Scheduling at Congested Airports: Current Practices and Opportunities for Improvement

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Global Challenges to Improve Air Navigation Performance

Joint work with: Amedeo Odoni, Thomas Morisset, Nikolas Pyrgiotis

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Massachusetts Institute of Technology
Engineering Systems Division

Talk Outline

1. Comparison of US/EU airside performance

   (Amedeo Odoni and Thomas Morisset; Part of FAA - EUROCONTROL initiative; MIT effort funded by FAA through NEXTOR)

   → Comparison of scheduling policies at US and European airports and their impact on system performance

2. Optimization of scheduling interventions at busy airports

   (Amedeo Odoni, Nikolas Pyrgiotis, and Alexandre Jacquillat)

   → Methodology to modify flight schedules to reduce demand-capacity mismatches, while minimizing interference with airline scheduling

→ Opportunities for improvements in scheduling practices

References

1. Comparison of US/EU airside performance

   T. Morisset and A. Odoni (2011), "Capacity, Delay, and Schedule Reliability at Major Airports in Europe and the United States", *Transportation Research Record*, 2214, 85-93

   A. Odoni, T. Morisset, W. Drotleff and A. Zock (2011), "Benchmarking Airport Performance: FRA vs. EWR", *USA/Europe ATM Seminar*, Berlin, Germany

   T. Morisset (2010), "Comparing Capacities and Delays at Major European and American Airports", SM Thesis, Massachusetts Institute of Technology

2. Optimization of scheduling interventions at busy airports

   N. Pyrgiotis and A. Odoni, "On the Impact of Scheduling Limits: A Case Study at Newark International Airport", *Transportation Science*, forthcoming

   A. Jacquillat and A. Odoni, "An Integrated Scheduling and Operations Approach to Airport Congestion Mitigation", *Operations Research*, in review

   N. Pyrgiotis (2011), "A Stochastic and Dynamic Model of Delay Propagation Within an Airport Network For Policy Analysis", PhD Thesis, Massachusetts Institute of Technology

   A. Jacquillat (2015), "Integrated Allocation and Utilization of Airport Capacity to Mitigate Air Traffic Delays", PhD Thesis, Massachusetts Institute of Technology

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Current Practice

Policies	Europe	USA
Operations	■ Use of IFR all the time	■ Use of VFR, weather permitting
Scheduling	■ Slot control	■ Weak scheduling constraints

→ How does the use of VFR at US airports impact **throughput**?

→ How do the differences in US and European scheduling policies impact **scheduling** practices?

→ How does it impact airport **on-time performance**?

☐ Databases:

- US: ASPM data
- Europe: CODA data, plus additional datasets at German airports

Airport Capacity Estimates

Rank	IATA	Optimal Capacity[a]	IFR Capacity[a]
1	ATL	180-188	158-162
2	ORD	190-200	136-144
3	DFW	270-279	186-193
4	LAX	137-148	117-124
5	DEN	210-219	159-162
6	LAS	102-113	70-70
7	IAH	120-143	108-112
8	PHX	128-150	108-118
9	CLT	130-131	102-110
10	PHL	104-116	96-96
11	DTW	184-189	136-145
12	MSP	114-120	112-114
13	EWR	84-92	61-66
14	JFK	75-87	64-67
15	SLC	130-131	110-113
16	BOS	123-131	90-93
17	LGA	78-85	69-74
18	MIA	116-121	92-96
19	IAD	135-135	105-113
20	SFO	105-110	68-72

Rank	IATA	Declared Capacity[b]
1	CDG	112
2	FRA	83
3	MAD	90
4	LHR	89
5	AMS	106
6	MUC	90
7	BCN	61
8	FCO	88
9	VIE	66
10	ZRH	68
11	MXP	69
12	LGW	50
13	BRU	74
14	IST	n/a
15	CPH	83
16	ORY	72
17	DUS	47
18	OSL	80
19	MAN	59
20	ARN	82

[a] Airport Capacity Benchmark Report, FAA, 2004.
[b] from EUROCONTROL or the individual airports

Capacity Comparison

- Use of VFR at US airports has a positive impact on capacity (overall capacity about 25% higher than IFR capacity)
  - Higher capacities for each individual runway
  - More efficient use of multiple runways

Capacity Comparison

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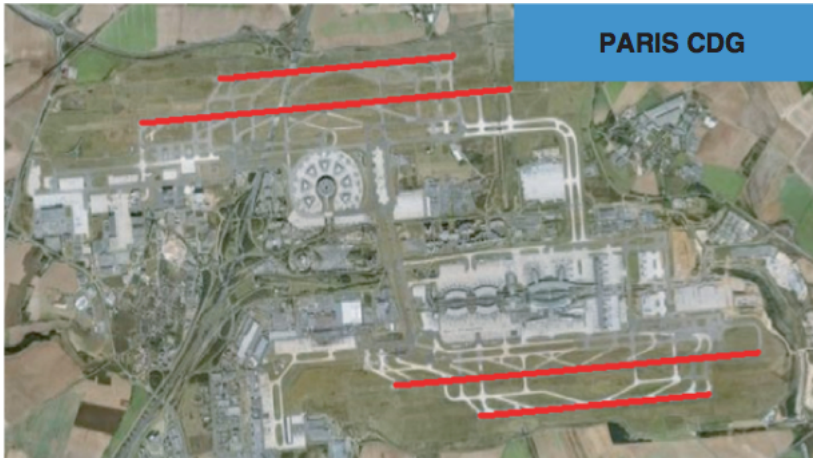
  - Higher capacities for each individual runway
  - More efficient use of multiple runways
- Comparison of airports with similar runway layouts



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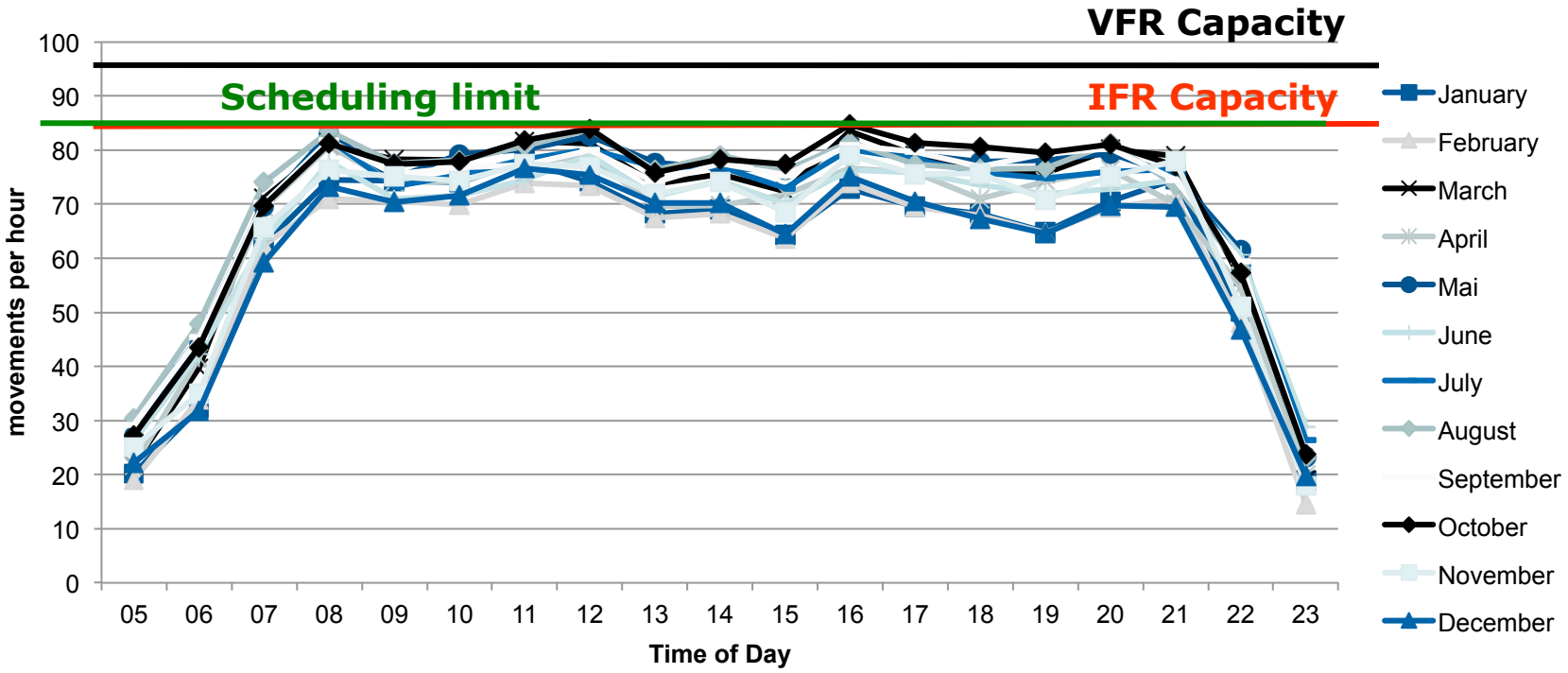
	US Airports				European Airports	
Layout	**Airport**	**Weighted**	**Optimal**	**IFR**	**Airport**	**Declared**
Single runway	SAN	55	57	49	LGW	50
					DUB	46
					TXL	48
					STR	42
Two closely spaced, parallel runways	SEA	76	82	59	DUS	47
					MAN	59
					NCE	52
Two pairs closely spaced parallel runways	ATL	179	184	160	CDG	112
	LAX	137	143	121		

Capacity Comparison

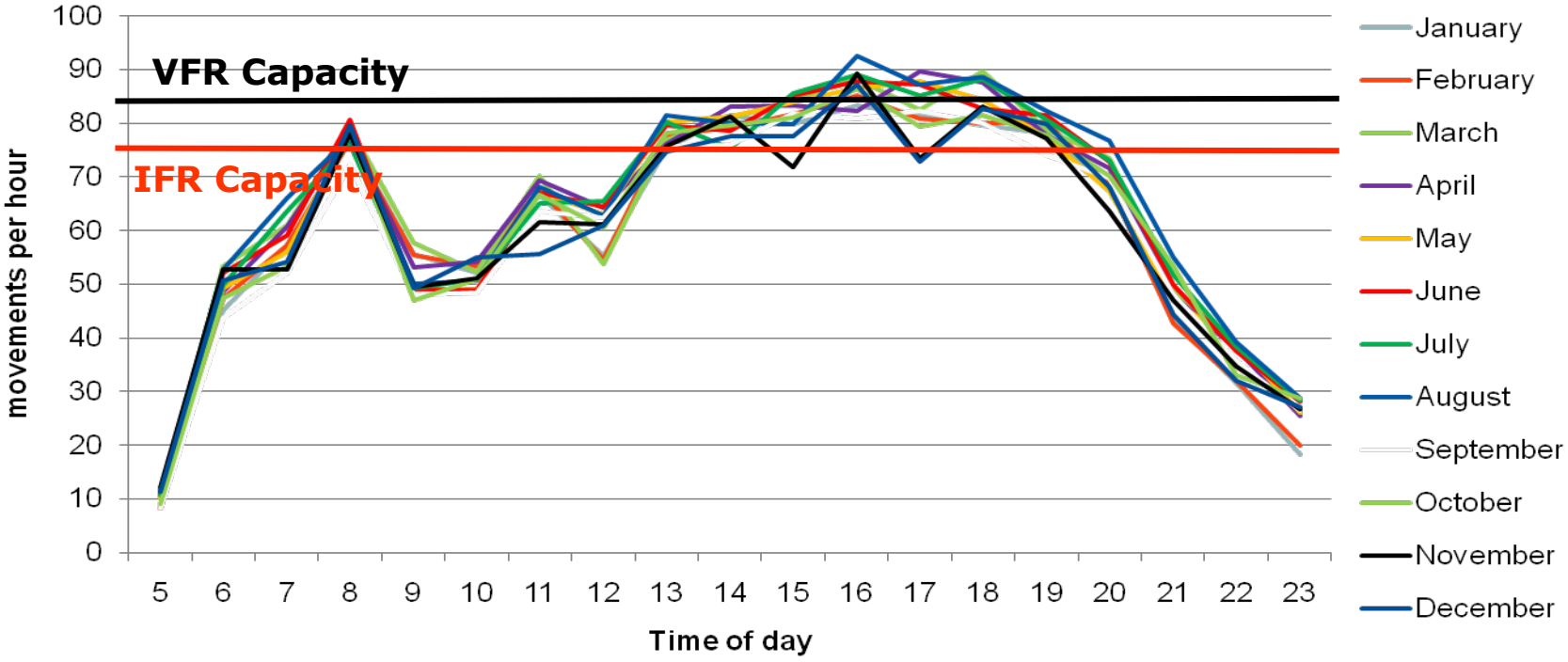
- → Use of VFR at US airports has a positive impact on capacity (overall capacity about 25% higher than IFR capacity)
  - Higher capacities for each individual runway
  - More efficient use of multiple runways
- ☐ Comparison of airports with similar runway layouts
- → IFR Capacities at US airports are relatively close to (generally, slightly higher than) declared capacities at European airports
- → With the use of VFR, the overall (weighted) capacities of US airports are much higher than the declared capacities of their European counterparts

Scheduling at EU Airports (FRA)



- → Evenly distributed demand profile from 07:00 to 21:00
- → Scheduling limit set w.r.t. IFR Capacity

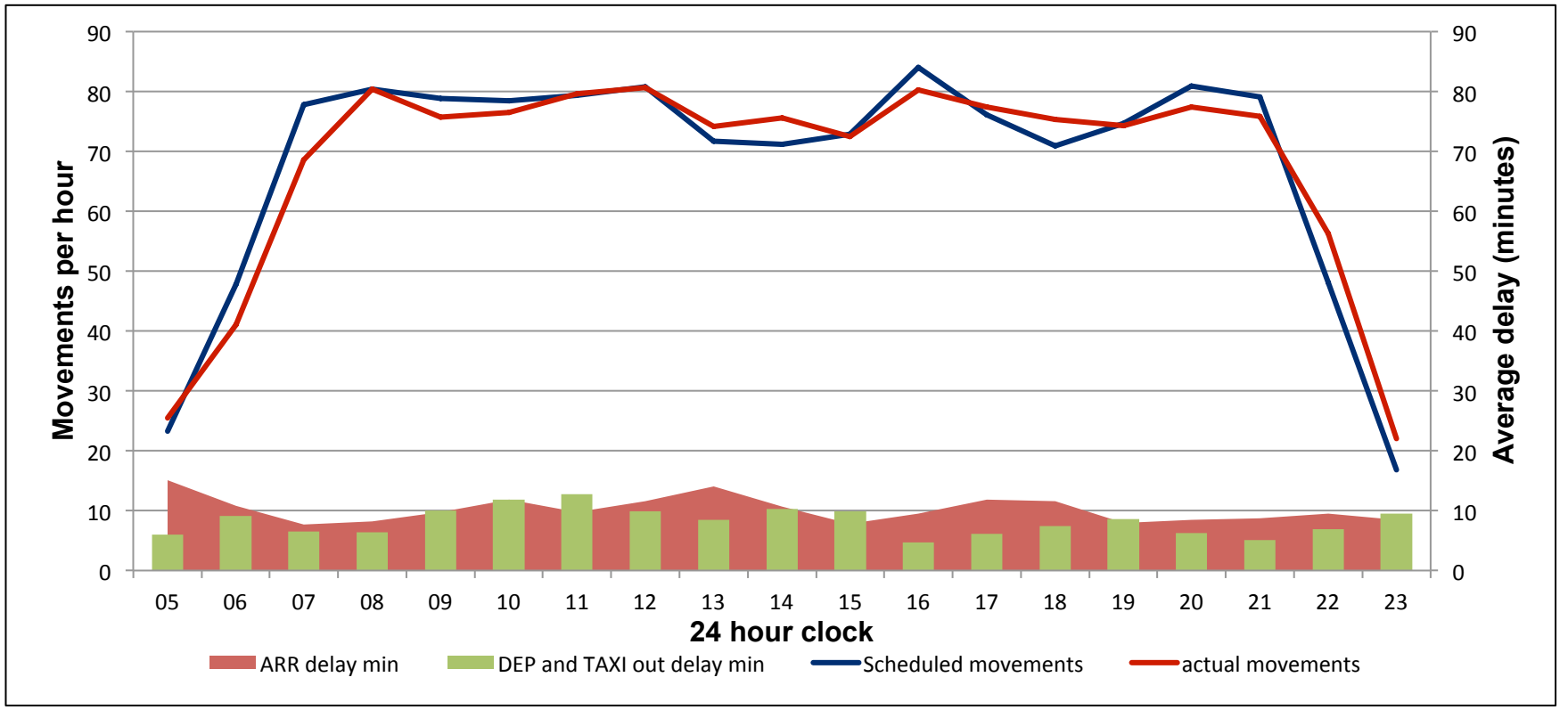
Scheduling at US Airports (EWR)



→ Uneven demand profile with extended afternoon peak

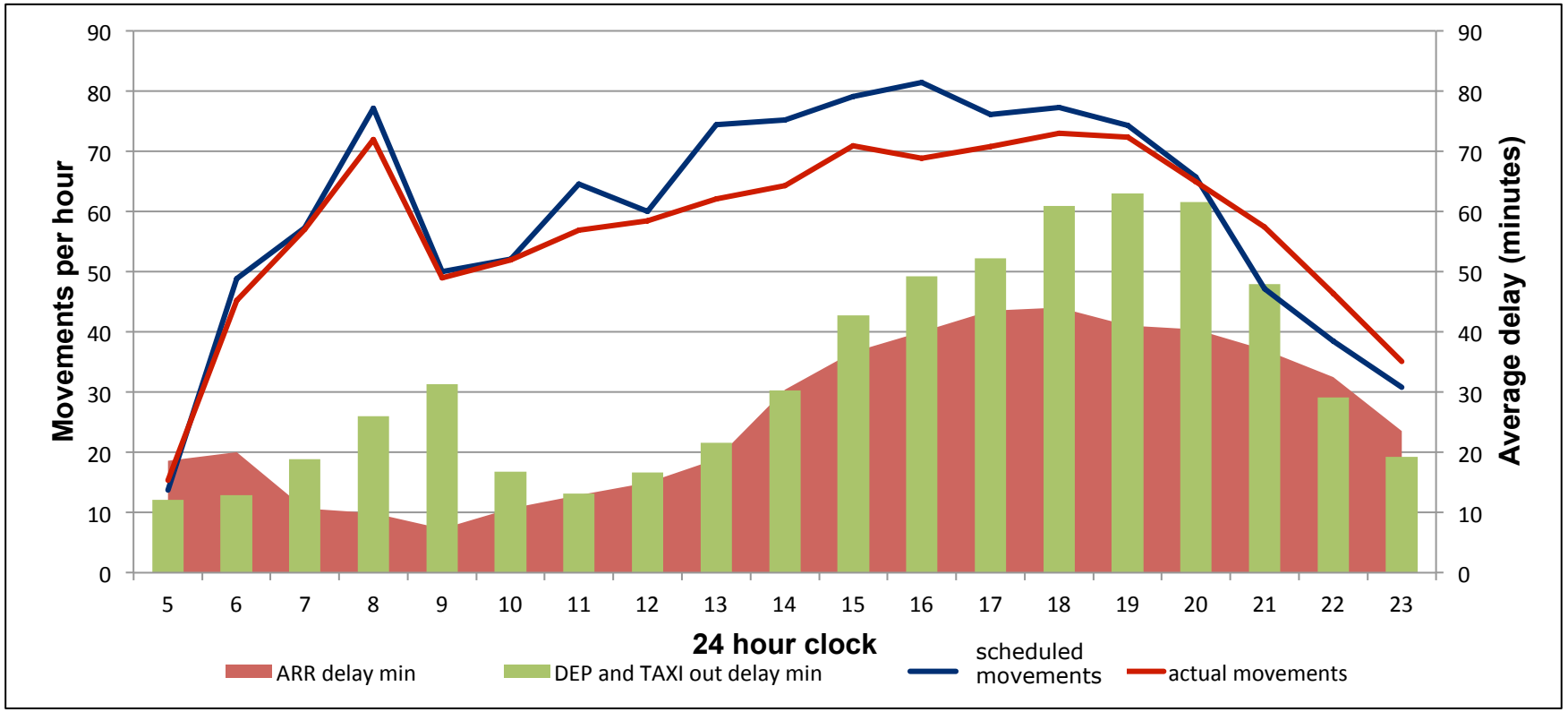
→ Schedules of flights produced w.r.t. VFR Capacity

Delays at EU Airports (FRA)



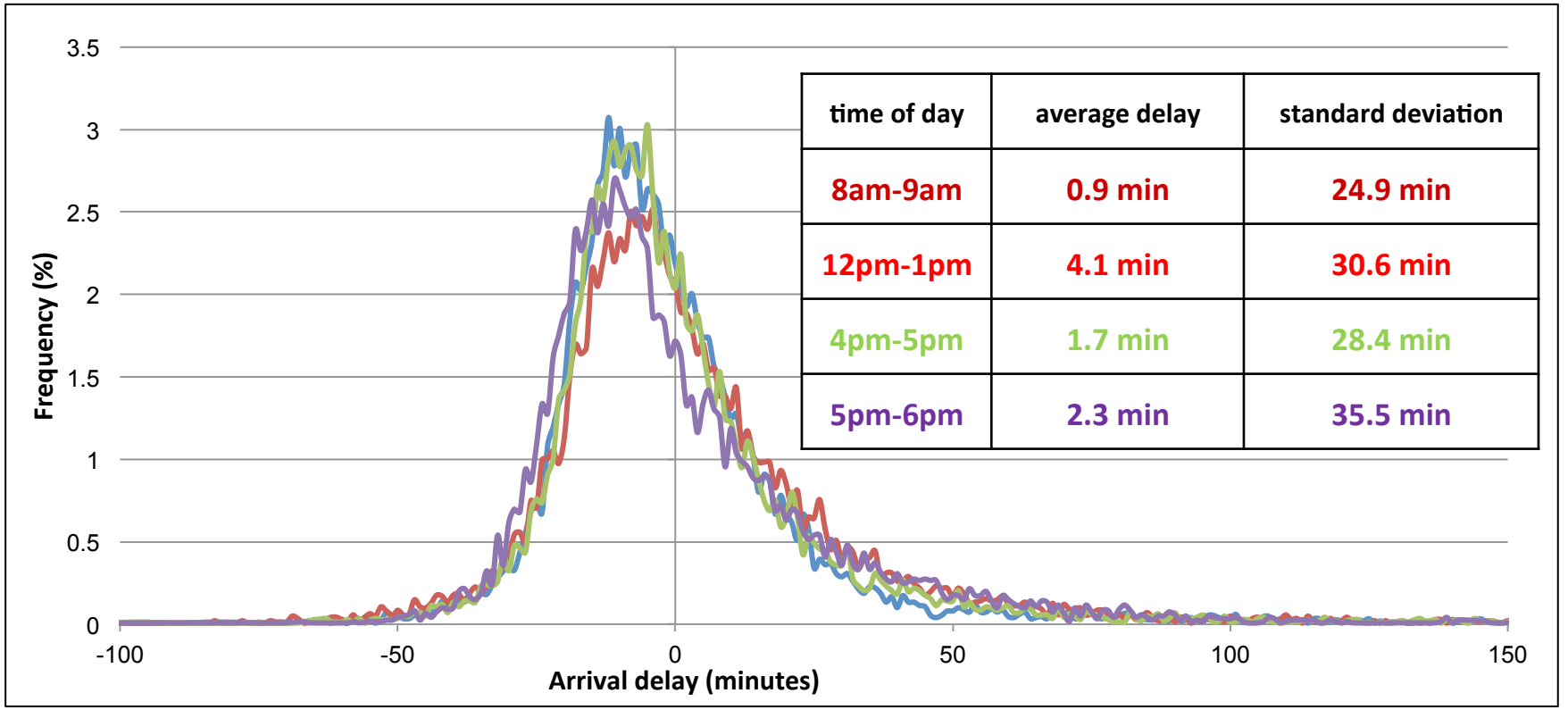
- → Average arrival/departure delays equal to 10/8 minutes
- → Average delays remain relatively constant over the day

Delays at US Airports (EWR)



- → Delays much larger than at FRA, on average
- → Delays increase over the day due to overscheduling

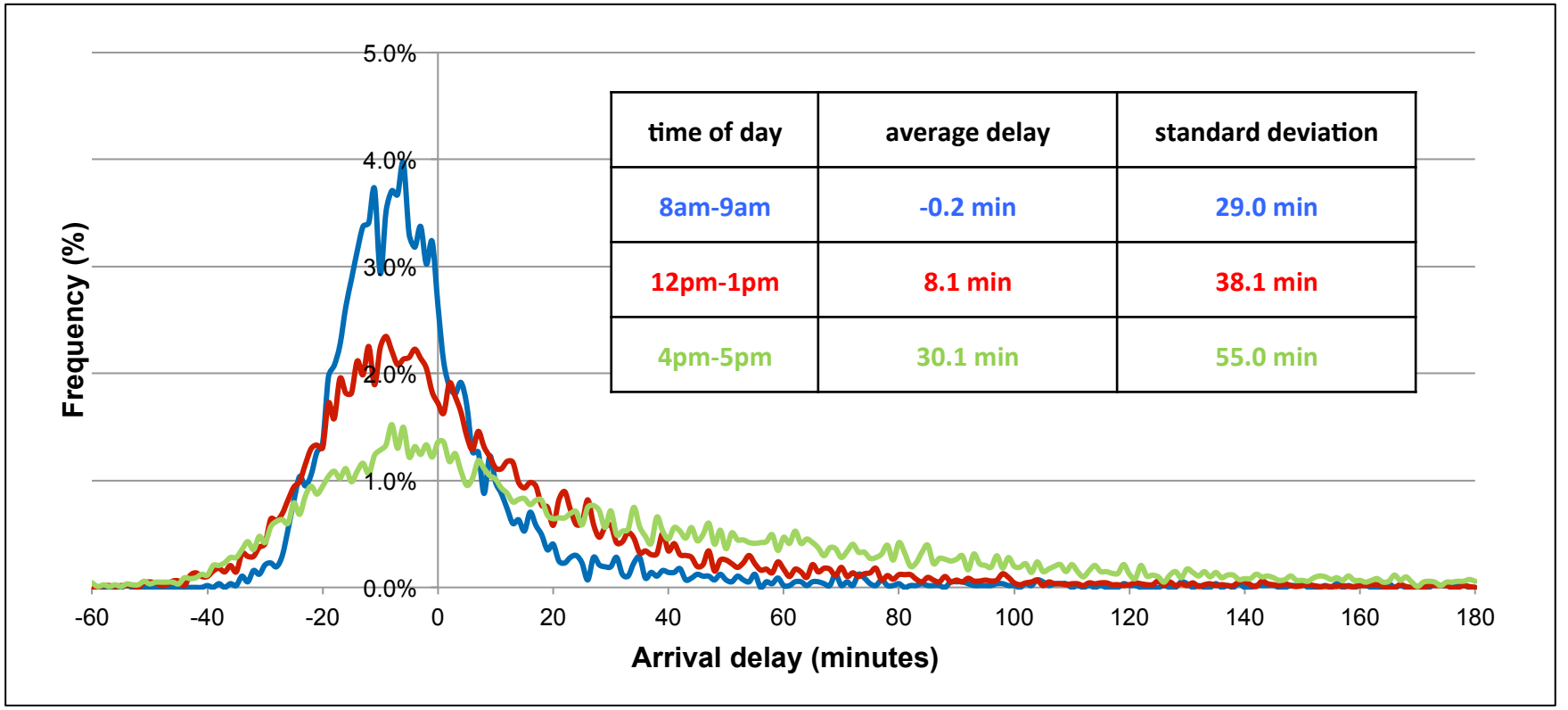
Reliability at EU Airports (FRA)



time of day	average delay	standard deviation
8am-9am	0.9 min	24.9 min
12pm-1pm	4.1 min	30.6 min
4pm-5pm	1.7 min	28.4 min
5pm-6pm	2.3 min	35.5 min

- → Similar average and variability of delays over the day
- → Schedule reliability remains constant throughout the day

Reliability at US Airports (EWR)



time of day	average delay	standard deviation
8am-9am	-0.2 min	29.0 min
12pm-1pm	8.1 min	38.1 min
4pm-5pm	30.1 min	55.0 min

- → Increase in average and variability of delays over the day
- → Schedule reliability deteriorates over the day

Takeaways (somewhat simplified)

Aspect	Europe	USA
Capacity	■ Use of IFR all the time ■ Lower throughput (may not be "pushing the envelope" at some airports?)	■ Use VFR ~80% of the time ■ **Larger throughput**
Scheduling	■ Slot control: Use of declared capacities ■ Scheduling w.r.t. IFR capacities ■ Lower scheduling levels	■ Weak scheduling constraints ■ Scheduling w.r.t. VFR capacities ■ Larger scheduling levels, with associated **economic benefits**
Delays	■ **Better on-time performance** ■ Lower delays ■ More predictable delays	■ Worse on-time performance ■ Higher delays ■ More variable delays (*e.g.*, sensitive to weather)
Overall	→ Premium on schedule reliability	→ Premium on capacity utilization

Opportunities

Throughput vs. On-time performance

- **US airports**: Demand management may be needed to avoid over-scheduling and extreme conditions
  - Hourly flight caps implemented at JFK, EWR and LGA in 2008, but loosely enforced and found too high to effectively mitigate congestion **(US DoT OIG, 2010; GAO, 2012; de Neufville & Odoni, 2013)**
- **European airports**: The approach to set declared capacities often lacks sophistication and may yield conservative results, resulting in access restrictions and capacity underutilization

→ Need for a better approach that quantifies and solves the trade-off between throughput and on-time performance

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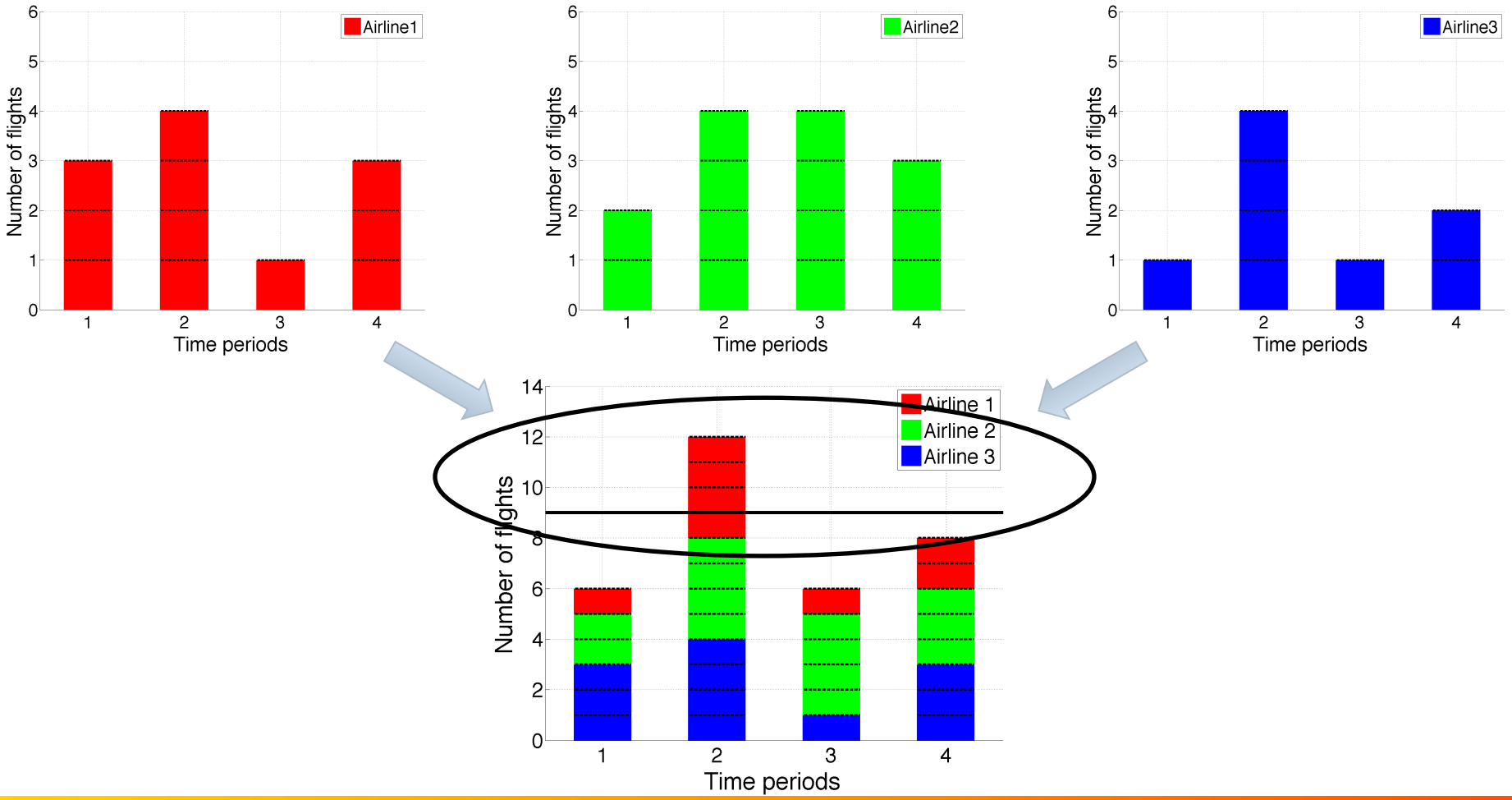
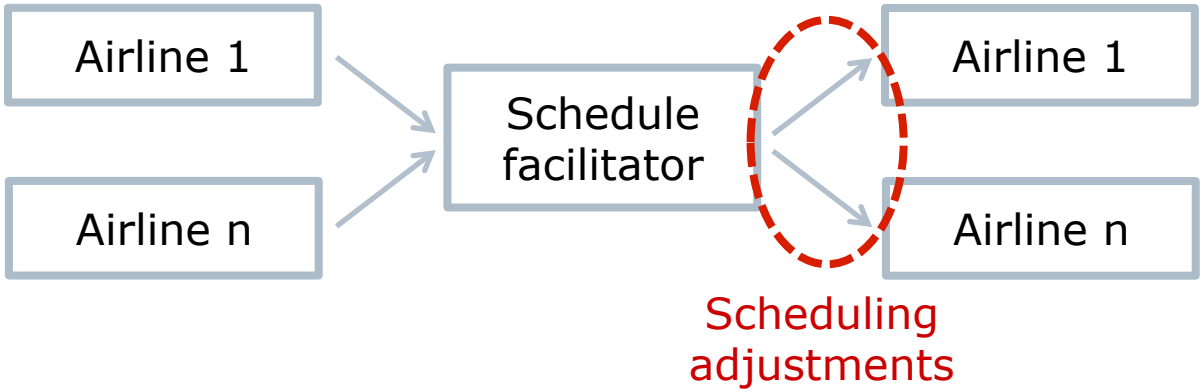
A Schematic Example



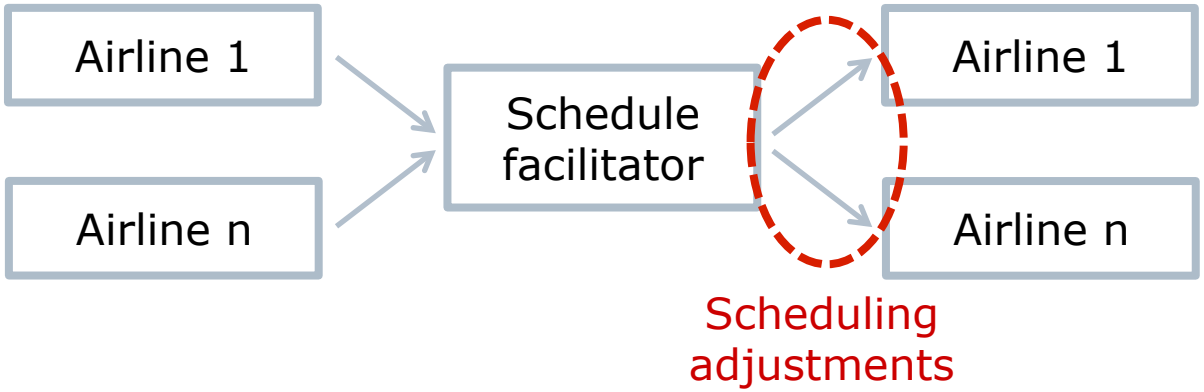
Model Presentation



- Inputs
  - Original schedule of flights on a given day
  - Estimates of airport capacity
- Objectives:
  - Reducing flight delays
  - Minimizing interference with airline scheduling and network planning

→ *Integrated Capacity Utilization and Scheduling Model (ICUSM)*

Model Presentation



minimize Schedule Displacement

subject to: Scheduling constraints

Network connectivity constraints

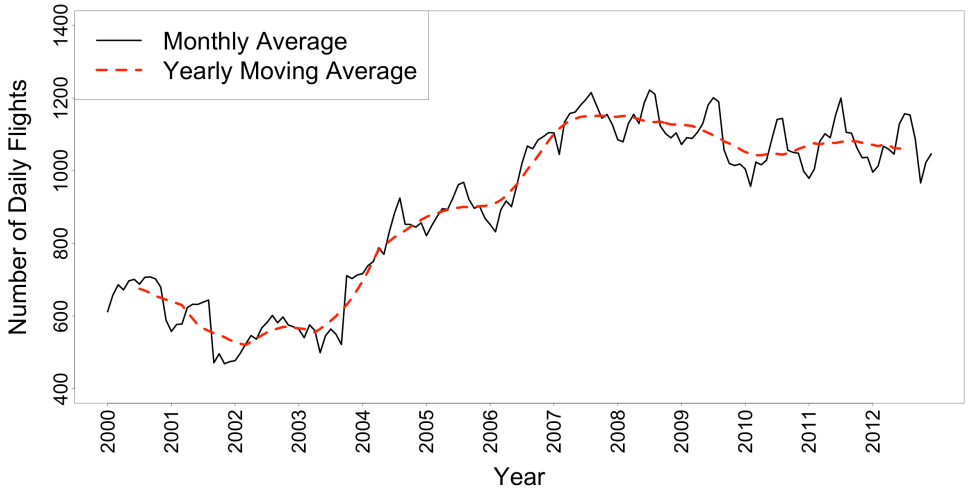
Arrival queue length lower than A_{MAX}

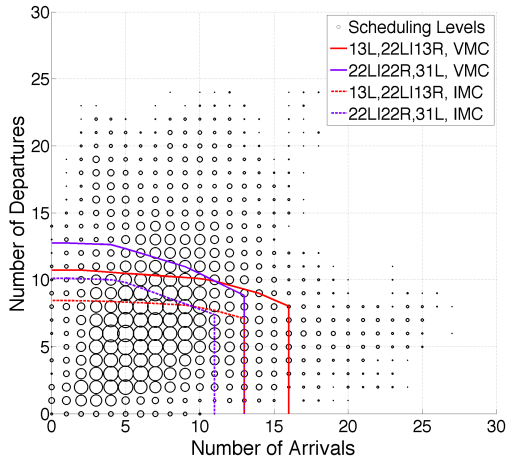
Departure queue length lower than D_{MAX}

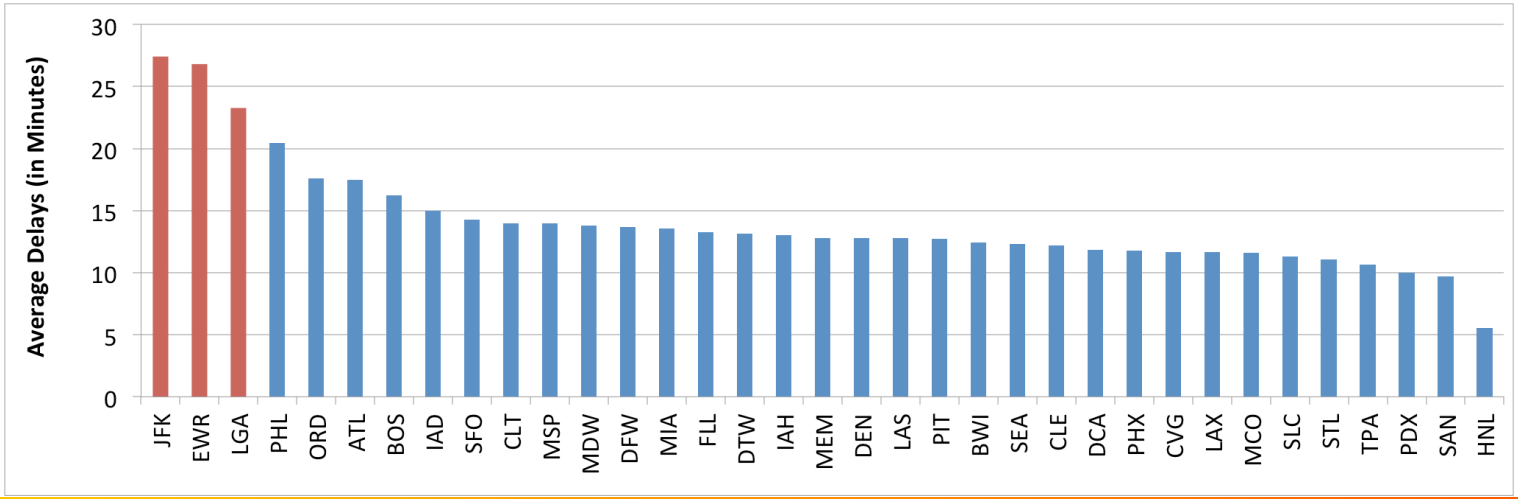
} Scheduling framework

} Model of airport operations

Experimental Setup: JFK Airport

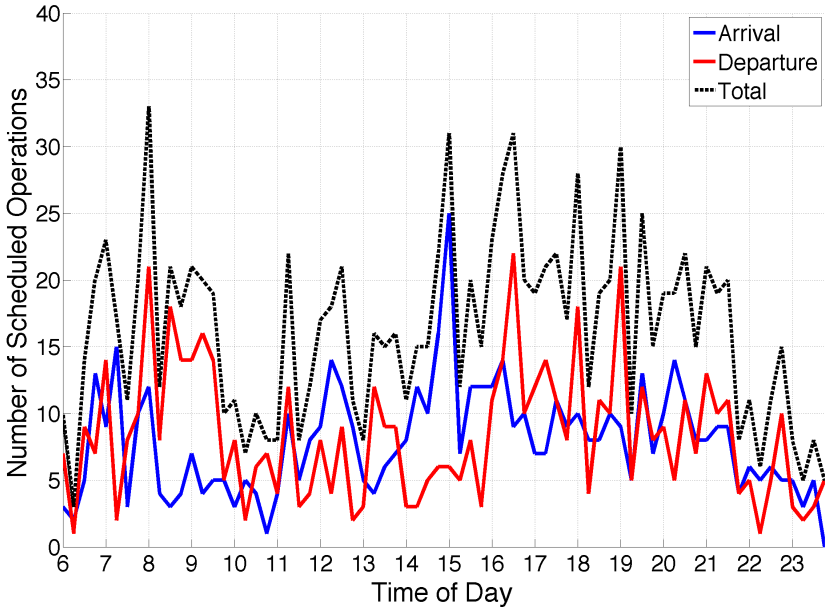




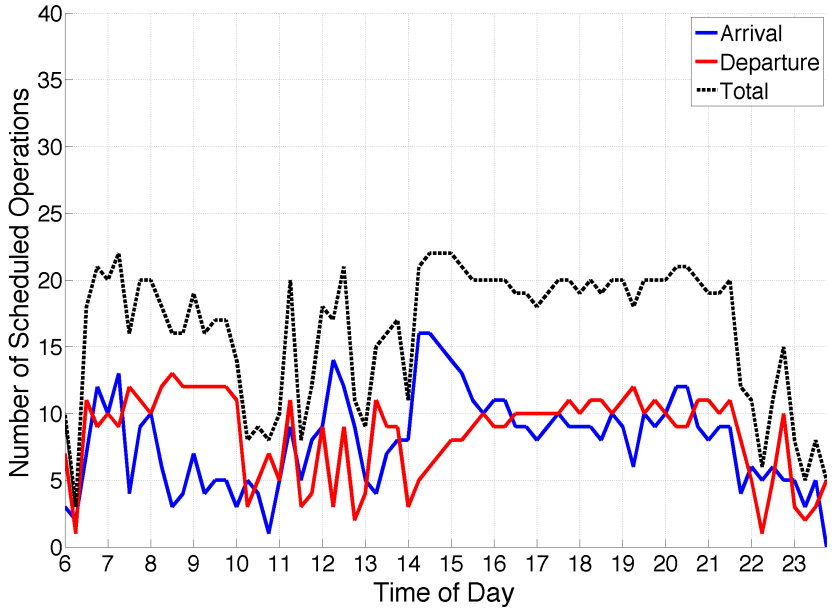


Effect on Flight Schedules

- Smoothing of flight schedules
- Nonetheless, peaks and valleys in the optimal schedule
- Optimal tradeoff: delay reduction vs. scheduling preferences

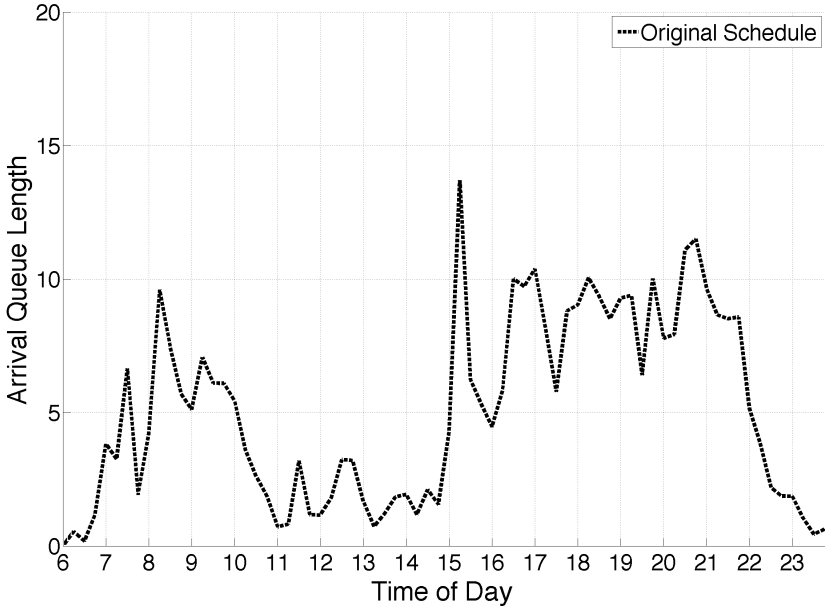


Original Schedule on 05/25/2007

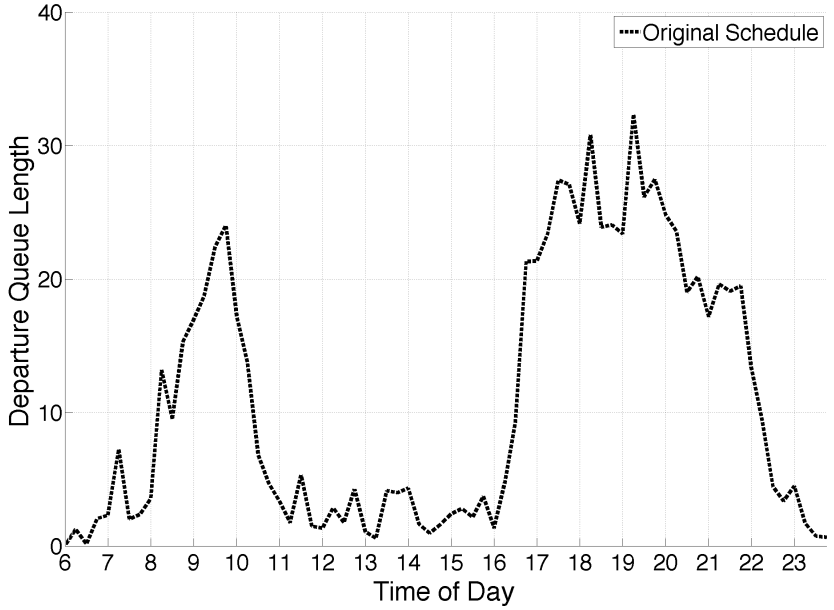


Modified Schedule on 05/25/2007

Implementation Results



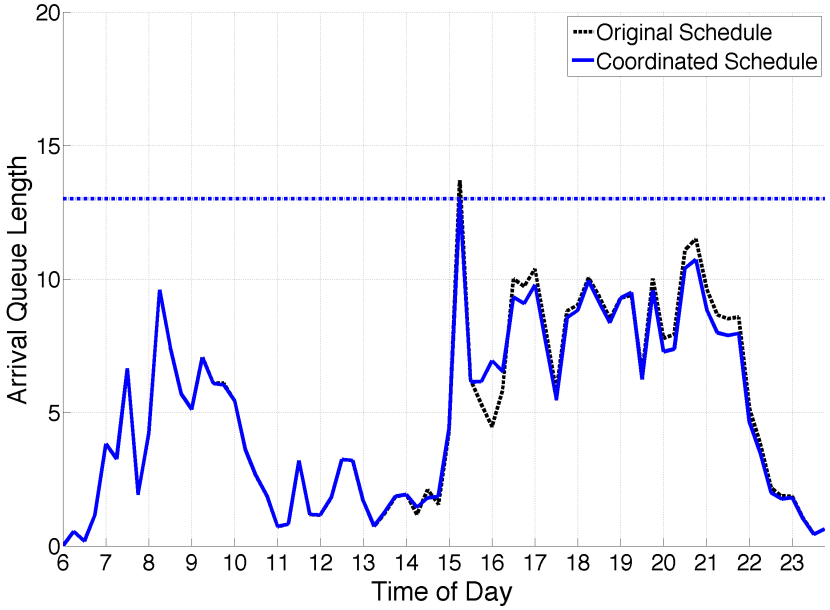
Arrival Queue



Departure Queue

A_{MAX}	D_{MAX}	Max. Disp.	Total Disp.
∞	∞	0	0

Implementation Results



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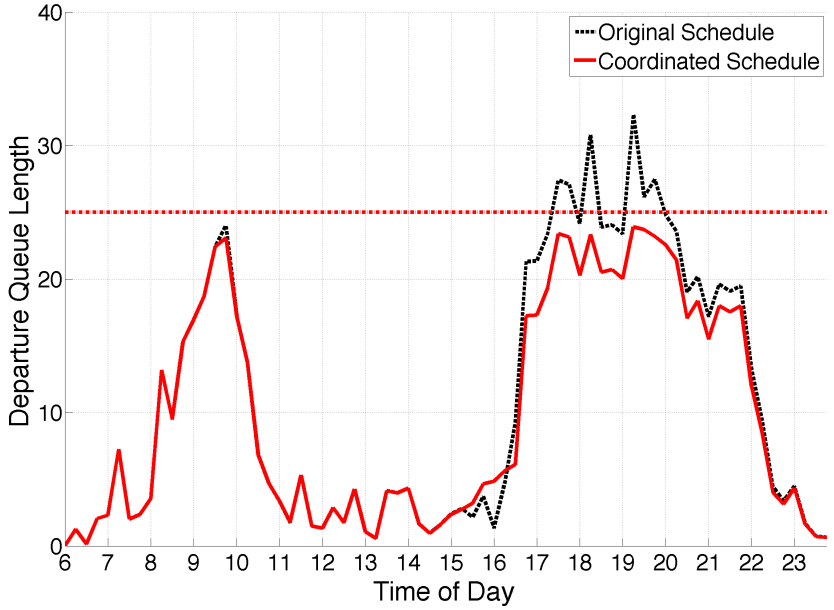
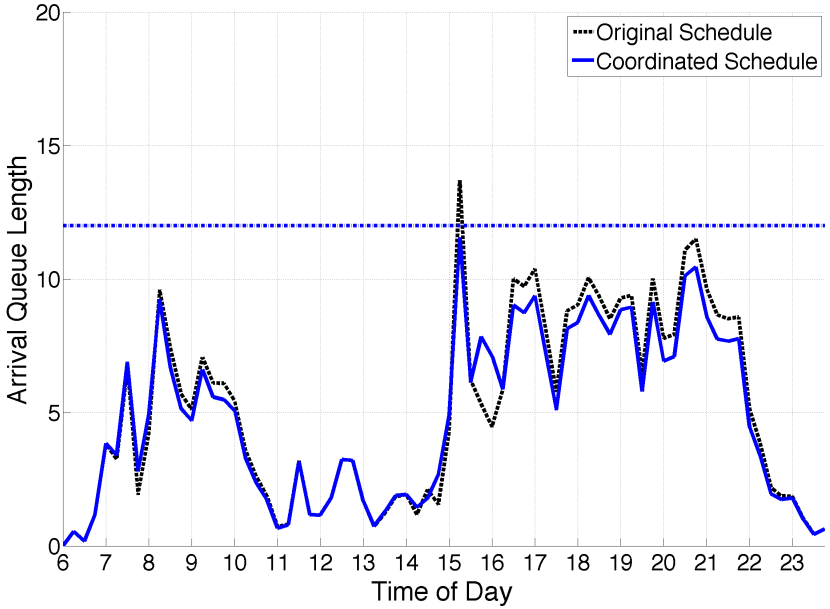


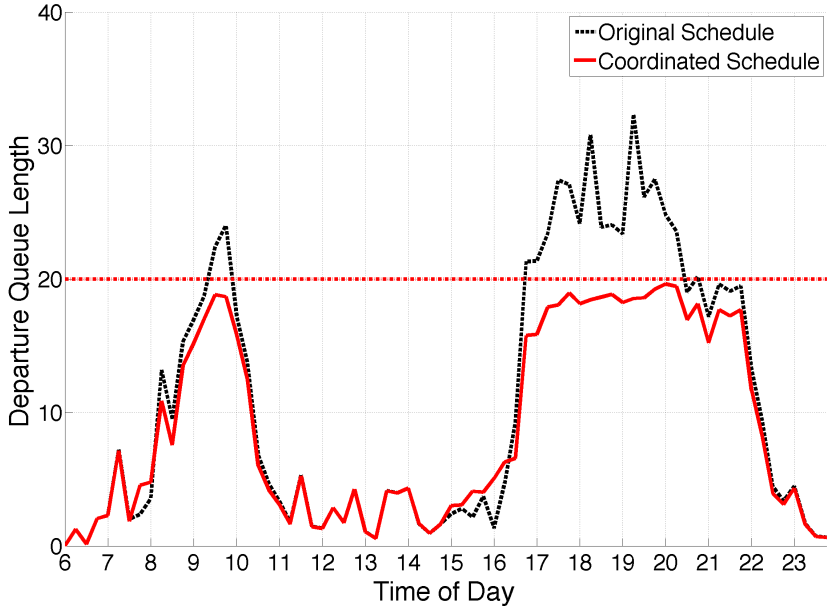
Departure Queue

A_{MAX}	D_{MAX}	Max. Disp.	Total Disp.
∞	∞	0	0
13	25	1	37

Implementation Results



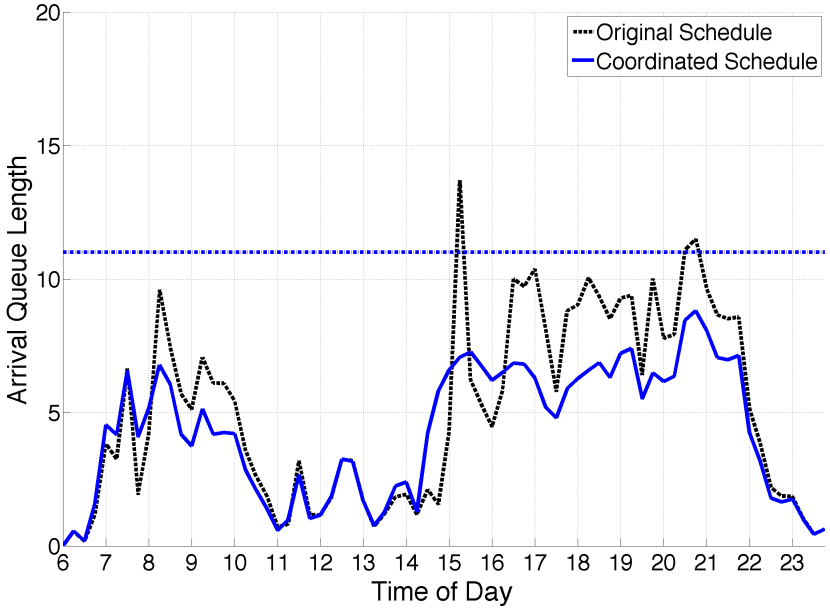
Arrival Queue



Departure Queue

A_{MAX}	D_{MAX}	Max. Disp.	Total Disp.
∞	∞	0	0
13	25	1	37
→ 12	20	1	105

Implementation Results



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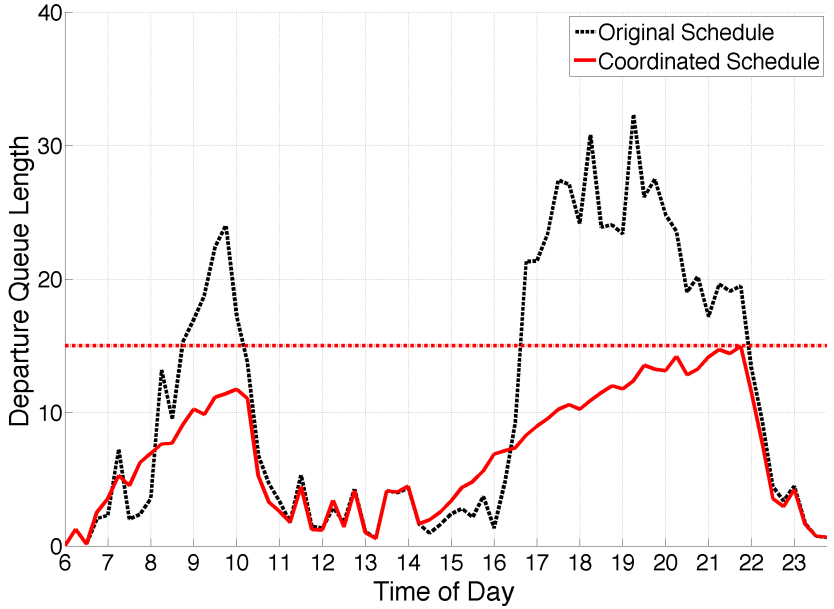
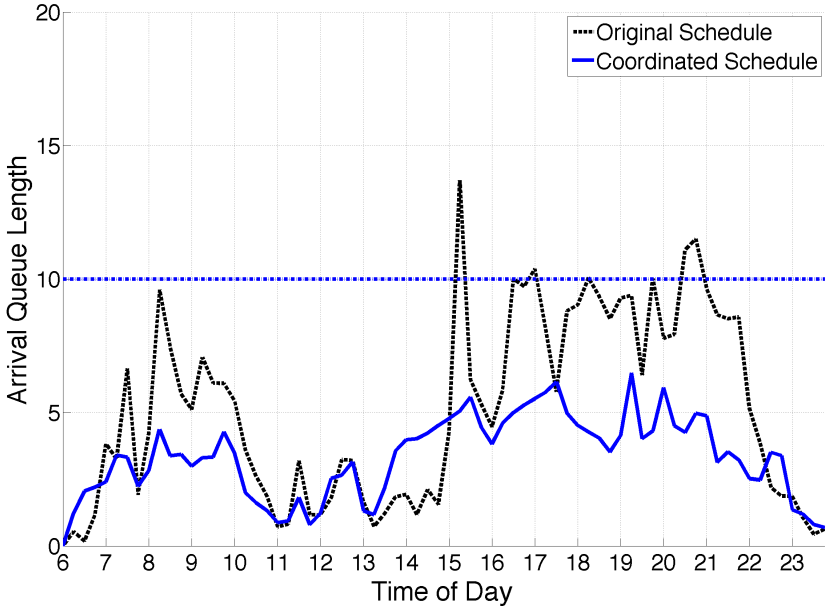


Departure Queue

A_{MAX}	D_{MAX}	Max. Disp.	Total Disp.
∞	∞	0	0
13	25	1	37
12	20	1	105
11	15	2	356

Implementation Results



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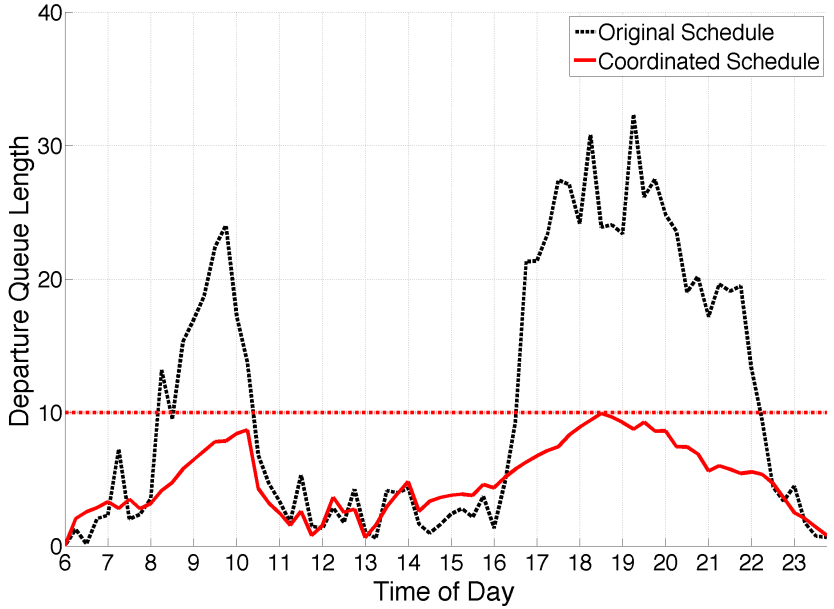
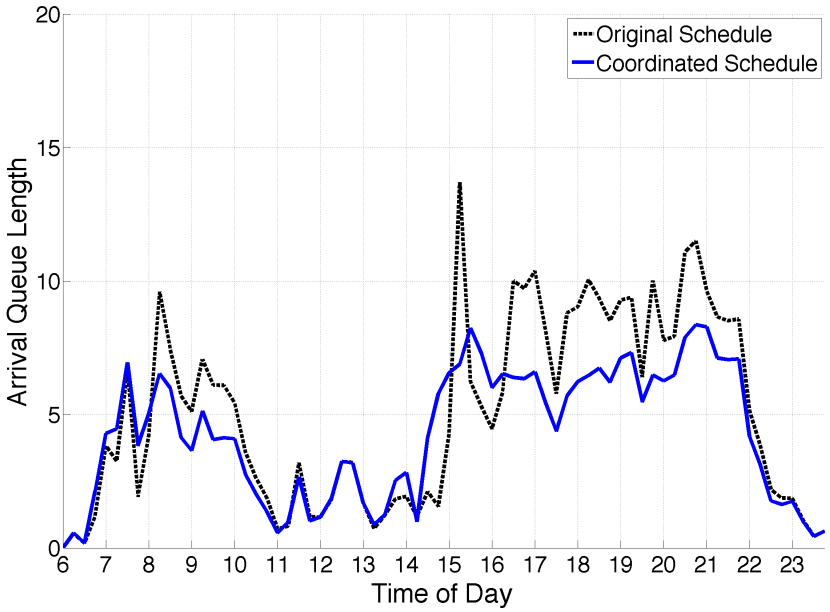


Departure Queue

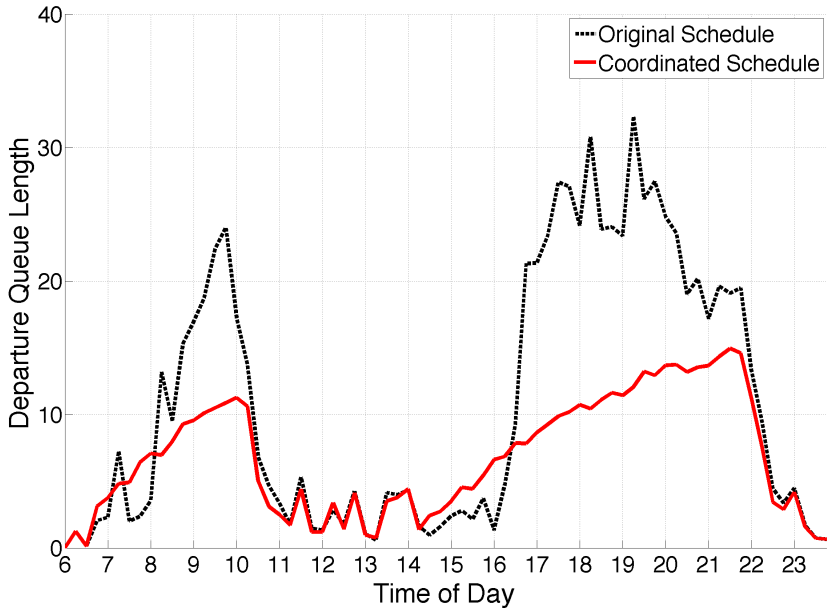
A_{MAX}	D_{MAX}	Max. Disp.	Total Disp.
∞	∞	0	0
13	25	1	37
12	20	1	105
11	15	2	356
10	10	2	1,129

Takeaways

- At US airports, large delay reductions may be possible
  - Peak arrival / departure delays reduced by ~ 35% / 55%
  - Average arrival / departure delays reduced by ~ 20% / 40%



Arrival Queue



Departure Queue

Takeaways

- At US airports, large delay reductions may be possible
  - Peak arrival / departure delays reduced by ~ 35% / 55%
  - Average arrival / departure delays reduced by ~ 20% / 40%
- … through limited changes in airline schedules:
  - No flight eliminated, all aircraft, passenger connections maintained
  - ~ 80% of the flights to / from JFK not displaced
  - No flight displaced by more than 30 minutes
- Optimal demand profiles may not be "flat", and depend on airline scheduling preferences
- The model presented here provides a flexible methodology to design scheduling mechanisms at busy airports, while accounting for practical and institutional constraints

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→ Opportunities for improvements in scheduling practices

Opportunities for Improvement

Throughput vs. On-time performance

- **US airports**: Design of a scheduling mechanism that introduces "marginal" adjustments to flight schedules
  - Capitalizes on the nonlinear relationship between scheduling and delays
  - Provides the airlines with scheduling flexibility (as currently practiced)
  - Enables collaboration between the airlines and the schedule facilitators
- **European airports**: Opportunity for a more flexible approach to coordinate flight schedules
  - Optimal schedule may not be "flat"; exclusive reliance on declared capacity may not be optimal
  - Schedule determination depends on airline scheduling preferences; data exchange would enhance schedule coordination/facilitation processes

Thank you!

Questions?