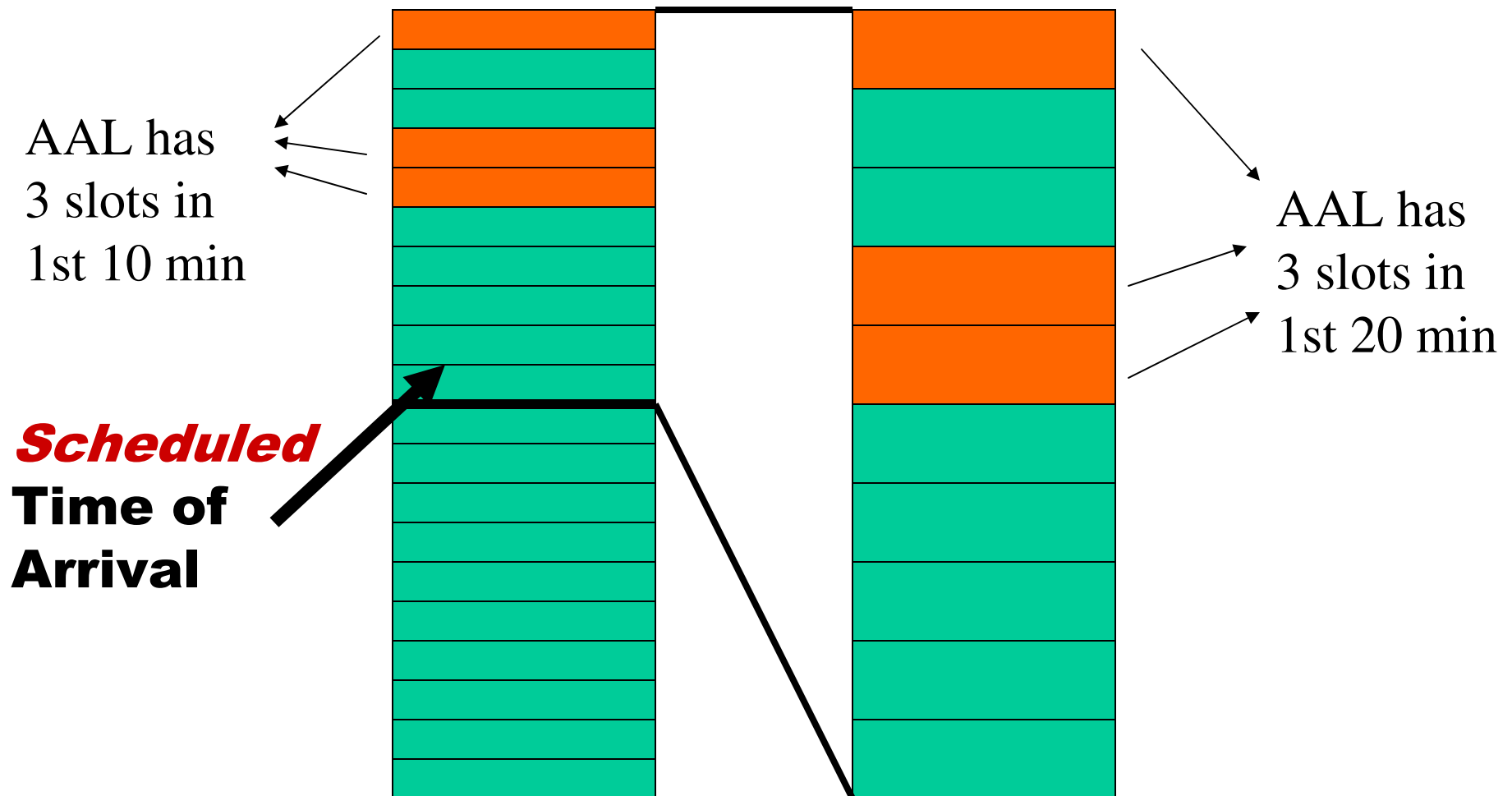




CDM Approach: Ration-by-Schedule (RBS)

Normal arrival rate = 60/hr

Degraded arrival rate = 30/hr





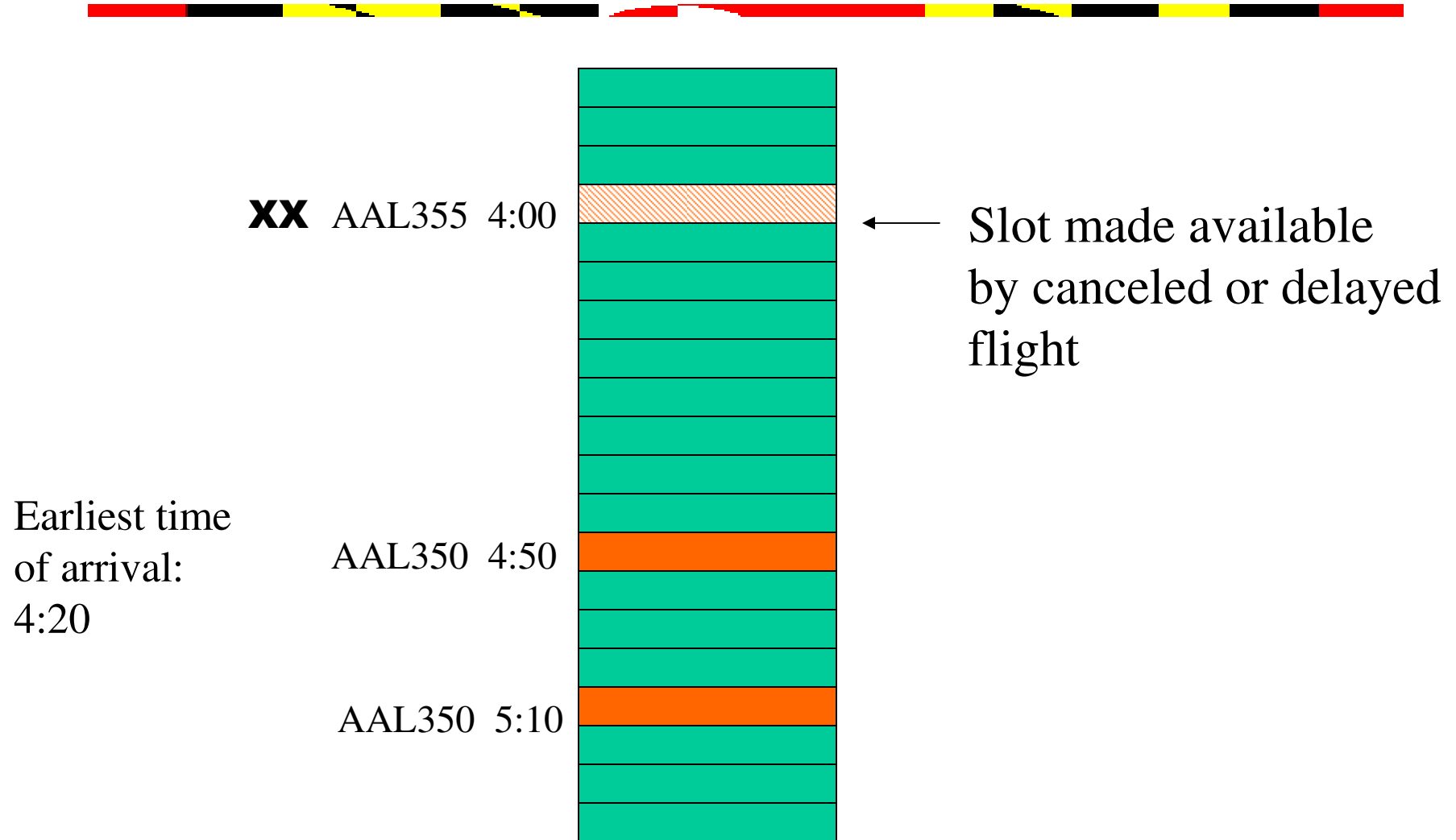
Overall Resource/Slot Allocation Process

FAA: initial “fair” slot allocation
[Ration-by-schedule]

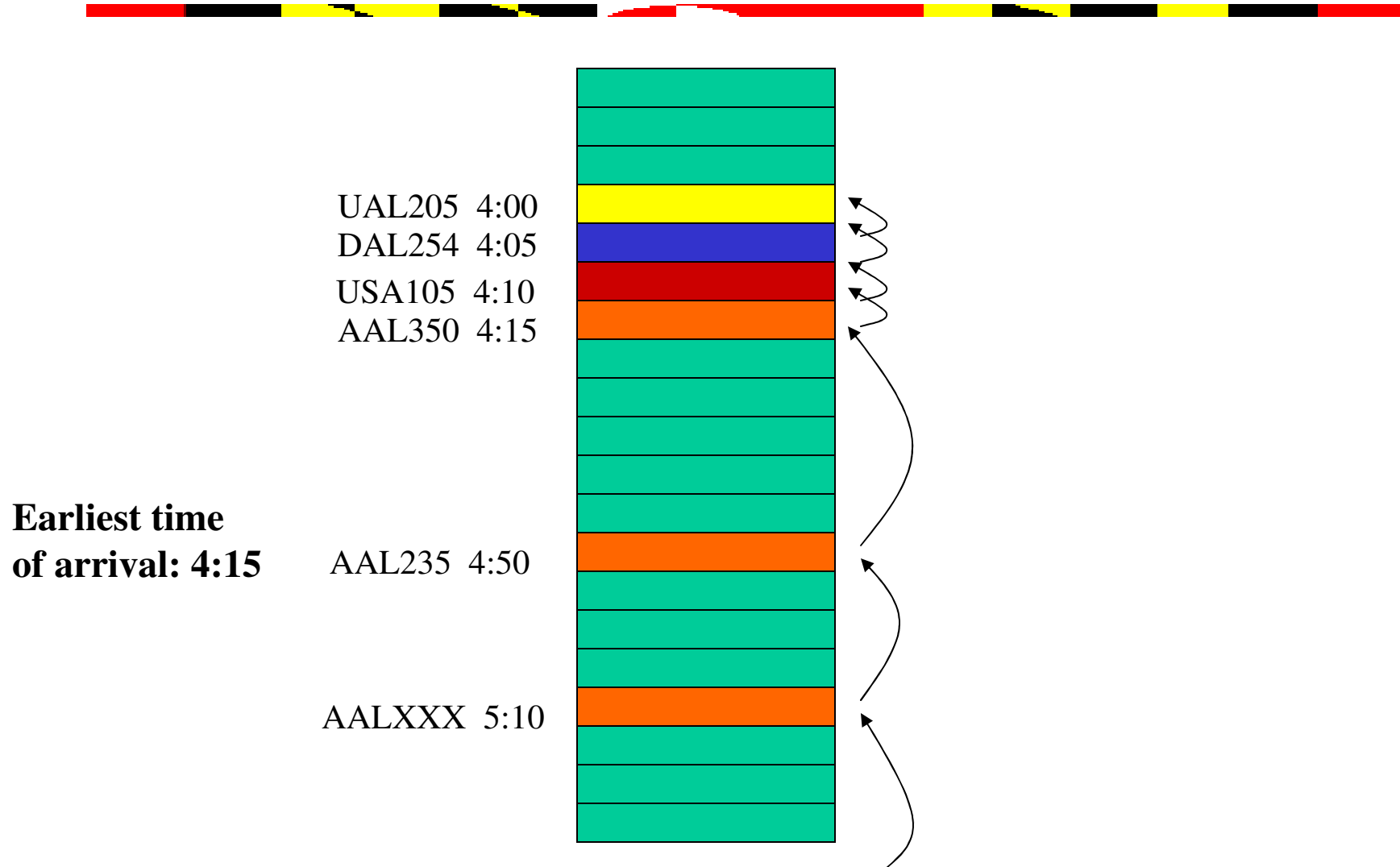
Airlines: flight-slot assignments/reassignments
[Cancellations and substitutions]

FAA: final allocation to maximize slot utilization
[Compression]

Compression: motivation



Compression: execution

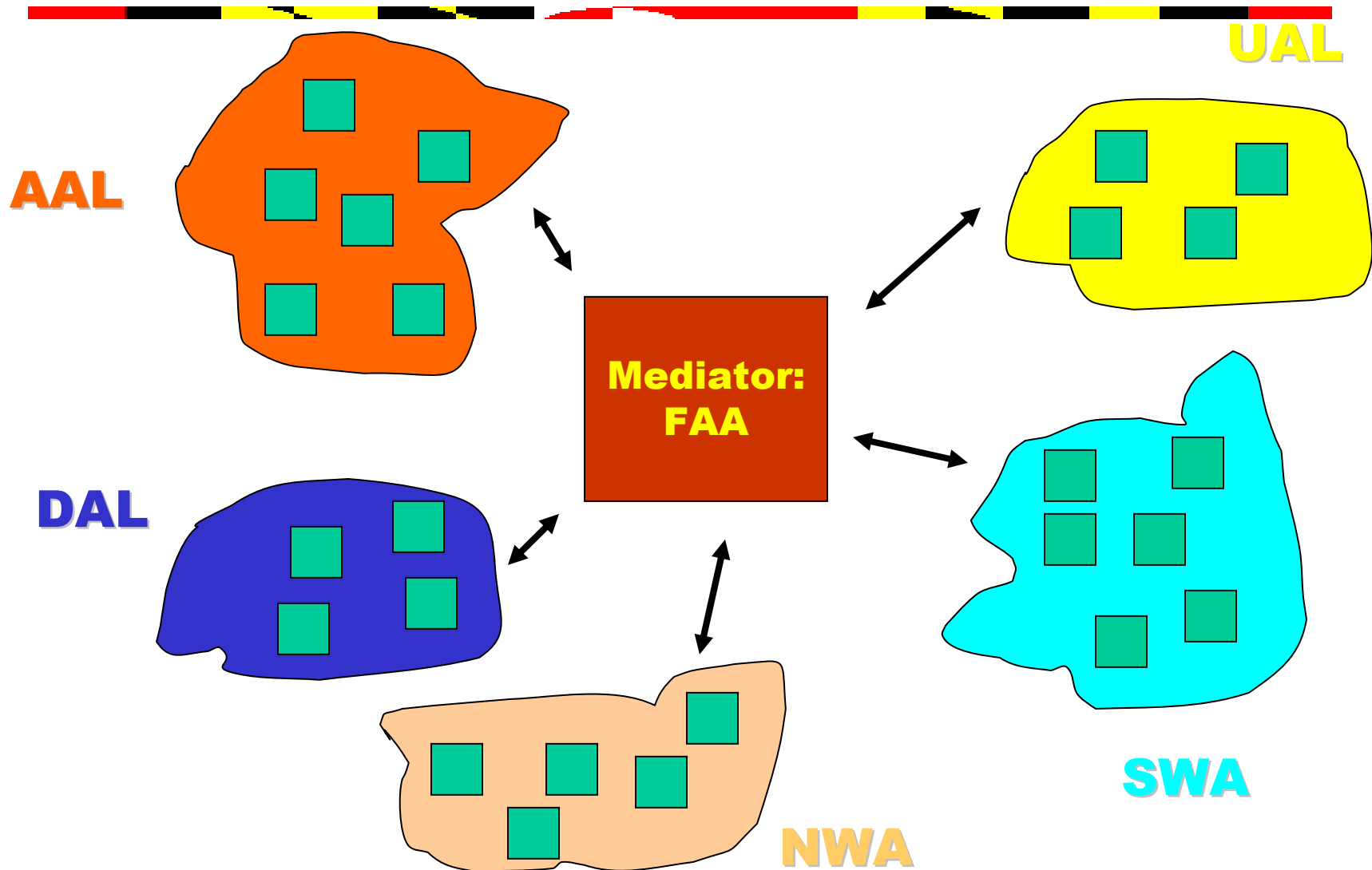




Revised View of GDP Processes

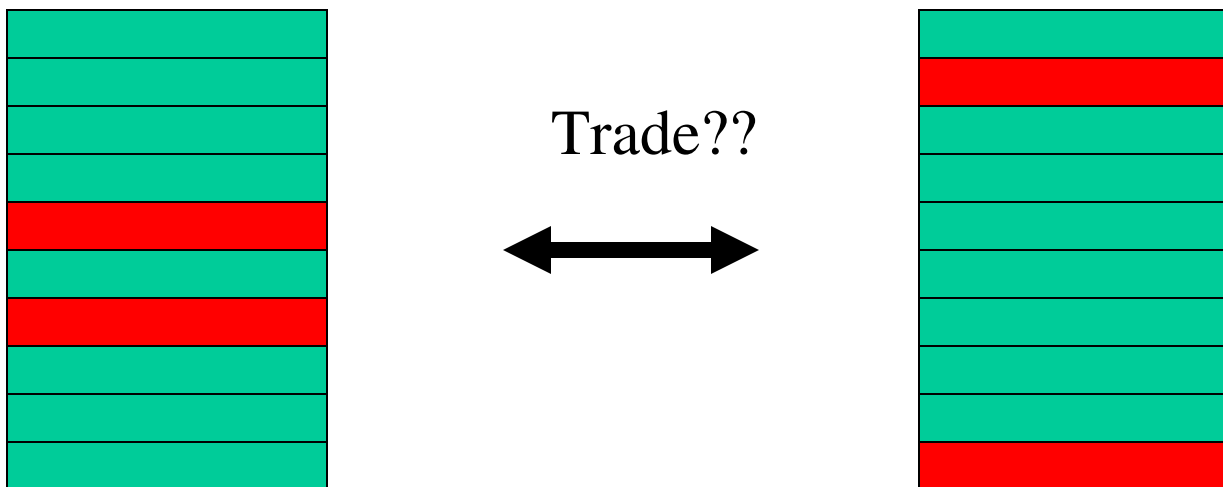
- Step 1: Fair allocation of landing time slots to *airlines*
- Step 2: Mediated, inter-airline bartering

Inter-Airline Bartering

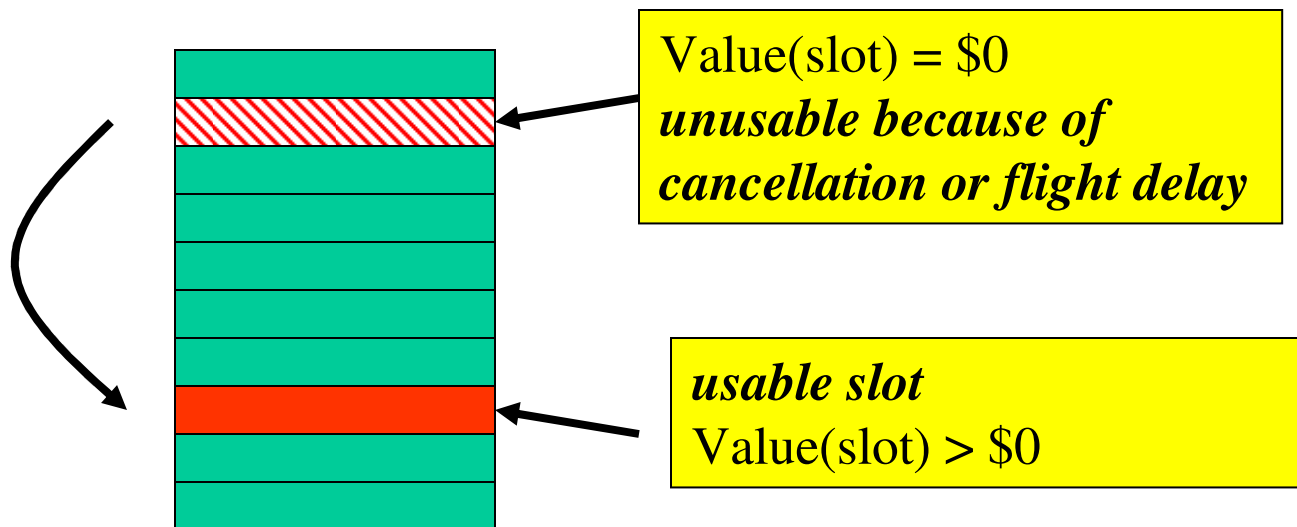


1-for-1 trades to 2-for-2 trades

- Compression and/or slot credit substitution can be interpreted as a 1-for-1 trading system, i.e. offers involve giving up one slot and getting one in return (many offers are processed simultaneously)
- What about k-for-k or k-for-n offers, e.g. 2-for-2:



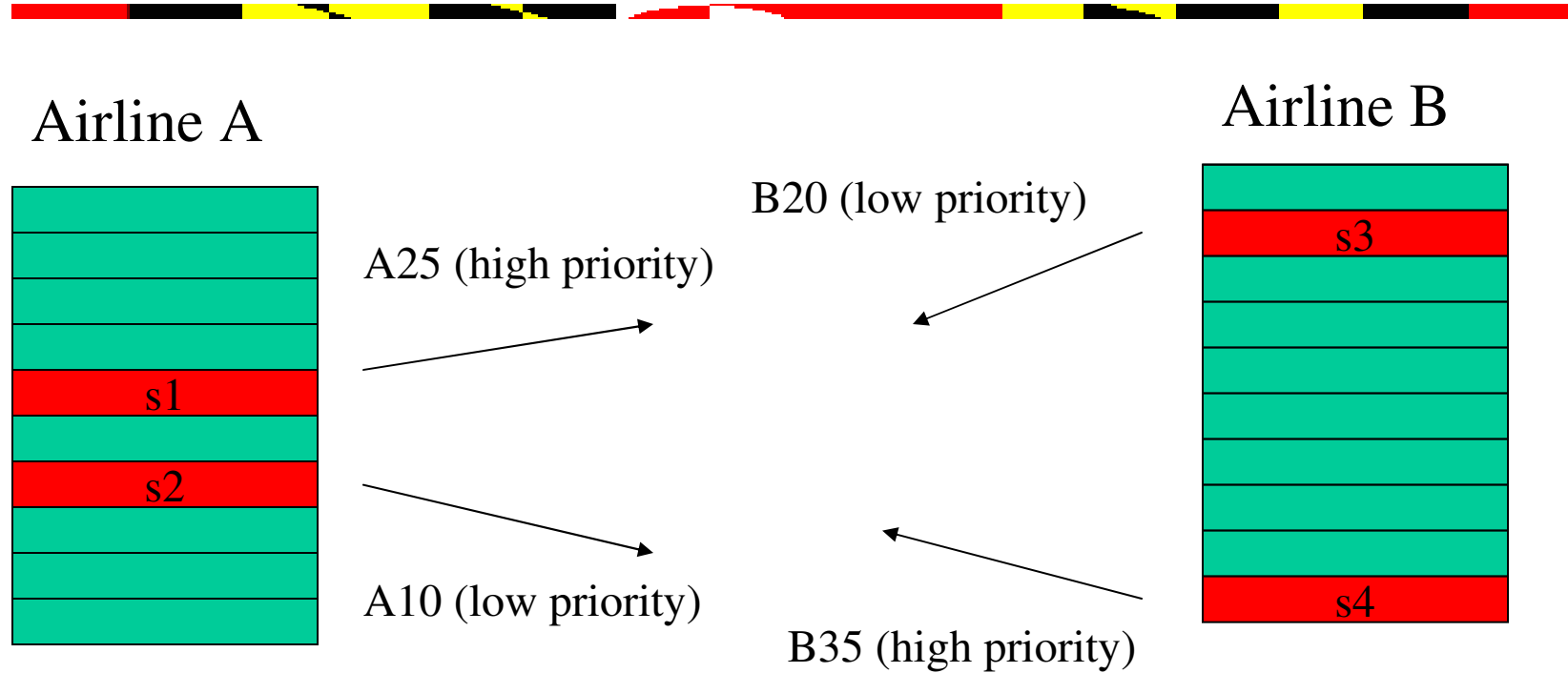
Value proposition for compression & SCS



SCS/Compression “trades” are always driven by the exchange of a slot with value 0 and a slot with value > 0!!



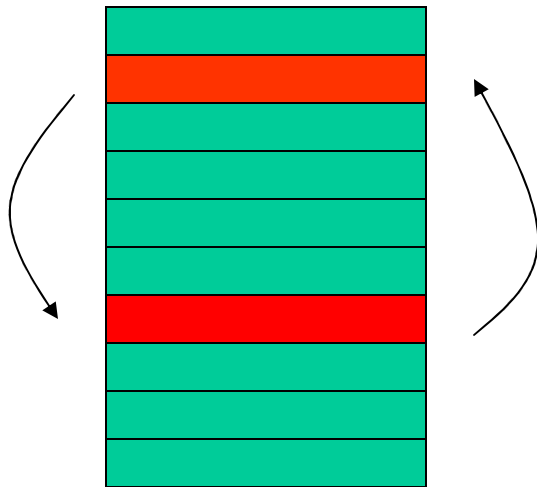
2-for-2 trades enable airlines to profit by exchanging pairs of usable slots that result in an increase in overall value to the carrier.



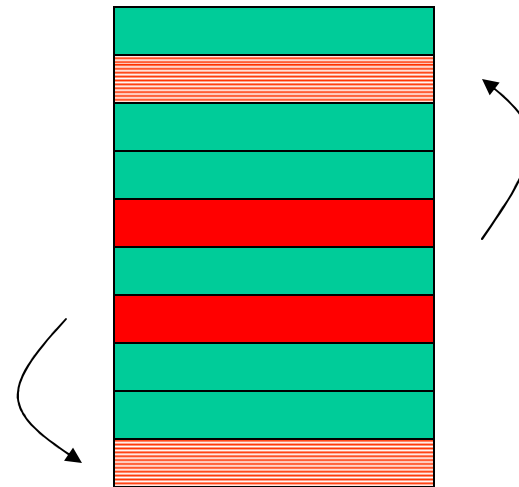
$$\begin{aligned} \text{A's value proposition: } & \text{val}_A(s3) - \text{val}_A(s1) + \text{val}_A(s4) - \text{val}_A(s2) = \\ & 2000 - 1500 + 300 - 500 = \$300 \end{aligned}$$

$$\begin{aligned} \text{B's value proposition: } & \text{val}_B(s1) - \text{val}_B(s3) + \text{val}_B(s2) - \text{val}_B(s4) = \\ & 500 - 800 + 2500 - 1800 = \$400 \end{aligned}$$

Another view of 2-for-2 trading: generalized substitutions



Normal Sub



Generalized Sub

System Design Issues:

- How do airlines represent and subsequently generate offers?
- Formulation and solution of FAA mediation problem.

Testing and Experimental Issues:

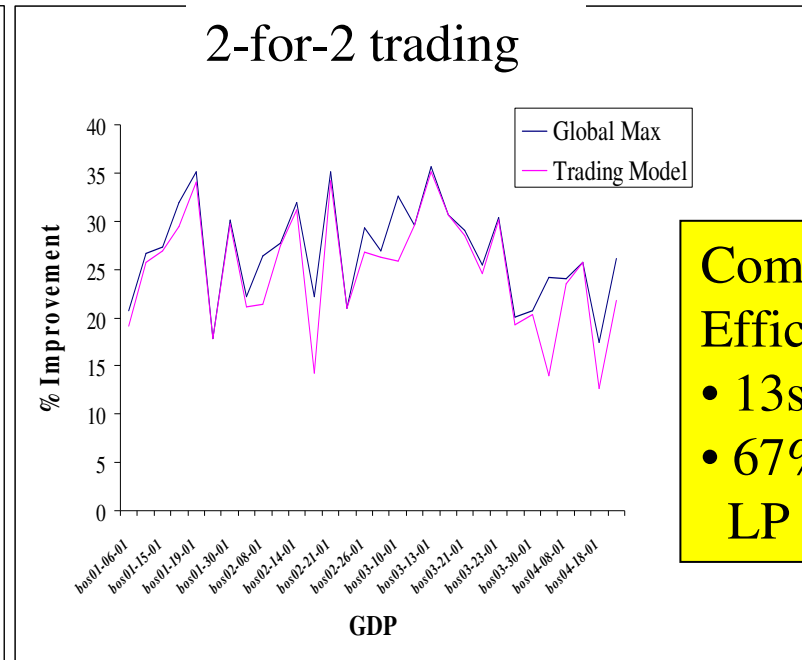
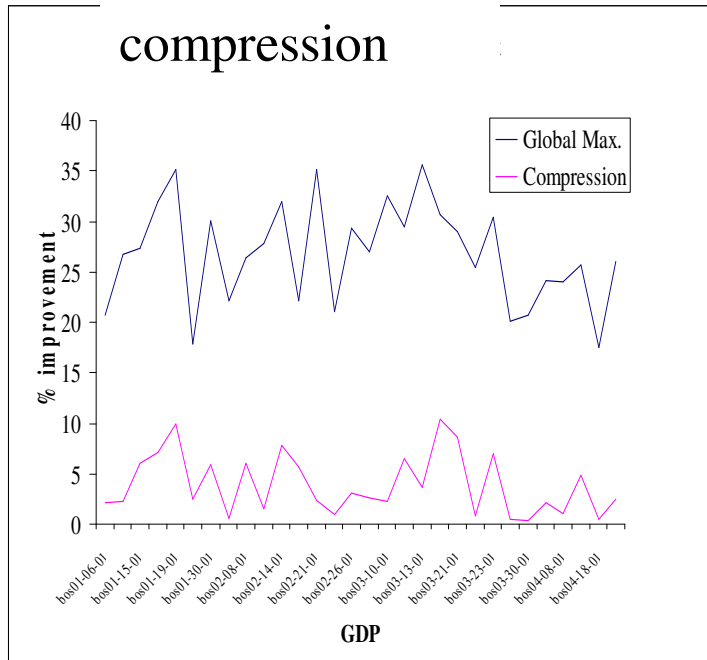
- Simulating airline cost functions
- Airline strategies for generating offers
- Measuring performance of trading system: generate optimal centralized solution (system efficiency) – evaluate degree to which trading system can achieve performance of centralized system

Basic Model and Test

Airline cost function: maximize on-time performance (delay ≤ 15 minutes)

For each carrier, generate all 2-for-2 trades

Mediator model: maximize number of trades accepted



Computational Efficiency:

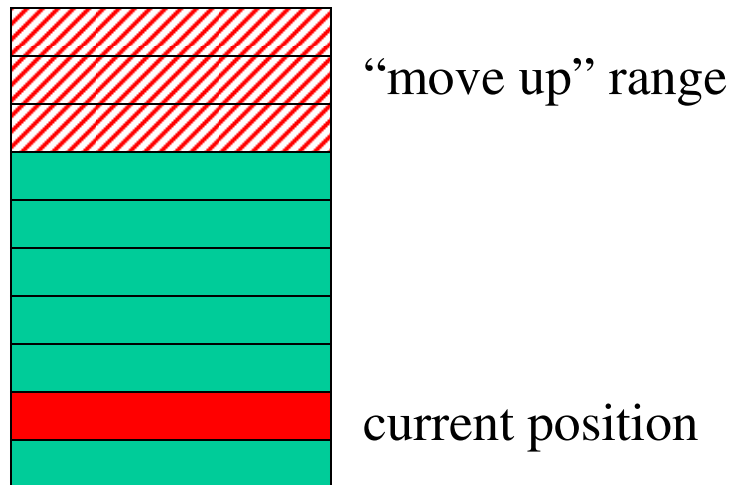
- 13sec avg.
- 67% solved by LP relaxation



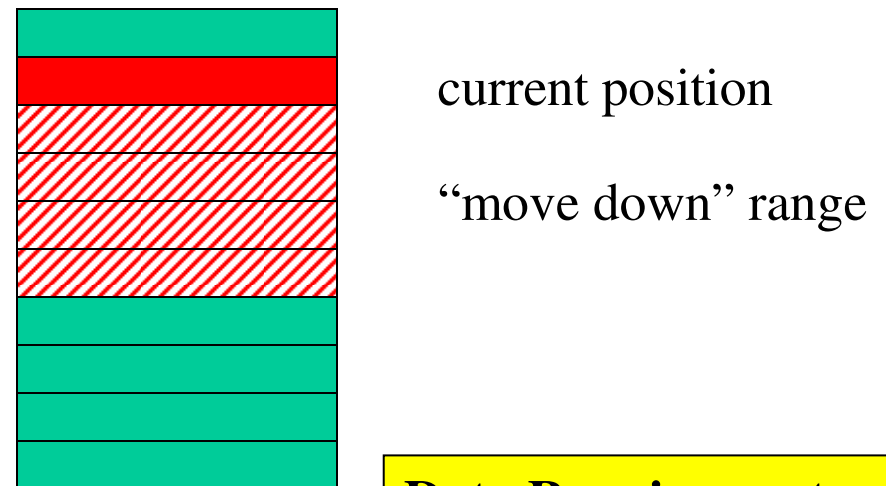
Creating a practical system: offer structure



high priority flights



low priority flights



**willing to accept high priority move up
in exchange for low priority move
down !!**

other flights: will to accept “free” move up

Data Requirements:

1 new data item per
flight -- LET: latest
exchange time

Note: there can be many strategies for generating offers



Creating a practical system: mediation problem



Airline performance function:

- w_a (tot up move distance) – (tot down move distance)
- w_a expresses relative per unit value of up-moves vs down-moves – individually set by each airline

Math Program:

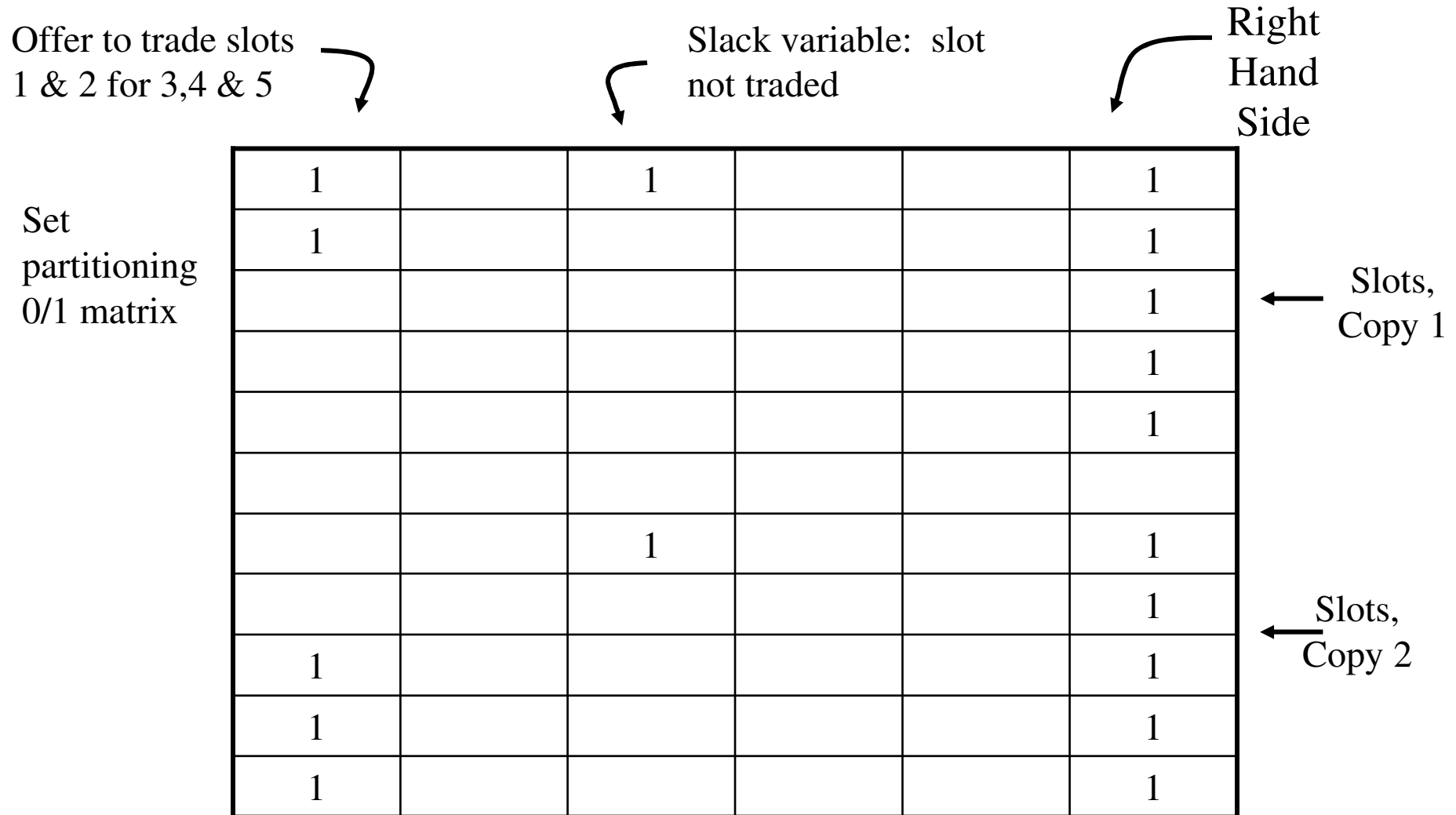
Starting point: assignment problem that assigns flights to slots in a manner consistent with offers

Side constraints:

w_a (tot up move distance) – (tot down move distance) ≥ 0 for each airline

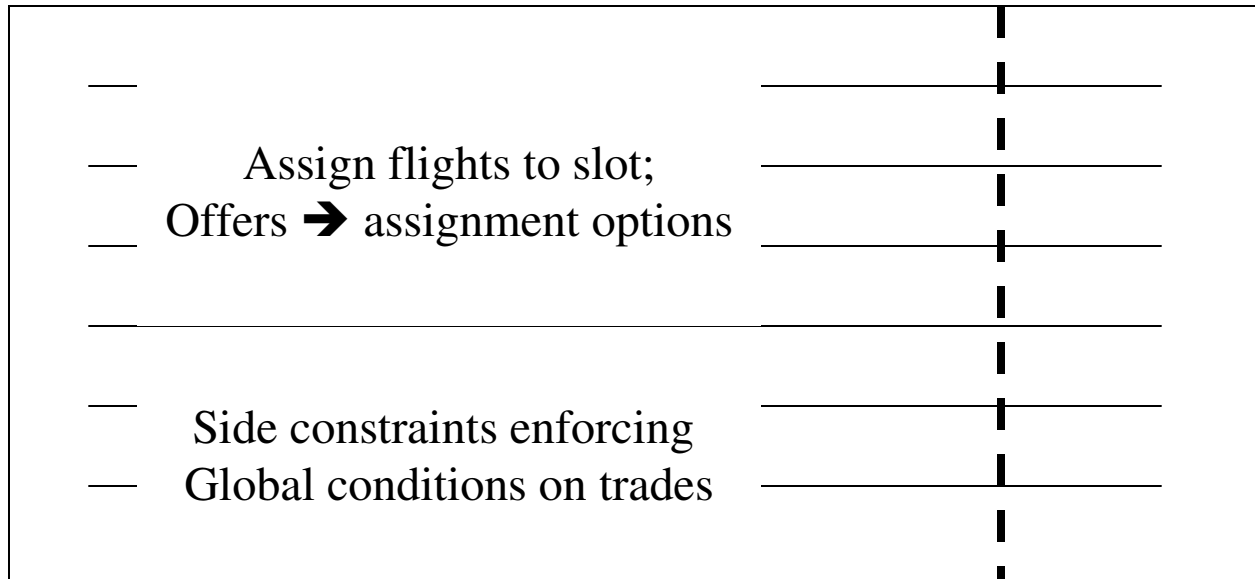
tot # up moves \geq tot # down moves for each airline

Prior Approach to Solving Mediator's Problem: explicit representation of 2-for-2 trades





New Approach to Solving Mediator's Problem: assignment problem with side constraints



New approach leads to much more efficient IPs;
Also implicitly handles k-for-n trades



Objective Function of Mediator's problem



- **System efficiency:** max tot distance of up moves or tot number of up moves
- **Equity:**

Define:

- $P(a)$ = Airline participation level = (tot up distance of all offers) * (tot down distance of all offers)
- $u(a)$ = tot up distance of airline a.

Equity objective:

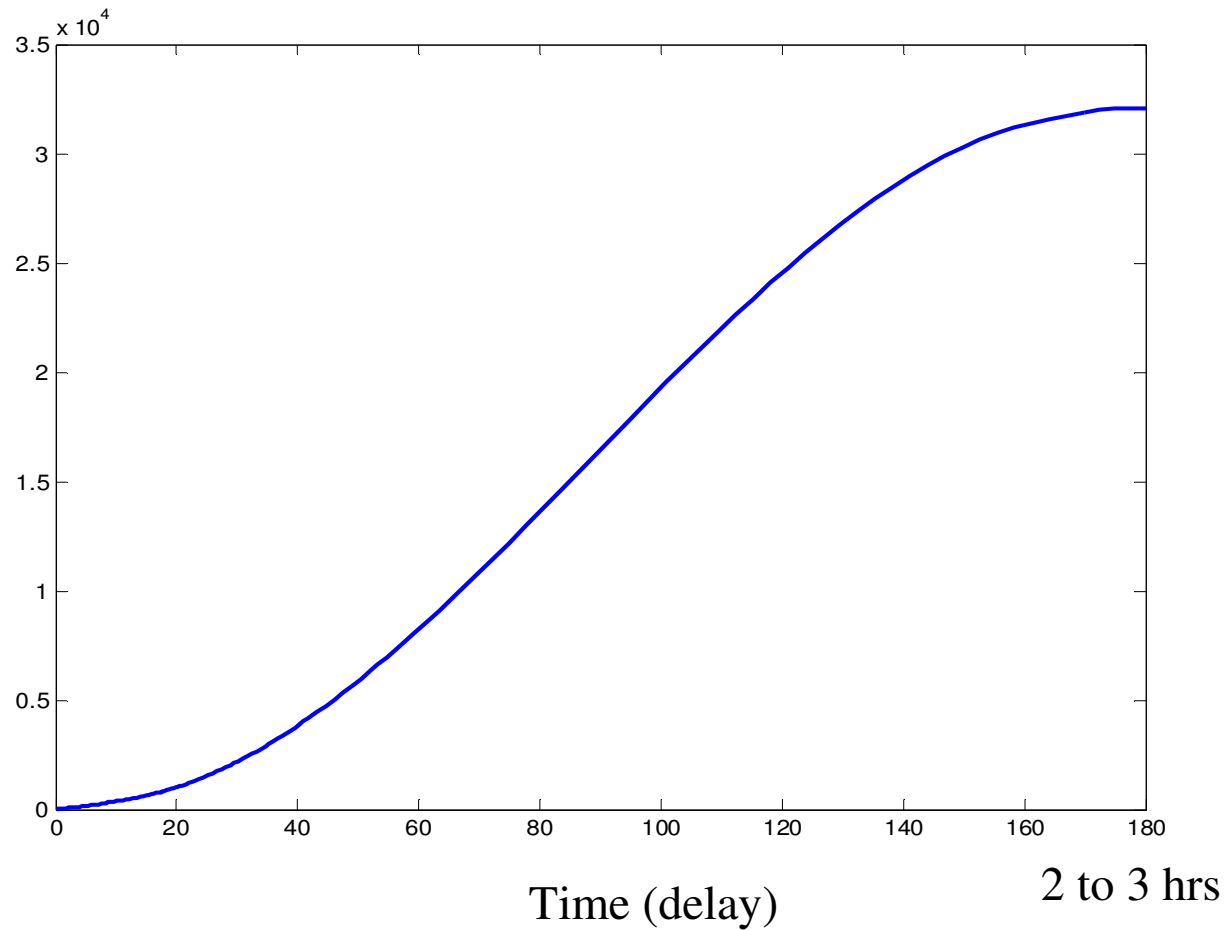
$$\text{Min } | u(a) / P(a) - \text{avg}(u(a) / P(a)) |$$



Airline Cost Function for Simulation

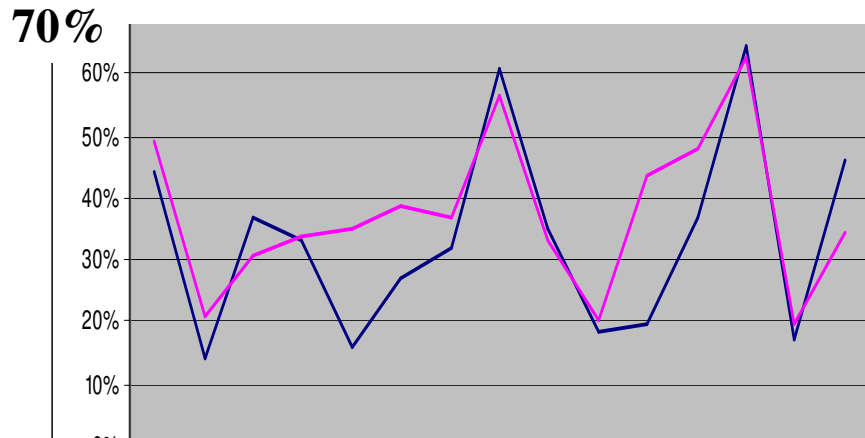


cancellation
cost





Performance of “practical” approach

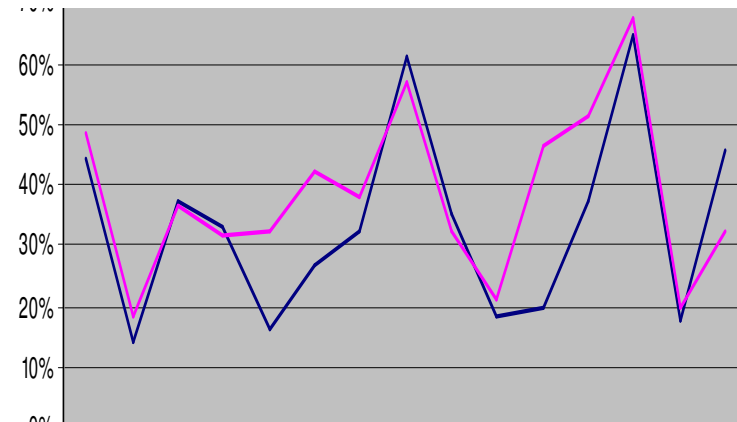


GDPs

Max distance

— 2-for-2 trading

— compression



GDPs

Max sum of distance and equity

— Compression
— Abs+Comp



Perspective on Results

- Results depend significantly on airline bid generation strategies.
- Best airline approach depends on internal schedule and cost structure, attitude toward risk and strategy of competitors.
- Competitive simulations currently being constructed.



Getting closer to system-wide efficiency: introducing a true marketplace



- With bartering model, “small” carriers with low-capacity, short-haul flights can “protect” their slots. This can be a significant impediment to achieving system-wide efficiency.
- The introduction of side payments and slot buying/selling will “induce” small carriers to transfer slots to larger carriers
- The underlying market is a combinatorial exchange: packages of goods bought, sold and exchanged.