

Foundations Of Resilient CybEr-physical Systems (FORCES)

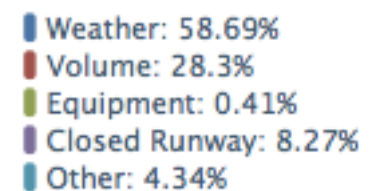
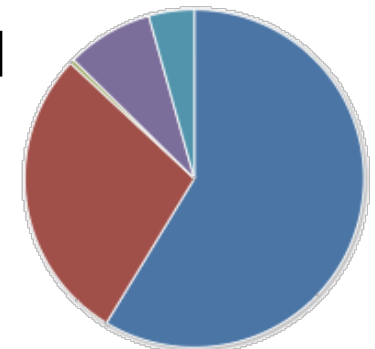
**Air Transportation Resource Allocation:
An Overview**

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Capacity constraints and delays in the National Airspace System

- Nearly all resources in the air transportation system are capacity-constrained
- Particular problem at airports: ~20% of delays at major airports are due to terminal-area volume
- Landside (gate availability, security, etc.) and airside (runway capacity, air traffic control, arrival/departure paths, etc.) limits constrain airport capacity
- Focus of resource allocation is typically on airports, especially on arrivals (landing slots)

NAS delays by cause (2012)

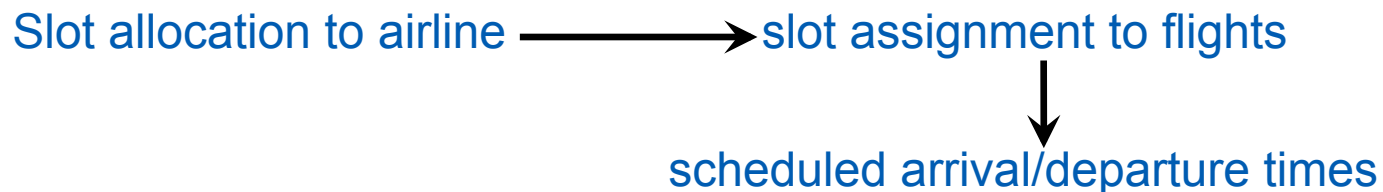


Economic Incentives & Resilient Control

- Slot auctions (**~6 months in advance**)

- “A reservation for an instrument flight takeoff or landing by an air carrier of an aircraft in air transportation”

[US Code Collection, Title 49]



- Ground Delay Programs/
Collaborative Decision Making (**~3-10 hrs in advance**)

- Tactical scheduling/air traffic control (**~5-30 min in advance**)

EI

RC

History of slot regulation in the US is not-so-brief

- 1968: FAA adopts high-density rule (HDR); 5 major airports: LGA, DCA, JFK, EWR and ORD put under operations quotas (slot restrictions) to control airspace congestion at the airports
 - Airline scheduling committees (Slot Committees formed)
 - (Soon after, EWR was not scheduled using a slot committee)
- 1978: Deregulation of airline industry
- 1978: Civil Aeronautics Board (CAB) commissions study on slot allocation by David Grether, Mark Isaac and Charles Plott
 - *“The Allocation of Scarce Resources: Experimental Economics and the Problem of Allocating Airport Slots”*
 - First attempt at proposing a market-based mechanism for slot allocation
 - Essentially a problem of assigning slots to airlines and determining how much the airlines should pay
 - Grether et al. propose a sealed-bid, one-price auction with a secondary after-market for trades

Sealed-bid, one-price auction [Grether et al.]

- Sealed-bid, one-price auction: Price paid by winning bidders is equal to lowest accepted bid
- This means that the value of a slot will be determined by the least profitable flight
- Treats all slots in one time-period as identical (substitutes)
 - It was recommended that each hour of the day over a six-month period be treated as a different commodity
- Since this proposal considers airport-specific slot auctions with no network issues being considered, an aftermarket in which airlines exchange slots will be needed

So what happened to the CAB study?

- Completed in September 1979.
- Study considered four different mechanisms: a lottery, an auction, grandfathering slots and “an administrative process of reviewing applications and applying some formula”, before recommending the sealed-bid, lowest-accepted price auction for the initial allocation
 - Most of the criticism (from the airlines) did not concern the design of the mechanism or the experiments, but rather were directed toward the use of auctions themselves, and contested the CAB’s authority to promote auctions
 - The IATA opposed the proposal citing fears that combining slots for flights between different airports would make the problem insurmountable
 - The CAB liked the findings, the FAA commissioned a second study...
 - Conducted by Econ, Inc., a Princeton-based firm contracted by FAA
 - The study supported the FAA proposal for the simultaneous auction of all slots at all four slot-controlled airports
 - Proposal was a multi-round auction in which bids would be revealed after each round. Bids could be altered until no new bids were obtained, The slot price was to be determined by highest rejected bid. Aftermarket for slot exchange between airlines

U. S., British Collaborative Efforts Urged

Groundwork should be laid for collaborative efforts between the U. S. and British aerospace industries for the development of future generations of aircraft, which could include hydrogen-powered transports, large cargo aircraft or a second-generation supersonic transport, according to Lawrence O. Kitchen, president of Lockheed Corp.

Kitchen told the British-American Chamber of Commerce in London last week that the capital requirements alone for such undertakings might necessitate resorting to broader-based collaborative efforts that would include other countries as well.

Such ventures should be approached so that the overseas partners participate on an equal basis in the marketing analysis, design, development, production and financing of the project.

He added that Lockheed procurement from the United Kingdom since 1966—either delivered or on order—totals more than \$2 billion, with the potential for as much or more procurement in follow-on business from current programs.

FAA's Slot Auction Plan For Washington Backed

Washington—Federal Aviation Administration's own proposed procedure for auctioning of airport slots, different from that suggested in a separate government-funded study, has been rated feasible for use at Washington National Airport.

Econ, Inc., a Princeton, N. J.-based firm under contract to the FAA, has concluded that the FAA-developed auction procedure would encourage an increase in the average stage lengths and load factors of flights serving National. It also could lead to a reduction of less profitable service to smaller communities, according to John M. Rodgers, acting chief, economic analysis branch, FAA's Office of Aviation

Policy. Econ reviewed the FAA procedure as it was developed in the last year and directed a runway slot allocation evaluation program for the FAA in February in which airline personnel participated in a mock auction to determine slots.

The FAA proposal calls for simultaneous auction of all slots at all airports affected by the high density airport traffic rule, which currently limits operations at Washington's National, Chicago's O'Hare International and New York's John F. Kennedy and LaGuardia airports.

Bidding Process

Rodgers described the bidding process as "give-and-take." Results of the first bidding round would be conditional, he said, with all participants being informed of the bids. Bidders would be permitted to alter their bids with each round. This procedure would continue until there was no apparent desire to change bids substantially.

The slot price would be determined by the price of the highest rejected bid. If there were 50 offers for 40 slots, as an example, the bid ranking 41st among 50 offers and those below that figure would not qualify for slots.

"The procedure lets the carriers work on their scheduling problems on the basis of their own flights and to revise bids to match up arrival and departure slots at various airports," Rodgers said.

He said the FAA favors its own bidding process proposal over the system advocated by the Polinomics Research Laboratories, Inc. (AW&ST Jan. 28, p. 27).

The Polinomics study, co-funded by the FAA and the Civil Aeronautics Board, proposed an initial allocation of slots through a sealed-bid, one-price auction. The slot price paid by each winning bidder would be based on the value of the lowest accepted bid. An after-market would per-

mit the carriers to trade or sell slots to another.

The FAA proposal also permits after-market exchange of slots for market adjustments.

The Polinomics study drew fire from domestic and international carriers, the International Air Transport Association, which feared problems of linking up flights between cities would be unmountable.

Movement Rate Limits

IATA, like its domestic counterpart Air Transport Assn., holds that the FAA should reexamine the movement rate limits set for the four high-density airports to determine whether the capacity constraints are too conservative, given development of computer-operated traffic controls.

Econ's formal report is circulating with the FAA. The report and an FAA evaluation of another slot allocation procedure proposal, termed administrative allocation, are expected to be available soon.

The administrative allocation procedure duplicates the procedure followed by airline scheduling committees, composed of airline representatives, that govern allocation of slots at the four capacity-controlled airports.

Administrative Procedure

But the administrative procedure would resolve conflicts on the basis of how passenger service could be "optimized" rather than by voluntary concessions and unanimous decision of carrier representatives according to the FAA.

The administrative allocation procedure also would give weight to carriers, based on such factors as the number of slots previously allocated, enplanements at depots, and the number of cities served.

Each of these proposals is designed to replace slot allocation procedures now handled by airline slot allocation committees whose work the CAB and others have considered to be anticompetitive.

Chicago Service

Northwest Airlines will match Midway Airlines' new service between Minneapolis and Chicago's Midway Airport beginning June 23.

The new service will involve four daily roundtrip Boeing 727-100 flights during the week and two each weekend day, the carrier announced last week. The aircraft will be reconfigured for 111 single-class seats.

Fares will match the \$44 one-way economy fare and \$65 one-way coach fare announced earlier in April by Midway Airlines, which said it would offer four roundtrips per day during the week and three roundtrips each weekend day, beginning June 1.

Aviation Week & Space Tech., May 5, 1980

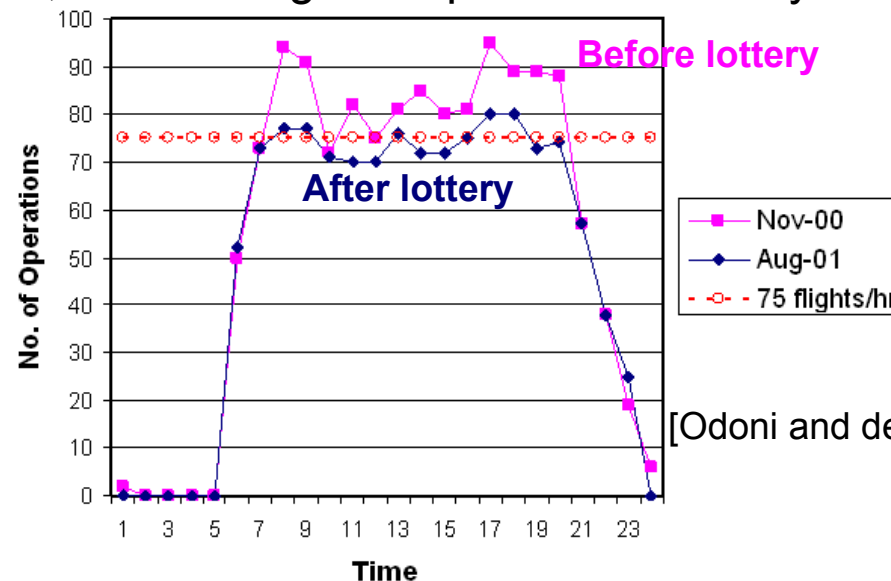
- While the FAA and CAB were lobbying for their proposals to be adopted in DCA...
- PATCO strike in 1981
 - As a result of all the turmoil, in March 1982, the slot committees stopped functioning
 - Unilateral slot trading allowed
 - Allocations/trading made for all airports simultaneously
 - For ~45 days starting 5/10/82, airlines were allowed to buy and sell slots for cash

Combinatorial auctions for airport slot allocation

- Rassenti, Smith and Bulfin, “*A combinatorial auction mechanism for airport time slot allocation*”, Bell Journal of Economics, 1982(!)
 - One of the earliest combinatorial auction applications
 - Recognize that value of a landing slot at a particular airport for an airline is dependent on the flight being allocated a corresponding takeoff time at a different airport
 - Propose a network-wide (two-stage) auction of links between airports

Little adoption in practice

- In 1983, the scheduling committees returned
- Airlines showed a preference for **grandfathering slots**
- In 2000: Slot exemptions for aircraft with < 71 seats, if operated either by new entrants or operating between LGA and small airports
 - Airlines schedule 600 new operations/week at LGA
 - Large delays and cancellations
 - LGA alone accounted for ~25% of US delays in 9/2000
 - Jan 2001: Lottery of available slots, restricting operations to 75/hour in good weather, and limiting exemptions to 159/day



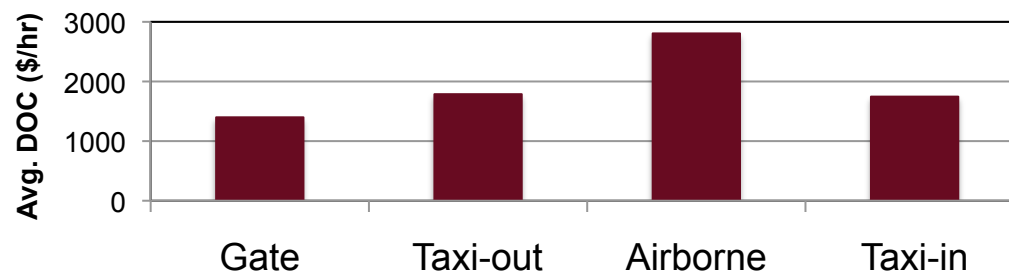
[Odoni and de Neufville, 2003]

Challenges to adoption of market-based mechanisms

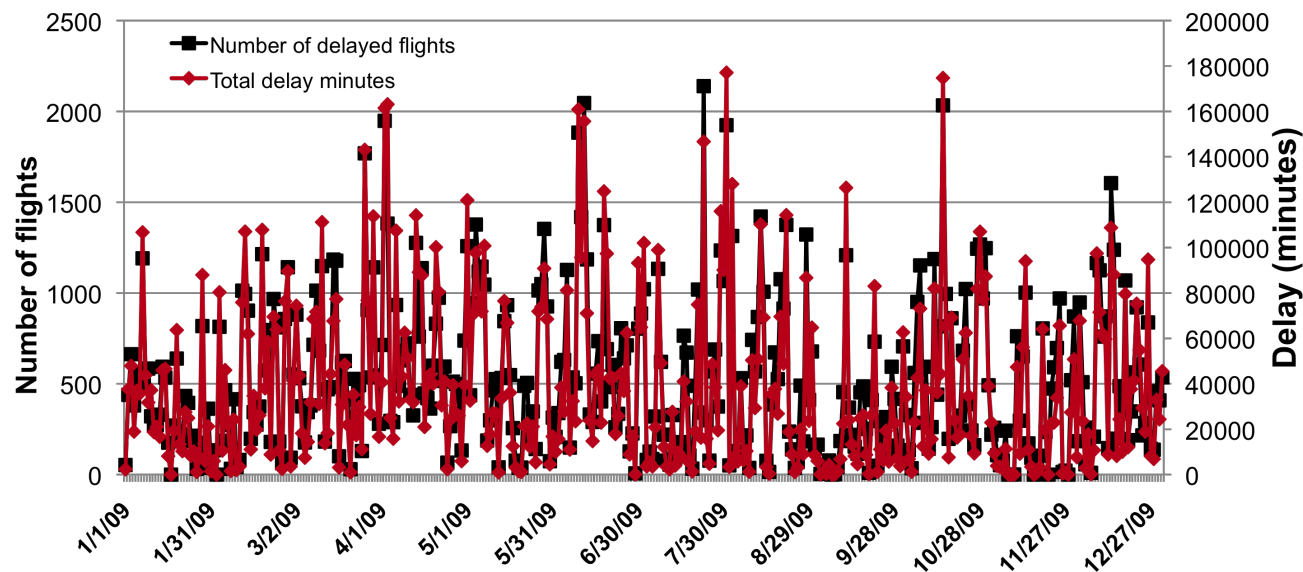
- Airlines oppose auctions because they do not want to bid for a service that is currently fixed-price
 - A 360,000-kg wide-body commercial jet pays 60x the landing fee as a 6,000-kg general aviation aircraft for the use of the same runway (even though their runway occupancy times are not that different)
 - However, airlines currently do trade airport resources, including slots
 - 1992: US Air purchased 62 LGA jet and 46 commuter slots, 6 national slots, a terminal under construction and a flight kitchen for \$61 million
 - 1993: Slots at O'Hare traded at \$2 million or more; United reported that each of its slots at ORD generates nearly \$5 million in revenue/yr
 - 1996: Reported that “new airlines have to pay as much as \$2 million to buy a slot from one of the majors to fly into airports such as LGA...”
- Need to define slots, property rights, enforcement, incentives for participation, valuation, price discovery, allocation efficiency,... [Ball et al. 2006, Harsha 2009]
- Reallocation in case of capacity impacts
- Ultimately, demand (and delays) may be big motivating factor

Reallocation in the event of weather: Ground Delay Programs (GDPs)

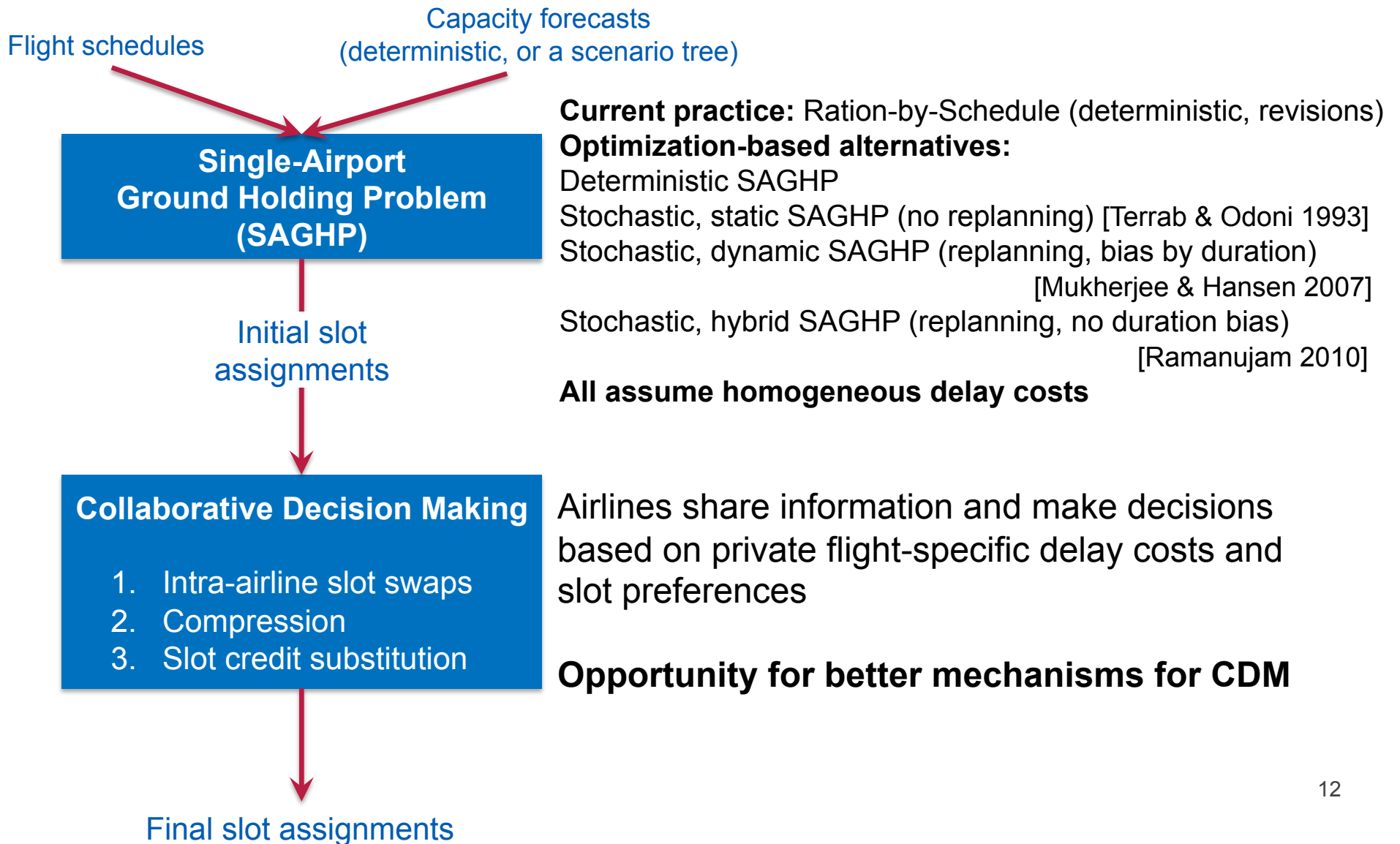
- Capacity is often lower than was initially predicted
 - Ground-holding (delay at origin airport): Also known as gate-holding
 - Ground delays are safer and less costly than airborne delays



- Ground delays very frequent in today's system

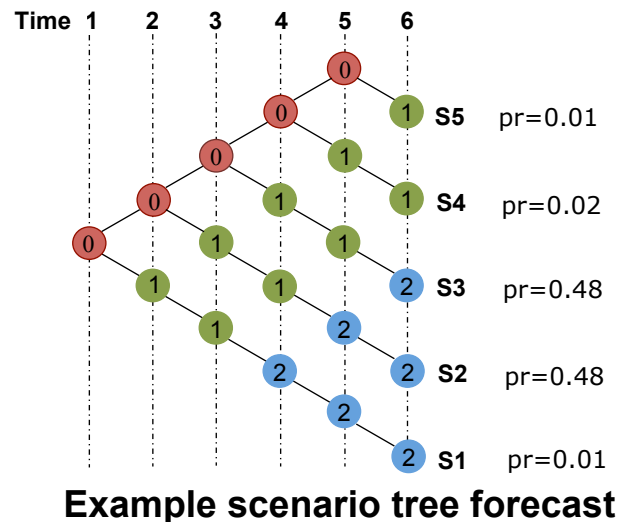
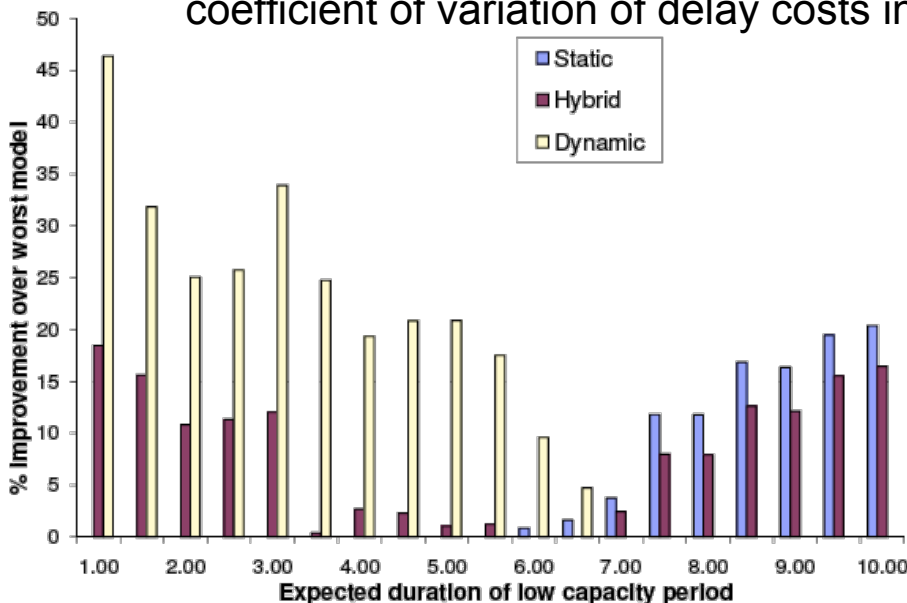


Ground Delay Programs (GDPs)



Design tradeoffs in GDPs

- Tradeoff between adaptability (extent of dynamic replanning in SAGHP) and available options for CDM
- Optimal allocation after SAGHP could result in suboptimal final allocation
 - Particular concern when costs are non-homogeneous
- LGA case studies, 10-hr GDP, 27 airlines (longest flt: 5 hrs), 20% coefficient of variation in delay costs
 - Dynamic model better for short duration of low capacity scenario
 - Hybrid is the most robust of the three models across different cases
 - Performance of dynamic SAGHP degrades as length of GDP increases, and coefficient of variation of delay costs increases



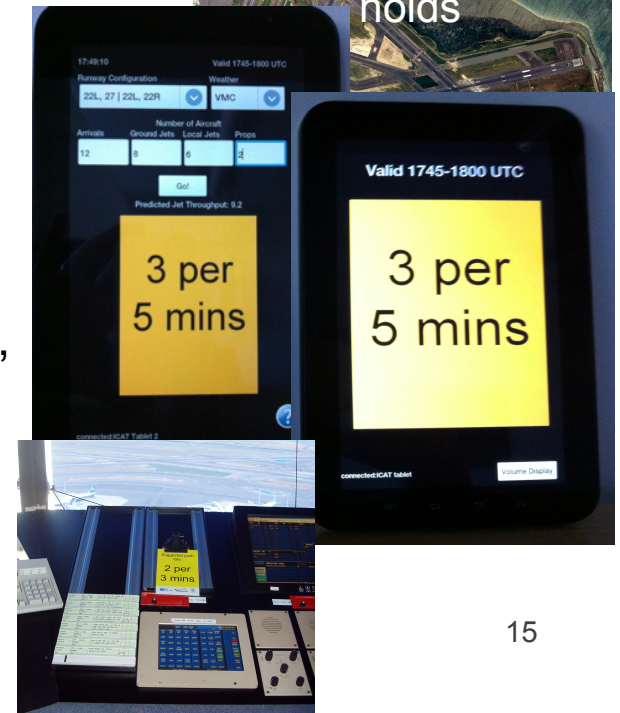
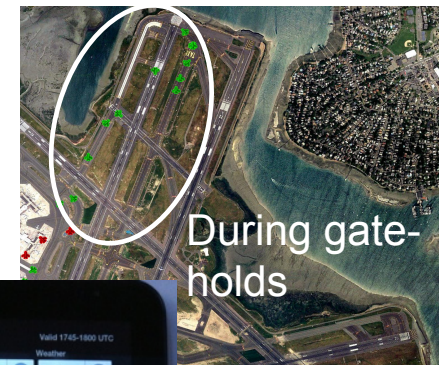
Resilient control: Tactical ATC

- Given a set of flights (in next 30 min) with estimated arrival times at the airport, the **aircraft need to be sequenced into the landing (takeoff) order**, and the **landing (takeoff) times** need to be determined
 - Need minimum (wt. class dependent) wake vortex separation (**Safety**)
 - Currently FCFS; resequencing could increase throughput (**Efficiency**)
 - “Fair” resequencing: Constrained Position Shifting (CPS) [Dear, Odoni 1976]
- Scheduling under CPS has been conjectured to have exponential computational complexity in the number of aircraft [Carr 2004]
 - **Key result:** We have proved that this is not true
 - **Basic idea:** We propose a way to represent solution space as a network whose size is linear in the number of aircraft
- Various interesting extensions can be solved in (pseudo-)polynomial time as shortest-path problems on variations of this network
 - Can evaluate tradeoffs between multiple objectives
 - Incorporated into future scheduling concepts simulations at NASA

Resilient control: Tactical congestion management

- Airport surface congestion results in increased delays, fuel burn and emissions
- Reduce surface congestion through Pushback Rate Control
 - Manage surface congestion by **controlling departures** alone
- Optimal rate at which aircraft pushback from their gates to reduce congestion and maintain runway throughput
 - Evaluate and adapt to uncertainty due to operational procedures, fleet mix, downstream route availability, human factors, etc.
- Field tests of concepts at BOS in 2010 and 2011

Simaiakis et al. ATM R&D Seminar 2011.
Khadilkar and Balakrishnan, IEEE ACC 2011.
Simaiakis et al. Intl. Conf. on Research in Air Transp. (ICRAT) 2012.



Some open EI + RC challenges in aviation

- Most existing approaches tend to look at either the mechanism design perspective or the resilient control perspective
- Important to consider that actual implementation of mechanisms (during GDPs, for example), is through a controlled time of departure (CTD)
 - Little understanding of uncertainty in GDP parameters (predicted capacity, expected duration of impact, ...)
 - Almost no research on network effects
- Focus has been on **landing slot auctions** and **arrival-centric GDPs**, but there is a known tradeoff between arrival and departure throughput at airports
- Can we design better EI, RC and combined EI+RC mechanisms for system-level efficiency?

