ActionWebs and Air Transportation

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Next Generation Air Transportation Systems

- Air transport is a key factor in global travel and commerce
  - 600M passengers/year in the US
  - 35,000+ commercial flights/day in the US
  - US traffic expected to grow ~2-3x by 2025 (rel. to 2004)
- NextGen is the "Next Generation Air Transportation System"
- Objectives:
  - **Expanding capacity**
  - **Ensuring safety**
  - **Protecting the environment**
  - Retaining US leadership in global aviation
  - Ensuring national defense and securing the nation

[www.jpdo.aero]

Problem: Taxi-out Fuel Burn and Emissions

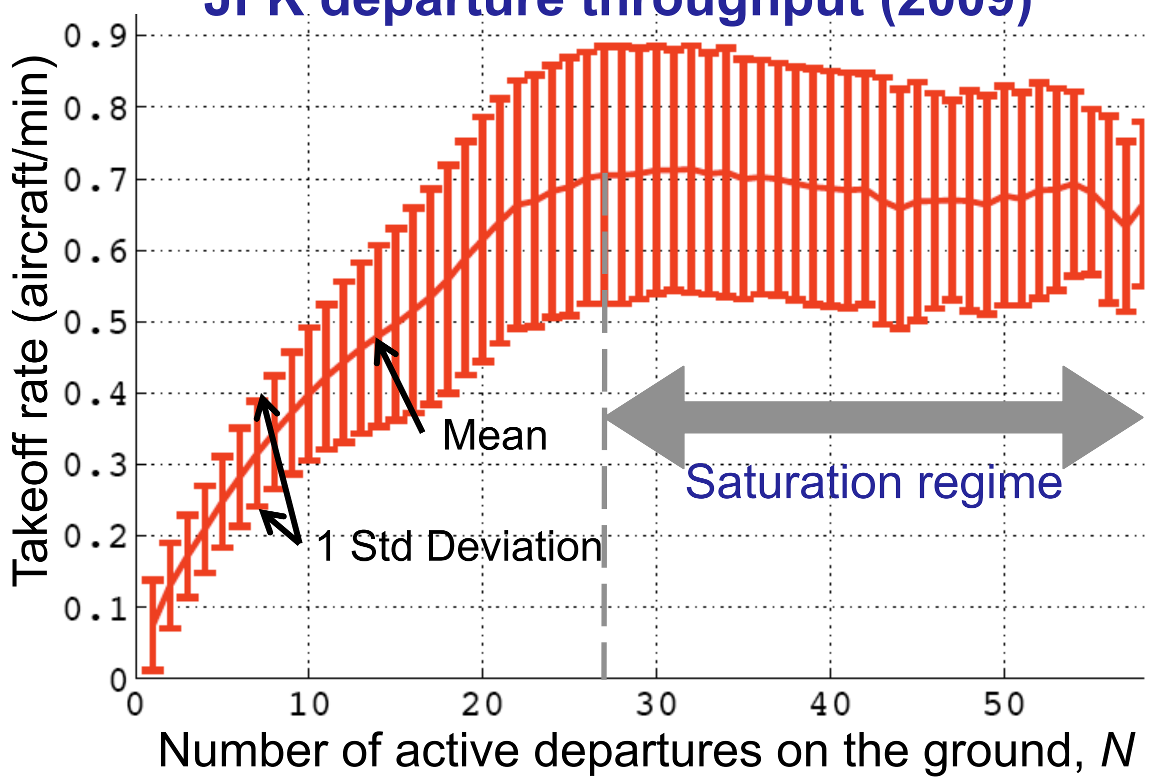
- Congestion leads to increased taxi times, fuel burn and emissions
- Annually, at major airports in the United States
  - Over 32M minutes taxi-out delays (over unimpeded times)
  - Over 13M minutes taxi-in delays (over unimpeded times)
  - 600M gallons of jet fuel expended in taxi-out process
  - Taxiing aircraft contribute to noise and surface emissions, e.g. CO_2, NOx, SOx, CO, HC, and Particulate Matter
  - 6M metric tons of CO_2 emissions due to taxi-out processes

[Joint work with Ioannis Simaiakis, Harshad Khadilkar, Tom Reynolds and John Hansman]

Main Culprit: Surface Congestion

- Major airports are frequently severely congested, resulting in large taxi-out delays and inefficient operations

JFK departure throughput (2009)



When JFK is saturated:

In Visual Meteorological Conditions, the average taxi-out time is **56 min**

In Instrument Met. Conditions, the average taxi-out time is **69 min**

Unimpeded taxi-out time: **16-19 min**

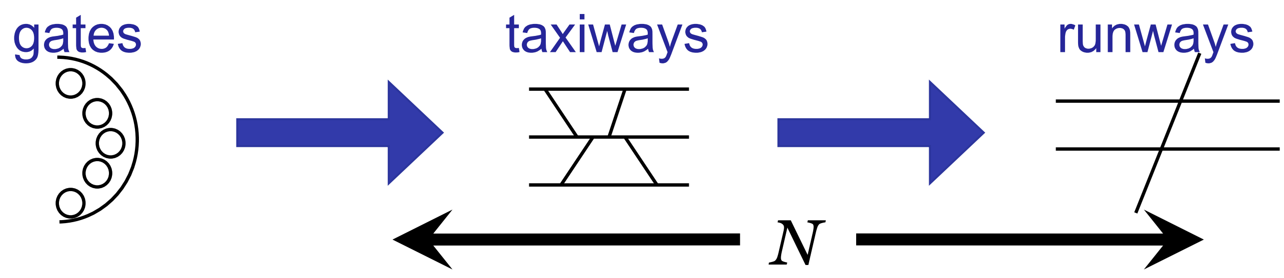
JFK is saturated 18% of the time in VMC, and 24% of the time in IMC

32% of departures at JFK takeoff during saturated periods

Simaiakis and Balakrishnan, *Transp. Res. Record: Jour. of the Transp. Res. Board*, 2010 (Confirms Pujet, Delcaire and Feron, BOS 1999).

Our Solution: Pushback Rate Control

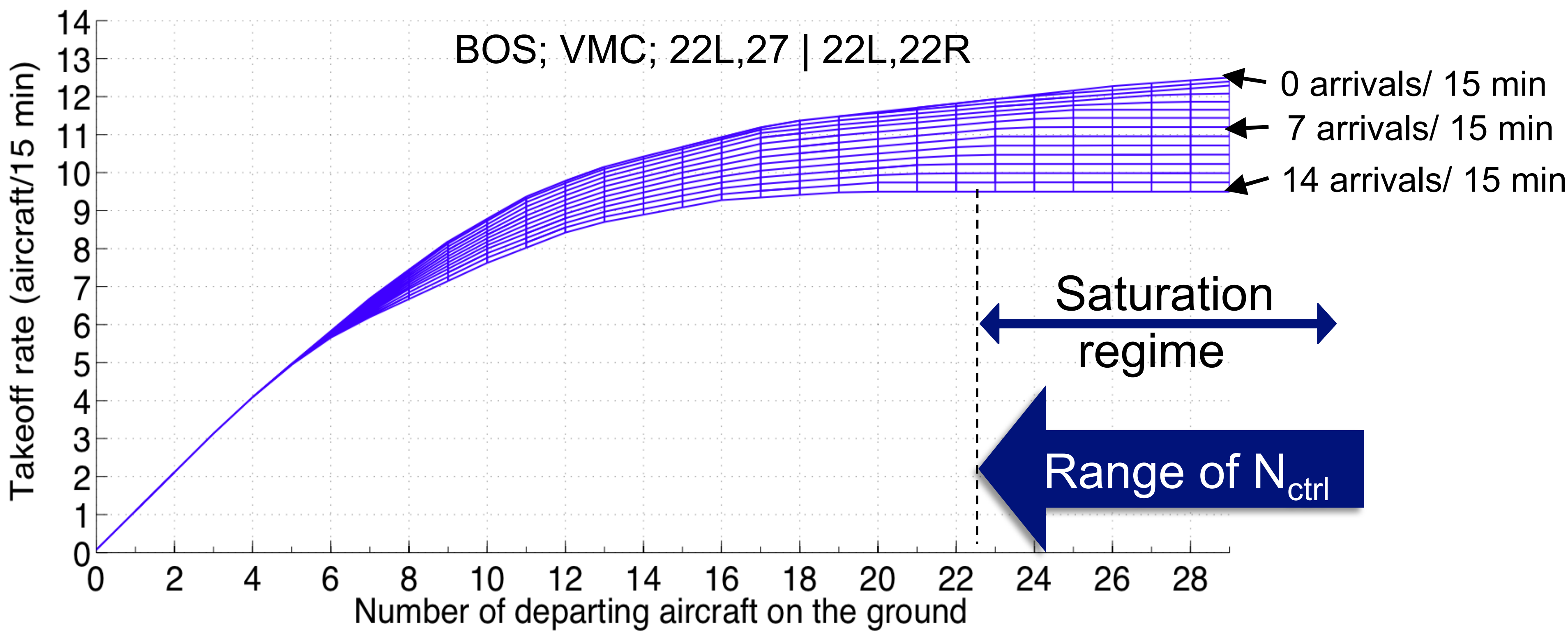
- Aircraft pushback from gates, start their engines, and then taxi until they takeoff



- Want to control pushbacks to keep N close to target value, N_{ctrl}
- Challenges:
  - How do we choose N_{ctrl}?
  - How do we implement control strategy?
  - How do we interface with the human controllers?

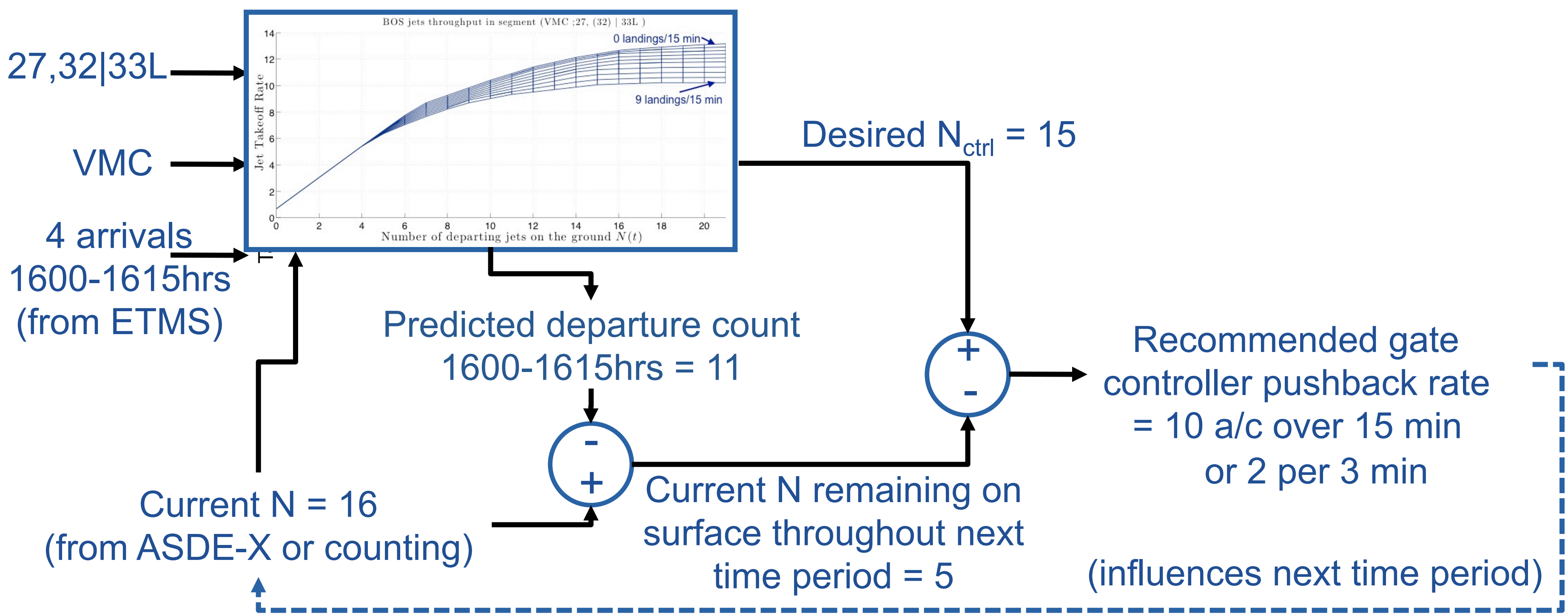
Choosing N_{ctrl}

- Departure runway throughput saturates when number of aircraft pushed back (denoted N) exceeds a certain value
- Estimation of N_{ctrl} and departure capacity under different conditions using historical data



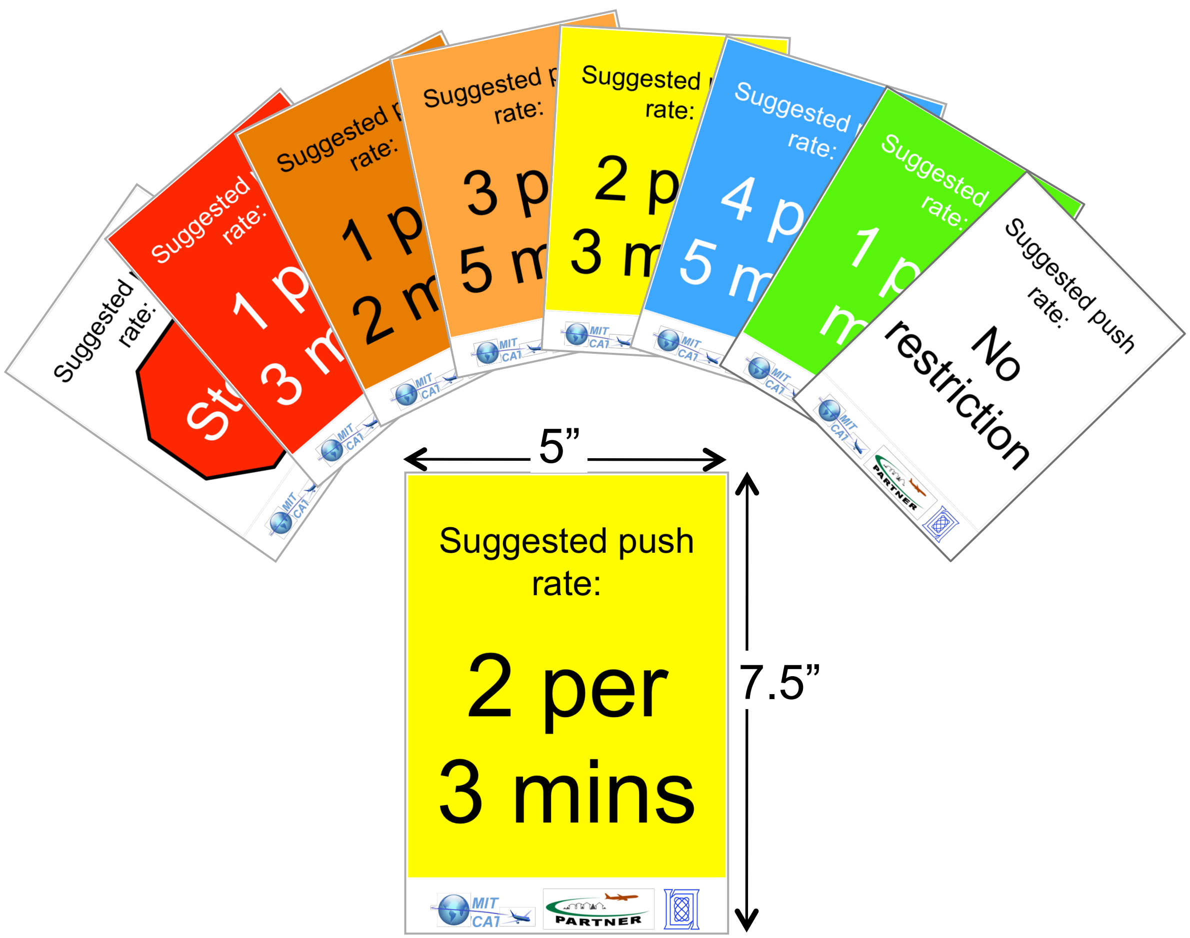
Implementing Control Strategy

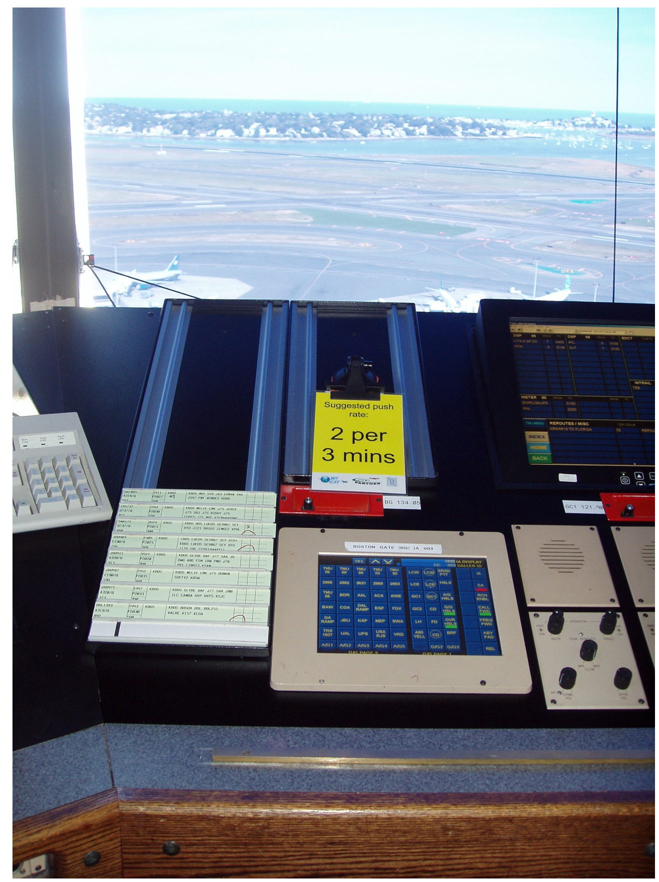
- On-off control does not work
  - Air traffic controllers are humans, not automata
  - Rather than release an aircraft every time that a flight takes off, controllers prefer a rate at which to let aircraft pushback from their gates
  - Rate is updated periodically



Interfacing with Human Controllers

- Suggest pushback rates using color-coded cards
- No verbal communications





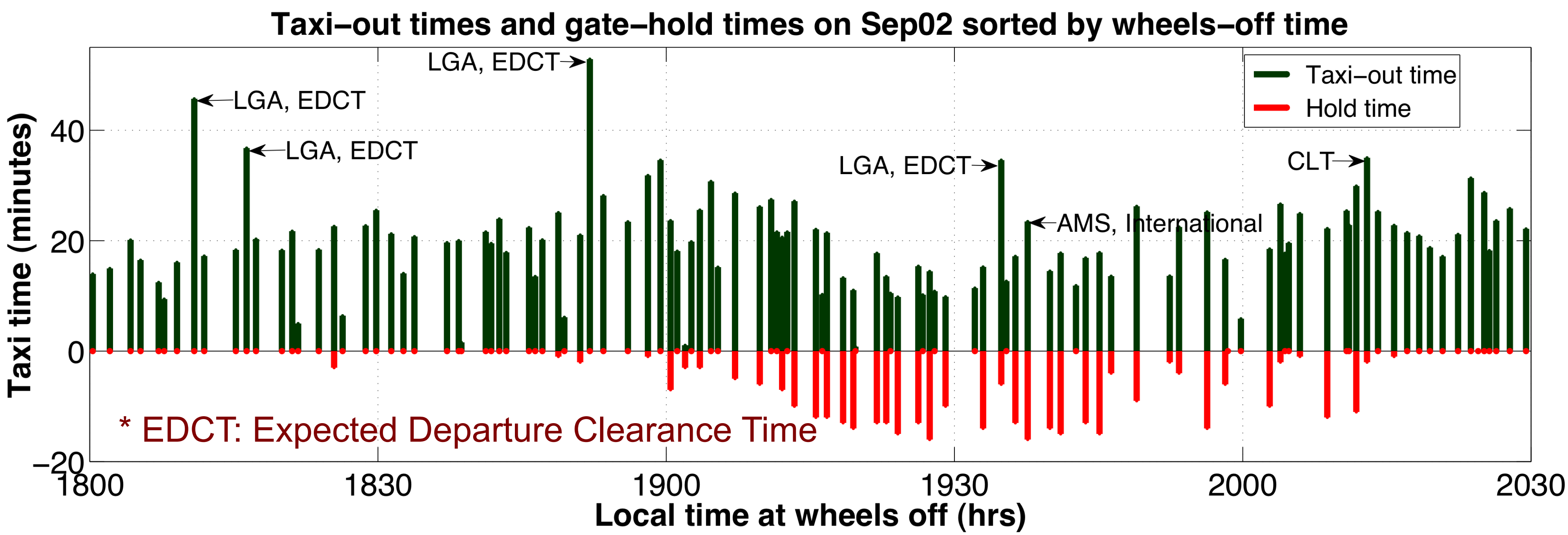
BOS Field Tests in 2010

- Aug 23 - Sept 24, 2010
- 4PM-8PM departure push
- 247 flights held at gate
- Average gate-hold: 4.3 min
- 13-16 tons (4,000-4,700 US gal) reduction in fuel burn
- 44-60 kg decrease in fuel burn / gate-held flight
- 43-51 tons of CO_2 emissions reduction
- Fair distribution of benefits among airlines

Number of Gate-holds	Average gate-hold (min)	Total taxi time savings (min)
63	4.06	257
34	3.24	114
8	4.75	38
45	8.33	295
19	2.21	42
11	2.09	23
11	2.18	24
56	3.70	210
247	**4.35 min**	1003 min **(16.7 hrs)**

[Supported by the FAA]

Gate-Holds from a Sample Demo Period



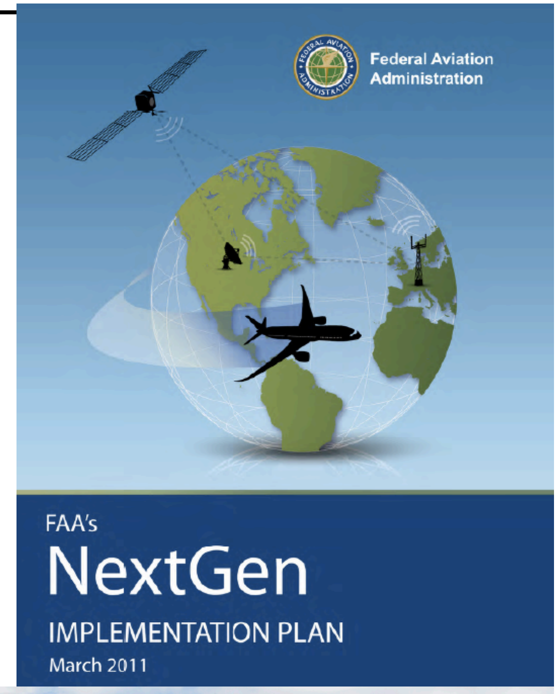
- Maintained runway utilization during metering: 3 min of "dry runway" in > 35 hours of active rate control of pushbacks
- Simulations also show that gate-hold times translate to taxi-out time reduction to first order
- Second-order benefits due to fewer acceleration events

[Simaiakis et al., USA/Europe Air Traffic Management R&D Seminar 2011]

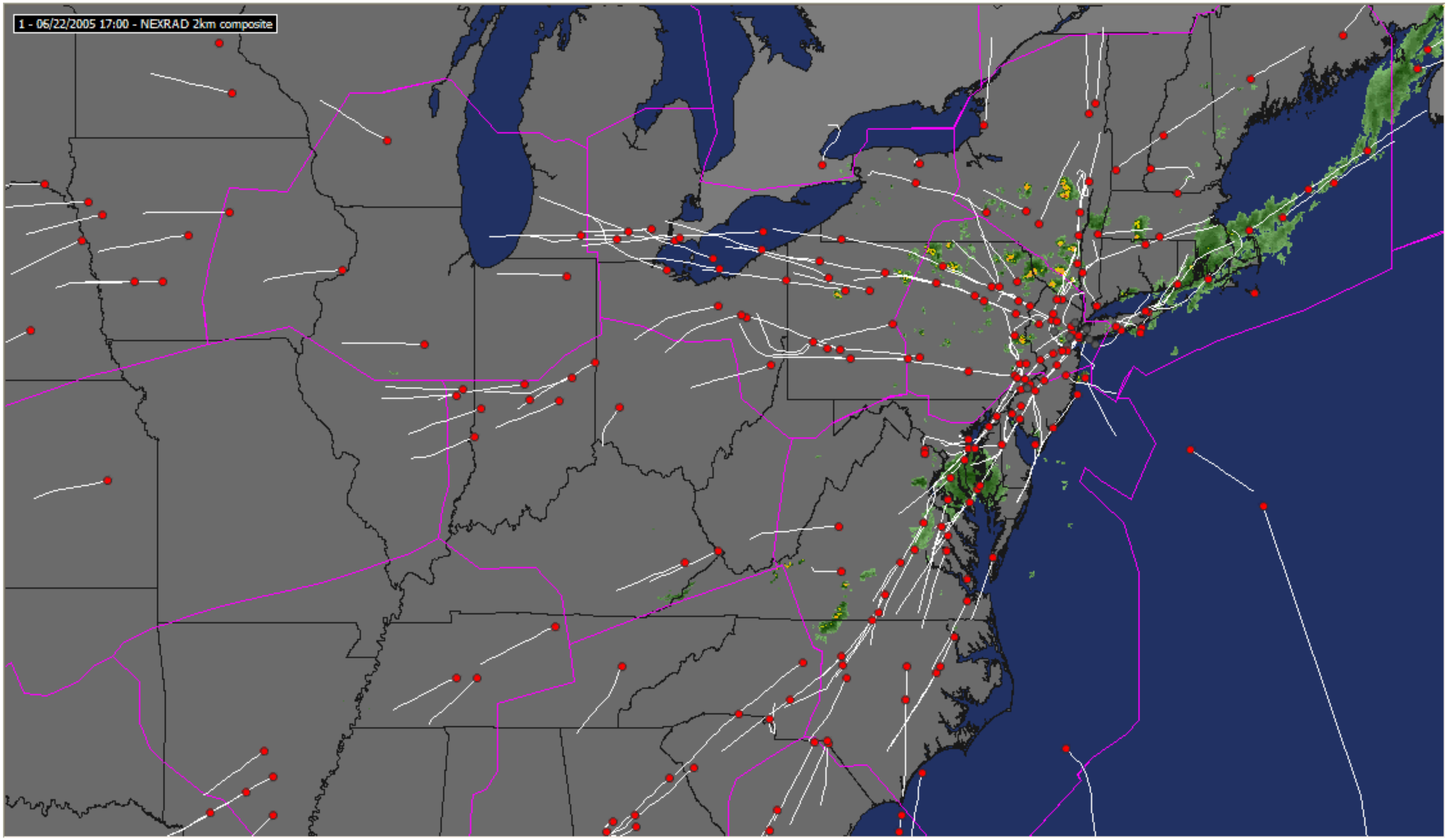
Playback of Surface Surveillance Data

Current Status

- Promising results from 2010 demo
- Featured in the FAA's NextGen Implementation Plan (March 2011)
  - "…meant for business-as-usual situations, too."
  - "…meant to be a relatively simple, low-cost program for airports…"
- Ongoing follow-up tests at BOS
  - Focus on convective weather
  - Control strategy refinement
  - Investigate deployment



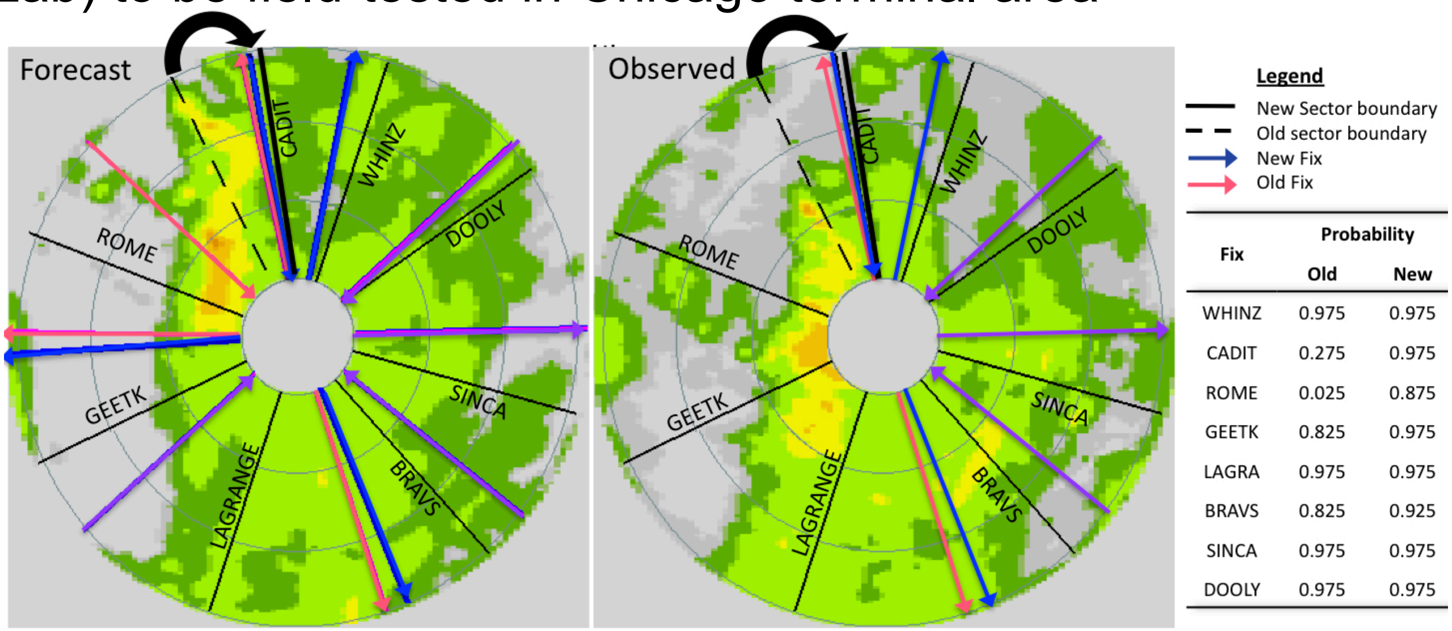
Need for Optimization under Uncertainty



[Visualization courtesy MIT Lincoln Laboratory]

Identifying Robust Routes in Convective Weather

- Given a deterministic weather forecasts and candidate routes, find probabilistic forecasts of routes likely to remain clear of weather
- Simulations with real weather scenarios show that 13% more routes open up, and error rates – i.e., a suggested alternate route is blocked – are low (<5%)
- Next steps: Prototype implementation (in collaboration with Lincoln Lab) to be field-tested in Chicago terminal area

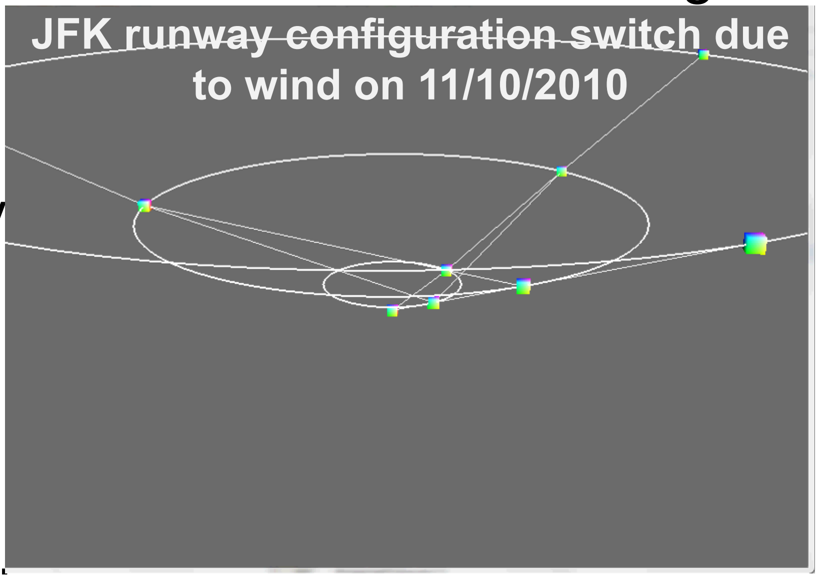


Fix	Probability	
	Old	New
WHINZ	0.975	0.975
CADIT	0.275	0.975
ROME	0.025	0.875
GEETK	0.825	0.975
LAGRA	0.975	0.975
BRAVS	0.825	0.925
SINCA	0.975	0.975
DOOLY	0.975	0.975

[Pfeil and Balakrishnan. IEEE Conference on Decision and Control 2010
Pfeil and Balakrishnan. *Transportation Science*. In press]

Optimization of Runway Configuration Changes

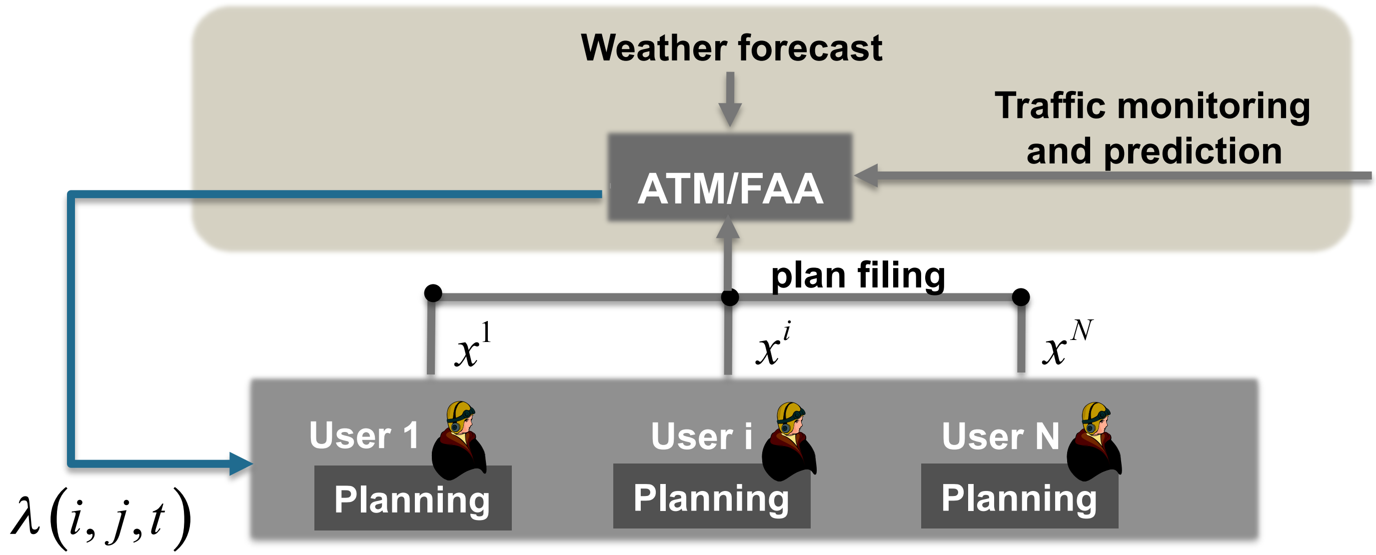
- Runway configuration (which runways are used for which operations) is a key driver of airport capacity
- Wind direction, speed determine feasible configurations
  - Can necessitate configuration switches
- Problem: How do we optimally coordinate arrival flows during configuration switches?
- Approach:
  - Model changing constraints by different "graph modes"
  - Weather forecast determines graph mode
  - Mixed Integer Linear Program for aircraft control and separation



[Maryam Kamgarpour, Wei Zhang and Claire Tomlin]

[Kamgarpour, Zhang, Tomlin, Proceedings of AIAA GNC 2011]

Hierarchical, Decentralized Trajectory Planning

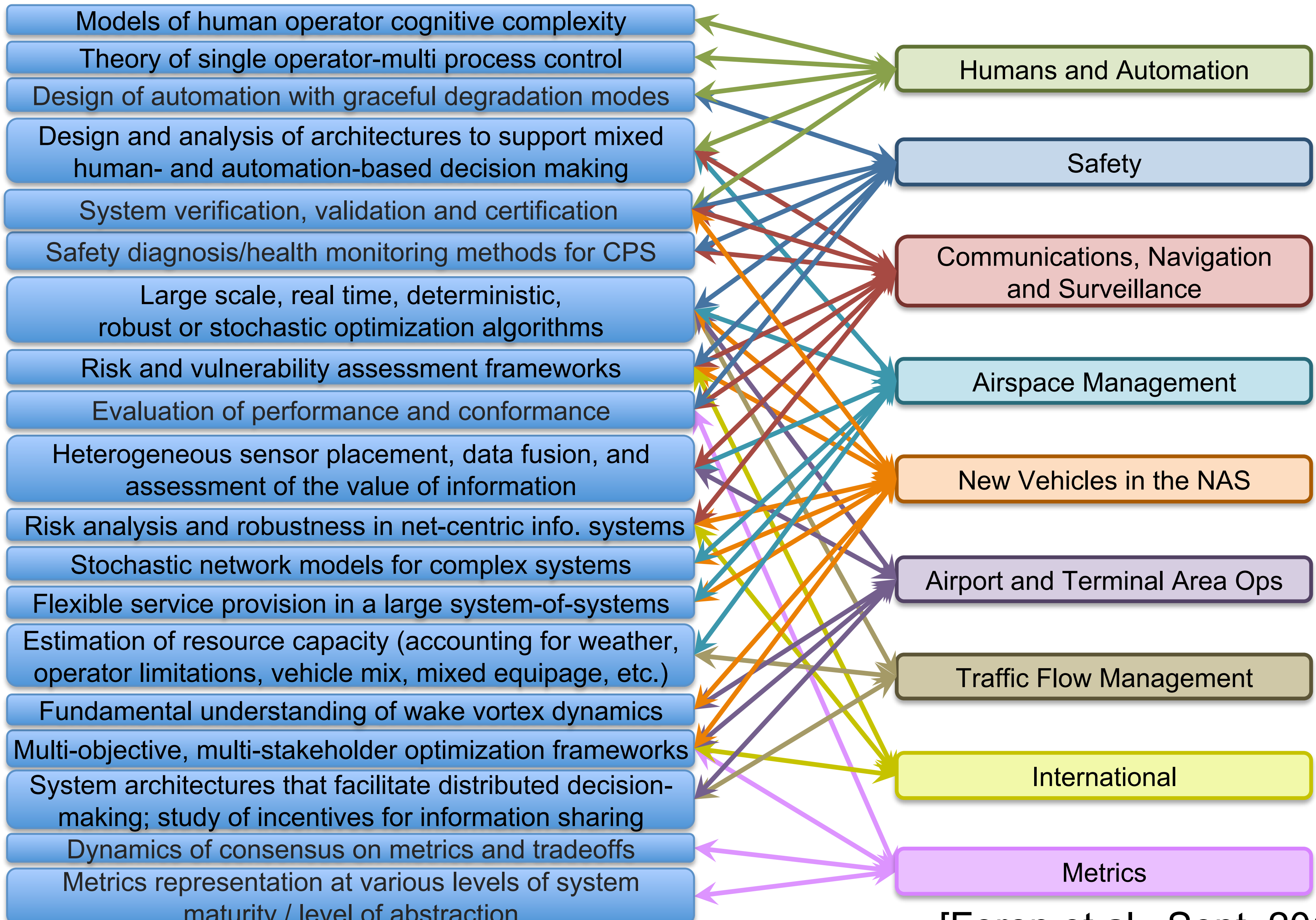


- Hierarchical Decentralized Flight 4D Trajectory Planning
  - Based on dual decomposition
  - Minimizes individual decentralized costs subject to centralized regulation rules
  - Incorporates user preferences
  - Guarantees safety
  - Low complexity: allows the legacy system to transform gradually

[Wei Zhang, Maryam Kamgarpour and Claire Tomlin]

[Zhang, Kamgarpour, Sun, and Tomlin, to appear in *Proceedings of the IEEE*]

NextGen CPS Challenges



[Feron et al., Sept. 2010]

ActionWebs CPS Themes

- Balakrishnan, Culler, Lee, Sastry and Tomlin (PI)
- *Foundations*
  - Model identification and estimation
    - Architectures and abstractions for CPS
    - Augmenting physics-based models with real data
  - Interplay between control and sensing
  - Algorithms for distributed and decentralized optimization
  - Hierarchical optimization vs. blending multiple objectives
  - Verification and validation of control protocols
- *Components, Run-time Substrates and Systems*
  - Energy-efficient, high-productivity buildings
  - Energy-efficient air transportation systems

Summary

- Next Generation Air Transportation System (NextGen) presents many important challenges that require the development and use of CPS methodologies
- ActionWebs addresses these challenges by developing necessary CPS methodologies
- Focus on two “grand-challenge” test-beds:
  - Energy-efficient, high-productivity buildings
  - Energy-efficient air transportation systems
- Solutions have the potential to increase NextGen system efficiency (reduce delays), robustness (reduce impact of weather disruptions) and energy efficiency (reduce fuel burn), and decrease environmental impact