A Networks Perspective of Air Traffic Delays

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Introduction: Air Transportation System

- Complex interconnected system
- Delays can spread through the entire system
- 22% of the flights in 2015 were delayed by more than 15 min
- 40% of these delays were due to late arrival of incoming aircraft

Aim: Understand Delay Dynamics on Networks

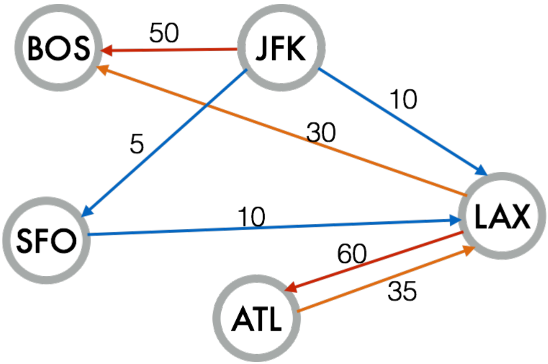
Motivation:

- Which airports have persistent delays?
- What is the susceptibility of an airport to delays from others?

Outline:

1. Representing the state of delay by a network
2. Identify characteristic patterns and model their evolution
3. Metrics for resilience

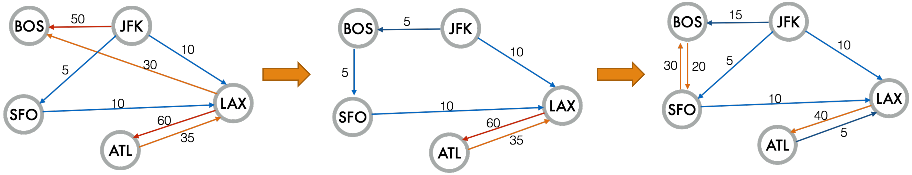
Delay Network



- Edge weights: Median delay on that link
- Total inbound delay at LAX $= 10 + 10 + 35 = 55$ min/flt
- Total outbound delay at LAX $= 60 + 30 = 90$ min/flt

Time series of Delay Network

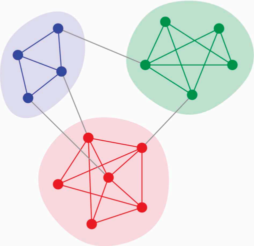
- Delay networks evolve in time
- Data: Bureau of Transportation Statistics (2011-12)
  - 158 airports
  - $\sim$ 1100 edges
  - $\sim$ 17,000 networks for 2 years



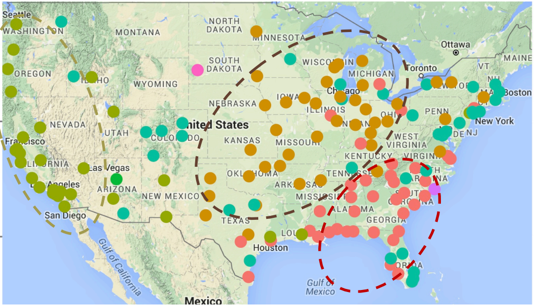
t_1 t_2 t_3

Insights from delay networks:
1. Community structure

Airports that form a community have high delay between them

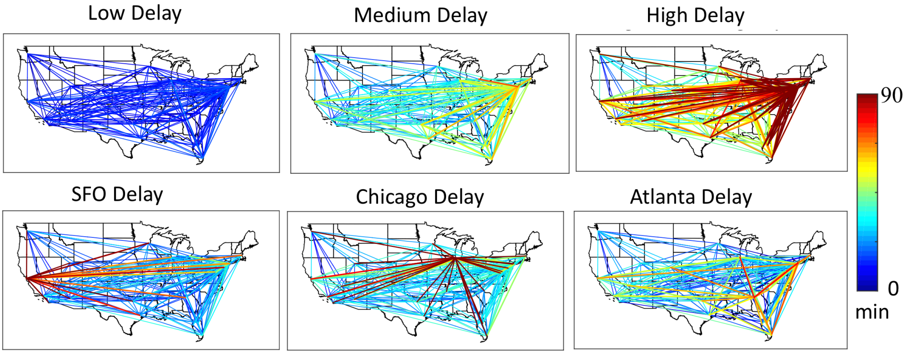


Example of community structure



Community structure for delay network (23 March 2011)

Insights from delay networks:
2. Characteristic delay states

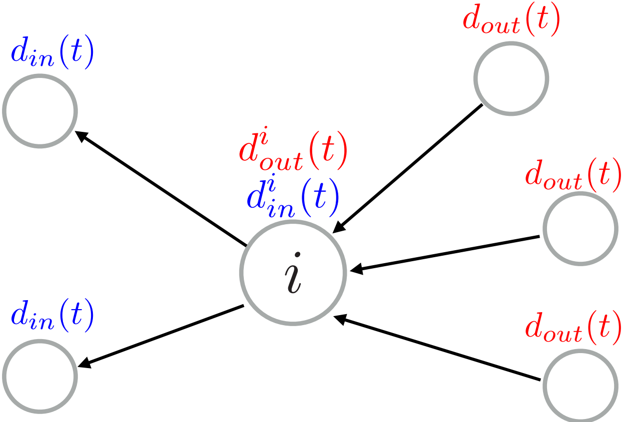


- These are the typical delay patterns seen in the US airspace

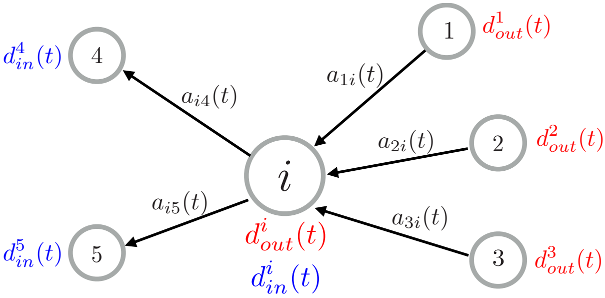
Model for evolution of airport delay

Features of airport delay:

- Delays at an airport tend to persist
- Delays at an airport depend on connectivity



Airport delay dynamics



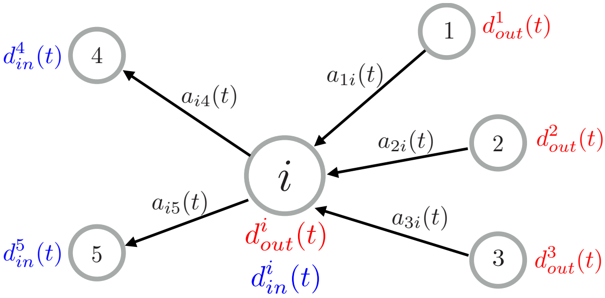
Network structure

$$A(t) = [a_{ij}(t)]$$

$$d^i_{in}(t+1) = \underbrace{\alpha^i_{in} d^i_{in}(t)}_{} + \sum_j \underbrace{\beta^{in}_{ji} \bar{a}_{ji}(t) d^j_{out}(t)}_{}$$

$$d^i_{out}(t+1) = \underbrace{\alpha^i_{out} d^i_{out}(t)}_{\text{Persistence}} + \sum_j \underbrace{\beta^{out}_{ij} \bar{a}_{ij}(t) d^j_{in}(t)}_{\text{Network effect}}$$

Airport delay dynamics



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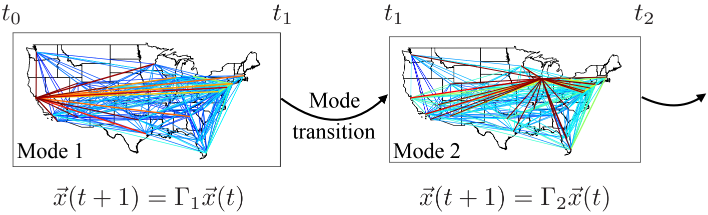
Delay propagation model

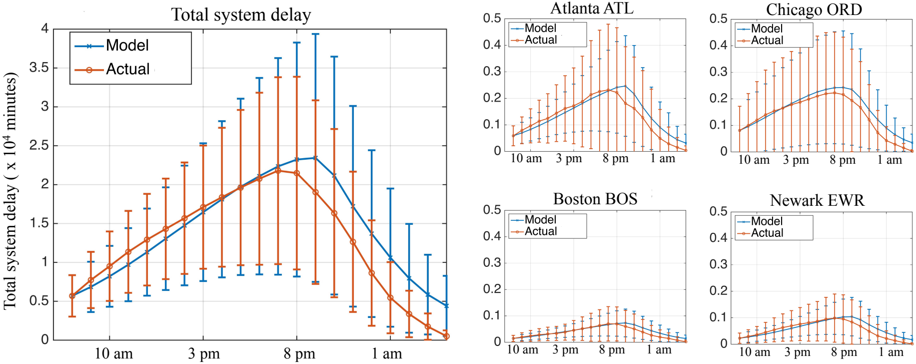
- Instead of $A(t)$, use the discrete networks from clustering



- Delay evolution within discrete mode: $\vec{x}(t+1) = \Gamma_{m(t)} \vec{x}(t)$
- Discrete mode evolution: Markov transitions

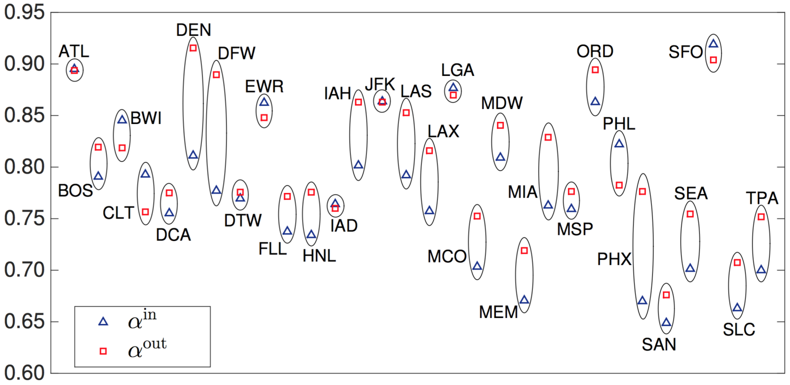
Validation: Evolution of delays

- Learn α and β from 2011 data
- Test data: 2012



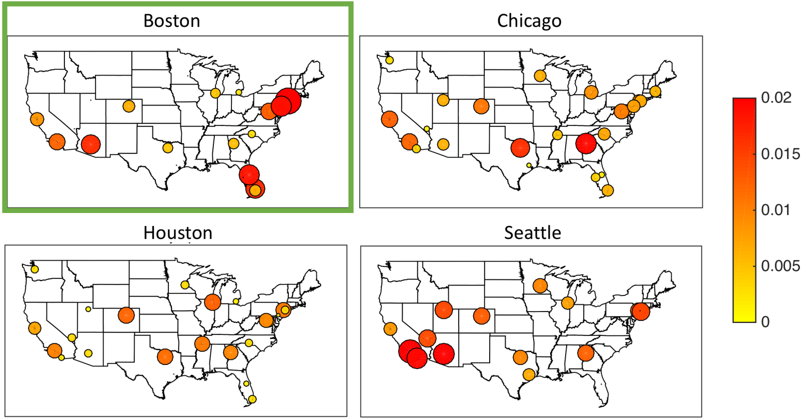
Resilience measure: Persistence of delays

- High $\alpha \Rightarrow$ delays will persist longer
- Airports with demand close to capacity have high α



Resilience measure: Influence of airports

- Inbound delay at an airport depends on outbound delay from other airports



Color and size both represent the induced delay per unit delay at other airport

Conclusions

1. Network representation is useful to identify characteristic delay patterns
2. We quantify the tendency for delays to persist and the influence of network on delays at the top 30 US airports
3. Applications: Delay prediction and developing control strategies