Resource Rationing and Exchange Methods in Air Traffic Management: Part 1

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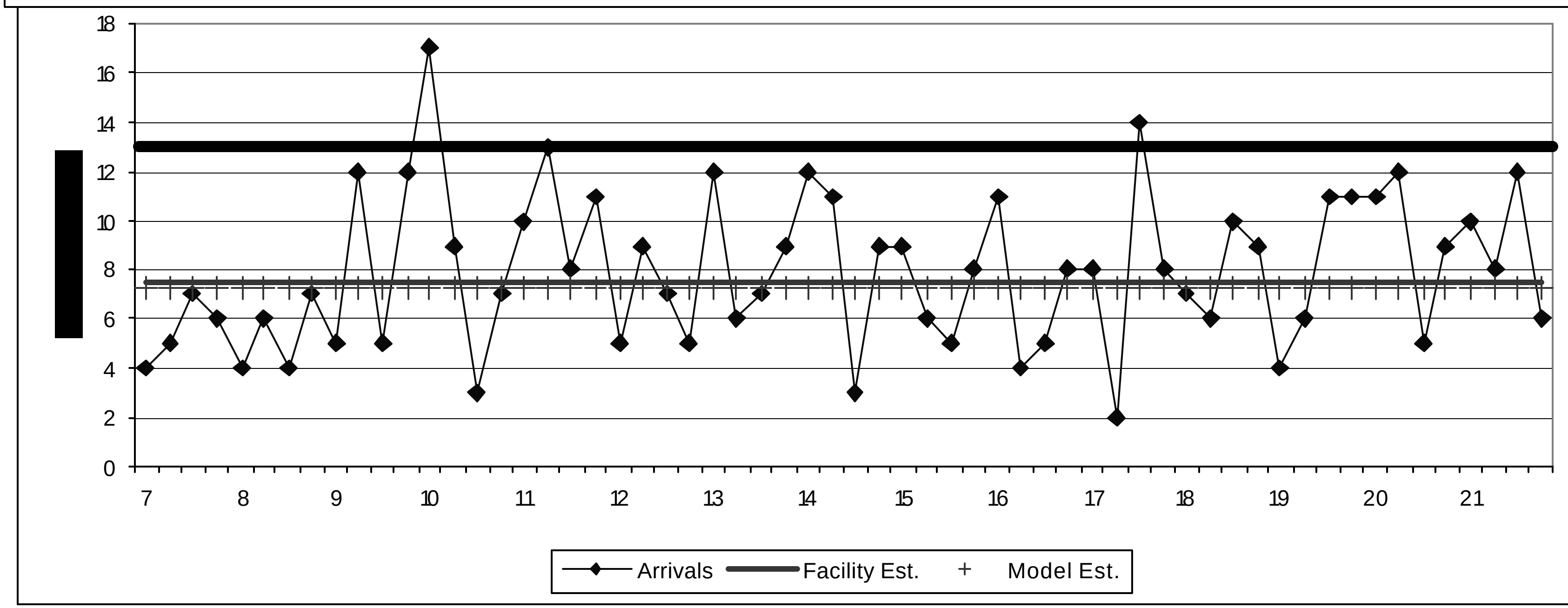
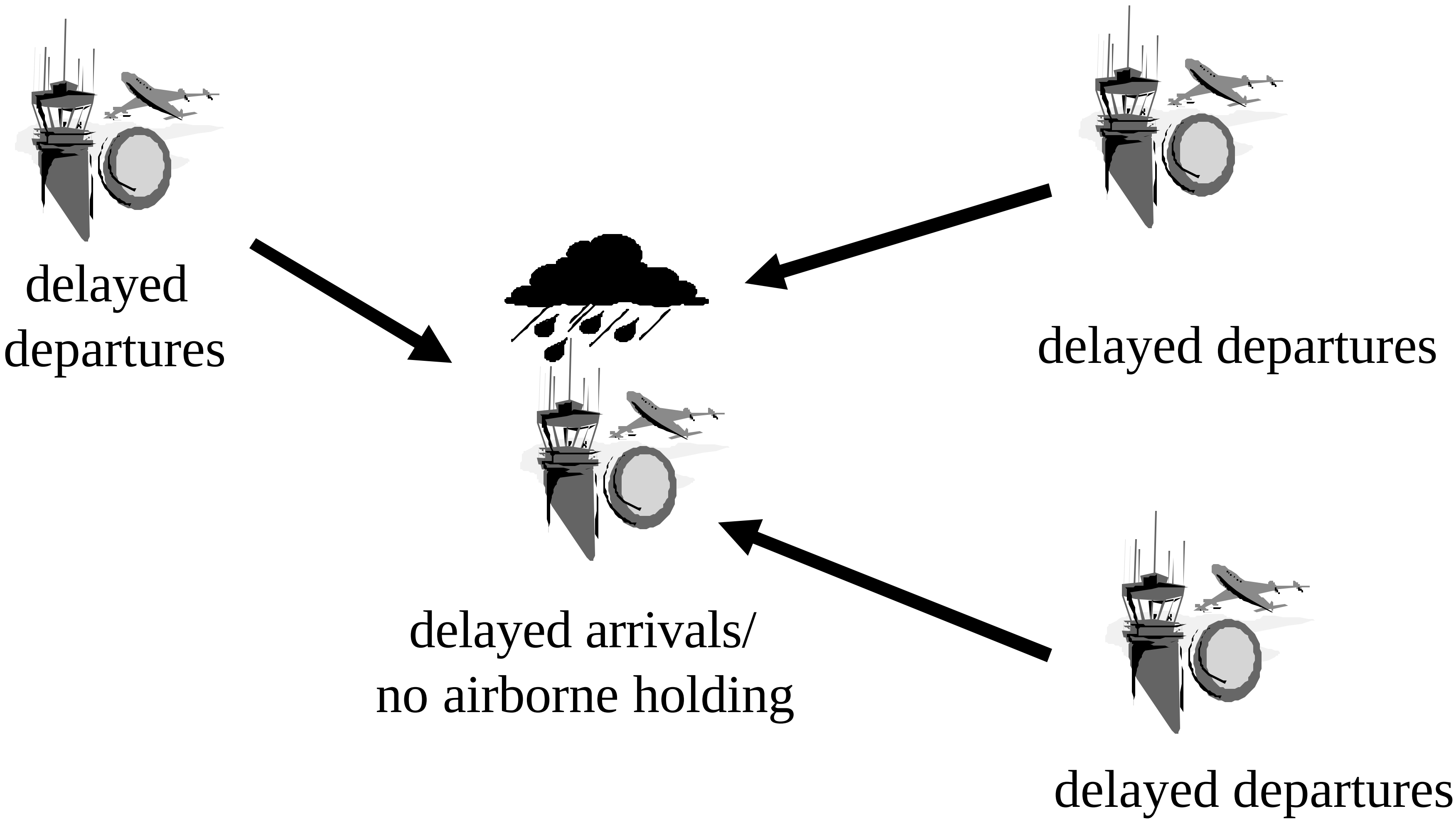
Motivation for Ground Delay Programs: airline schedules “assume” good weather

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?

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Determining fair shares

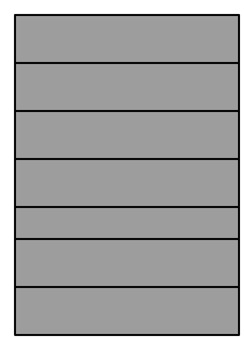
Sketch:

- 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

AA654
US345
AA455
…
…
…

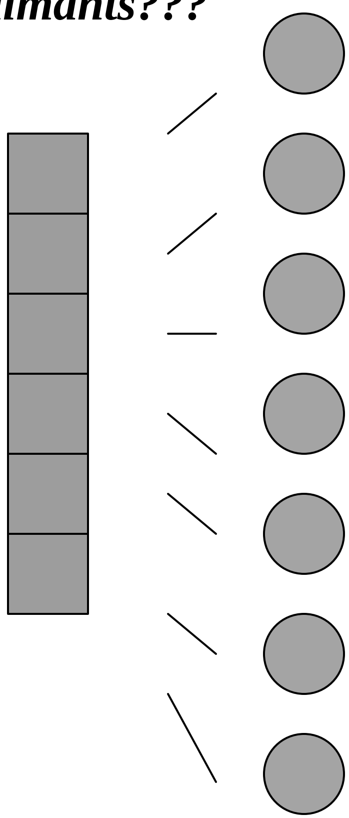
vs



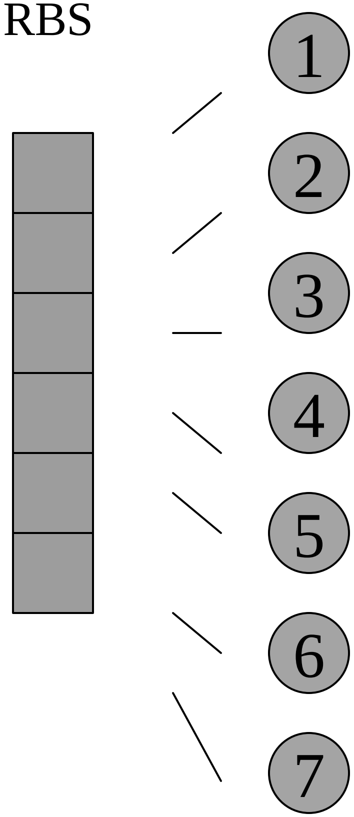
Slots Available

Allocation Principles

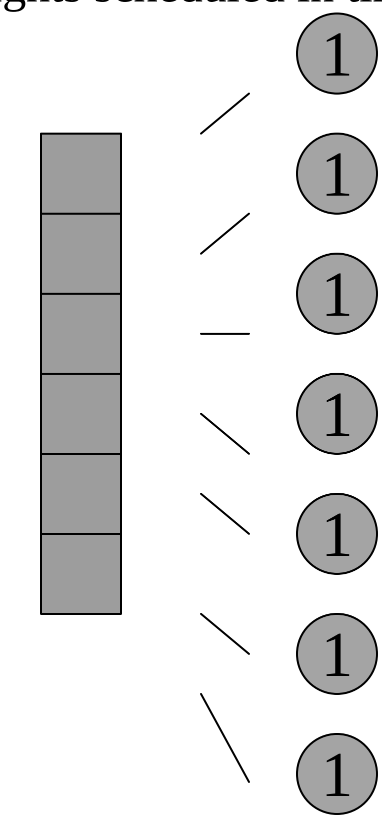
How to allocate limited set of resources among several competing claimants???



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

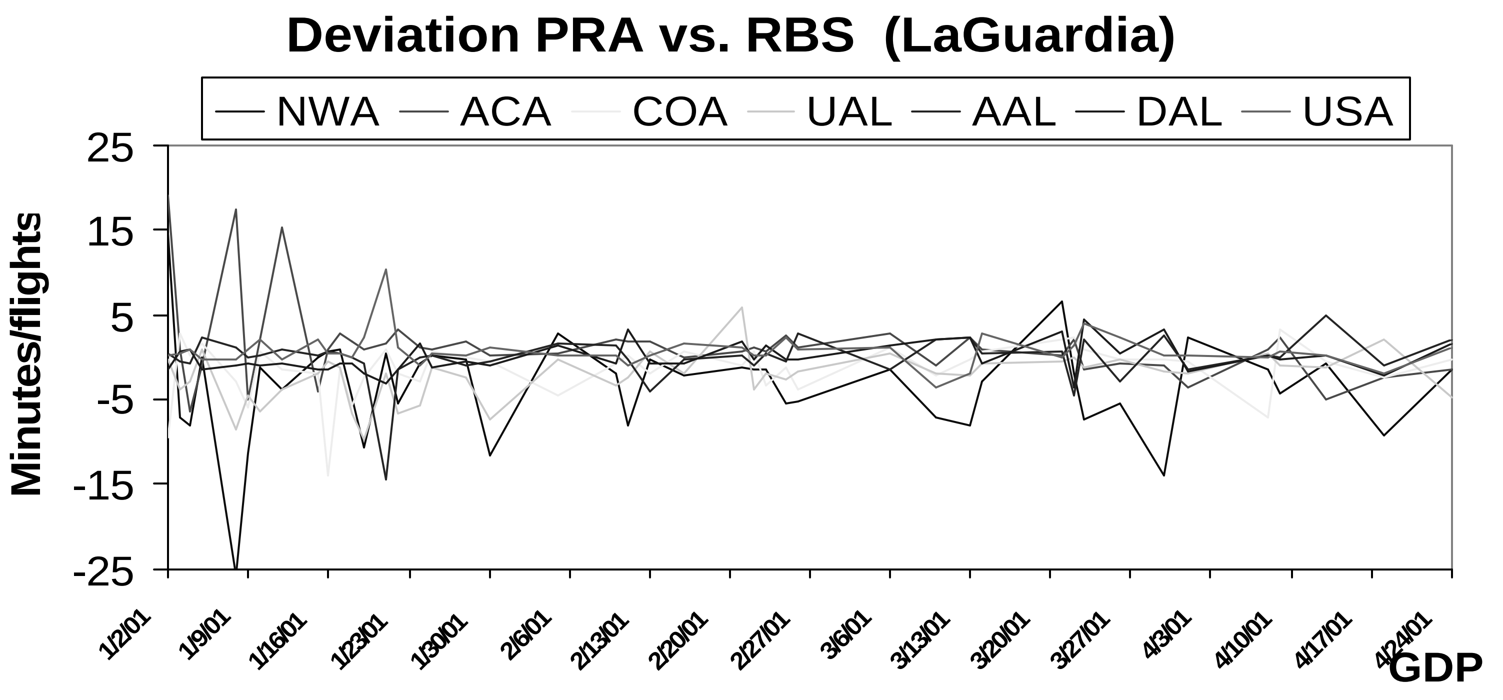
Cum wgt

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

Airlines alloc

UA	1		1		
US		1		1	1

Empirical Comparison



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

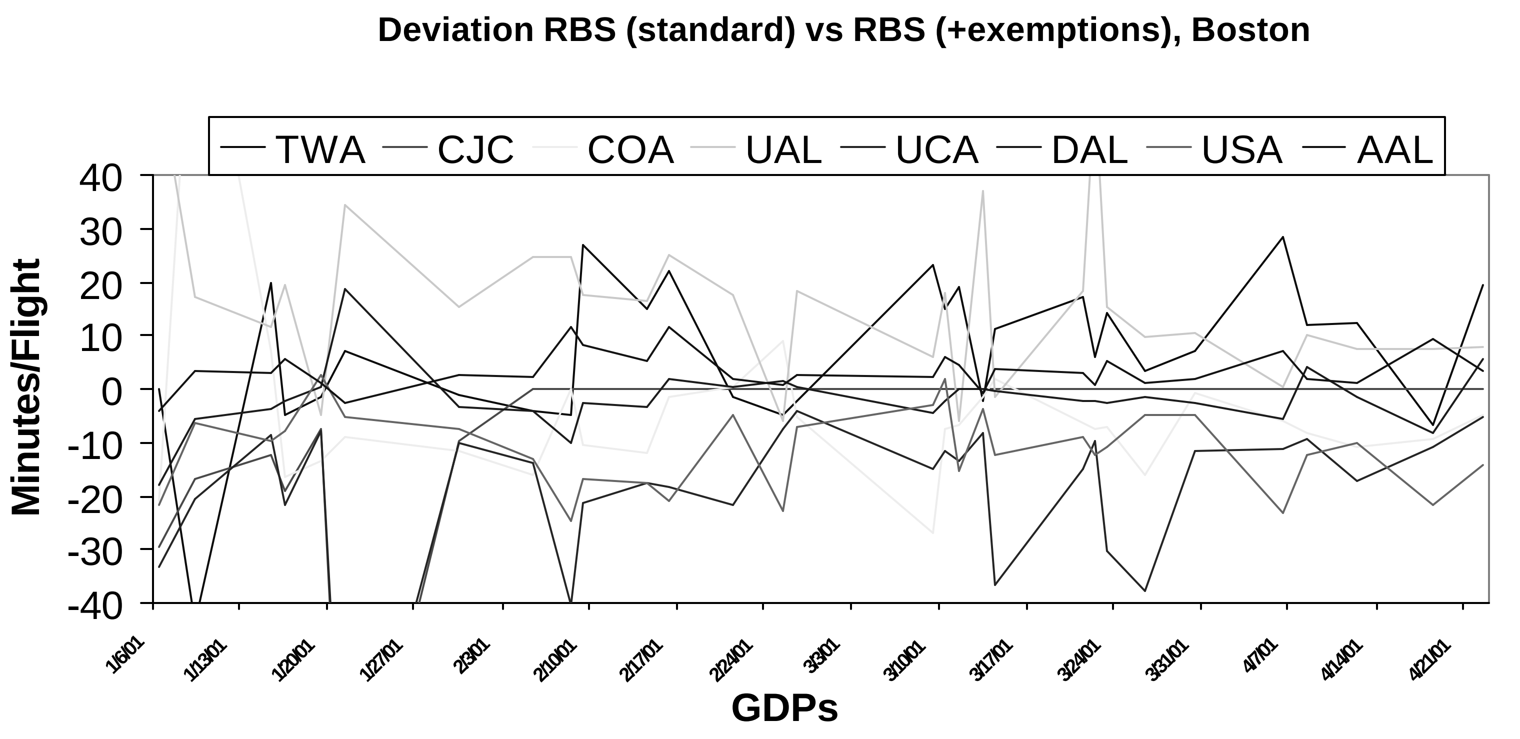
Issues

- 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?

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??

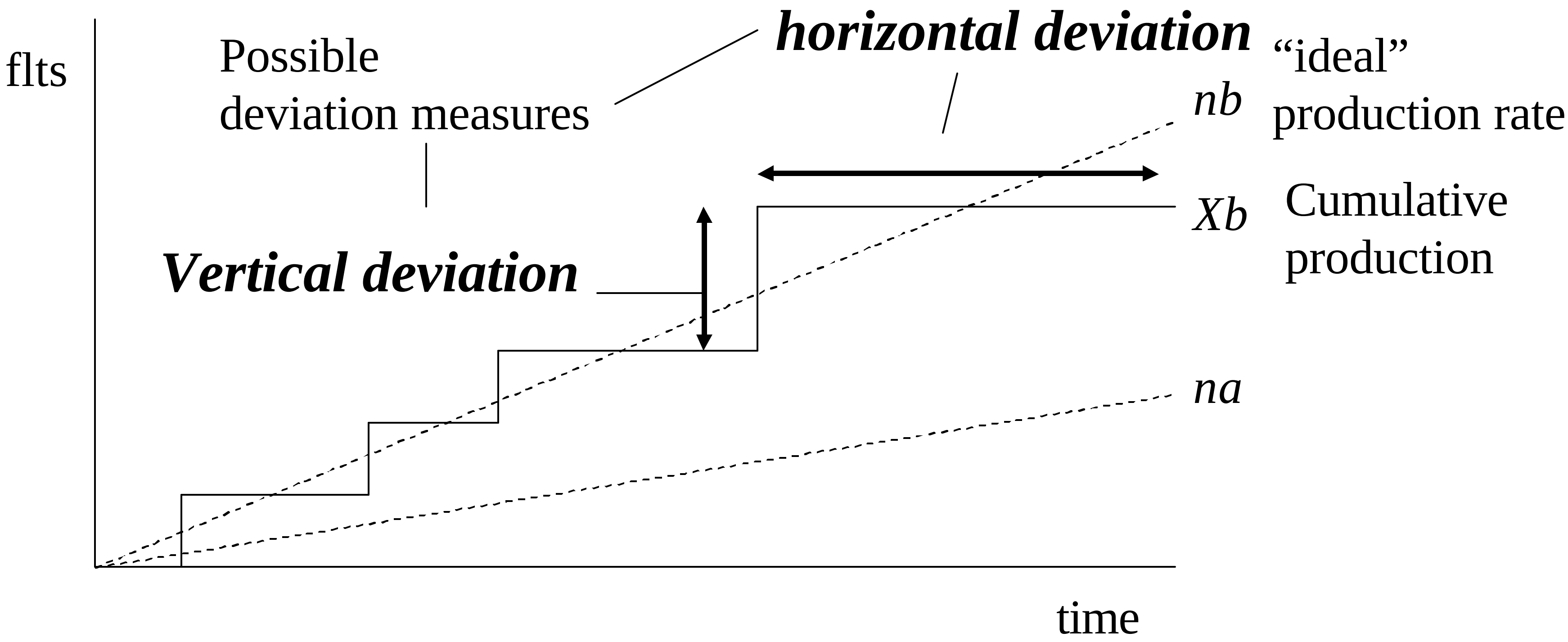
Analysis of Flight Exemptions (Logan Airport)



Flight exemptions introduce systematic biases:

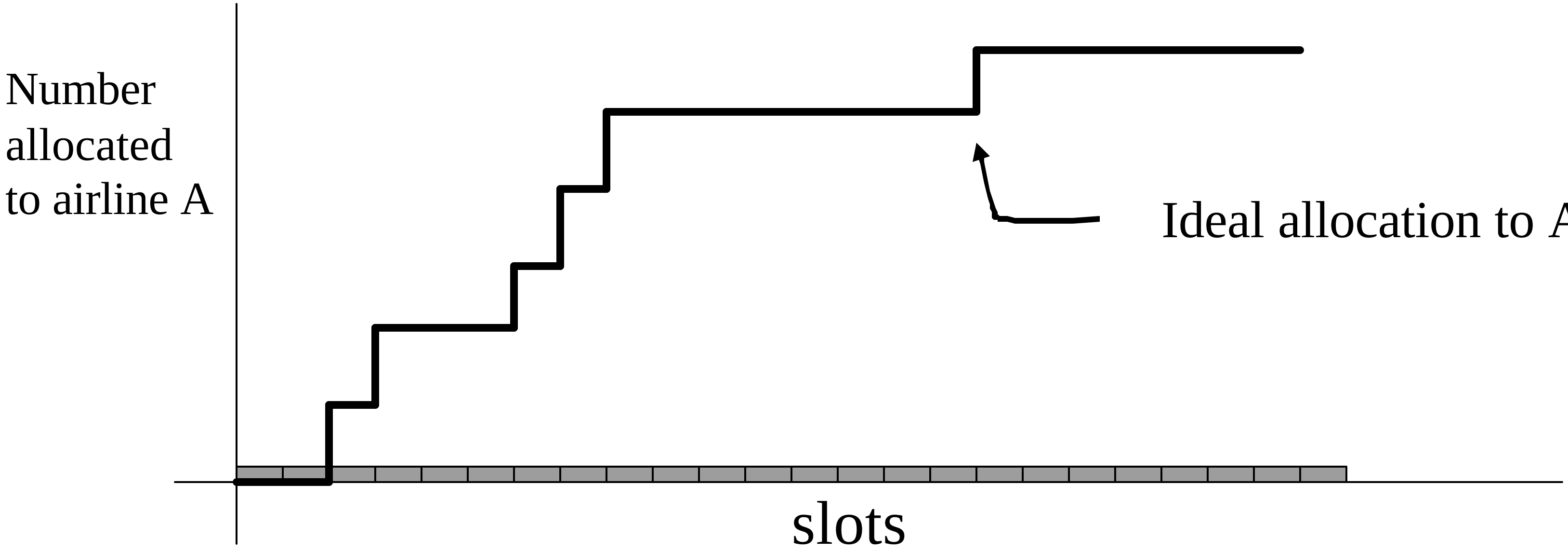
- USA (11m/flt), UCA (18m/flt) “lose” under exemptions

GDPs as Balanced Just-in-Time Scheduling Problem



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

How do we measure deviation from ideal??



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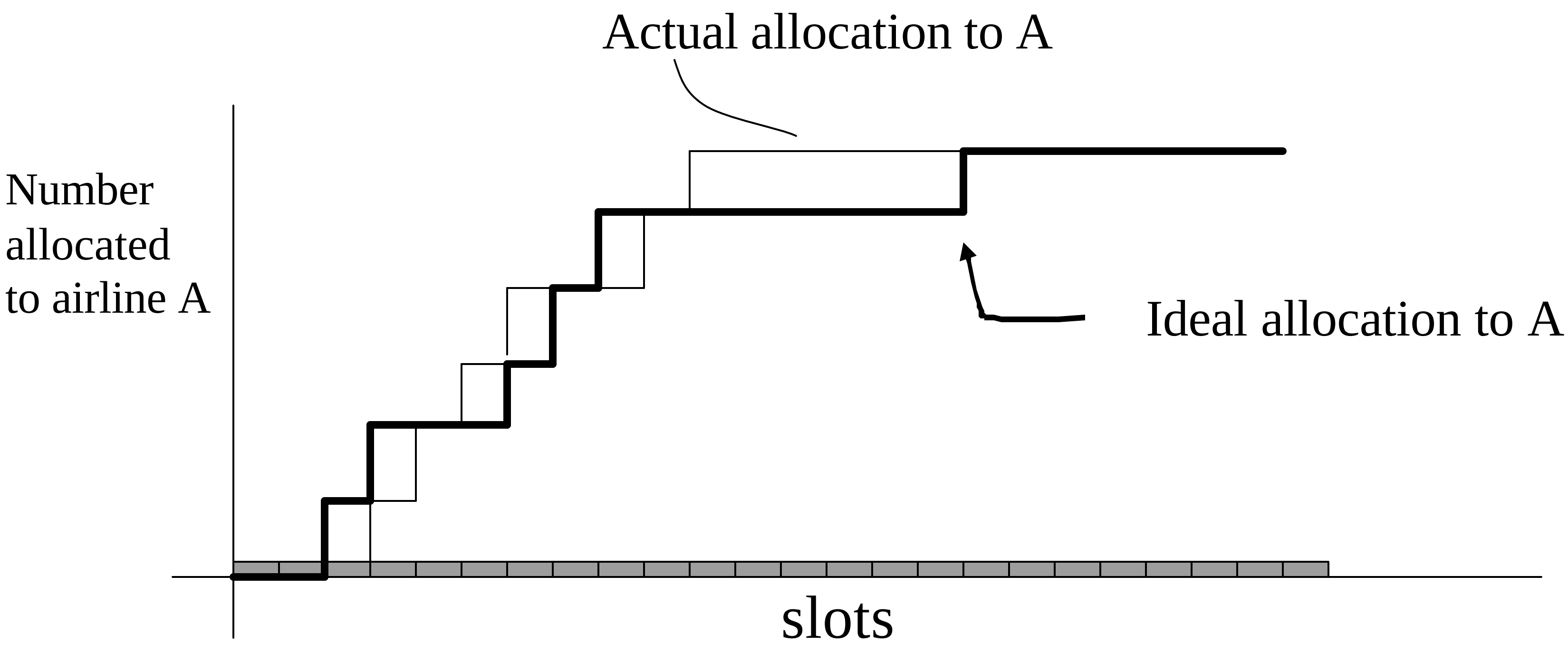


Horizontal deviation: When did A get 3rd slot vs when should A get 3rd slot??
Vertical deviation: After time t, how many slots did A receive vs how many should have A received??

How do we minimize deviation from ideal??

Two models based on horizontal deviation measure:

- Assignment model:

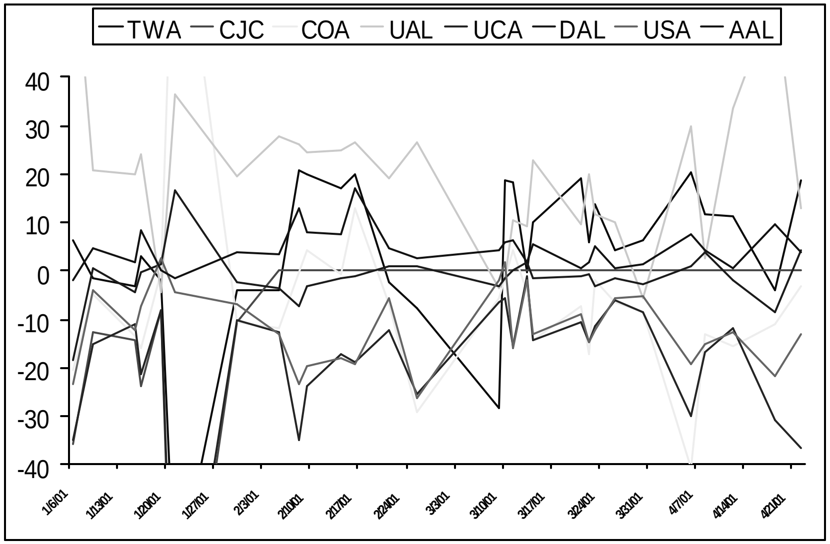
  $\text{Min} \sum_{\text{airlines}} \sum_{\text{slots}} (\text{ideal slot k} - \text{actual slot k})^2$

- "Greedy Algorithm" – looks more like current rbs

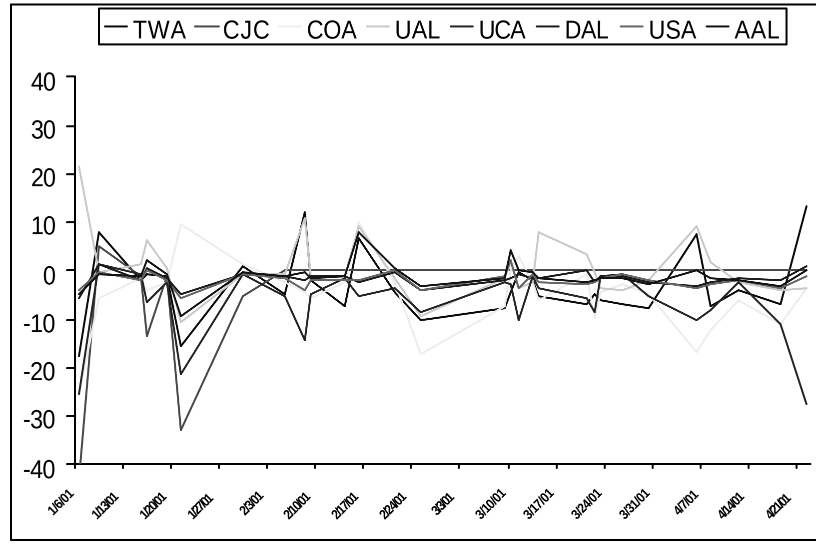
Also models based on vertical deviation

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”