Resource Rationing and Exchange Methods in Air Traffic Management

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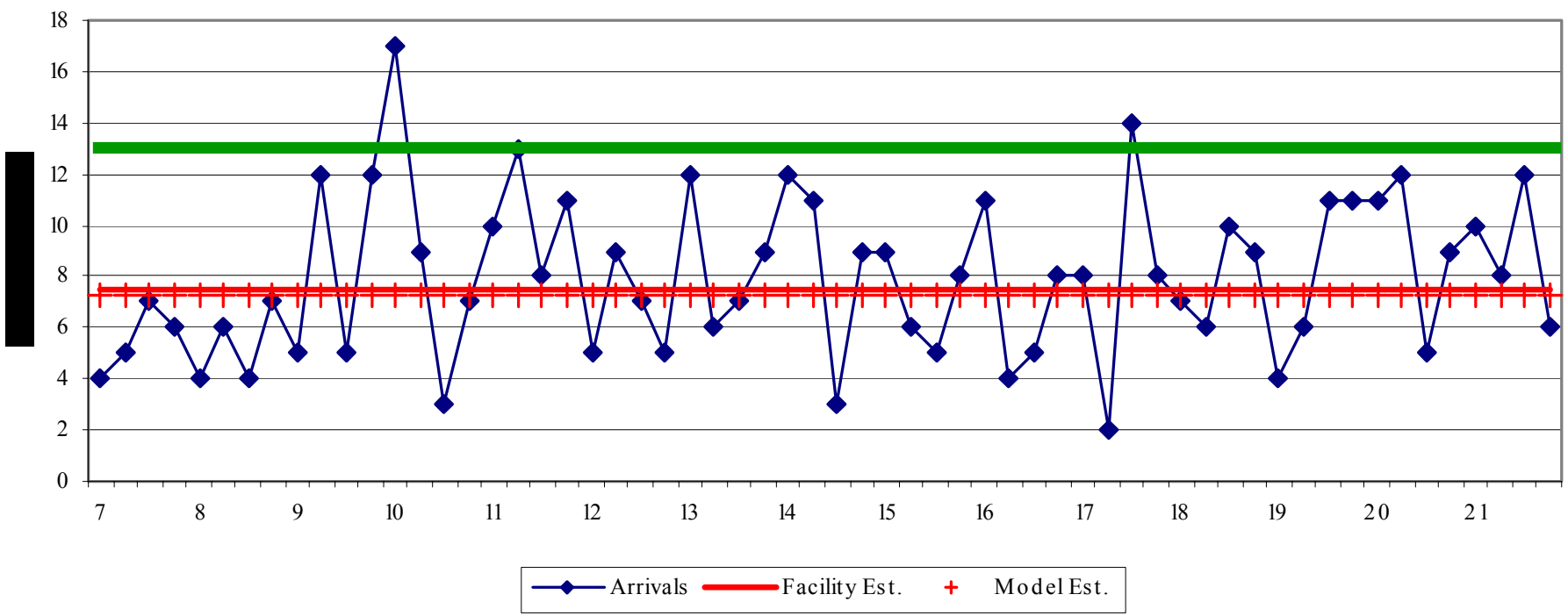
Motivation for Ground Delay Programs: airline schedules "assume" good weather

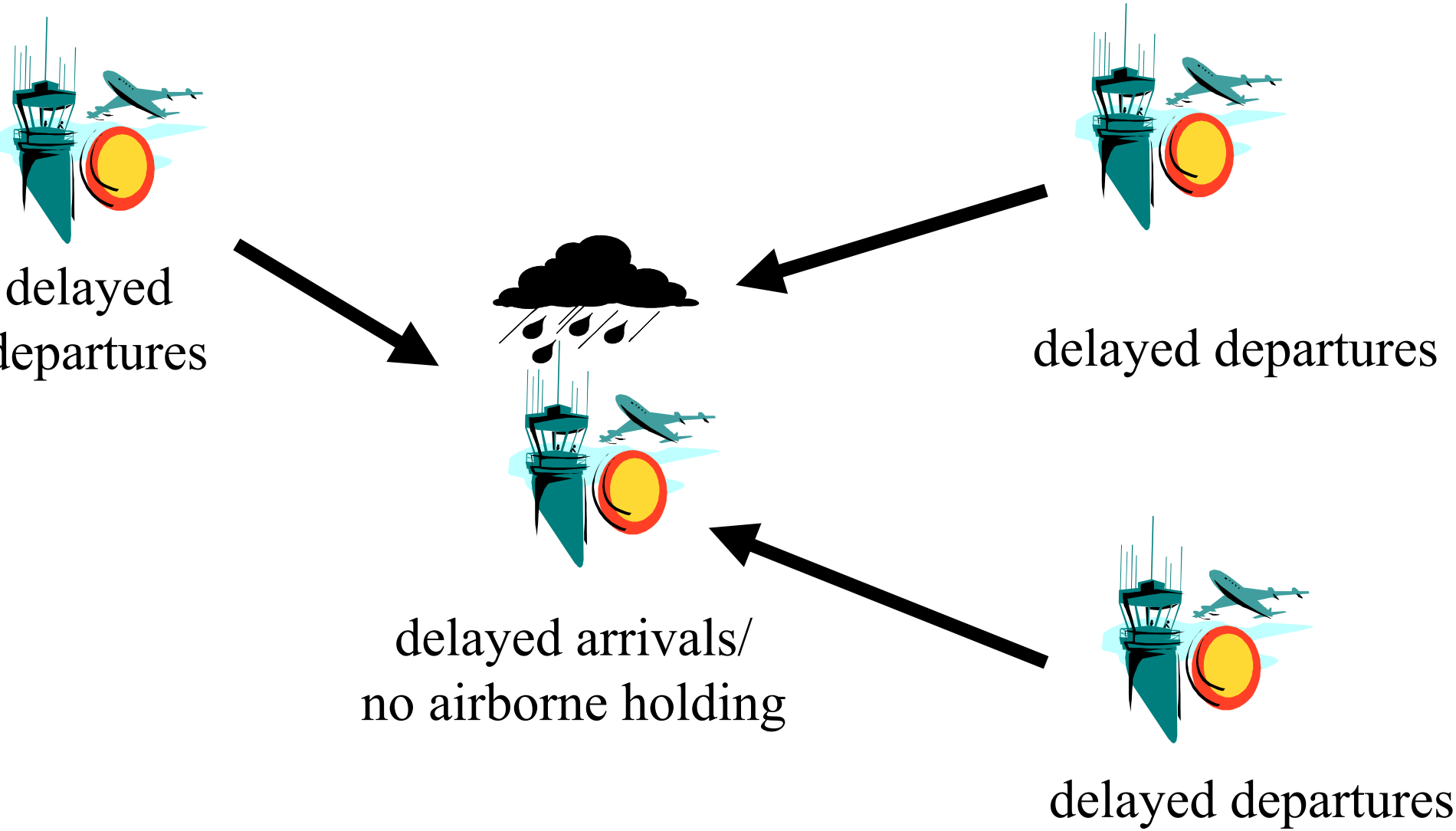
SFO: scheduled arrivals:

VMC airport acceptance rate:

IMC airport acceptance rate:



Ground Delay Programs



Collaborative Decision-Making

Traditional Traffic Flow Management:

- Flow managers alter routes/schedules of individual flights to achieve system wide performance objectives

Collaborative Decision-Making (CDM)

- Airlines and airspace operators (FAA) share information and collaborate in determining resource allocation; airlines have more control over economic tradeoffs

CDM in GDP context:

- CDM-net: communications network that allows real-time information exchange
- Allocation procedures that increase airline control and encourage airline provision of up-to-date information

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*

Issues

- What is an ideal (fair) allocation?
- How can an allocation be generated that is very close to the ideal while taking into account dynamic problem aspects?
- How can airlines exchange resources they receive as part of their allocation?

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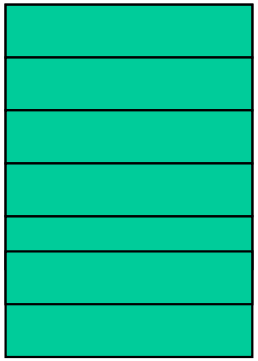
Determining fair shares

Sketch:

- Assume slots are *divisible*
  - leads to probabilistic allocation schemes
- Approach: impose properties that schemes need to satisfy
  - fairness properties
  - structural properties (consistency, sequence-independence)

OAG Schedule

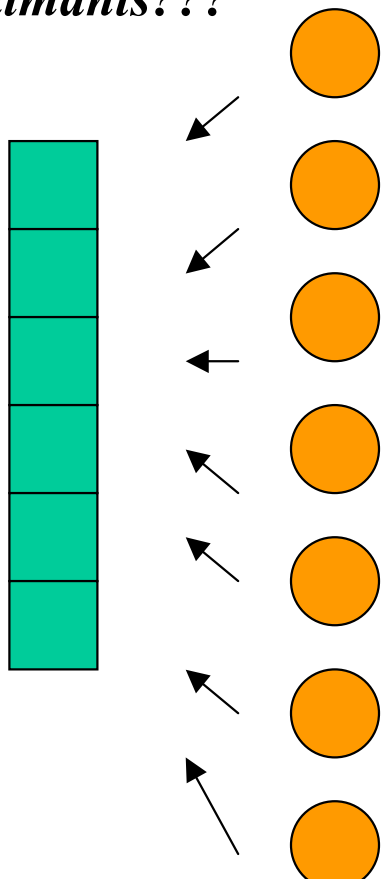
vs



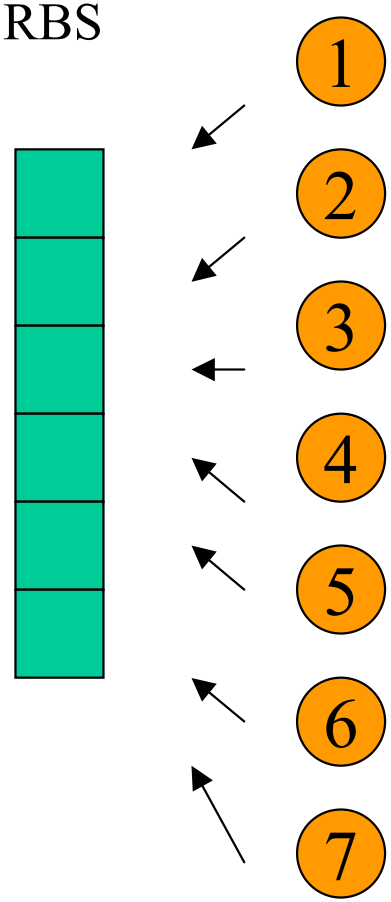
Slots Available

Allocation Principles

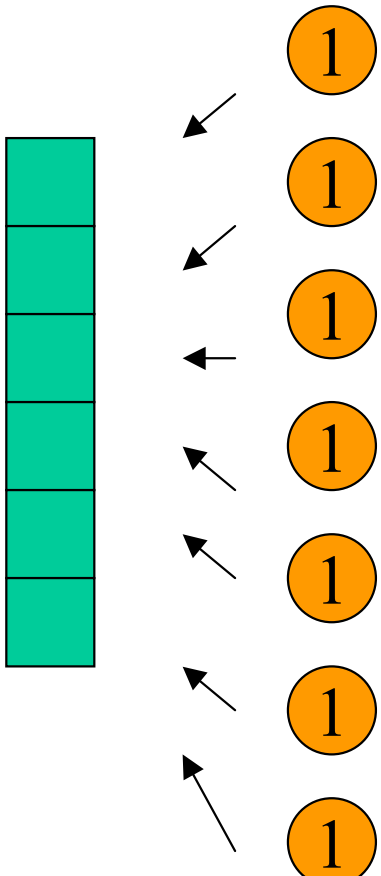
How to allocate limited set of resources among several competing claimants???



First-come, first-served: strict priority system based on oag times ⇔ RBS



Equal access: all claimants have equal priority ⇔% slots received by airline = % flights scheduled in time period



Comparison

- First-come/first-served – RBS:
  - implicitly assumes there are enough slots to go around, i.e. all flights will be flown
  - lexicographically minimizes max delay
  - implicitly treats flights as independent economic entities
- Equal Access:
  - implicitly assumes there are not enough slots to go around – some flight/airlines will not receive all the slots they need
  - does not acknowledge that some flights cannot use some slots
  - strict interpretation leads to Shapley Value

Equal Access to Usable Slots: Proportional Random Assignment (PRA)

UA33 **US25**

UA19 **US31**

US19

Flight shares

	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5
UA33	1/2	1/8	1/8	1/8	1/8
UA19	1/2	1/8	1/8	1/8	1/8
US25	-	1/4	1/4	1/4	1/4
US31	-	1/4	1/4	1/4	1/4
US19	-	1/4	1/4	1/4	1/4

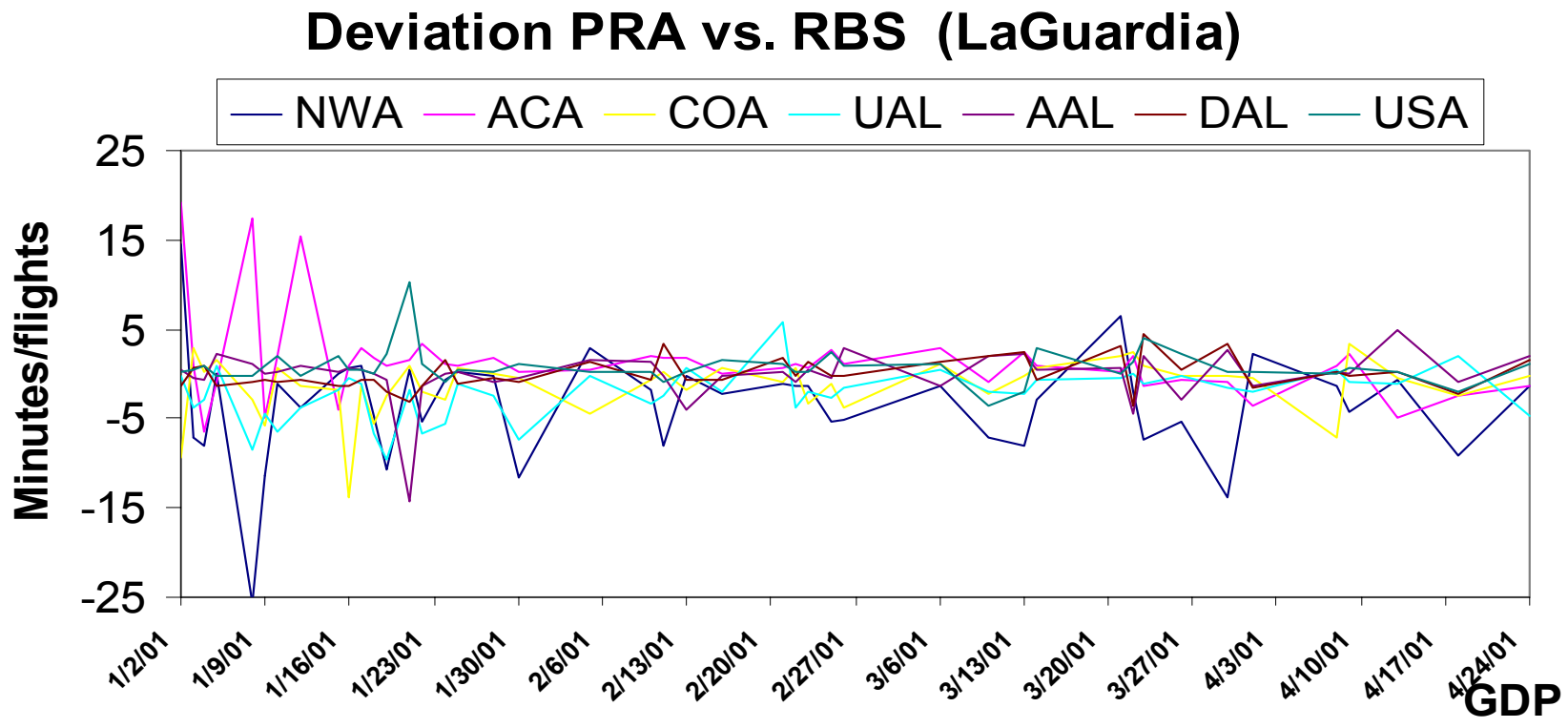
um wgt

UA	1	1.25	1.50	1.75	2
US		.75	1.50	2.25	3

irlines alloc

UA	1		1		

Empirical Comparison

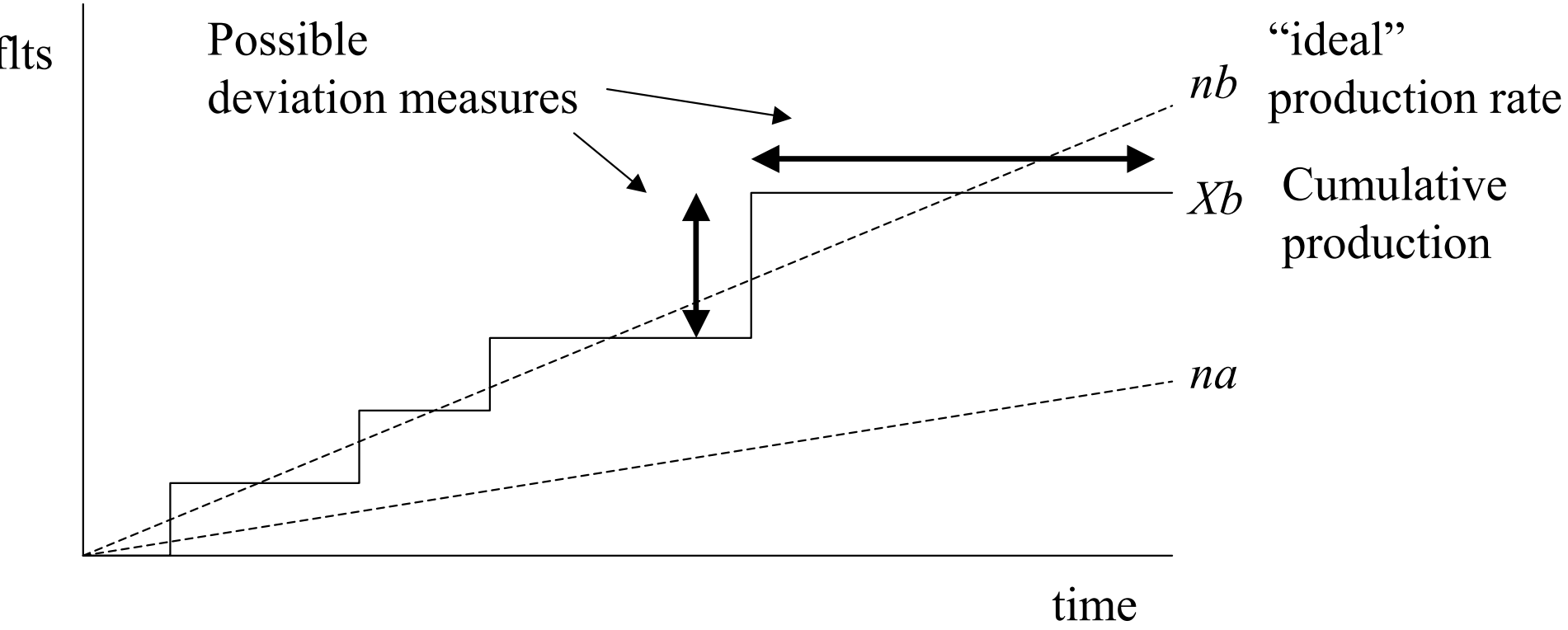


- On the aggregate, both methods give similar shares
- No systematic biases

Issues

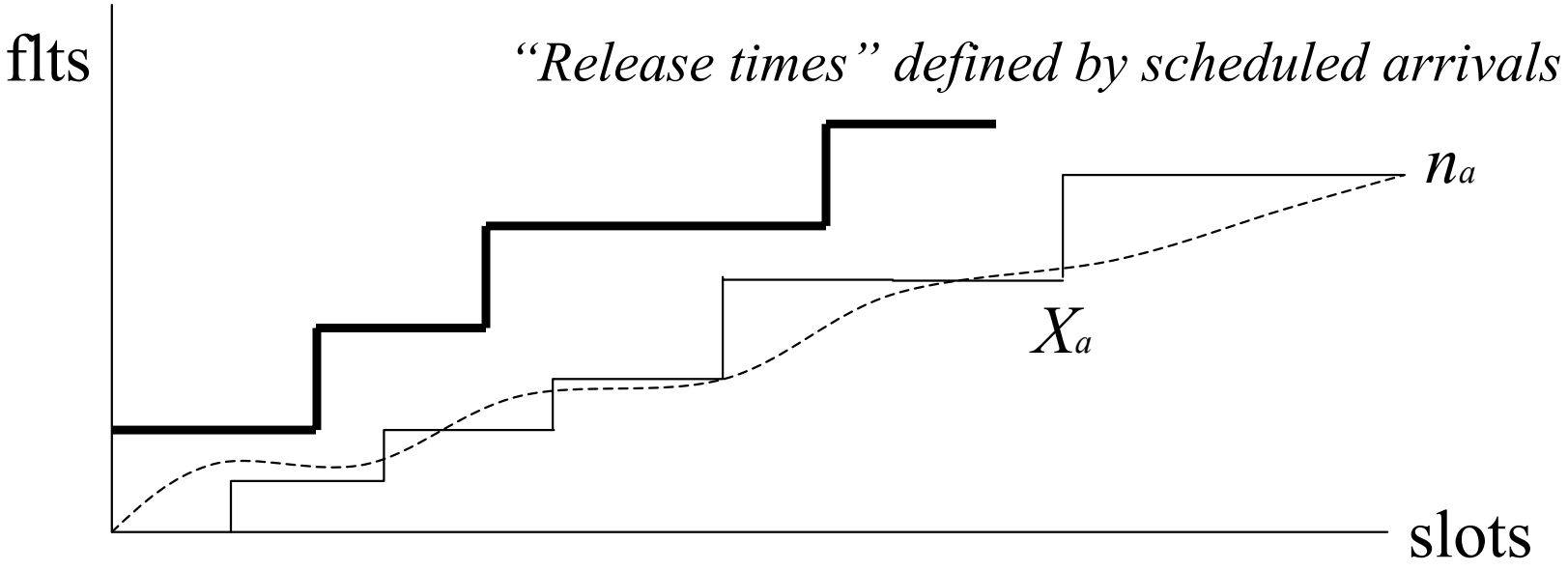
- What is an ideal (fair) allocation?
- How can an allocation be generated that is very close to the ideal while taking into account dynamic problem aspects?
- How can airlines exchange resources they receive as part of their allocation?

GDPs as Balanced Just-in-Time Scheduling Problem



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

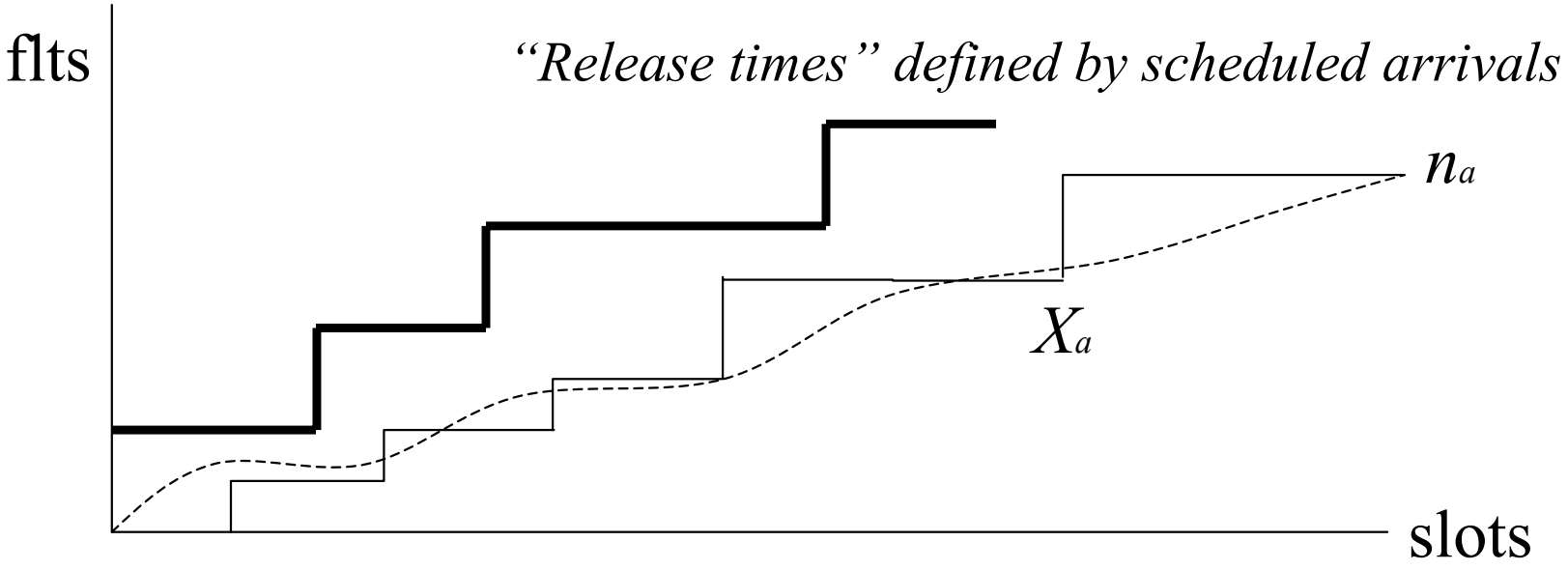
GDP Situation



Questions:

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

GDP Situation



Questions:

- What are appropriate "production rates" ? **ANS: RBS**
- How to minimize deviations ?
- Managing program dynamics

Models and Algorithms for Minimizing Deviation from Ideal Allocation

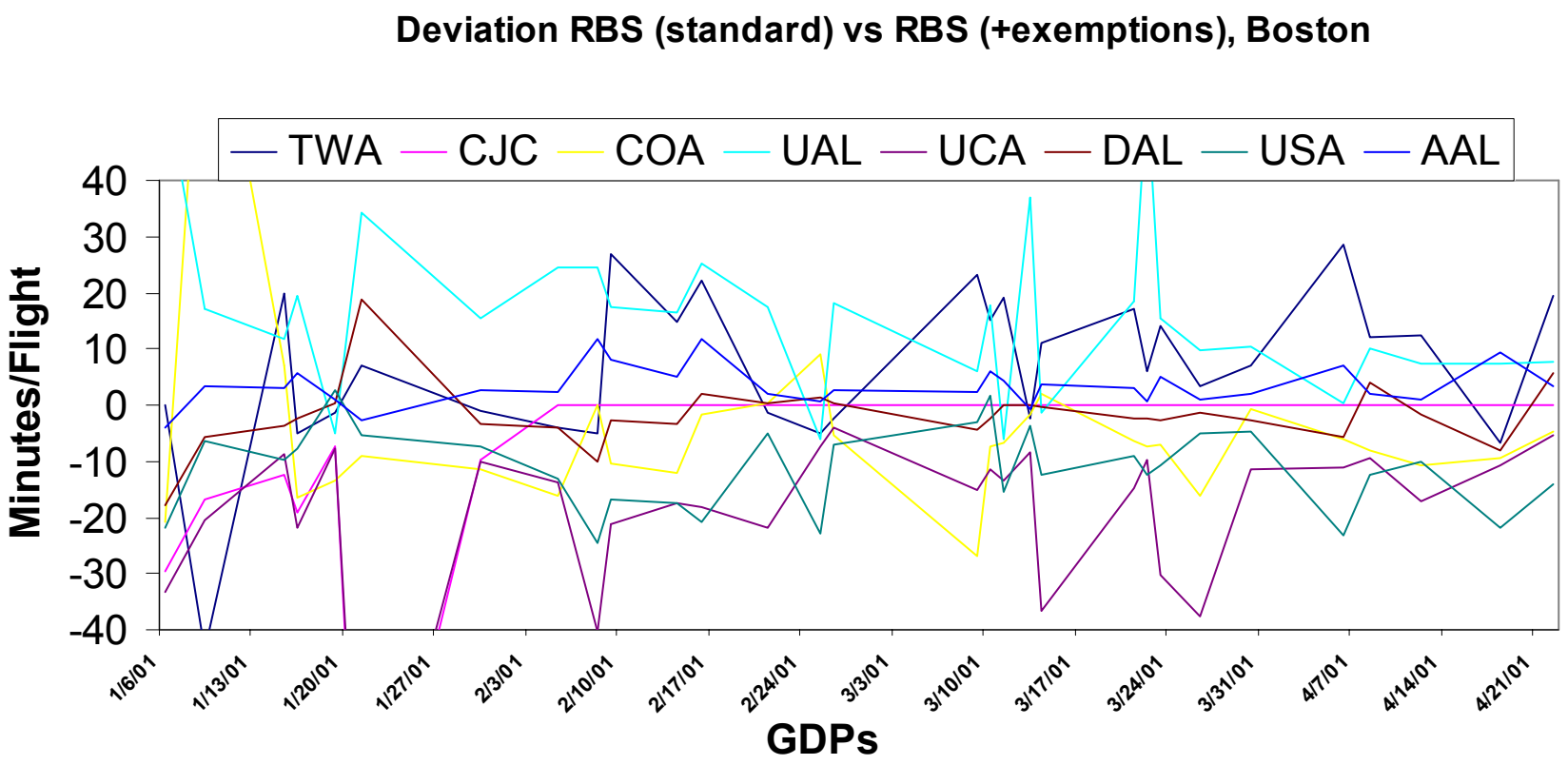
- General class of problems: minimize deviation between actual slot allocation and ideal slot allocation

  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 :

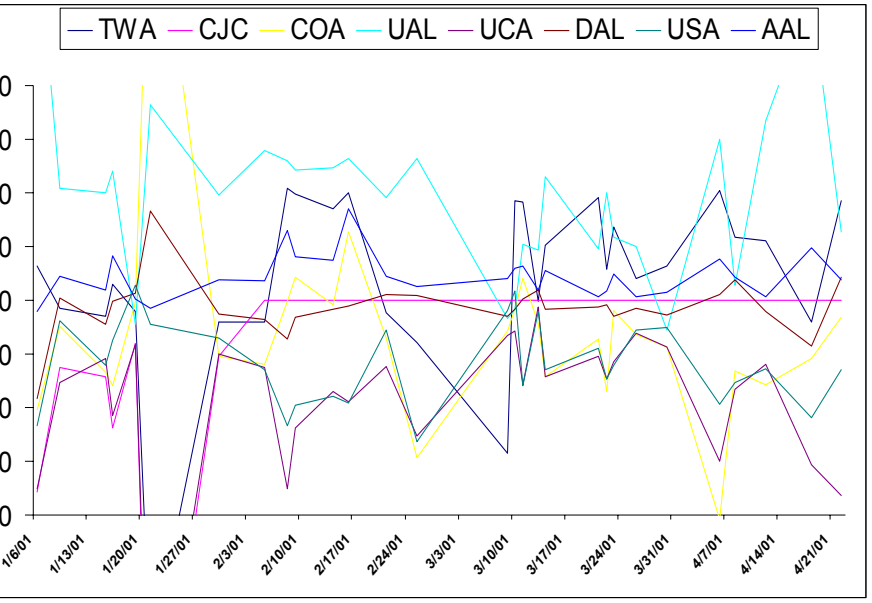
- Use deviation model to mitigate exemption bias
  - i.e. “inverse” compression

Approach:

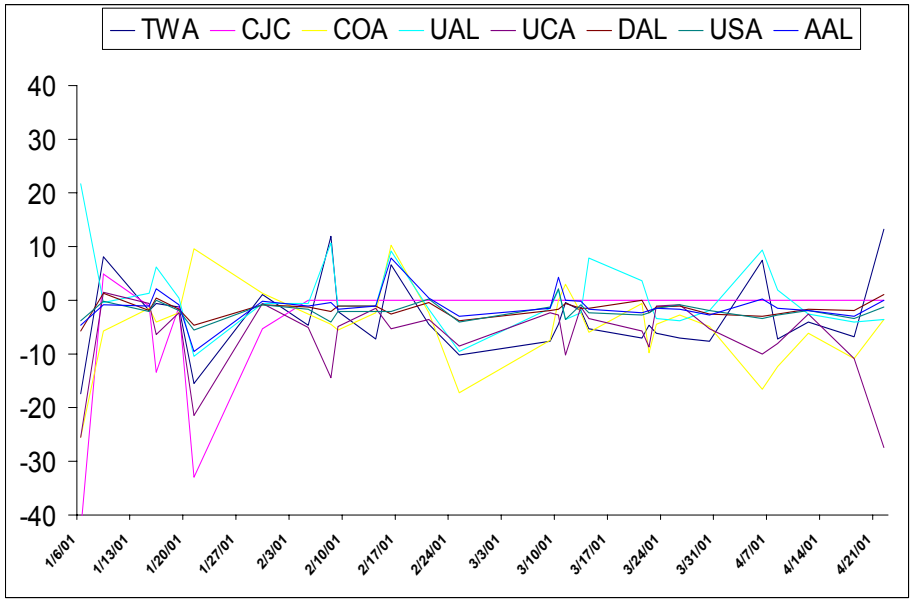
- RBS applied to all flights whose arrival times fall within GDP time window ➔ ideal allocation
- Set of exempted flights are defined as before (there are good reasons they are exempted)
- Time slots given to exempted flights “count against” allocation
- Delays allocated to non-exempted flights so as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

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

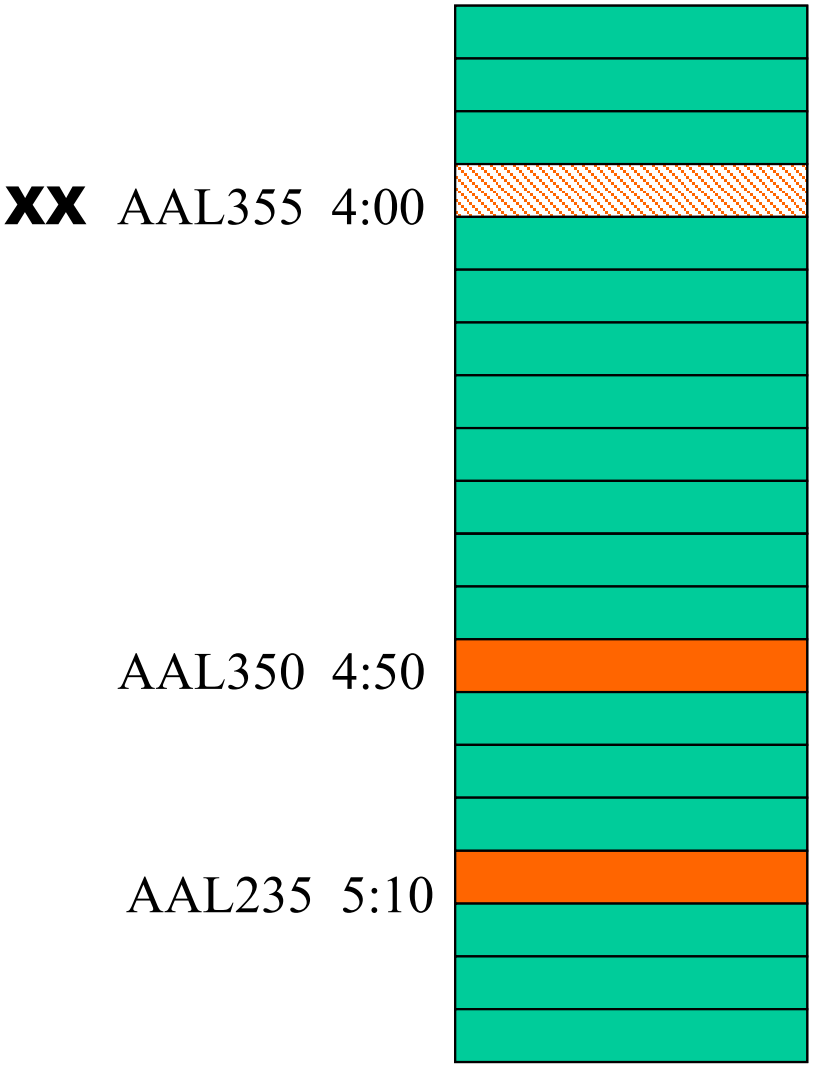
Discussion

- Define “ideal” allocation
- Manage program dynamics based on models that minimize deviation of actual slots allocated from ideal allocation
- Provides single approach to both RBS and compression
- Provides approach for mitigating bias due to exemptions
- Other potential application, e.g. handling “pop-ups”

Issues

- What is an ideal (fair) allocation?
- How can an allocation be generated that is very close to the ideal while taking into account dynamic problem aspects?
- How can airlines exchange resources they receive as part of their allocation?

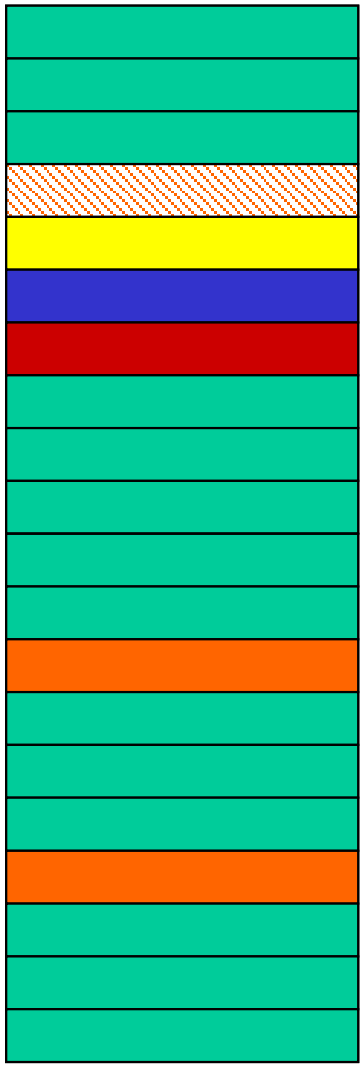
Why Exchange Slots??



Slot made available by canceled or delayed flight

arliest time
f arrival:
:15

Current Procedure: Compression



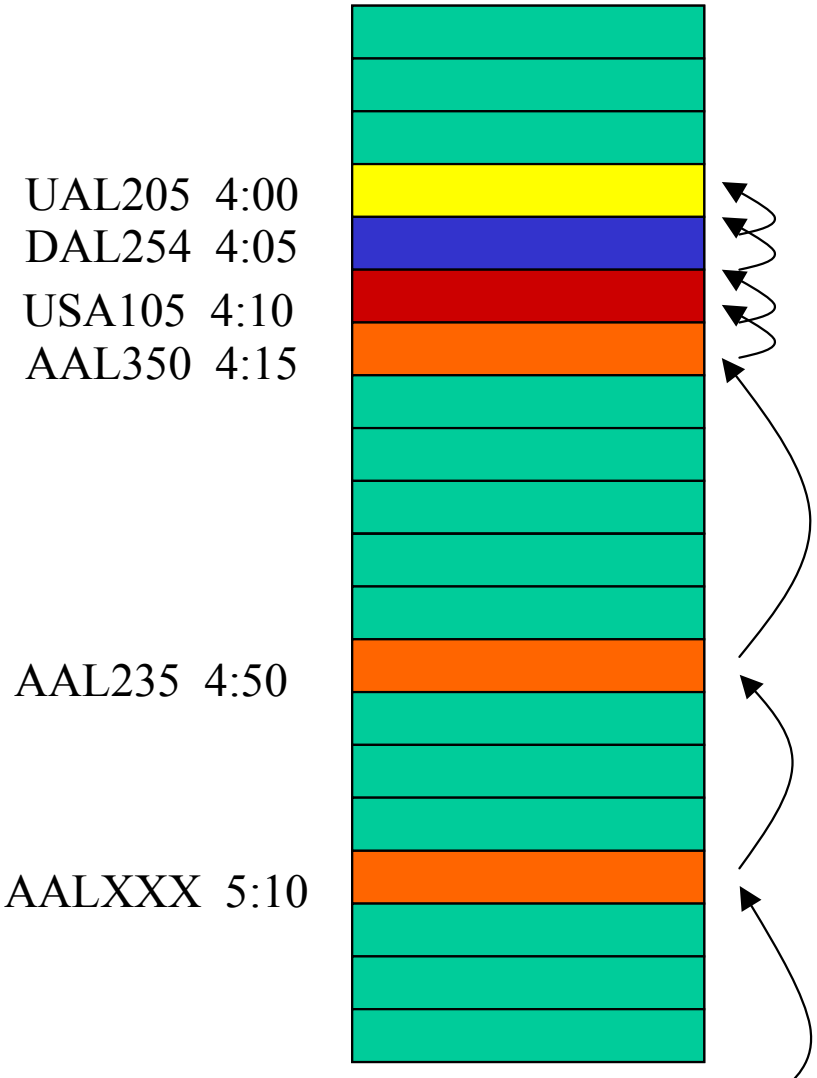
XX AAL355 4:00
UAL205 4:05
DAL254 4:10
USA105 4:15

AAL350 4:50

AAL235 5:10

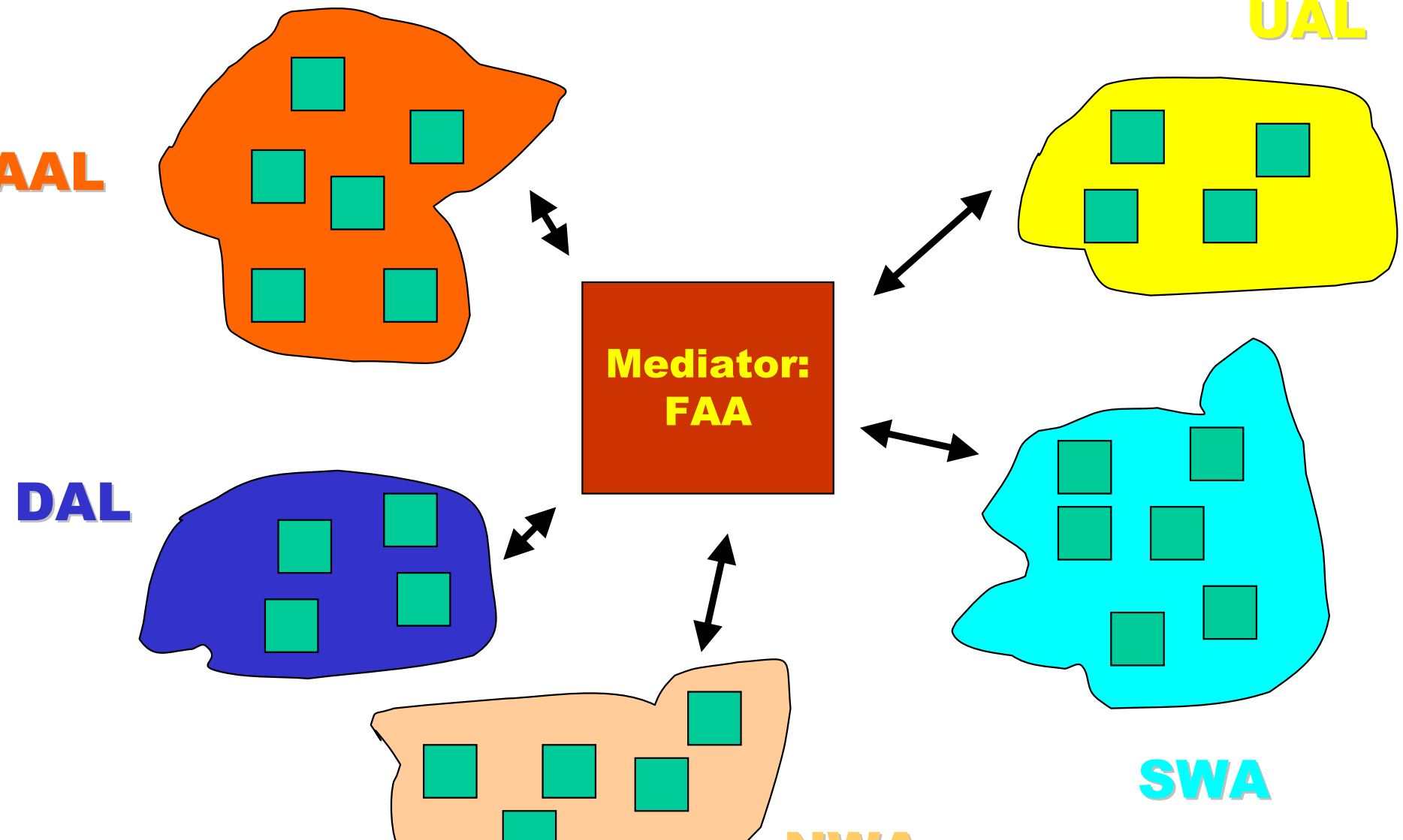
arliest time
f arrival: 4:15

Current Procedure: Compression



arliest time
f arrival: 4:15

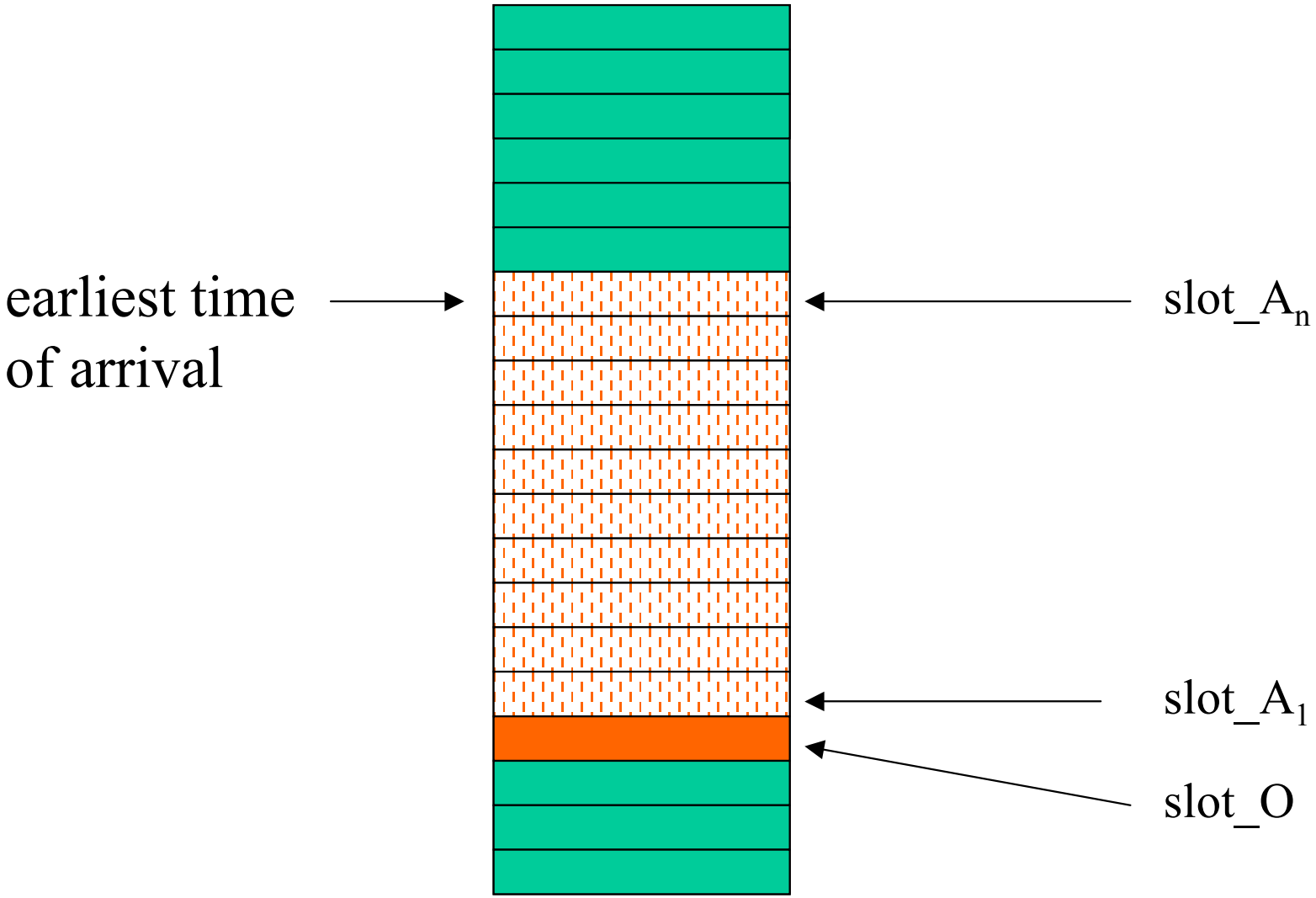
Inter-Airline Bartering



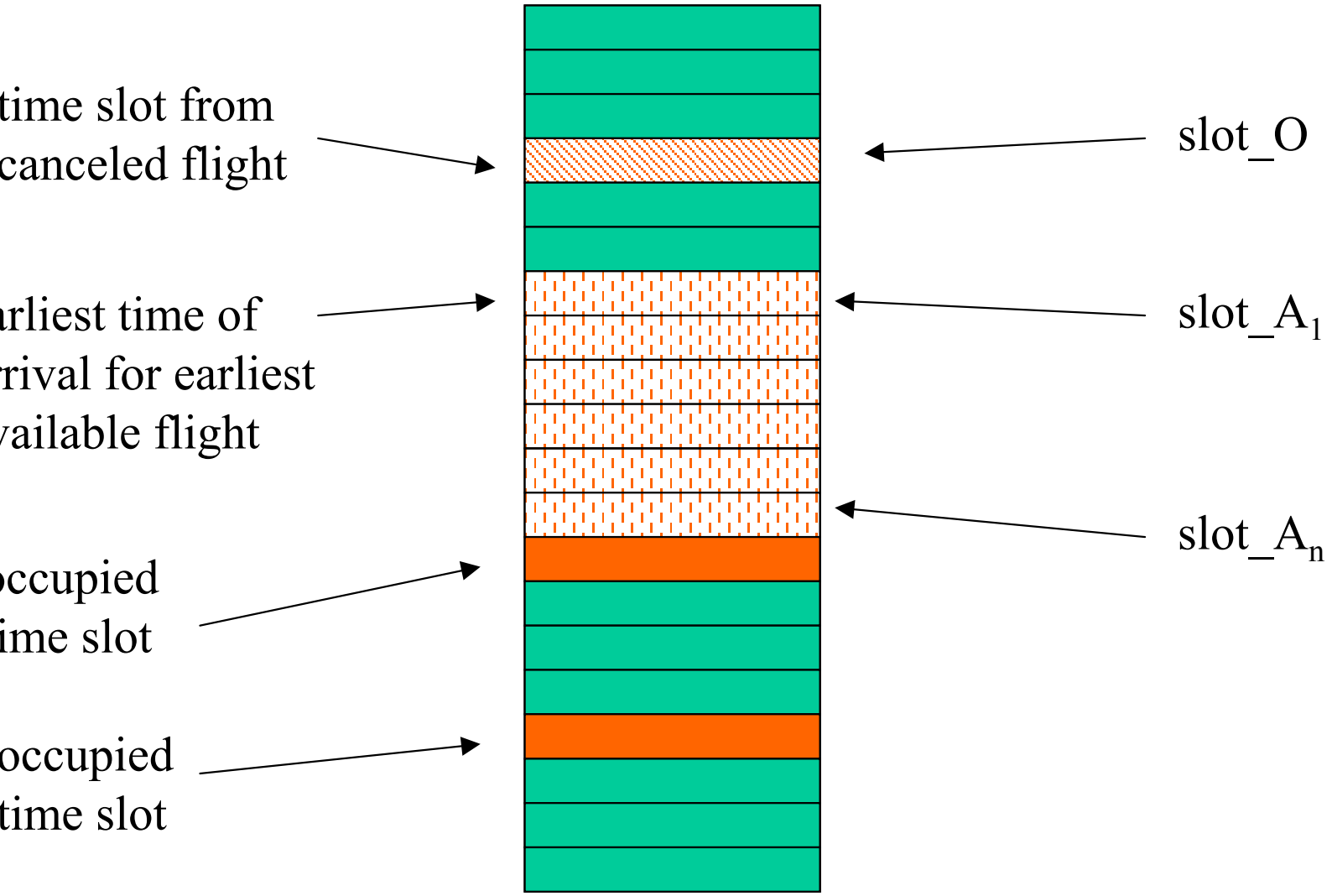
Mediated Slot Exchange

- 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

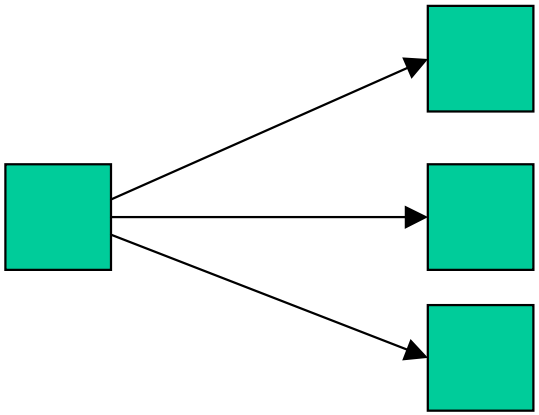


Offer Associated with Canceled or Delayed Flights

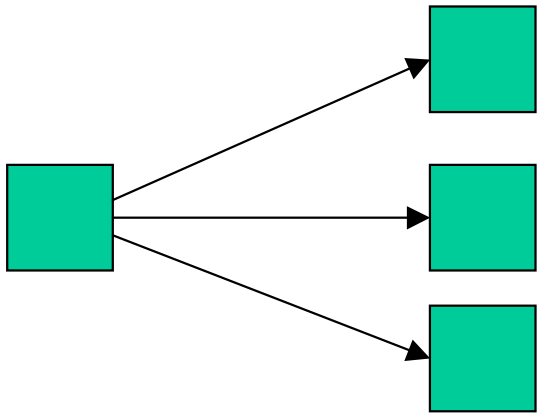


Mediation Problem

Input -- list of offers:

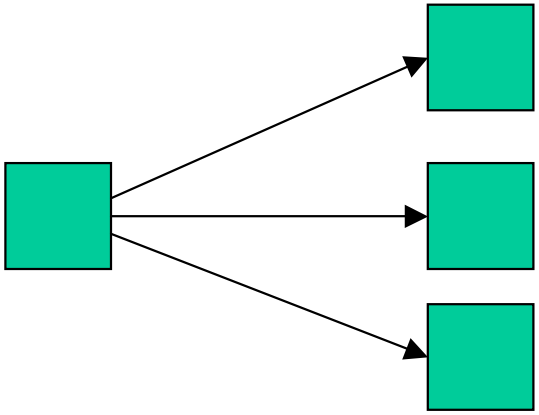


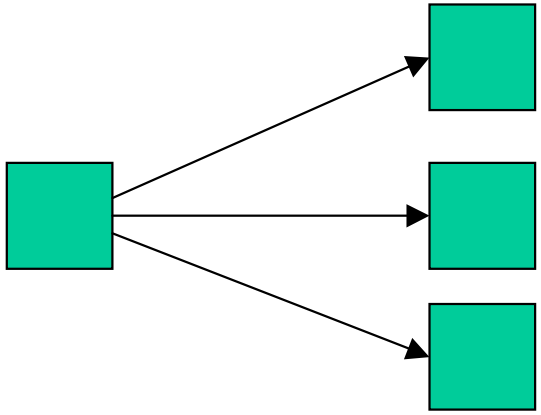
slot_O



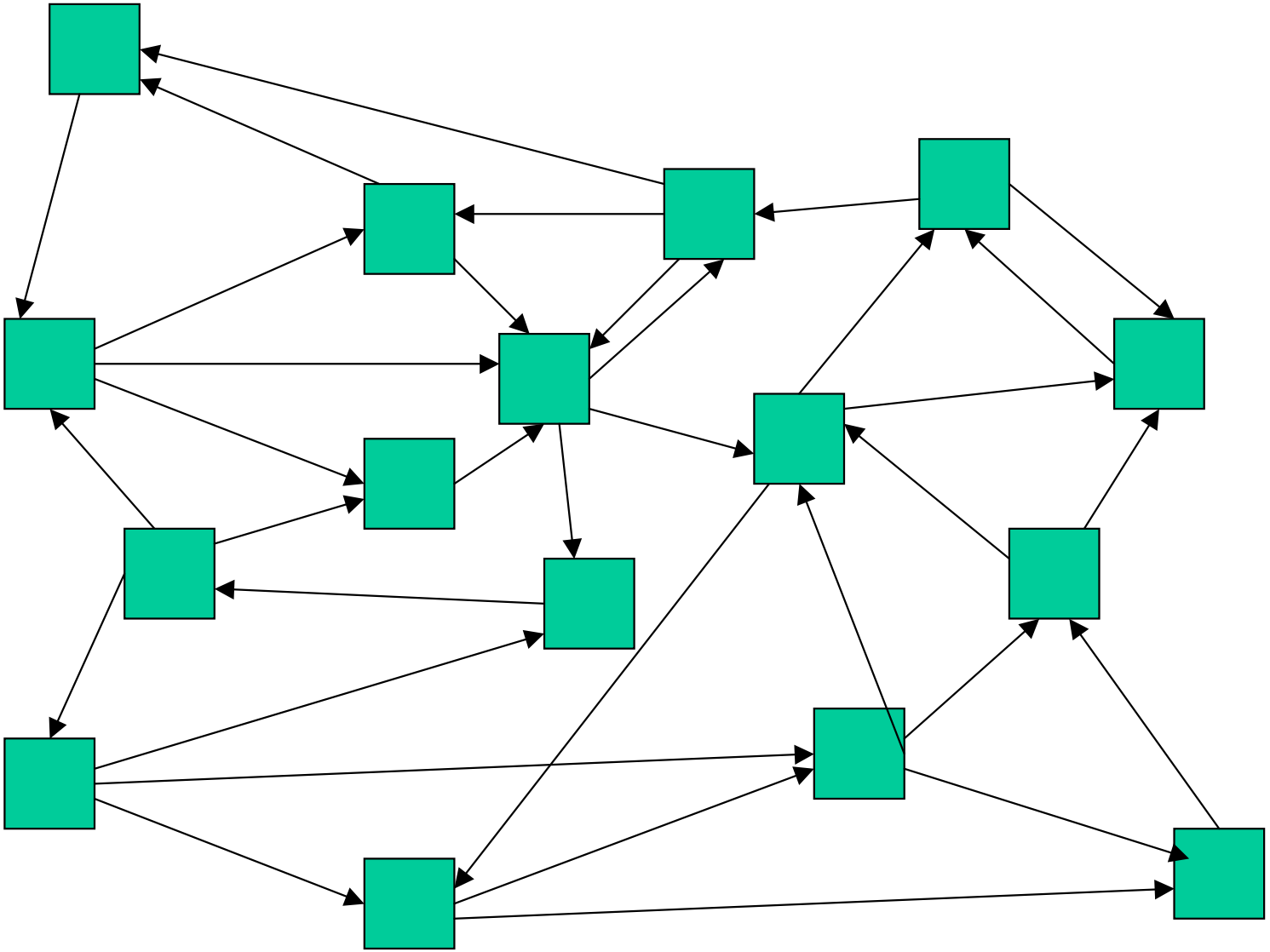
slot_A_1

slot_A_n

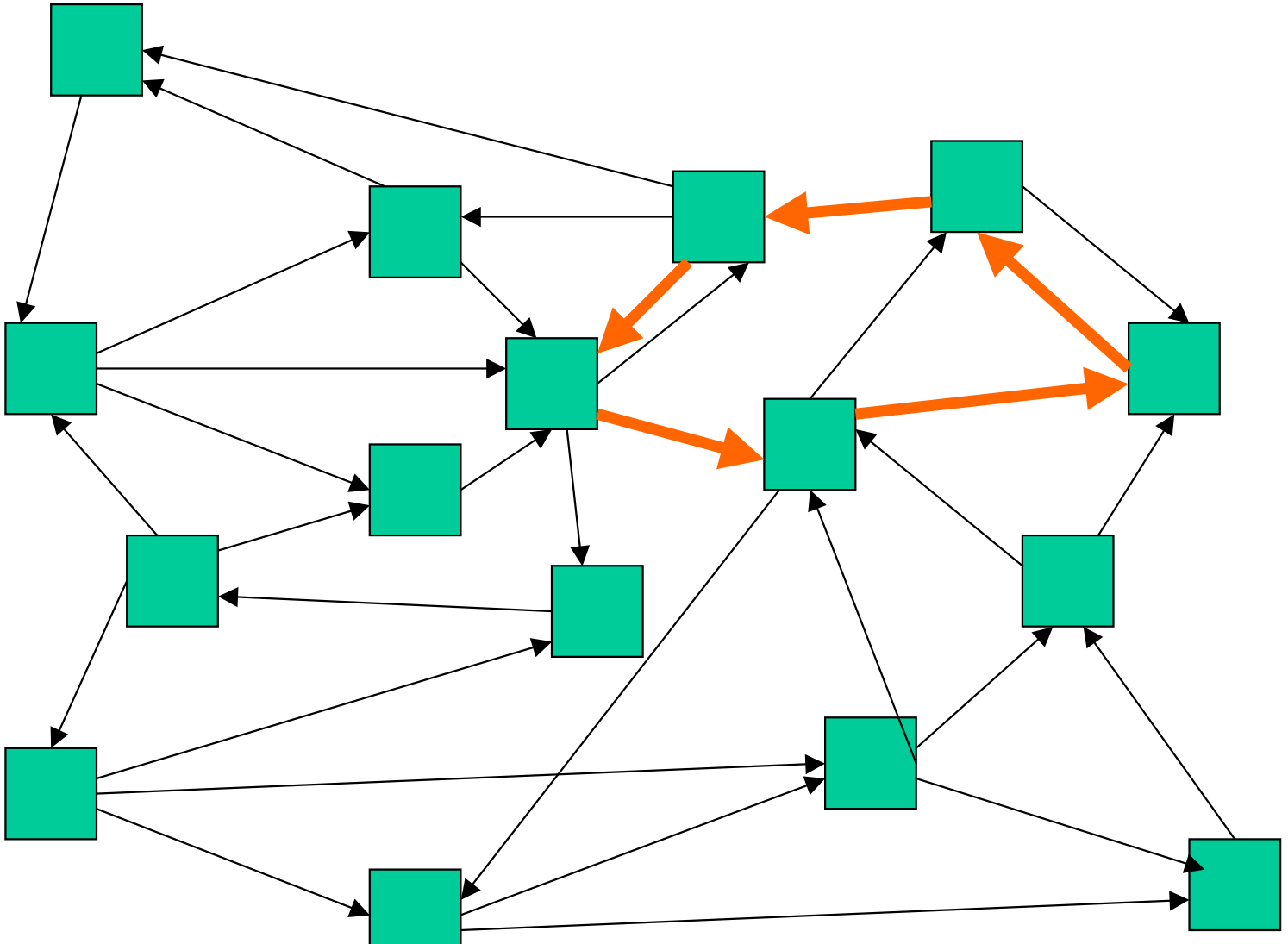




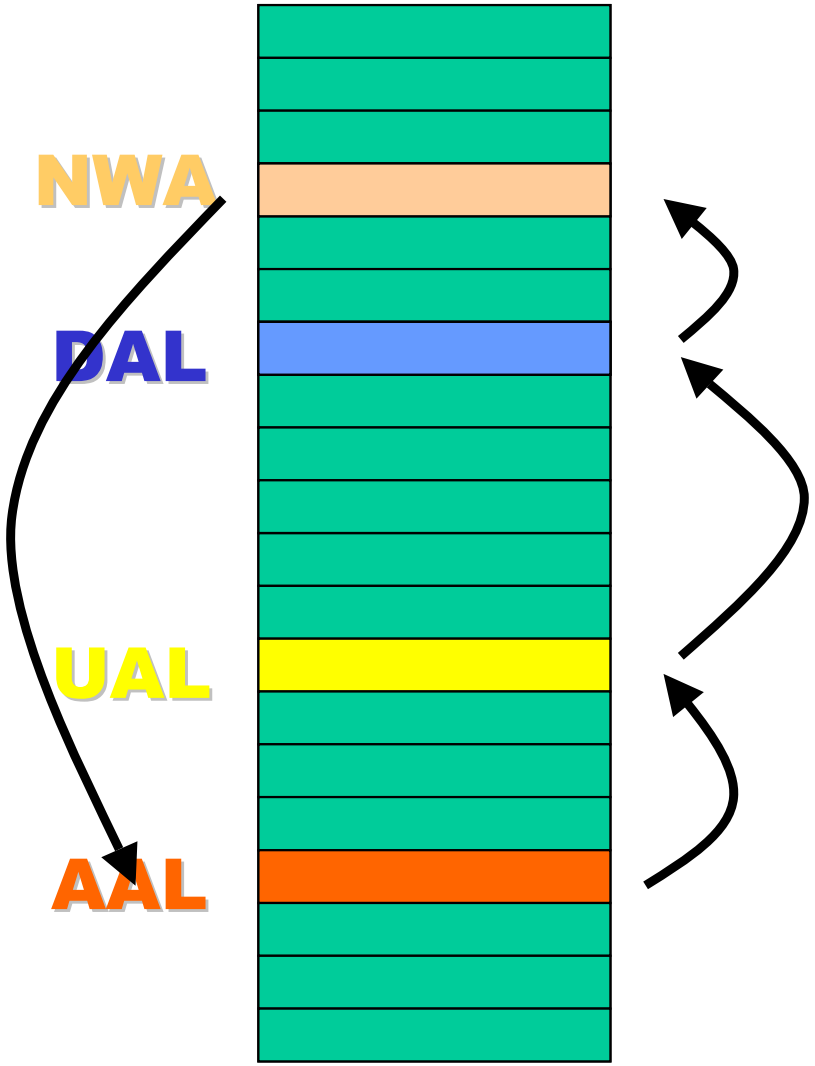
Problem: Which offers to accept



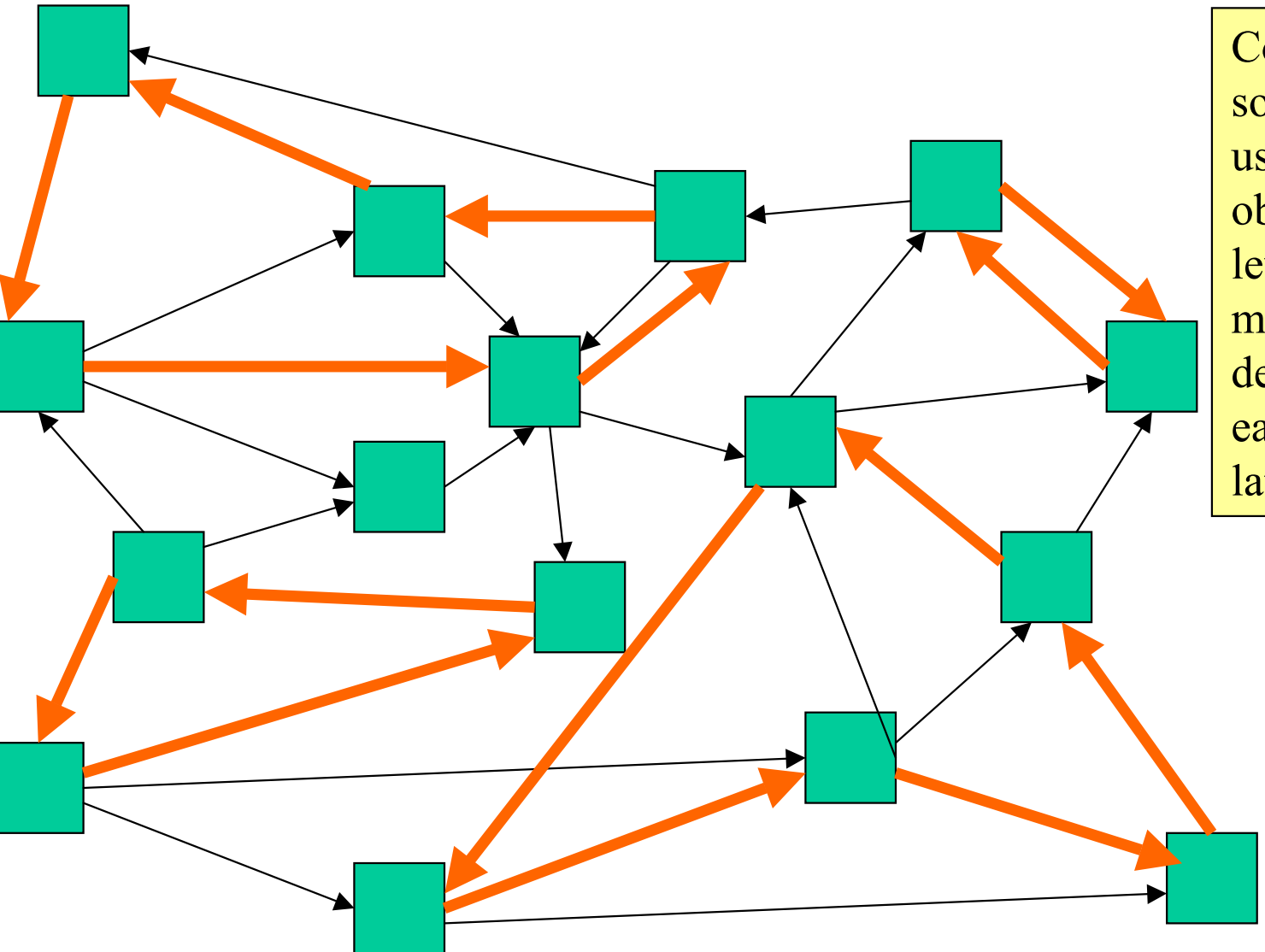
Cycle = set of mutually compatible set of exchanges



Schedule Movements Associated with Cycle



Overall Solution: find non-intersecting set of cycles – problem can be formulated as an assignment problem



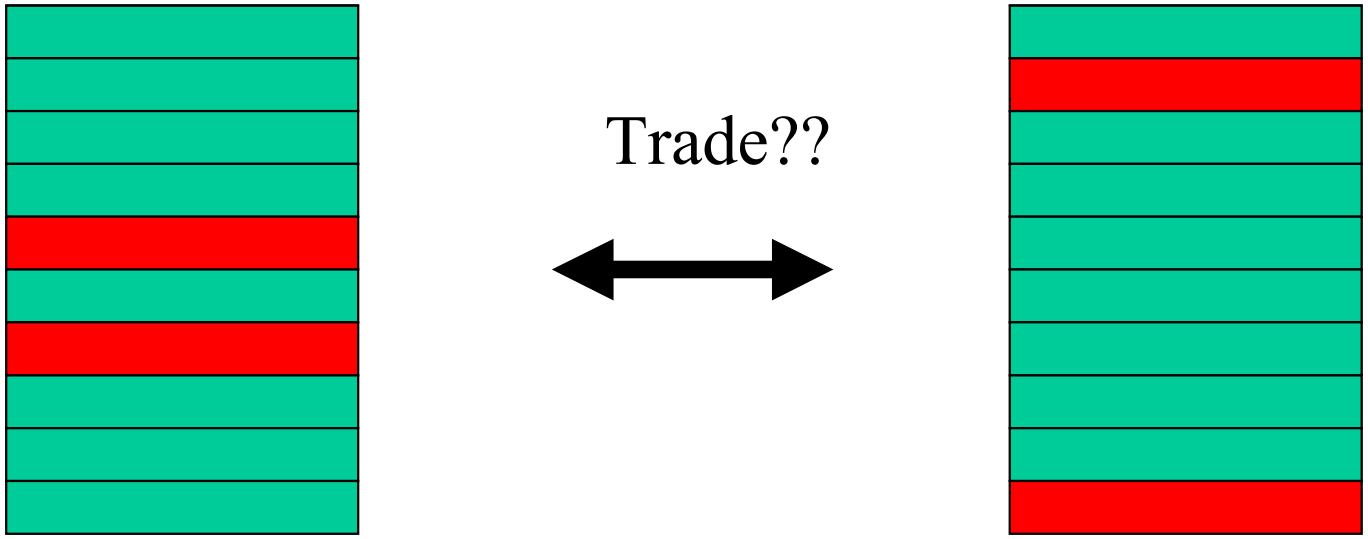
Compression-like solutions can be found using a bi-level objective function (1st level lexicographically minimizes max deviation between early slots released on later slots obtained)

Mediated bartering model suggests many possible extensions:

- Dynamic trading (w conditional offers)
- Alternate mediator objective functions
- K-for-N trades
- Side payments

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:



Formulation of general mediator's problem as set partitioning problem:

Offer to trade slots & 2 for 3,4 & 5

Slack variable: slot not traded

Right Hand Side

Set partitioning 0/1 matrix

1		1			1
1					1
					1
					1
					1
		1			1
					1
1					1
1					1
1					1

Slo
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Slots,
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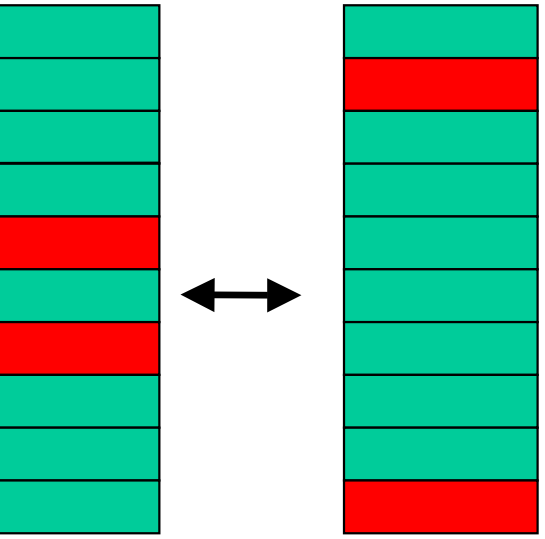
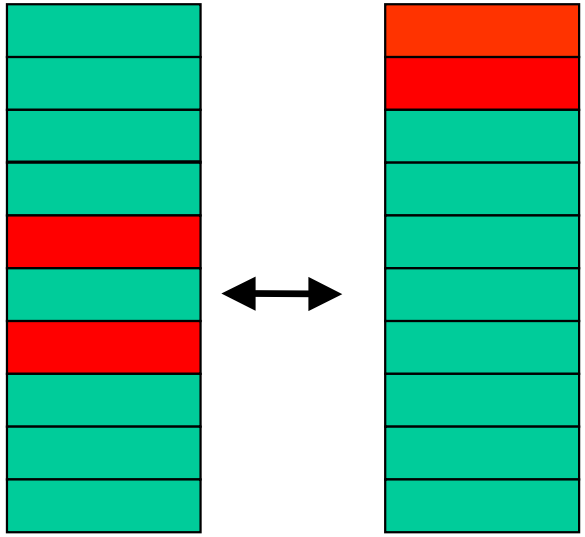
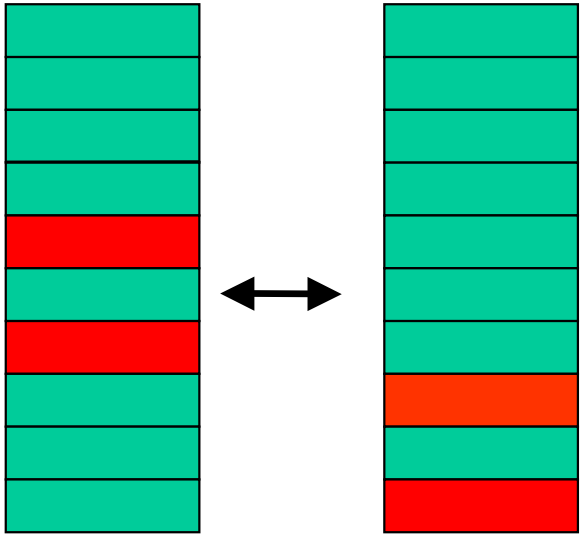
Possible 2-for-2 trades:



1 up for 1 down: reduce delay on 1 flight/increase delay on another;
Model as reduce delay *at least* d^- on f1 in exchange for increasing delay *at most* d^+ on f2.

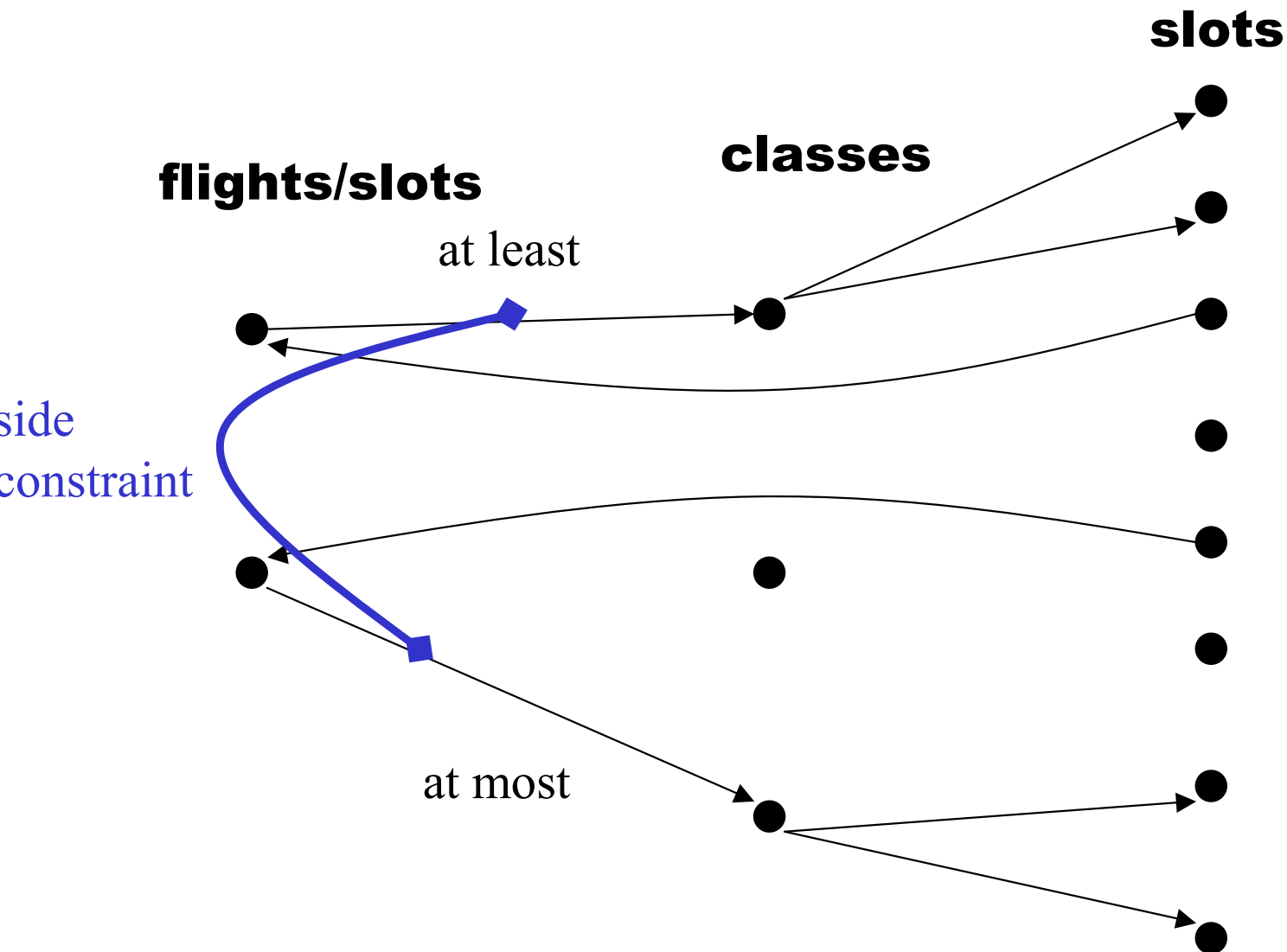


2 down: reduce delay on two flights; handled by 2 "reduce delay" single flight trades.



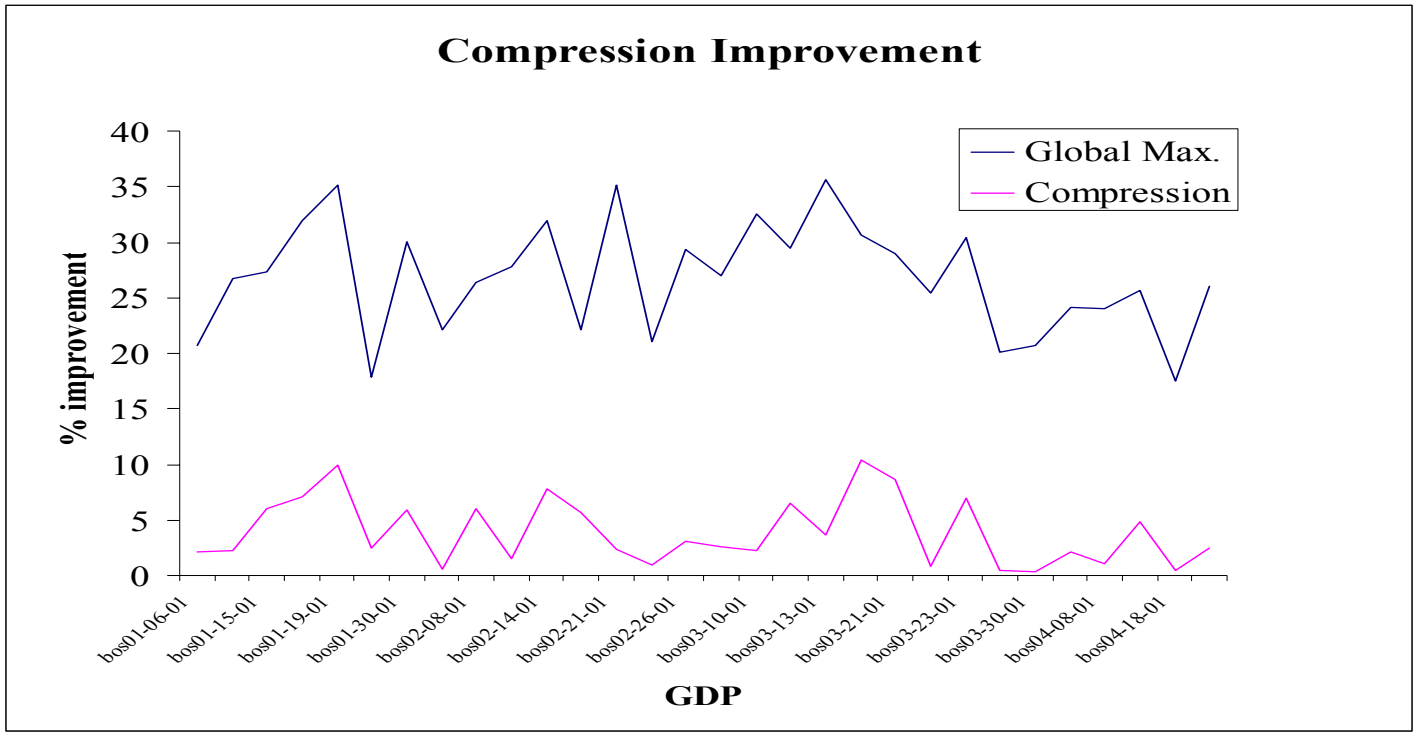
2 down: increase delay on two flights; not reasonable.

Formulation of 2-for-2 trading problem as network flow problem w side constraints:



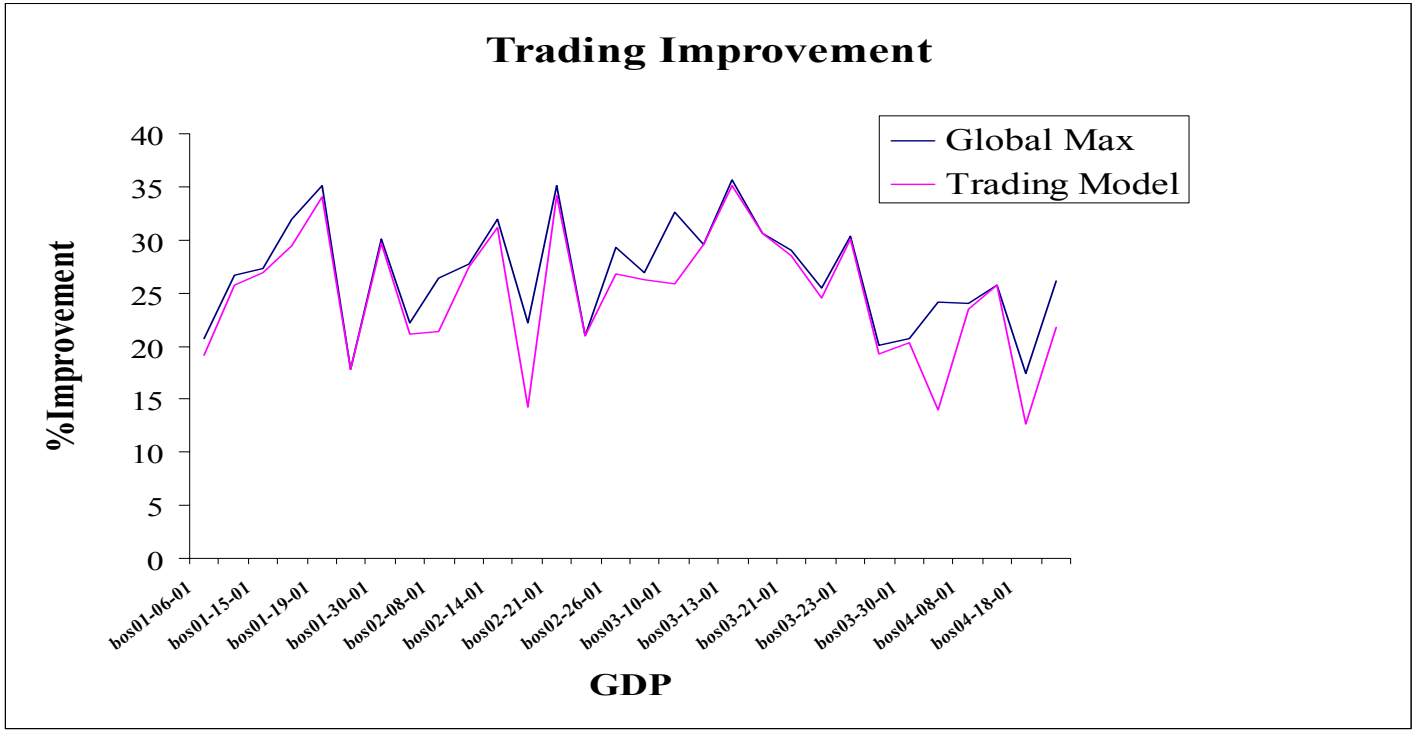
On-Time (Flight)Performance Airline Performance Function

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



Improvement Using 2-for-2 Trading System

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

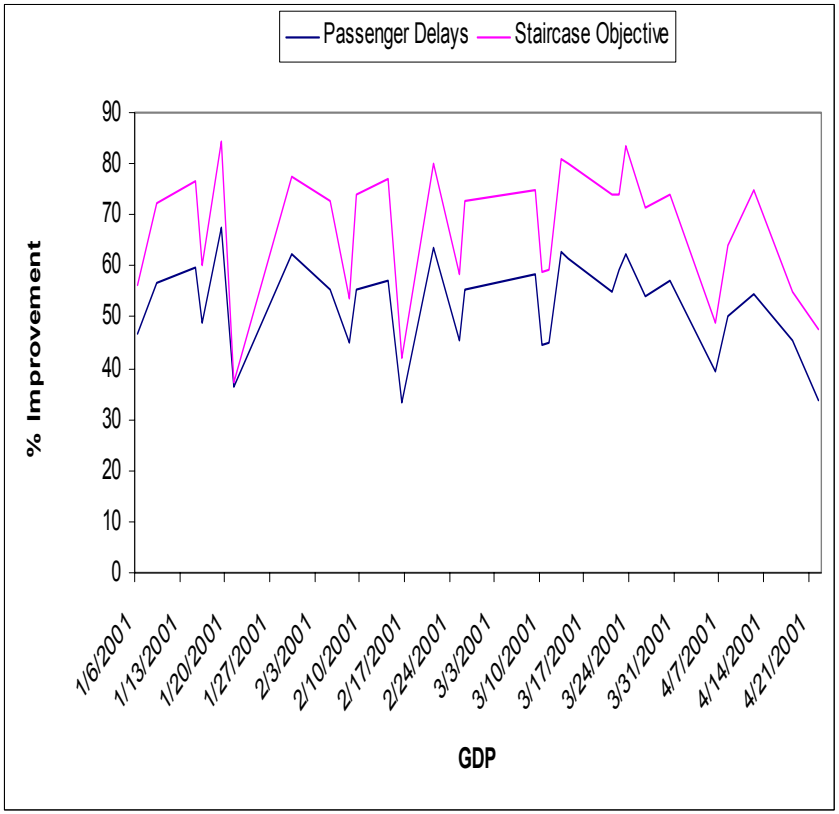


Computational Efficiency:

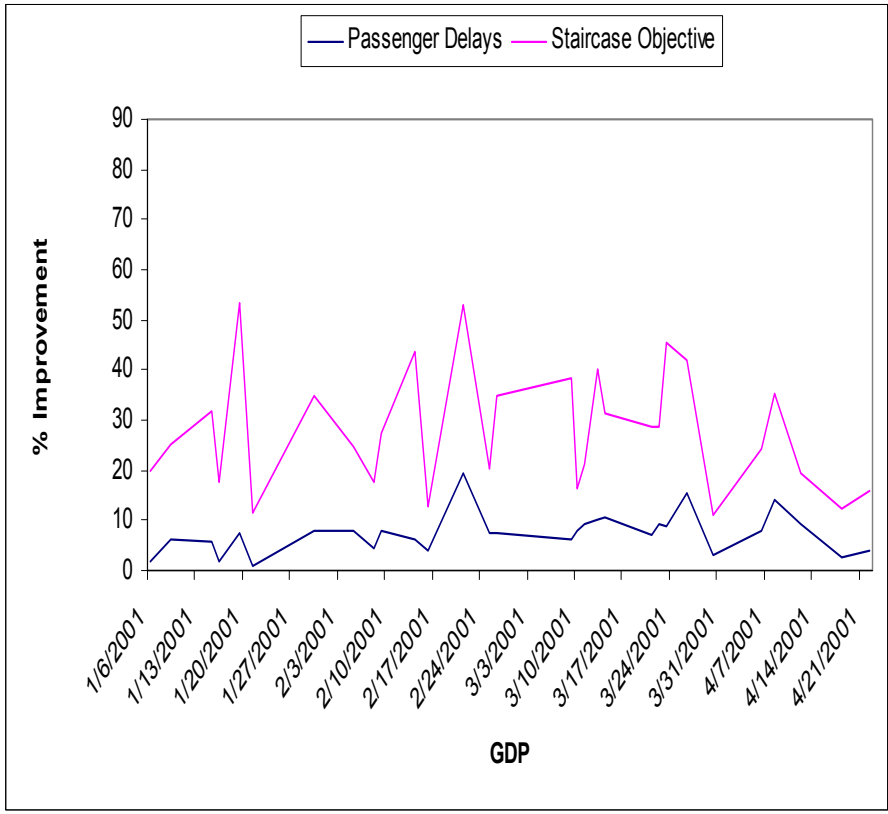
- 13sec avg.
- 67% solved by LP relaxation

Results for Total Passenger Delay Airline Performance Function

Max achievable improvement:

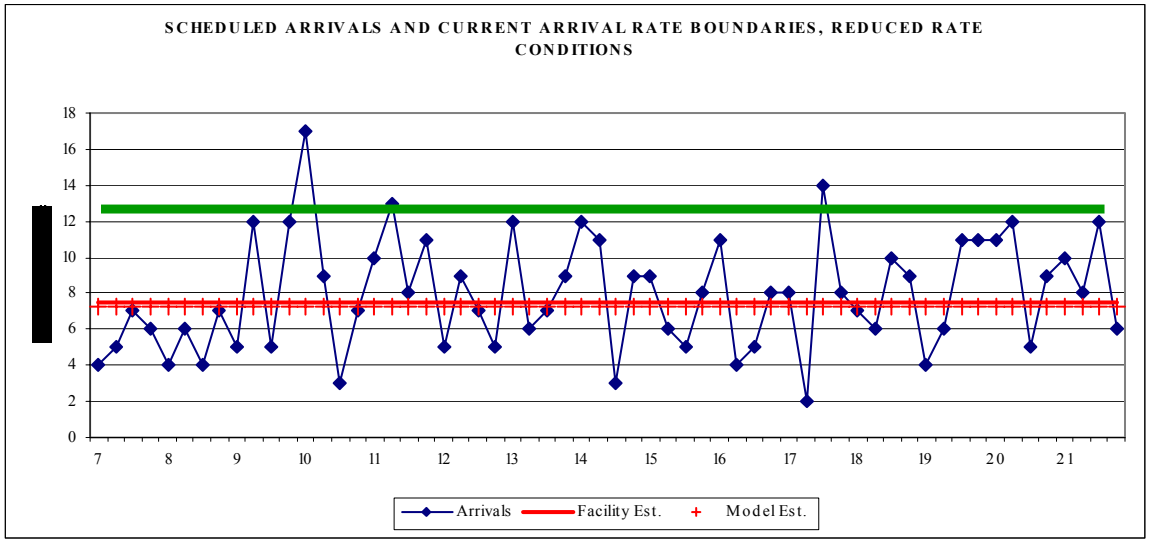


Improvement from 2-for-2 trading:



Final Thought: Options for providing airlines ability to trade-off $$ & delay reductions

- Concept 1: Inter-airline slot trading with side payments and slot buying & selling
- Concept 2: Auction long term leases on airport slots with two "levels" of airport capacity



"as-available capacity"

"guaranteed capacity"