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AVIATION OPERATIONS RESEARCH

NAS Resource Allocation and Reallocation on Day-of-Operations

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OUTLINE

- Review of Collaborative Decision Making (CDM)
- A Broader Perspective on Ration-By-Schedule (RBS) and Compression
- Fundamental Questions

Review of CDM

CDM Concepts and Features

- **Philosophical components**:
  - improved information and common situational awareness
  - distributed control and decision making:
    - decision made by most appropriate party
    - economic tradeoffs made by airlines/users
  - strong and continuous interaction among airspace system managers and airspace system users
    - FAA—airlines
    - airline—airline; peer pressure
- **Technical accomplishments:**
  - new allocation principles and mechanisms
  - shared decision support tool (FSM)
  - shared communications network (CDMnet)
- **Reliance on data analysis and objective critique**

Background on Collaborative Decision Making (CDM)

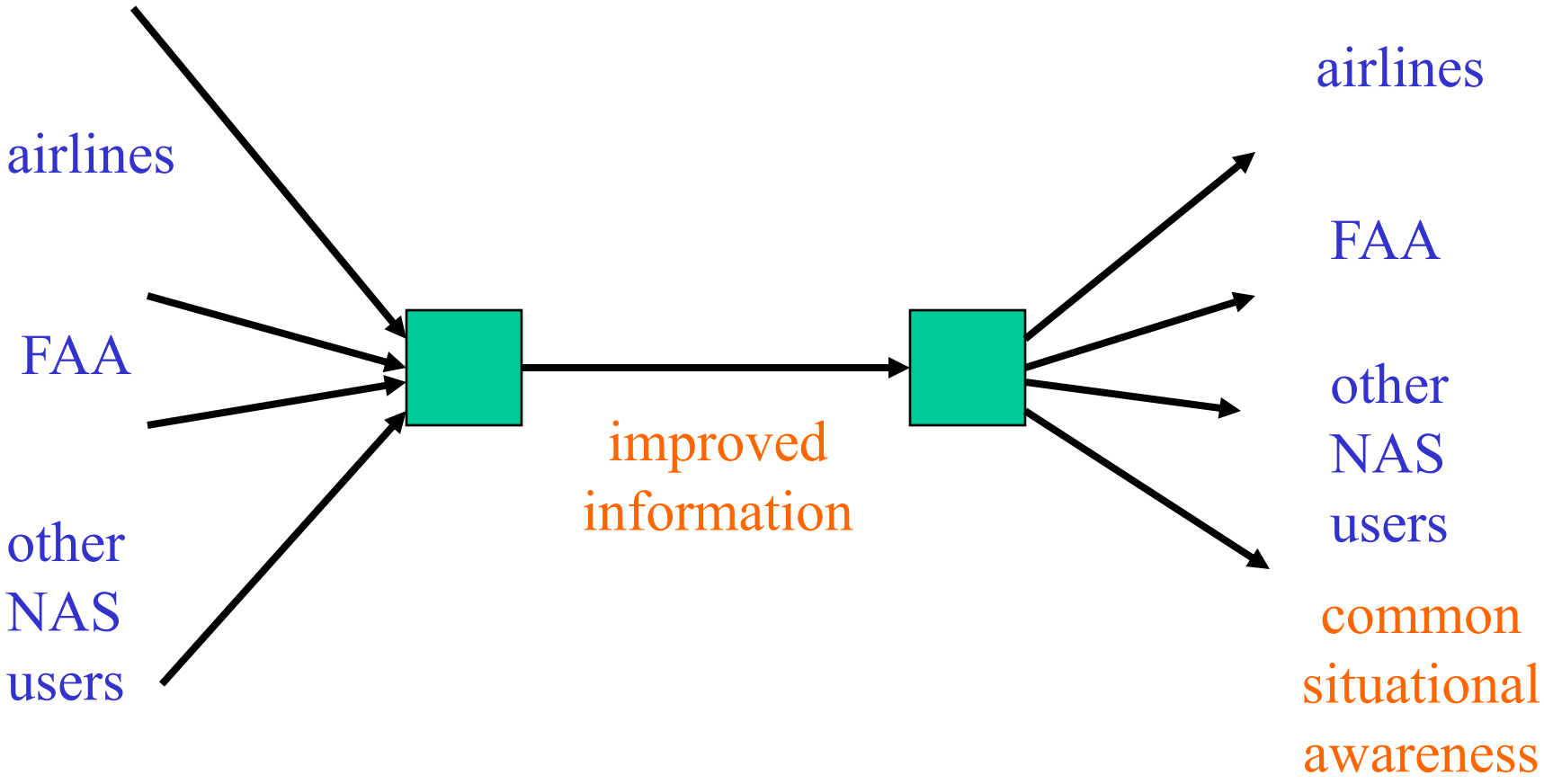
Fundamental Motivators for CDM in Ground Delay Program (GDP) Context:

- FAA (ATCSCC): desire for more up-to-date information on status of aircraft/flights to make better GDP decisions
- Airlines: desire for more control over allocation of delays to their flights

Solution:

- Communications network (CDM-Net) that allows real-time airline/FAA information exchange
- Resource allocation procedures (ration-by-schedule & compression) that give airlines more control *and encourage (or at least do not penalize) airline provision of up-to-date information*

Improved Information and Common Situational Awareness



CDM Resource Allocation Mechanisms for Ground Delay Programs

- **Ground Delay Program:** Traffic Flow Management initiative instituted by Air Traffic Control System Command Center (ATCSCC) when arrival capacity for an airport is reduced usually due to poor weather.
- Flights destined for afflicted airport are given ground delays so that the arrival rate of flight matches arrival capacity.
- Planning problem: assignment of arrival time slots to flights.

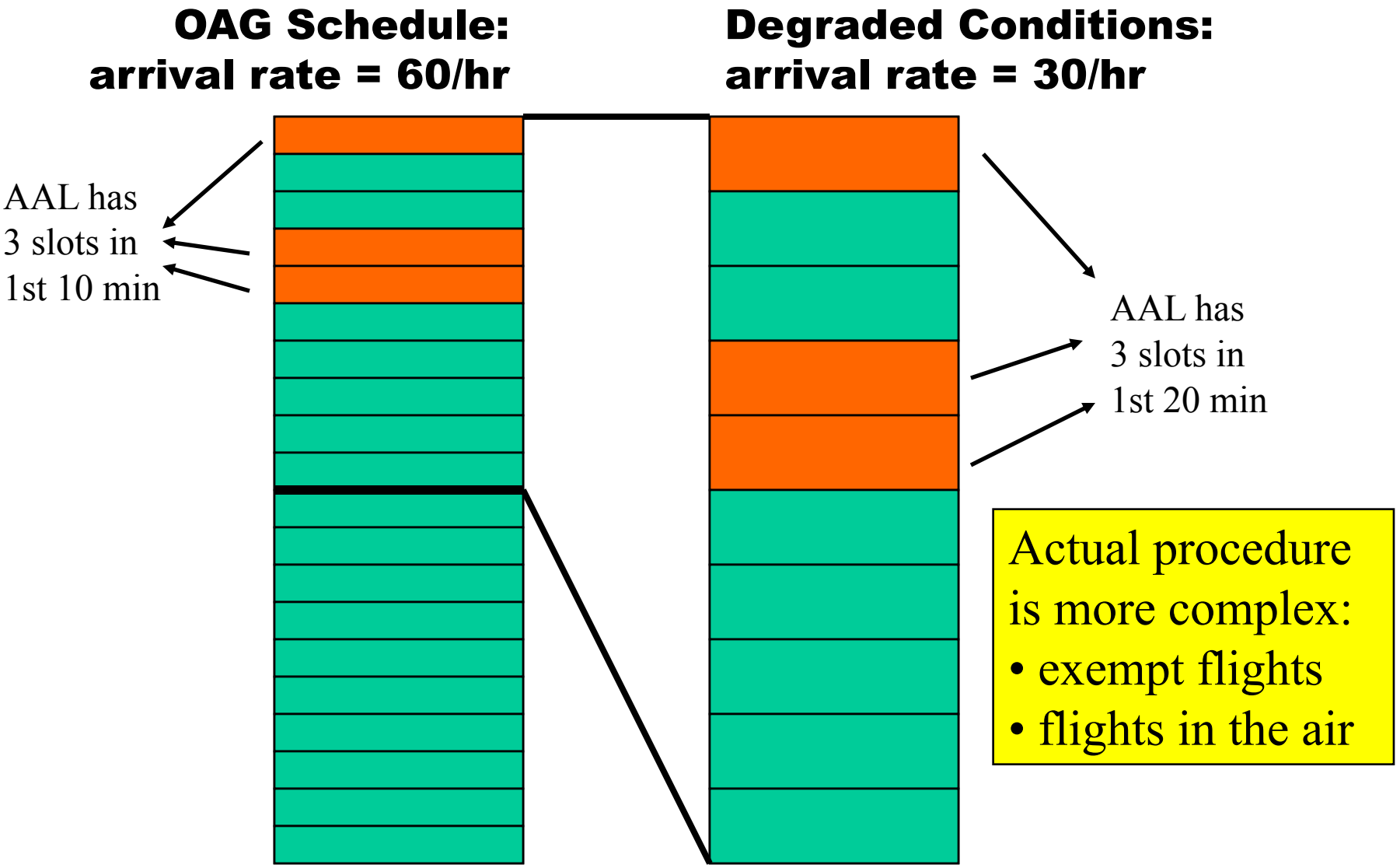
Resource Allocation Process

FAA: initial "fair" slot allocation
[Ration-by-schedule (RBS)]

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

FAA: final allocation to maximize slot utilization
[Compression]

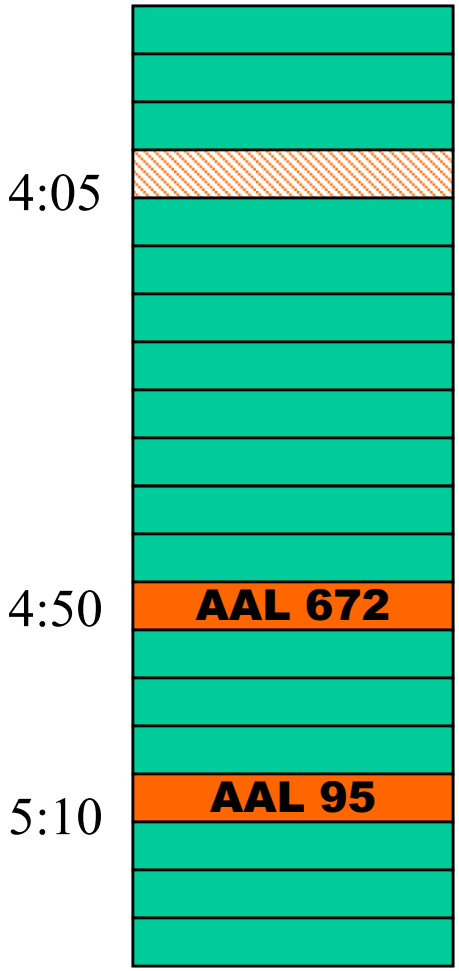
Basic RBS Allocation Principle



Key Properties of RBS

- Allocation independent of current status of flights ➔
  - Not affected by information provided by airlines ➔ no disincentive to provide information
  - Implicit allocation to airlines rather than allocation to flights

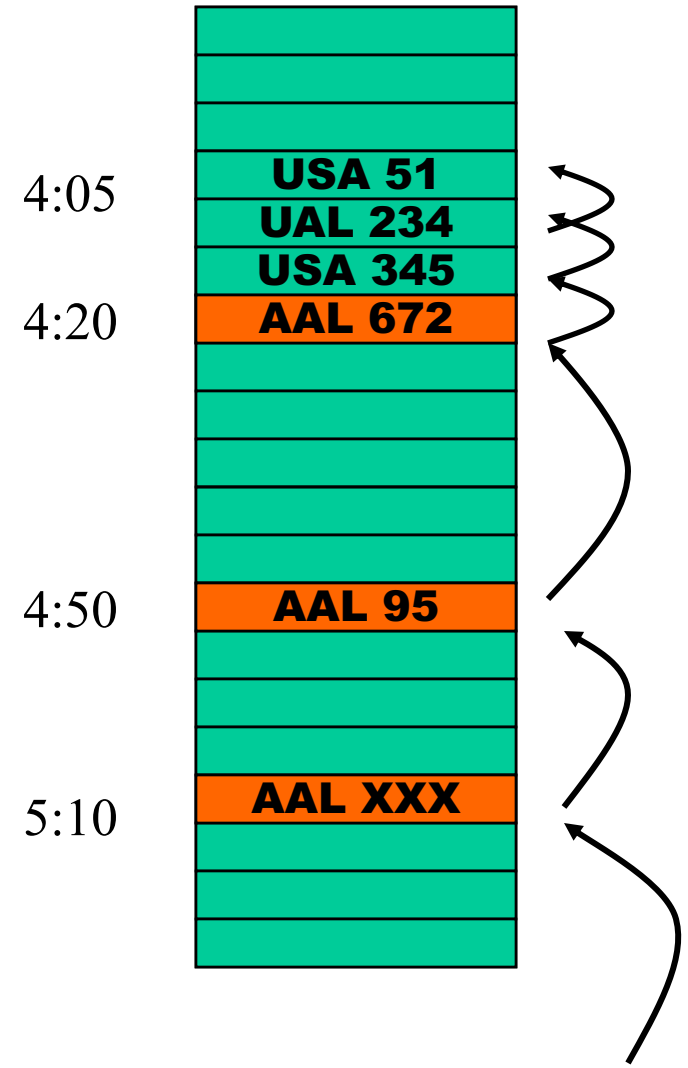
Need for Inter-Airline Slot Exchange



Slot made available by canceled or delayed flight

Earliest time of arrival = 4:20

Inter-Airline Slot Exchange: The Compression Algorithm



Earliest time of arrival = 4:20

Key Properties of Compression

Airlines paid back for vacated slots ➔

- Incentive to announce cancellations or mechanical delays early
- Leads to improved system predictability, higher slot utilization and/or less delay
- Provides benefits, otherwise not attainable, to "small players" at airports dominated by other airlines

Slot Credit Substitution (SCS)

- Issues:
  - compression is a batch process
  - executed periodically
  - execution not guaranteed
- SCS: Recent proposal to increase airline control over the slot exchange process
  - Airline submits SCS message:
    - "I will cancel flight *f* and release slot *s* only if I can can move flight *f* * to slot *s** " (where s* is later in time than s)
  - This single transaction is immediately executed as long as appropriate sequence of flight movements exist to fill slot *s* and open slot *s**

Major Challenge: Extension of CDM Concepts to Enroute Resource Allocation

- Enroute congestion:
  - Convective weather
  - Demand surges caused earlier incidents
  - Ripple effects from airport congestion
- Challenges:
  - Multiple dimensions: time & space
  - Multiple decision makers: AOCs, pilots, ATCSCC, ARTCCs
  - Uncertainty
  - Tradeoffs between system efficiency and fairness

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A Broader Perspective on RBS and Compression

Relationship to Equity Principles

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.

Individual Flight Perspective vs Airline Perspective

The equity principles underlying RBS are based on a *flight centric model*

➔

Implicit assumptions:

- flights are independent economic entities
- all flights will be flown

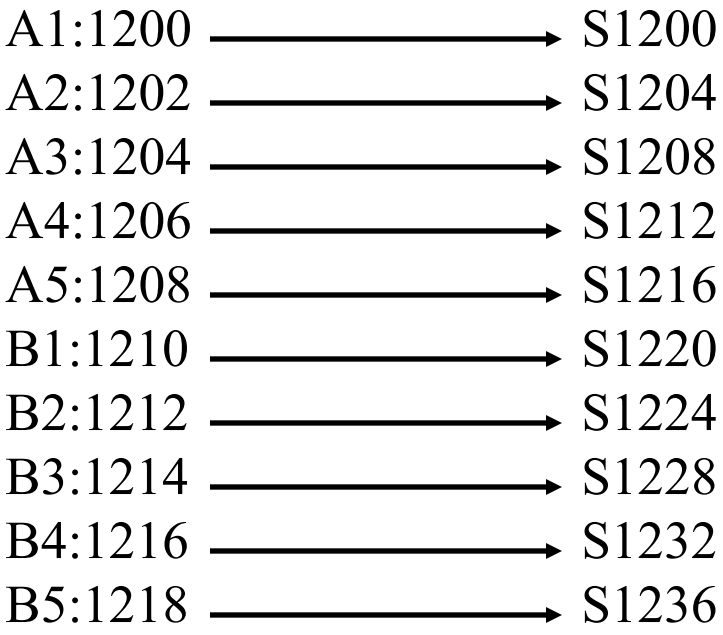
It is not unusual for very large numbers, e.g. hundreds, of flights to be canceled in intensive GDPs

➔

Should consider airline centric approaches

Example

RBS

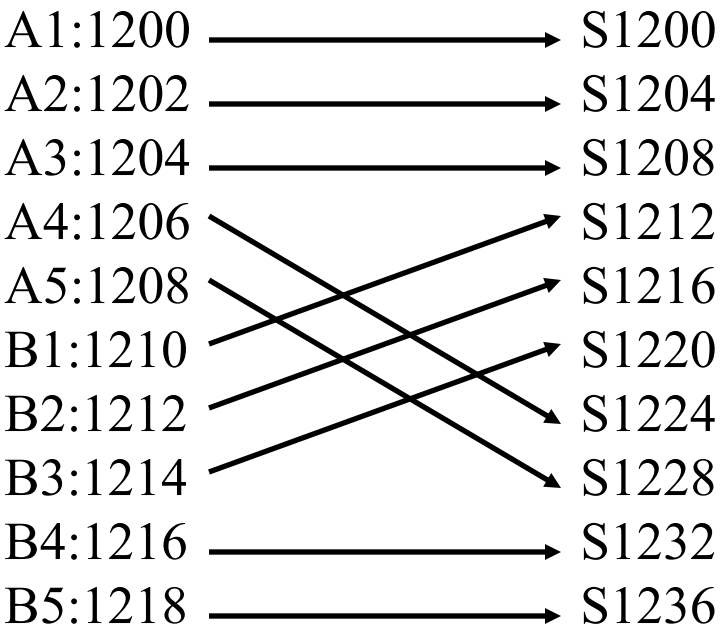


Avg. Delay:

A: 20/5 = 4 min.

B: 70/5 = 14 min.

AIRLINE PROPORTIONAL



Avg. Delay:

A: 44/5 = 8.8 min.

B: 46/5 = 9.2 min.

In fact, in long/congested GDPs, flights at the end of program can be delayed 2 hours or more making these slots effectively useless

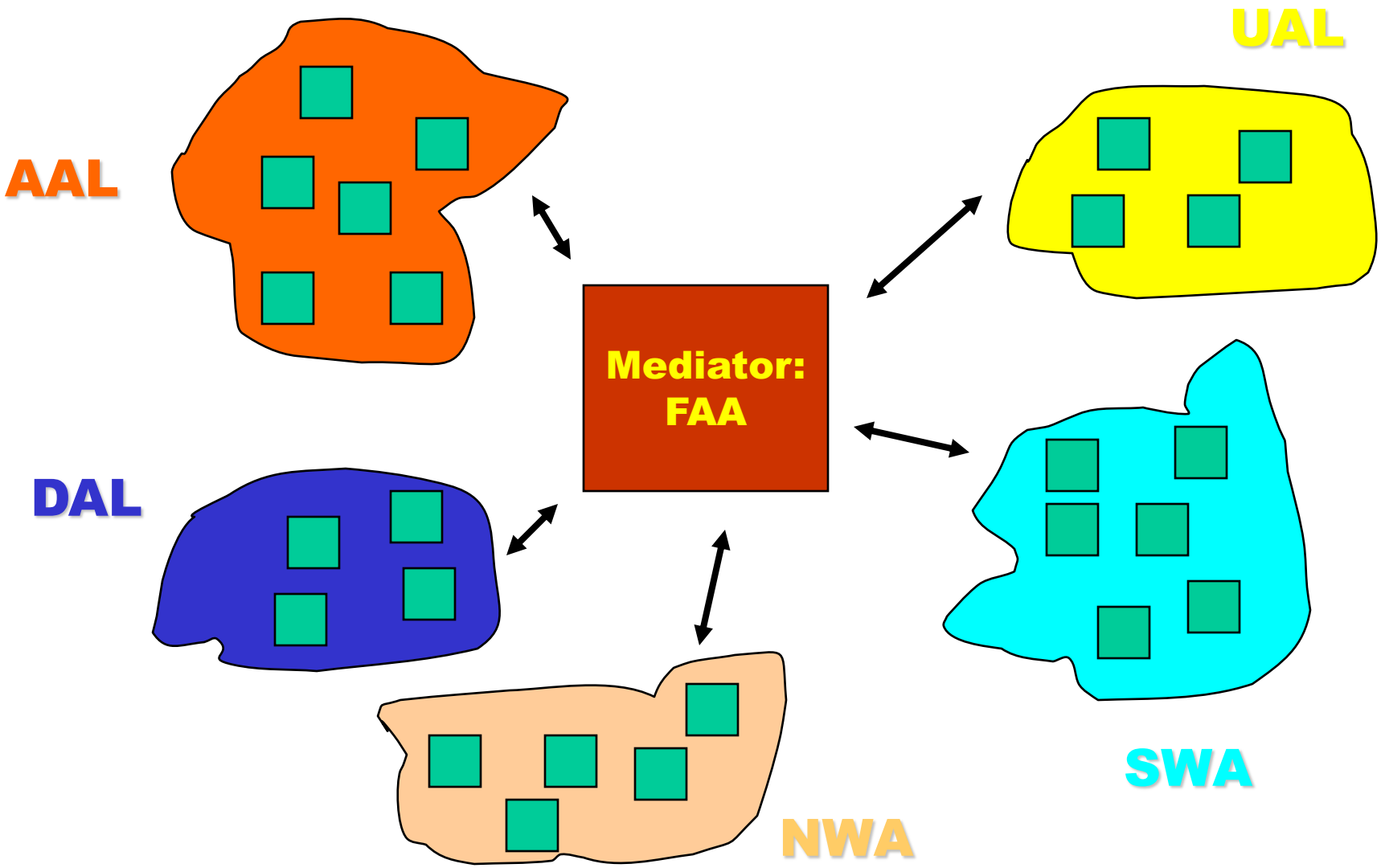
Airline Centric Allocation Methods

Direct interpretation of airline proportional does not recognize differences in OAG times

Possible alternatives:

- Probabilistic Methods:
  - *Proportional random assignment*: repeatedly assign next slot to airline w. probability proportional to its currently eligible unassigned flights
- Optimization-based approaches
  - Minimize deviation between airlines' "ideal" and actual number of slots at each time instant
  - closely related to apportionment, balanced just-in-time production problems

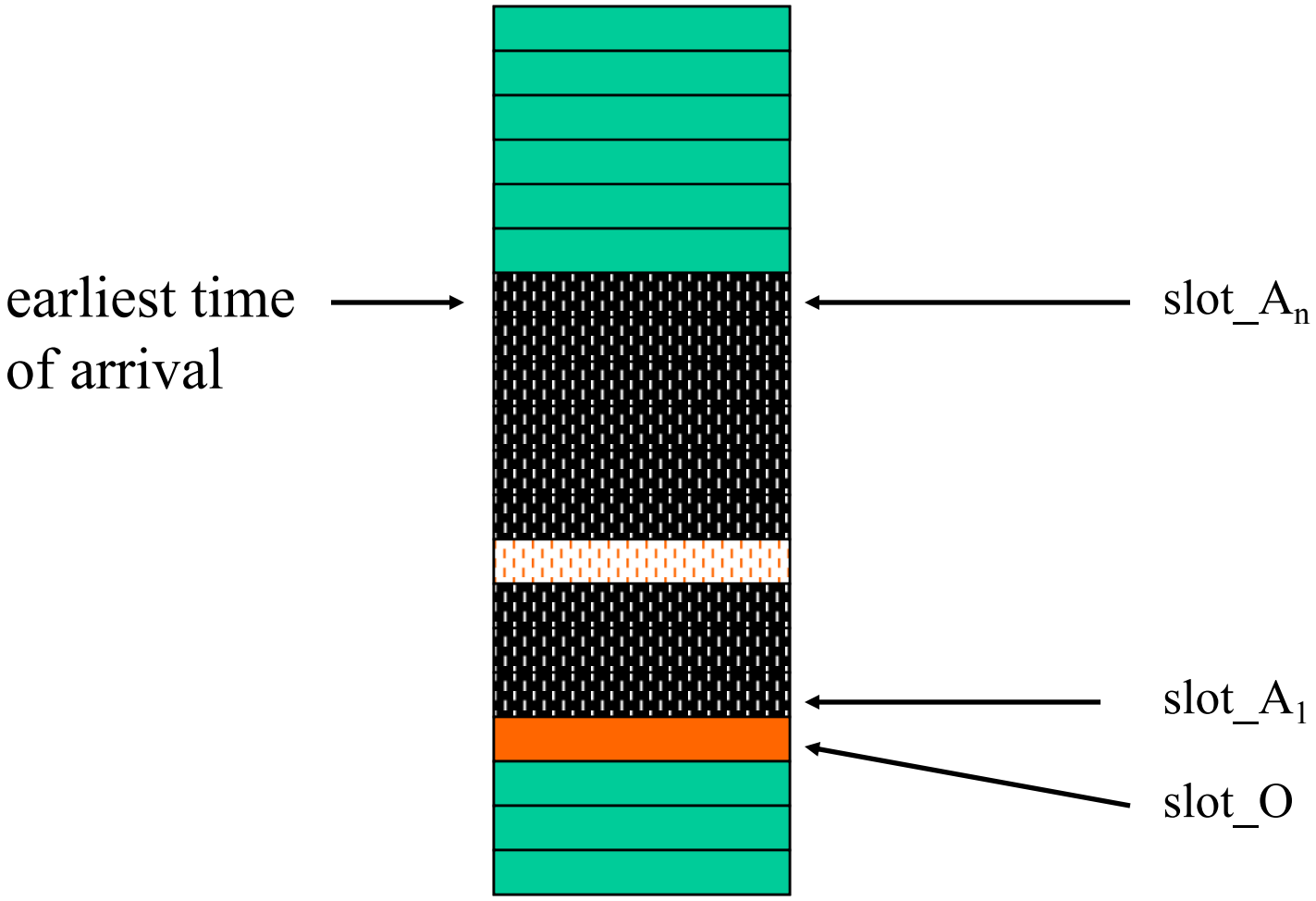
An Alternate View of Compression: Inter-Airline Bartering



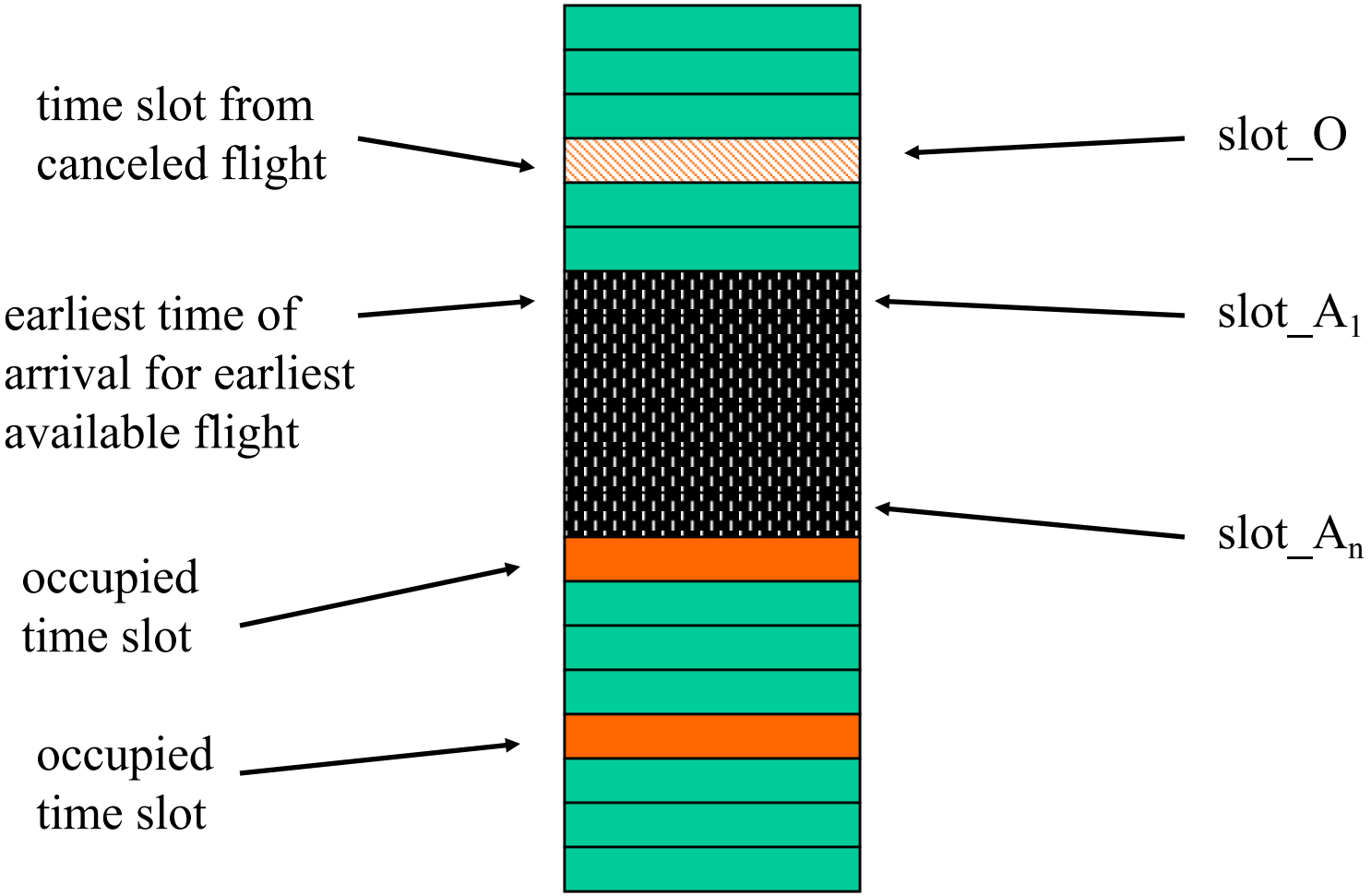
Mediated Slot Exchange

- 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

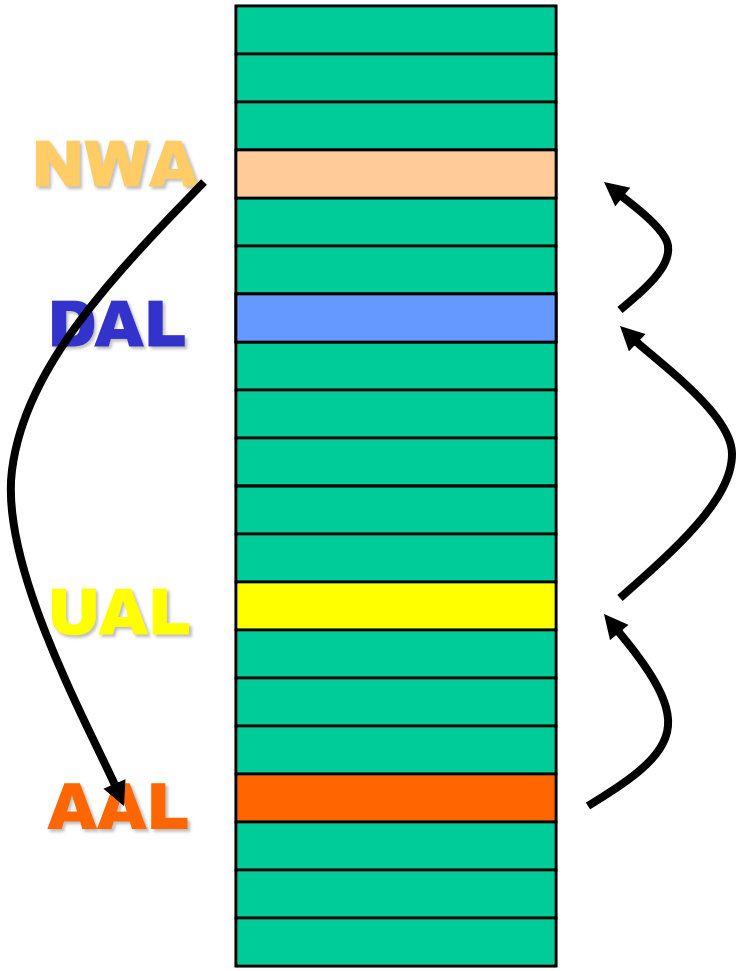
Default Offers



Offer Associated with Canceled or Delayed Flights



Mediator Must Find Complex Exchanges



Mediated Bartering vs Compression

- Solution of mediator's problem requires cost function to evaluate offers to accept
- Special cost function → compression-like solutions obtained
- Many extensions possible under bartering model

Fundamental Questions

If an airline has purchased a long-term lease on an arrival slot, what rights should they expect on an arbitrary day-of-operations??

Issues:

- Reduced capacity
- Safety
- Failure on part of airline or air traffic system to meet slot time

OAG Slot vs Day-of-Operations Slot

The Iata scheduling guidelines state:

"The Conferences deal with adjustments to planned schedules to fit in with the slots available at airports. This activity has nothing to do with adjustments to schedules on the day of operation for air traffic flow management. The two types of slot allocation are quite different and unrelated."

At slot-controlled airports, a "slot" is often interpreted as

"the right to schedule or advertise a flight at a specific time"

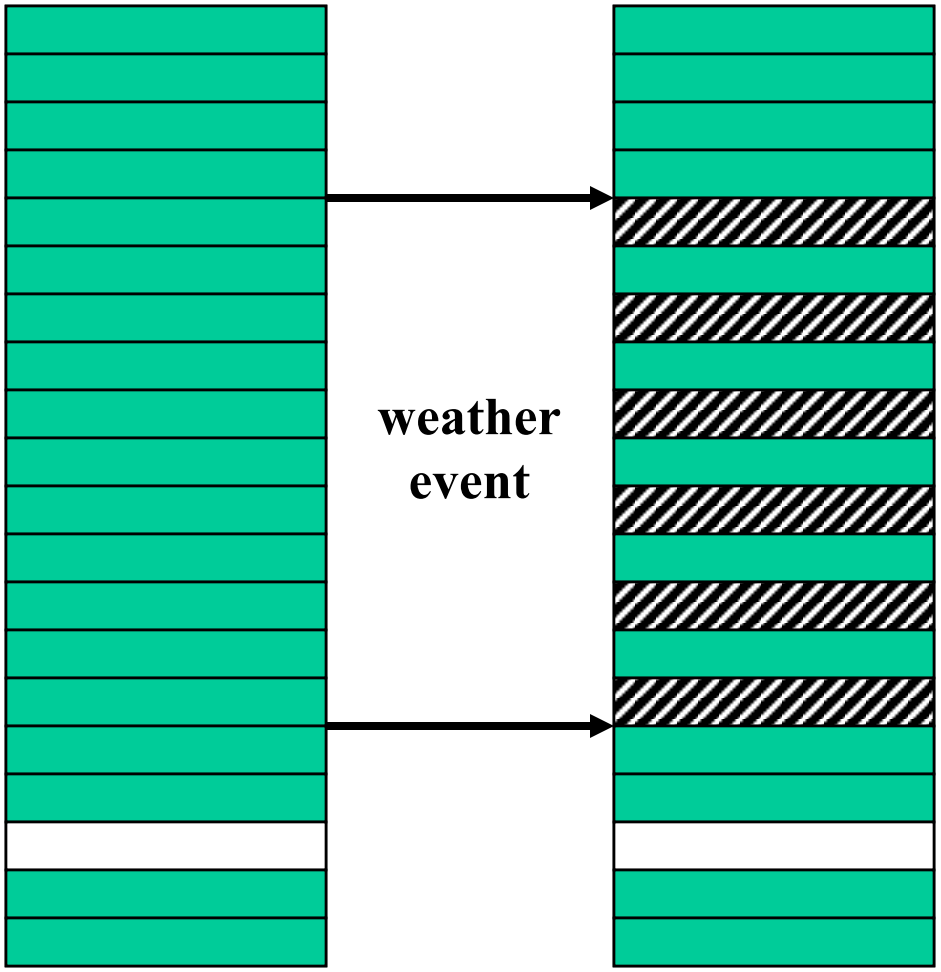
(I.e. [Riker and Sened, 1991], [Jones and Viehoff , 1993])

BUT

Under CDM, each airline is allocated a share of the resources during GDPs based on the original flight schedules

If airlines must pay for a slot then it would seem imperative to define well-defined rights resulting from slot ownership on the day-of-operations

Impact of Capacity Reduction



Problem:

Weather event causes elimination of ½ the slots during a time period; How is reduced set of slots allocated among owners?

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Possible Solutions

1. Extension of RBS:

- Auction "appropriate" number of permanent slots
- On day-of-operations, spread slots out over longer time period
- Allocate slots/delay among all owners using "appropriate" fair allocation principles

➢ **Advantages:**

- Robust to timing of degraded conditions, levels of demand reduction, demand induced problems.
- Since no resource can ever be guaranteed similar system may need to be implemented in all cases

2. Two-level slot auction:

- Auction two or more "levels" of slots, e.g high priority and low priority
- High priority slots "guaranteed" under all conditions
- Low priority slots are delayed and/or eliminated based on day-of-operations conditions

➢ **Advantages:**

- Greater predictability
- Allows for better economic evaluation/planning

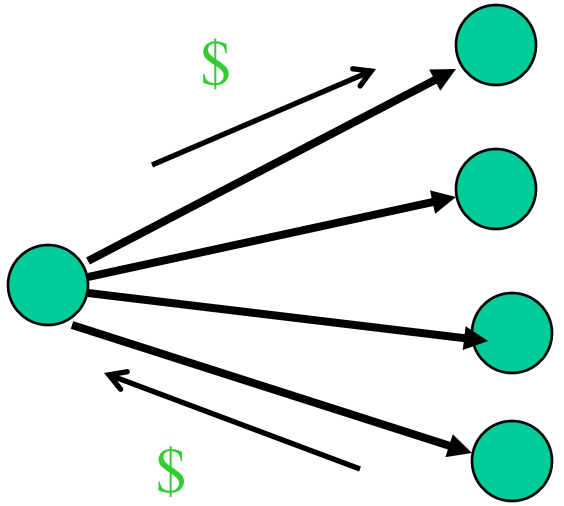
Issues

- Under 1:
  - What is an "appropriate" allocation?
    - Flight centric vs airline centric
  - How many permanent slots should be allocated?
- Under 2:
  - What should be done during time of severe congestion (when priority 1 slots cannot be honored)?
  - How should airlines modify their scheduling philosophy?

Aftermarket for Slots on Day-of-Operations

- Mediated Bartering + side payments

- Offer includes possibility of side payment



What are benefits associated with allowing monetary side payments??

Failure to Meet a Slot Time

- The ability of a flight to meet a designated arrival time slot depends on the overall performance of the air traffic system, i.e. it depends on:
  - Airline performance
  - Traffic management (FAA) performance
- What if flight fails to meet slot time??
  - Let flight land on first come first served basis (today's process)
  - Flight/airline pays penalty
  - Flight is diverted

What are the implicit airspace rights/priorities associated with ownership of a pair of arrival and departure slots??

Issues:

- Airspace congestion could cause delays and inability to meet slot times.
- "Optimal" flight path depends on daily conditions and airline policies.
- Arrival and departure slots are dynamically reallocated among flights based.
- Should slot pair and airspace rights be auctioned as package of goods?

FINAL THOUGHTS

Any treatment of slots as economically valuable commodities must define the rights implied by ownership of those commodities on the day-of-operations

Even under current scheduling policies, there is a need to define principles underlying fair allocation of resources and tradeoff between fairness and system efficiency