


Determining the Number of Slots to Submit to a Market Mechanism at a Single Airport



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Research Question



Given various economic concerns, and airport-specific conditions, how many arrival slots should be made available in a given time period?

Outline:

1. Background
2. Models
3. Calibration
4. Slot value determination
5. Sensitivity analysis
6. Conclusions



Background Information



- U.S. slot control
 - High Density Rule (HDR) enacted 1969 for ORD, DCA, EWR, JFK, and LGA
 - FAA NPRM released in 2006 concerning redistribution of slots at LGA
 - New York Aviation Rulemaking Committee 2007
 - FAA SNPRM April 2008, Final Rule October 2008
- Motivation
 - Cannot simply use VMC or IMC capacity
 - Higher value times-of-day
 - Cascading queuing delays
- LGA used as case study
 - Because of its significance as a slot-controlled airport
 - *Methodology is not limited to application at LGA*



Literature



- Primarily focused on **how** to allocate slots
 - Grether, et al. (1979,1989)
 - Rassenti , et al. (1982)
 - NEXTOR
 - Le et al. (2004)
 - Ball et al. (2006)
 - Daniel (1995)
 - Brueckner (2002)
- International interest
 - DotEcon (2001)

Auctions

Congestion pricing



Modeling Framework



- Two formulations
- Common elements
 - Integer-valued linear optimization problems
 - Posed as network flow problems
 - Objects in network are flights
 - Exits from network are landings and cancellations
 - Model cancellation behavior
- Different elements
 - Objective functions
 - Policy trade-offs

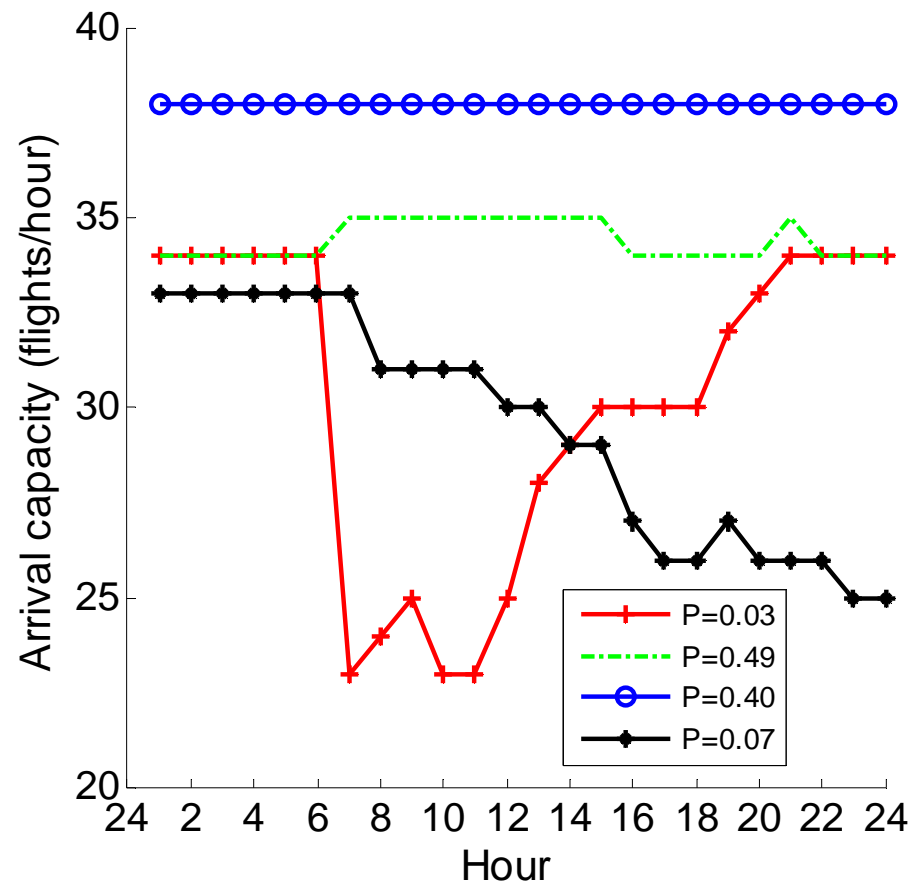


Assumptions

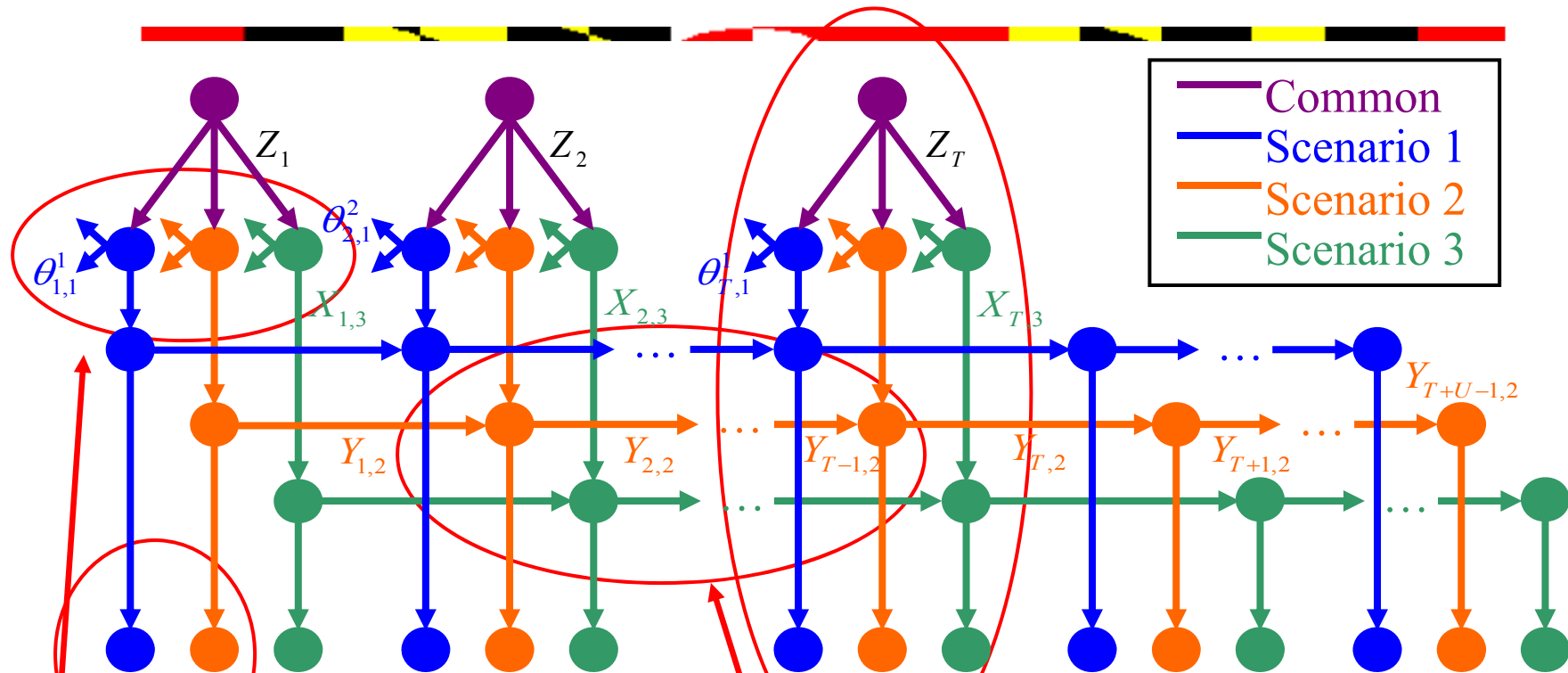


- Day broken into discrete periods (e.g. hour, quarter hour)
- Number of slots to offer in each hour has upper and lower bounds, D_{min} and D_{max}
 - Driven by operational limits and policy constraints
- Costs normalized to one unit delay cost
- Cancellations
 - Modeled as exits from network
 - Several capacitated arcs, each with increasing cost
- Delays
 - Modeled as horizontal arcs in flow diagrams
 - Flights can be delayed up to U time periods

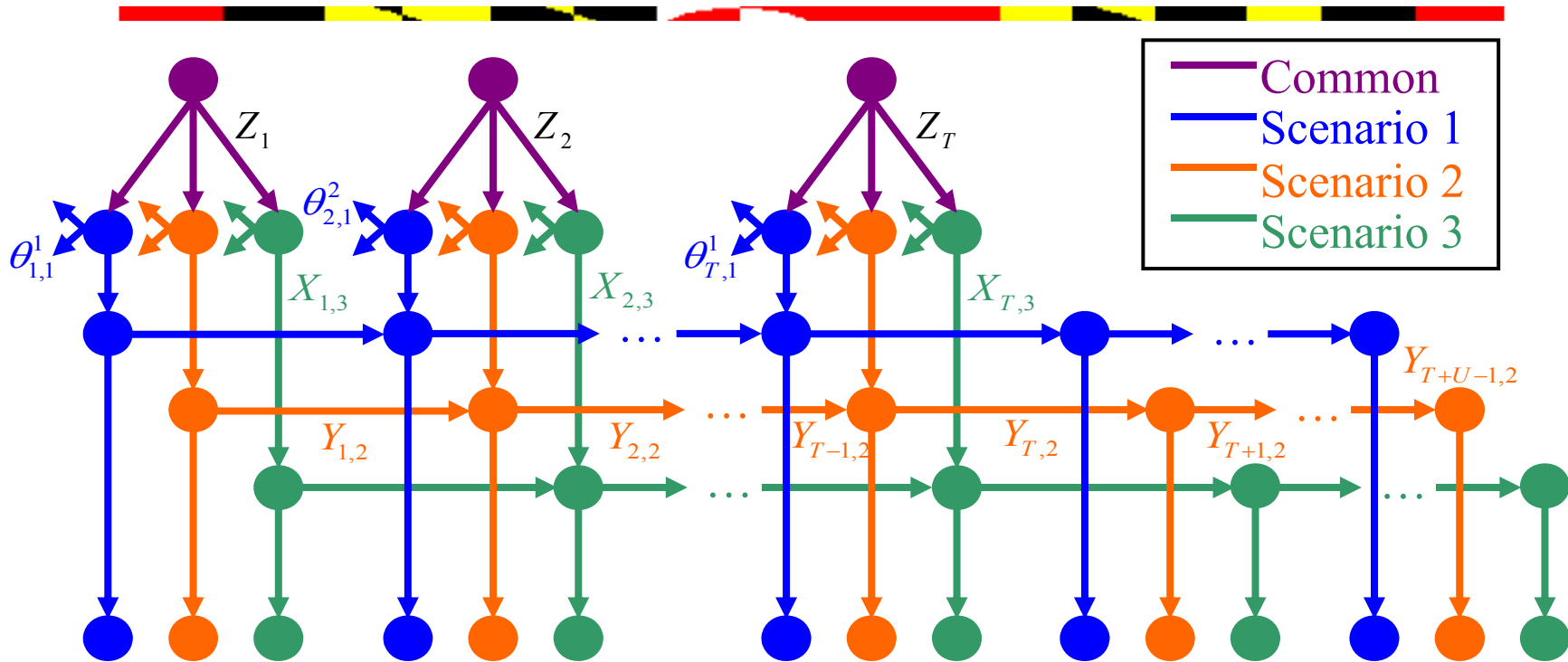
- Work undertaken by Liu, et al. (2005) to cluster arrival capacity (AAR) profiles



Results shown for LGA, 2003



- Constraints: Flow balance
- Objective function: Maximize total net benefit, as difference between total value of slots offered and cost of delays and cancellations



- Same network structure as base model
- Constraints: Flow balance, **cap on average delay per flight and overall cancellation percentage**
- Objective function: Maximize total value of slots offered; no longer requires pecuniary equivocation between delays and cancellations



Mathematical Properties



- Base constraint matrix is TU under limited conditions
 - Very small problem sizes (not useful)
 - Even-valued b vector
- Parametric constraint matrix is not TU under any conditions
- However, ...
 - The base formulation solves with LP relaxation
 - The parametric formulation solves quickly



Parameter Calibration



- Need method to estimate several parameters from historical data
 - U - maximum delay length
 - N - number of cancellation arcs
 - P - cancellation arc capacity
 - $\{\lambda_i\}$ - cancellation cost vector = $\alpha[1, 2, 4, 7, 11, \dots]$

Parameter	Lower Bound	Upper Bound	Additional Constraints
U	4	20	Multiple of 4
N	1	5	
P	2	6	
α	1	10	



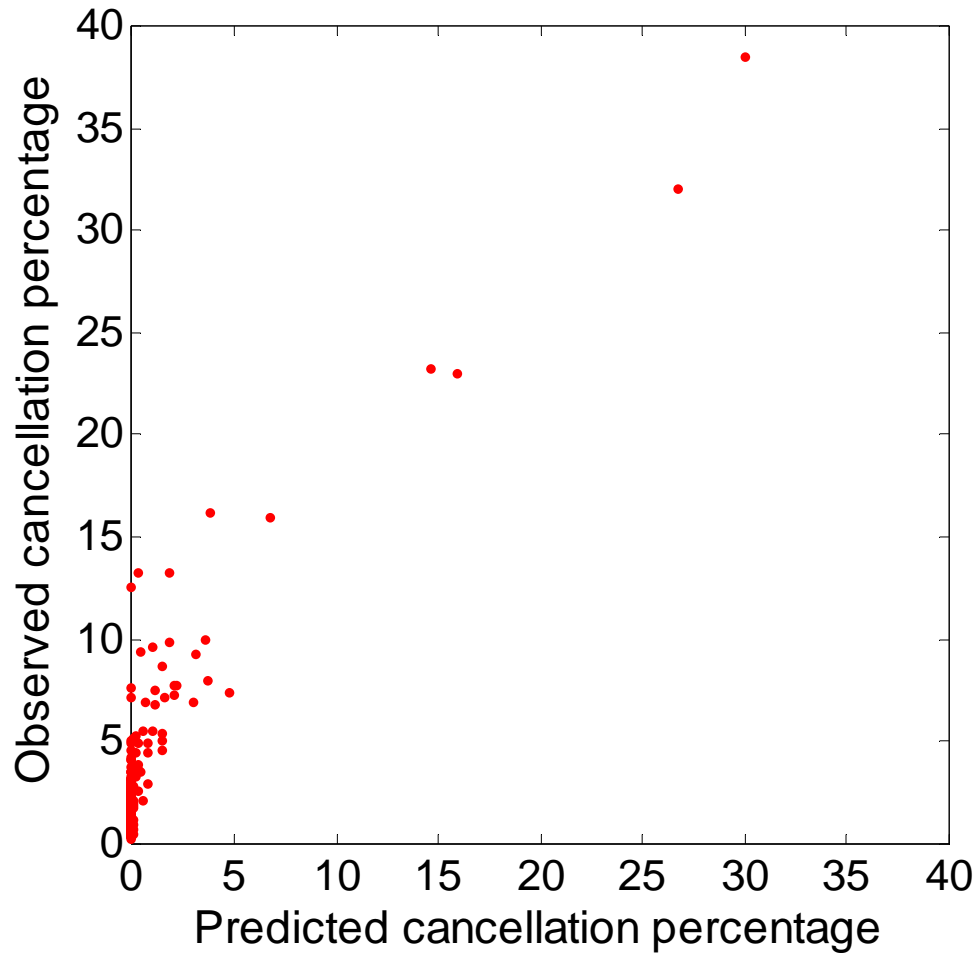
Parameter Calibration Procedure



- Define search space by bounding parameters
- For each unique combination of parameters
 - Apply same network as Base model with one capacity scenario (historical realization) and historical demand
 - Objective: minimize total cost, as weighted sum of cancellations and delays
 - Conduct analysis for many days (1 year)
 - Quantify relationship between observed and predicted data for all days using several metrics
- Choose “best” set of parameters based on metric criteria



Sample Calibration Results





Determining Slot Valuation



- Acquire proprietary data
 - Best to have data from many carriers
 - Carriers obviously reluctant to release such data
- Inference from ticket pricing data
 - High cost of data access
 - Confounding issues in ticket pricing
- Infer from auction results
 - True values revealed
 - Phased in over several years



Value Inference from Auctions

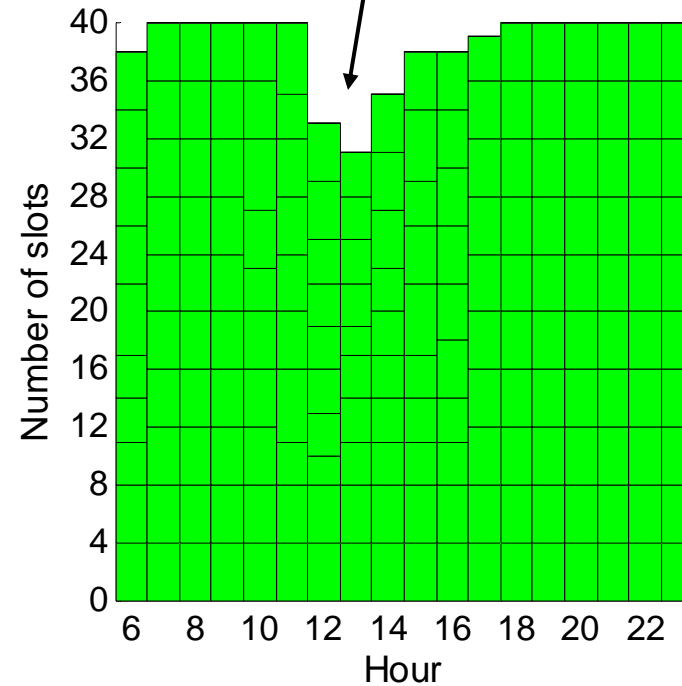
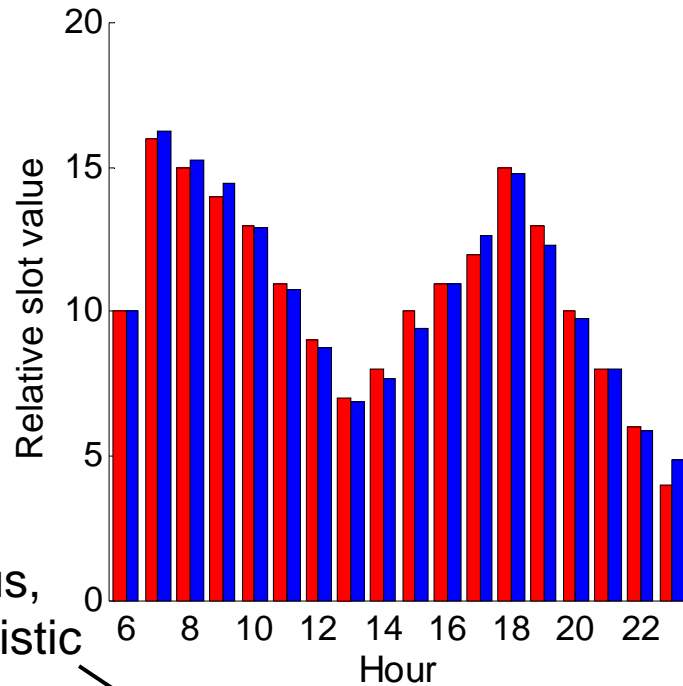


- Goals
 - Determine true slot valuations
 - Spread slot removal over several years
 - *Combines value inference, slot removal, and distribution*
- General process
 - Wait several years for prices to stabilize
 - Use model to determine number of slots to offer in each time period
 - Remove slots from circulation over several years
 - Update values and slots to be removed each year until process stabilizes

Value Inference Example

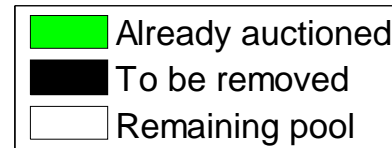
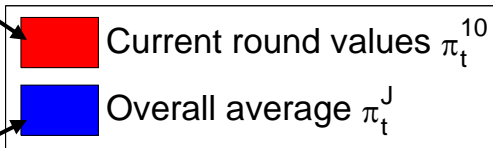


Real results, generated by Parametric model



Fictitious, but realistic

Average of red values



Parameters: Delay: 15 minute/flight, 3.0% cancellations



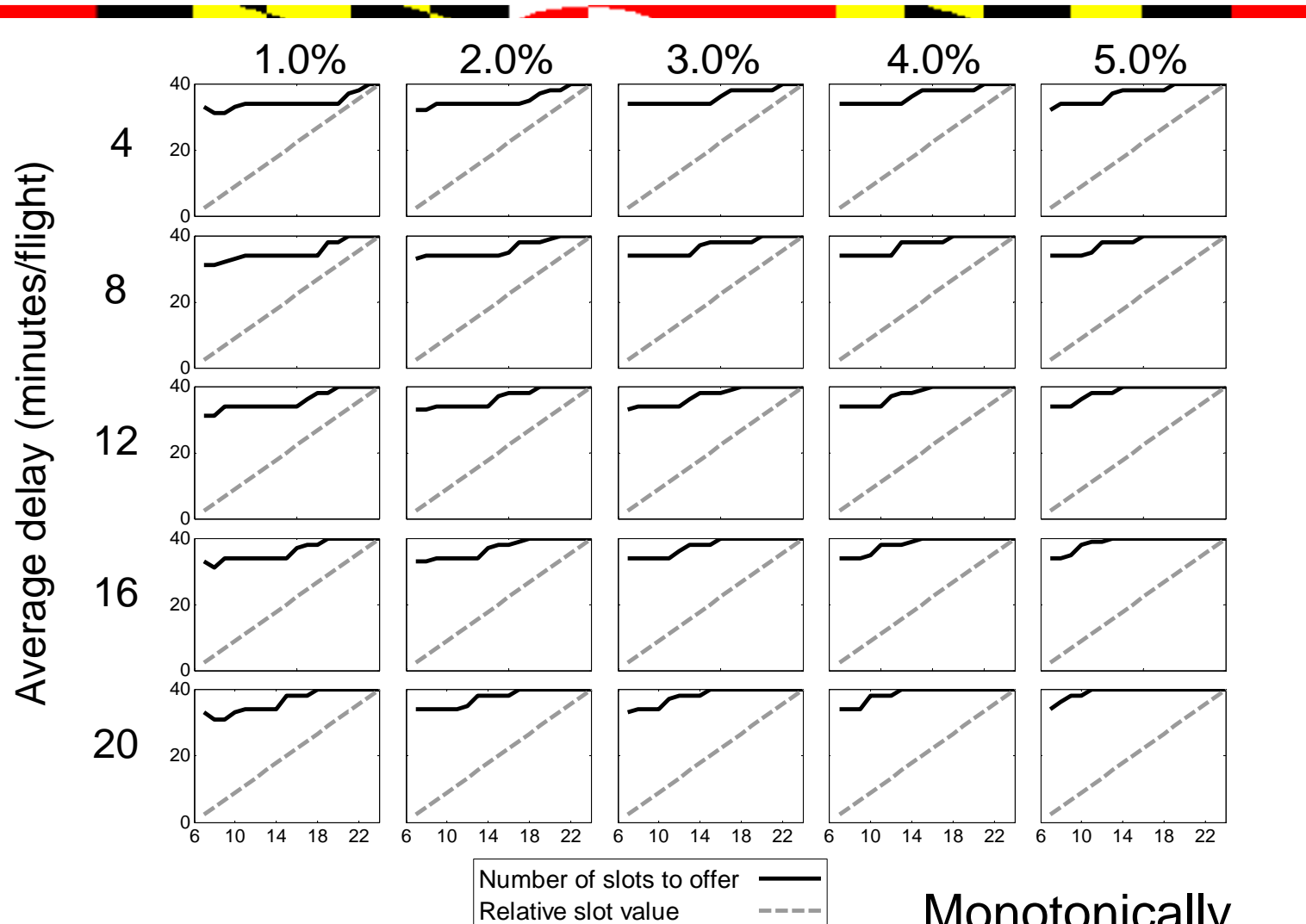
Sensitivity Analysis



- Tested effects of variations in slot values V_t
- Used Parametric formulation
 - Data from LGA, 2003
 - Slot valuations from Year 10 of auction example
 - Cancellations: maximum of 9 per hour permitted
 - Delay: 15 minutes/flight
 - Cancellations: 3.0%



Model Sensitivity to Slot Valuation



Monotonically increasing slot values



Summary of Results



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- Presented two possible formulations to determine number of arrival slots to offer
 - Addressed model calibration
 - Discussed various methods to estimate slot valuation
 - Proposed procedure that integrates valuation, removal, and allocation
 - Examined model sensitivity to slot values