Schedule Improvements at Congested Airports

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Dissertation and Awards

- Jacquillat, A., *Integrated Allocation and Utilization of Airport Capacity to Mitigate Airport Congestion*. Ph.D. thesis, Eng'ring Systems Division, MIT, June 2015.
  - **2015 George B. Dantzig Dissertation Award [Top dissertation award of INFORMS]**
  - **2015 Dissertation Prize of Transportation Science and Logistics Section, INFORMS**
  - **Council of University Transportation Centers (CUTC) Milton Pikarsky 2015 Award, Best Ph.D. dissertation in science and technology**
  - **2015 Industry Studies Association (ISA) Dissertation Award**

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Papers

- Jacquillat, A. and A. Odoni, An Integrated Scheduling and Operations Approach to Airport Congestion Mitigation. *Operations Research*, Vol. 63, No. 6, 2015, pp. 1390-1410.
- Jacquillat, A., A. Odoni, and M. Webster, Dynamic Control of Runway Configurations and of Arrival and Departure Service Rates at JFK Airport under Stochastic Queue Conditions. *Transportation Science*, *Articles in Advance,* 2016.
- Pyrgiotis, N. and A. Odoni, On the Impact of Scheduling Limits: A Case Study at Newark International Airport. *Transportation Science*, Vol. 50, No. 1, 2016, pp. 150-165.
- Jacquillat, A. and A. Odoni, Endogenous Control of Arrival and Departure Service Rates in Dynamic and Stochastic Queuing Models with Application at JFK and EWR. *Transportation Research Part E*, Vol. 73, No. 1, 2015, pp. 133–151.

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Outline

- Motivation and Background
- Description of Targeted Scheduling Interventions (TSI) Approach
- Example and Observations
- Discussion and Potential of TSI Approach

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Context

- Interventions into scheduling of flights at airports, aimed at mitigating air traffic congestion, are referred to as **Demand Management** measures
- Practically all existing demand management systems involve non-monetary scheduling interventions to limit overcapacity scheduling
  - We propose a new approach for optimizing non-monetary scheduling interventions
- The demand management approaches we consider do **not** include "market-based" mechanisms (slot auctions, congestion pricing, etc.), except possibly for post-allocation trading of schedule slots

Airport Classification per IATA

- Level 3 – Schedule Coordinated ("an airline or other aircraft operator must have a slot allocated to it by a duly appointed coordinator") – 181 airports in 2016, *including practically all of the world's busiest outside US*
- Level 2 – Schedule Facilitated ("schedule adjustments mutually agreed between the airlines and a facilitator") – 119 airports outside US
- Level 1 – Free Scheduling ("the capacity of the airport infrastructure is generally adequate to meet the demands of airport users at all times")

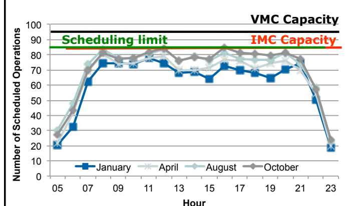
U.S. airports

- One Level 3 airport (JFK), five Level 2 (EWR, LAX, ORD, MCO, SFO) [for international slots mostly]
- NY's airports (JFK, LGA, EWR) operate with FAA-imposed "slot caps" (as well as Washington DCA)
  - Cap levels in NY heavily criticized (e.g., DOT Inspector General's Report, 2010)
  - Long delays in less than ideal conditions
- No caps at all other airports [**"Hands Off"** Approach]
  - Several "uncapped" US airports operate at delay levels that would classify them as Level 3 elsewhere

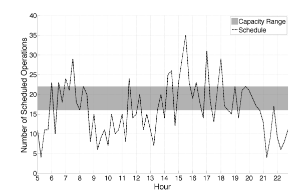
A Level 3 schedule (FRA) and an uncapped schedule (JFK)

- Slot control
- Lower capacity utilization
- Lower and more predictable delays

- Limited demand management
- Higher capacity utilization
- Higher and more variable delays



Scheduling at a Level 3 airport (FRA; 2007)



Scheduling at a US airport (JFK; 2007)

Problems with Existing Approaches

- Level 3: Entirely "supply-side" perspective!
  - Limits/caps per unit of time ("declared capacity") set by considering only airport capacity
  - Inflexible coordination procedure: "flat" or nearly-flat limits, "Excess" flights are often refused
  - No consideration of:
    - user preferences for certain times of the day
    - user willingness to accept delays
  - Method for determining limits/caps varies widely
- Hands Off: Risks "tragedy of the commons"
  - Nationwide impact of flight delays in 2007 over $30 billion (Total Delay Impact Study)

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Motivation

Lots of Room for Improvement!

- Our Proposal:

Targeted Scheduling Interventions (TSI)

A model-based, transparent schedule optimization approach, also highly amenable to a collaborative decision-making (CDM) environment

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The Basic Idea

- Develop a model that allows users to explore fully and optimize the trade-off between

Level-of-Service (LOS)

and

Scheduling Interventions (SI)

- LOS specified through maximum values of expected length of arrival queue and of departure queue during a day
- SI specified through metrics of displacement of flight schedules form airline-preferred times
  - Maximum flight displacement, δ [15-minute intervals]
  - Total displacement, Δ, suffered by all flights in a day

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Underlying Observations

- The intensity of scheduling interventions should be based on capacity availability under the full range of operating scenarios (and their associated probabilities)
- MOTIVATION: At near-capacity operating levels, flight delays are very sensitive to even small changes in:
  - Number of flights ("traffic volume")
  - Distribution of traffic over the course of the day
- A daily schedule which is **not flat** (i.e., with "peaks and valleys") may be preferred by passengers and airlines, even at cost of some additional flight delays
- Any change in the scheduled time of a flight also affects all flights "connected" to that flight

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TSI: The "Targeted Scheduling Interventions" Approach

- Given, for any airport:
  - An initial, full-day, airline-preferred schedule of flights
  - Estimates of airport capacity under all possible operating scenarios (runway configurations, weather, mix of arrivals and departures)
  - A target LOS: limits A_{MAX} and D_{MAX} for expected arrival and departure queue lengths respectively.
- TSI proposes an alternative schedule that
  - Maintains all flights scheduled by the airlines
  - Minimizes timetabling changes
  - Meets on-time performance targets

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TSI Formulation [Suite of Models]

(I) Minimize schedule displacement (first minimize maximum displacement, δ, then minimize total displacement, Δ)

- Subject to:

(II) Scheduling constraints ensuring that the scheduling interventions are feasible and that no flights are eliminated

(III) Network connectivity constraints that preserve connections of aircraft and of transferring passengers throughout each airline's network

(IV) Operating capacity constraints that reflect the expected number of movements that the airport can operate

(V) Level-of-service constraints that ensure that queue lengths are kept below A_{MAX} and D_{MAX}

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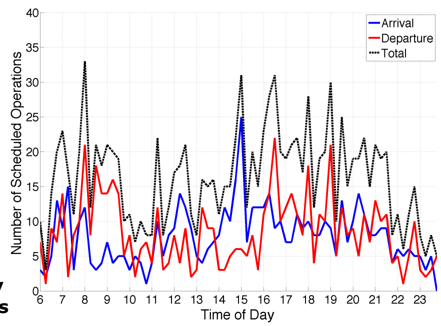
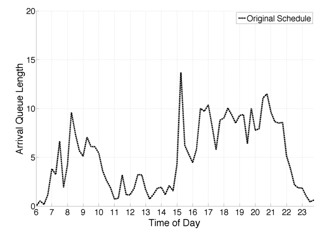
15-minute Flight Schedule, JFK 5/25/2007

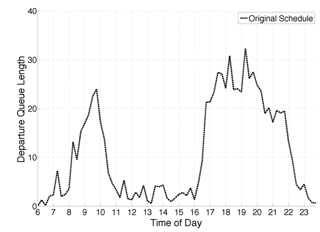


Total of 1,276 daily movements

Expected Queue Lengths – Original Schedule



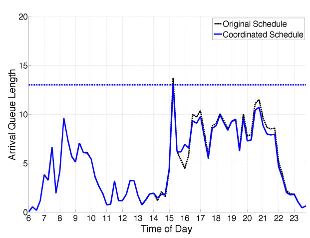
Arrival Queue



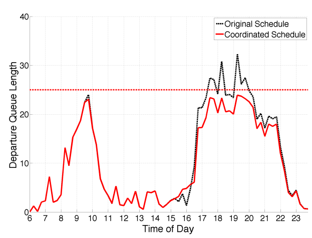
Departure Queue

- Maximum flight displacement: 0 15-minute period
- Total schedule displacement: 0 15-minute period

Effect on Delays (A_{MAX}=13, D_{MAX}=25)



Arrival Queue



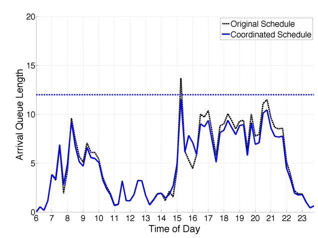
Departure Queue

- Maximum flight displacement: 1 15-minute period
- Total schedule displacement: 37 15-minute periods

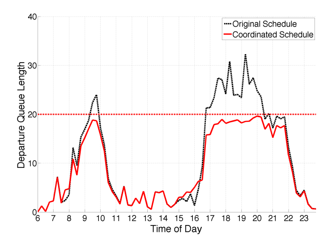
Expected max queue lengths: Arrivals -6%; Departures -26%

Average delay per movement: Arrivals -2%; Departures -12%

Effect on Delays (A_{MAX}=12, D_{MAX}=20)



Arrival Queue



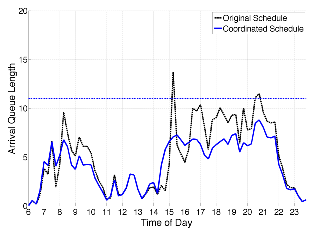
Departure Queue

- Maximum flight displacement: 1 15-minute period
- Total schedule displacement: 105 15-minute periods

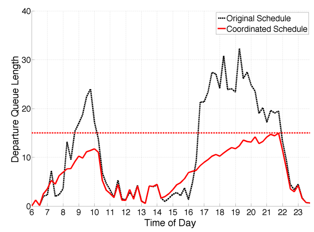
Expected max queue lengths: Arrivals -15%; Departures -39%

Average delay per movement: Arrivals -4%; Departures -21%

Effect on Delays (A_{MAX}=11, D_{MAX}=15)



Arrival Queue



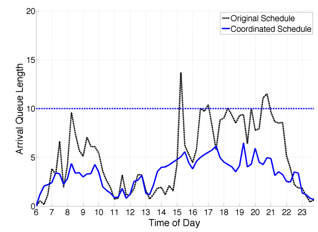
Departure Queue

- Maximum flight displacement: 2 15-minute periods
- Total schedule displacement: 356 15-minute periods

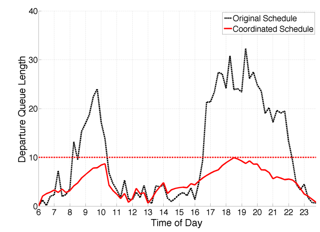
Expected max queue lengths: Arrivals -36%; Departures -53%

Average delay per movement: Arrivals -18%; Departures -43%

Effect on Delays (A_{MAX}=10, D_{MAX}=10)



Arrival Queue



Departure Queue

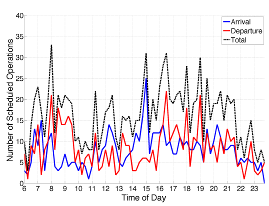
- Maximum flight displacement: 2 15-minute periods
- Total schedule displacement: 1,129 15-minute periods

Expected max queue lengths: Arrivals -53%; Departures -69%

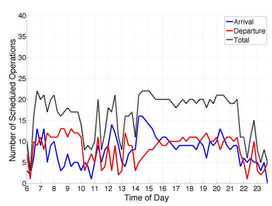
Average delay per movement: Arrivals -38%; Departures -62%

Takeaways

- Smoothing of flight schedules, but with peaks and valleys
- Nonlinear increase in displacement with stringency of delay reduction targets
- **Main takeaway: Congestion can be substantially mitigated through limited changes in schedules**



Original Schedule on 05/25/2007



Modified Schedule; A_{MAX}= 11 , D_{MAX}= 15

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Short-Term Use

- **TSI suite of models can be a powerful tool for the FAA, airport operators and even airlines**
- In anticipation of "next season" (i.e., once flight requests are known) can obtain estimates of
  - What level-of-service (in terms of delays during the course of a day) can be expected
  - What it would take, in terms of schedule displacement, to achieve different improved levels-of service (how many flights would have to be displaced and by how much)
- Assess: whether it makes sense to "intervene"; how intensively to intervene?; and exactly how?

Long-Term Potential

- **TSI offers an alternative conceptual approach for airport demand management**
- Could be carried out in a CDM environment with airport users, airport operators and ANSPs selecting the preferred tradeoff of delay mitigation vs. schedule displacement
- Decisions made with full knowledge of the Pareto-optimal frontier (congestion vs. displacement)
- A scheduling mechanism that mitigates excessive delays (and "tragedy of the commons") through limited adjustments to flight schedules

Some Extensions/Enhancements

1. (At Level 3 airports) Treat "grandfathered" slots as immovable.
2. Add equitable treatment of airlines as an objective (Jacquillat and Vaze, 2016)
3. Allow airlines to prioritize flights (i.e., some flights will be more costly to displace than others)
4. Offer post-assignment options
   a. Each airline may re-shuffle the assignment of its own flights among the slots it has been given
   b. Swaps and secondary trading permitted
5. Assign the same "slot" to any given flight on all days when the flight is operated

Benefits compared to current approaches ("do nothing" or "slot controls")

- **Considers simultaneously the supply and the demand sides – not just the supply**
- Treats scheduling levels as decision variables; thus, generates schedules that may exhibit peaks and valleys reflecting airline scheduling preferences
- Considers "network effects" of schedule changes, thus preserving connections of aircraft, crews and passengers
- Considers entire range of airport operating conditions (runway configurations, weather, mix)
- All stakeholders (ATC, airlines, passengers, airport operators) may be better off as a result