UNIVERSITY OF CAMBRIDGE

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Institute for Aviation and the Environment

Simulating Flight Routing Network Responses to Airport Capacity Constraints in the US

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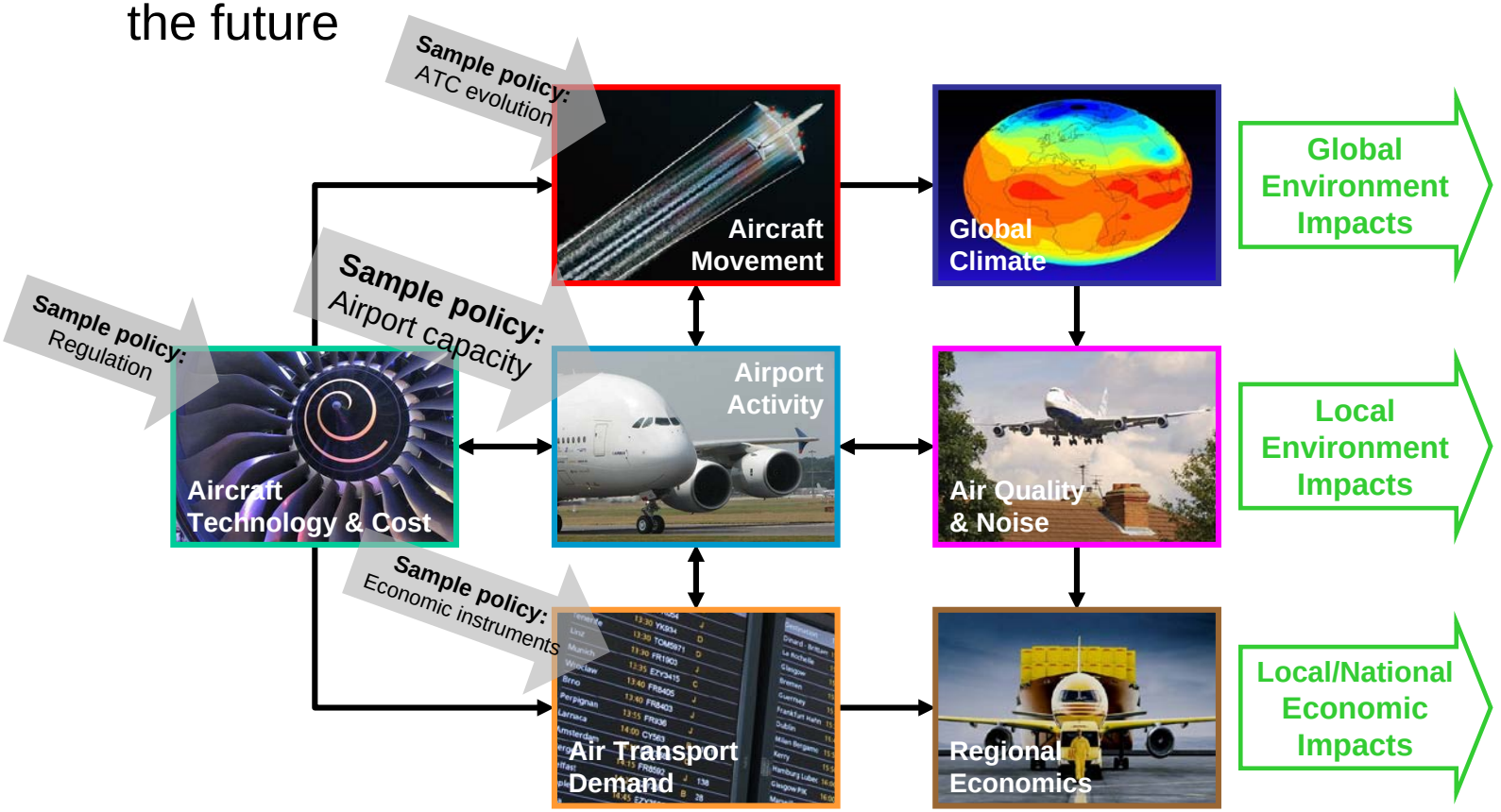
Context

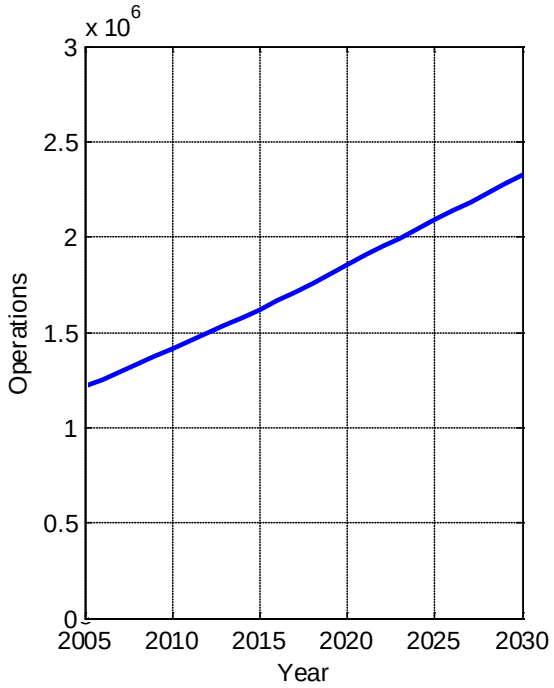
- Aviation Integrated Modelling (AIM) Project
  - Goal: Develop policy assessment tool for aviation, environment & economic interactions at local & global levels, now and into the future



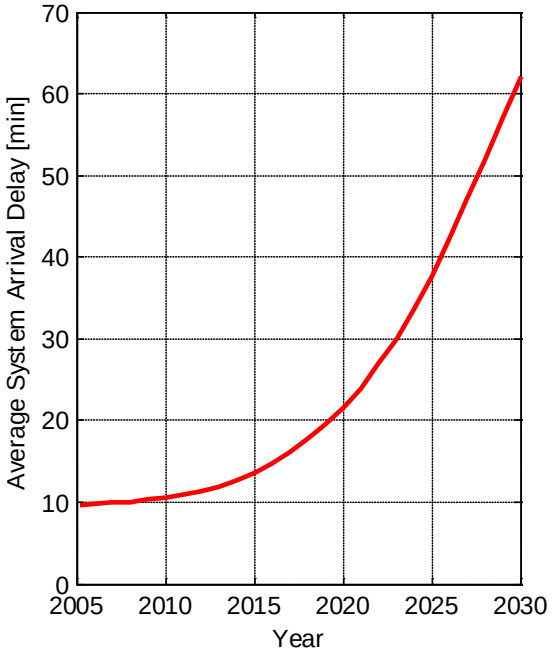
Motivation

Unconstrained forecast of US domestic air transport system growth
Network of 22 primary airports

System Operations



Average Airport Arrival Delay



- Delay forecast unrealistic: Airlines and passengers would respond to delay
  - Potential impact on scheduling, aircraft operated, and routing network
  - Potential impact on air traffic growth, and emissions

Objectives & Methodology

- Objective: Develop a model of airline responses to airport capacity constraints
  - Routing network changes
    - Avoiding congested hubs
    - Shift to secondary airports
  - Changes in flight frequency
  - Changes in aircraft size
- Methodology: Select each airline's routing network, flight frequencies, and aircraft to maximize individual profit
  - Simulate game between airlines to capture effects of competition endogenously
  - Model effects of airport capacity constraints on airline costs and demand endogenously

Methodology

- Airline profit function:

Delay a function (among others) of flight frequency (*Fltfreq*) – modeled by a Delay Calculator

$$\max\left(\sum_{i,j}\sum_{p\in Itin_{i,j}}\overline{Fare}_{i,j}\cdot Pax_{i,j,p,a}-\sum_{m,n,k}Cost_{flt_{m,n,k,a}}\cdot Fltfreq_{m,n,k,a}-\sum_{i,j}\sum_{p\in Itin_{i,j}}Cost_{pax_{i,j,a}}\cdot Pax_{i,j,p,a}\right)$$

Operating cost ($Cost_{flt}$ & $Cost_{pax}$) a function (among others) of delay – modeled by an Operating Cost Calculator

- Decision variables: itinerary demand ($Pax_{i,j,p,a}$)
- Constraints:
  - Demand constraint:

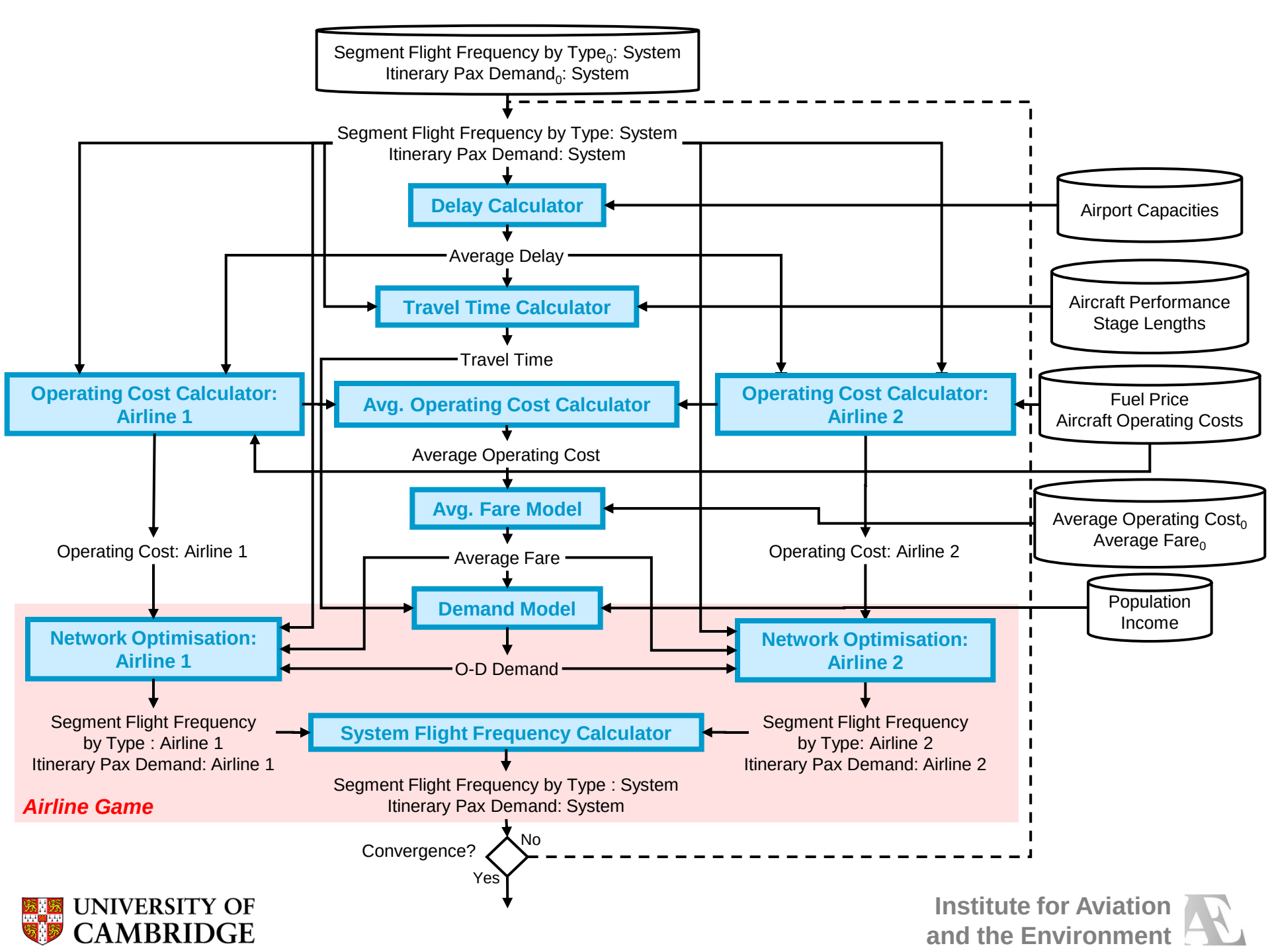
$$\sum_{p\in Itin_{i,j}}Pax_{i,j,p,a}\le\frac{Fltfreq_{i,j,a}}{\sum_{a\in A}Fltfreq_{i,j,a}}\times D_{i,j}$$

  - Seat c
  - Airport balance constraint:

$$\sum_{n,k}Fltfreq_{m,n,k}=\sum_{n,k}Fltfreq_{n,m,k}$$

  - Only non-stop and single connection itineraries modeled

Available passenger demand (D) a function (among others) of delay (travel time) and fare ($Fare$) – modelled by a Demand Model



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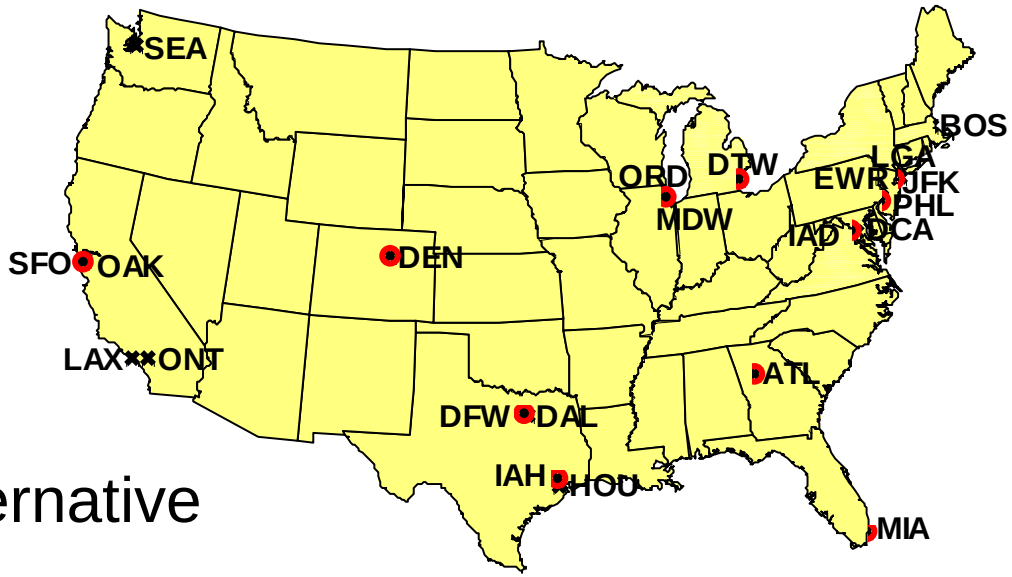
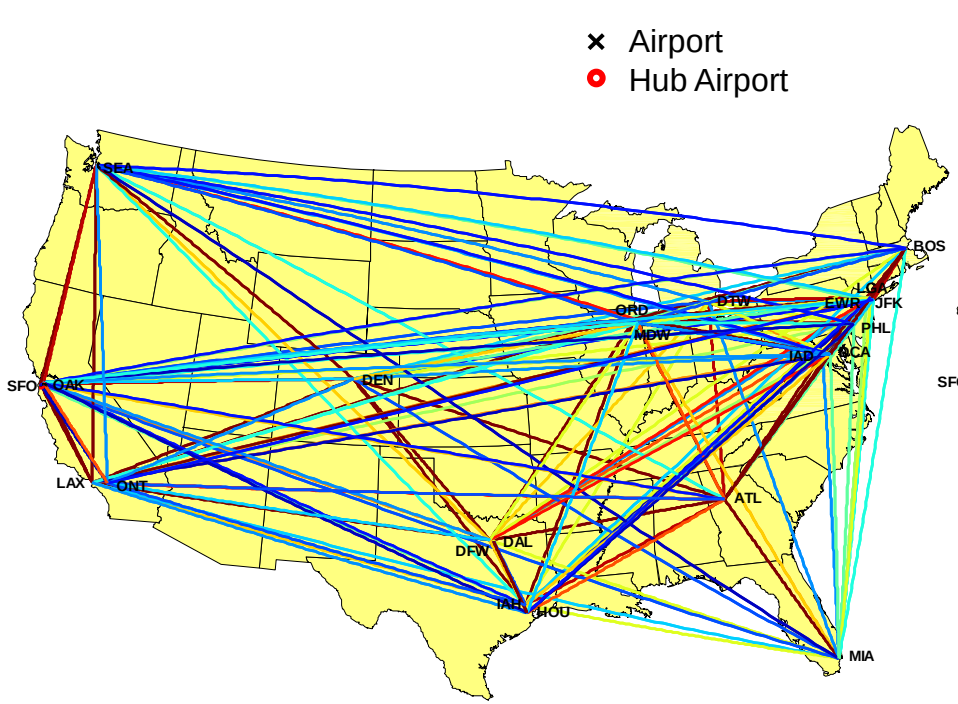
Sample Problem

- Model 5 airlines in 14 cities / 22 airports / 11 hubs in the US
  - Served 75% of scheduled flights in the domestic US in 2005
- Validate model by comparing results with 2005 input data to observed data for 2005

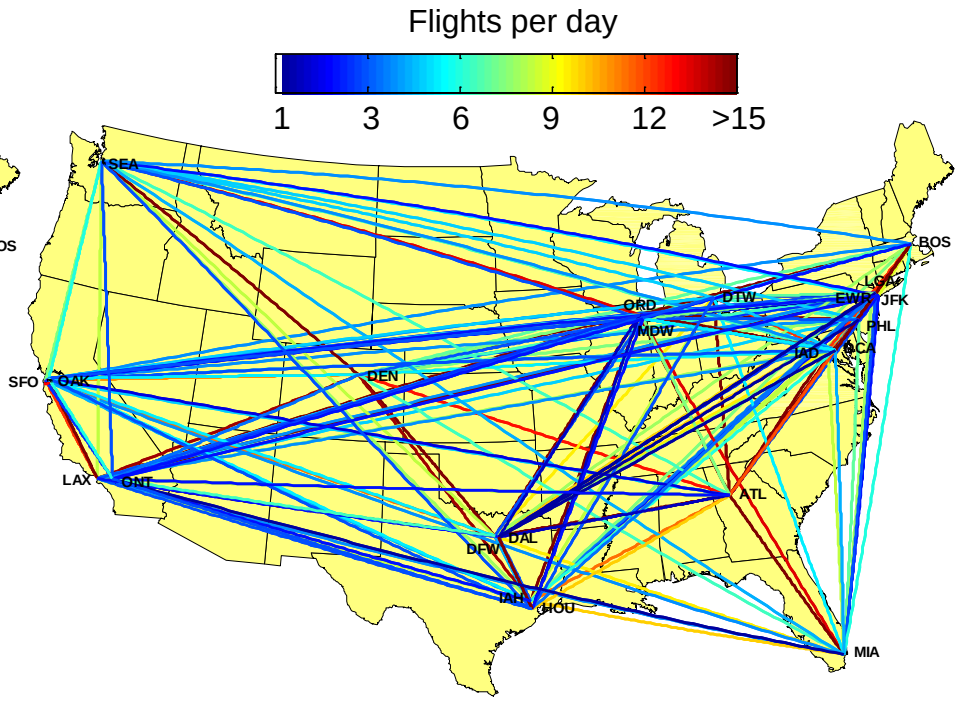


- Simulate to 2030 under alternative airport capacity scenarios
  - Proposed airport capacity expansion
  - No airport capacity expansion
  - No airport capacity expansion at ORD, proposed elsewhere

Model Validation



Observed Network, 2005



Airline Game Theoretical Equilibrium Network

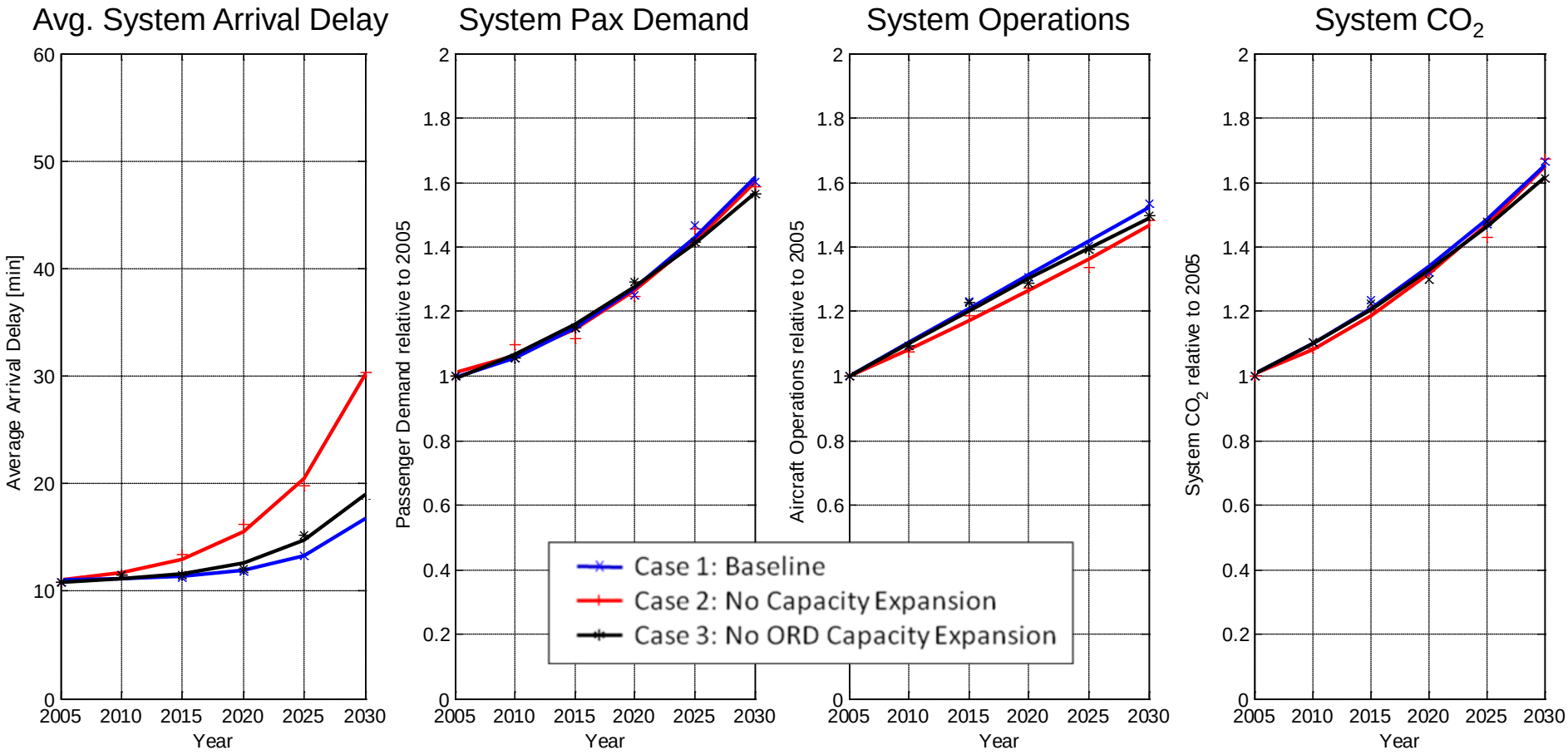
Model result comparison to Actual Network Operated, 2005

Segment Flight Frequency		Fares		OD Demand	
% diff. System	R^2	Mean % diff.	R^2	% diff. System	R^2
12% low	0.777	11% high	0.493	10% low	0.509

Percentage connecting passengers: 5.8% (observed) 13.4% (modeled)

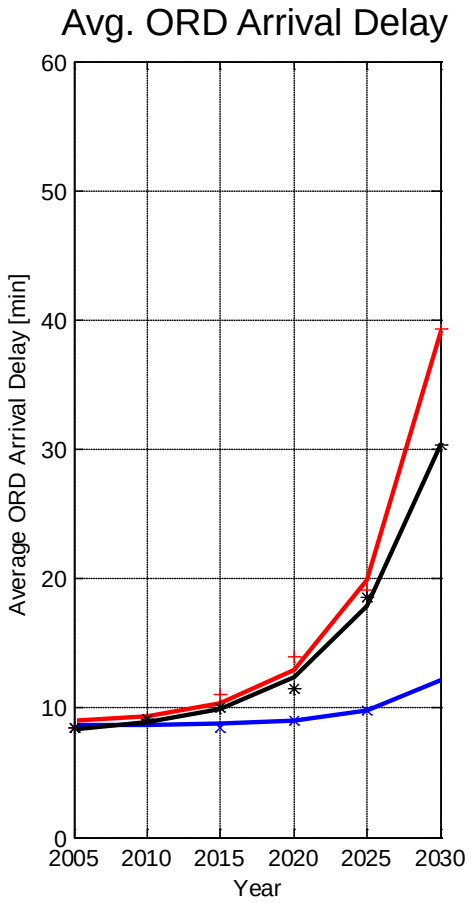
Simulating to 2030: System

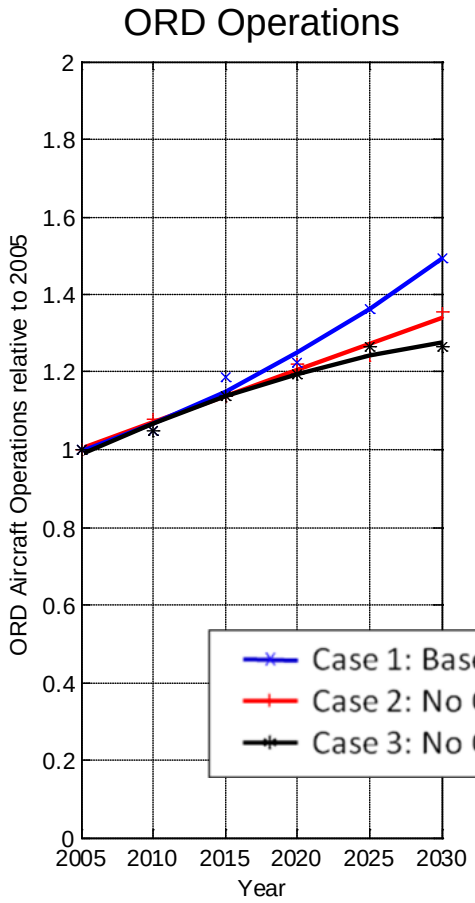
- Population, income, oil price based on MIT CCSP (2007) IGSM scenario

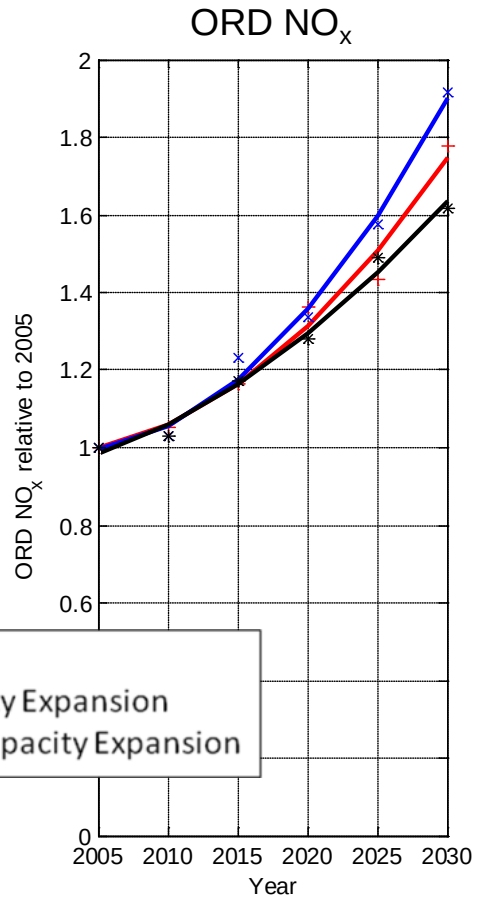


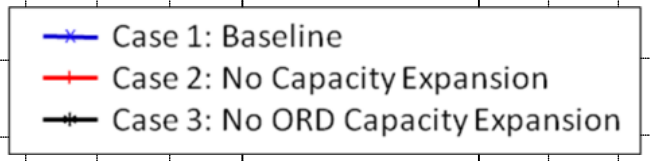
Simulating to 2030: ORD

- Population, income, oil price based on MIT CCSP (2007) IGSM scenario



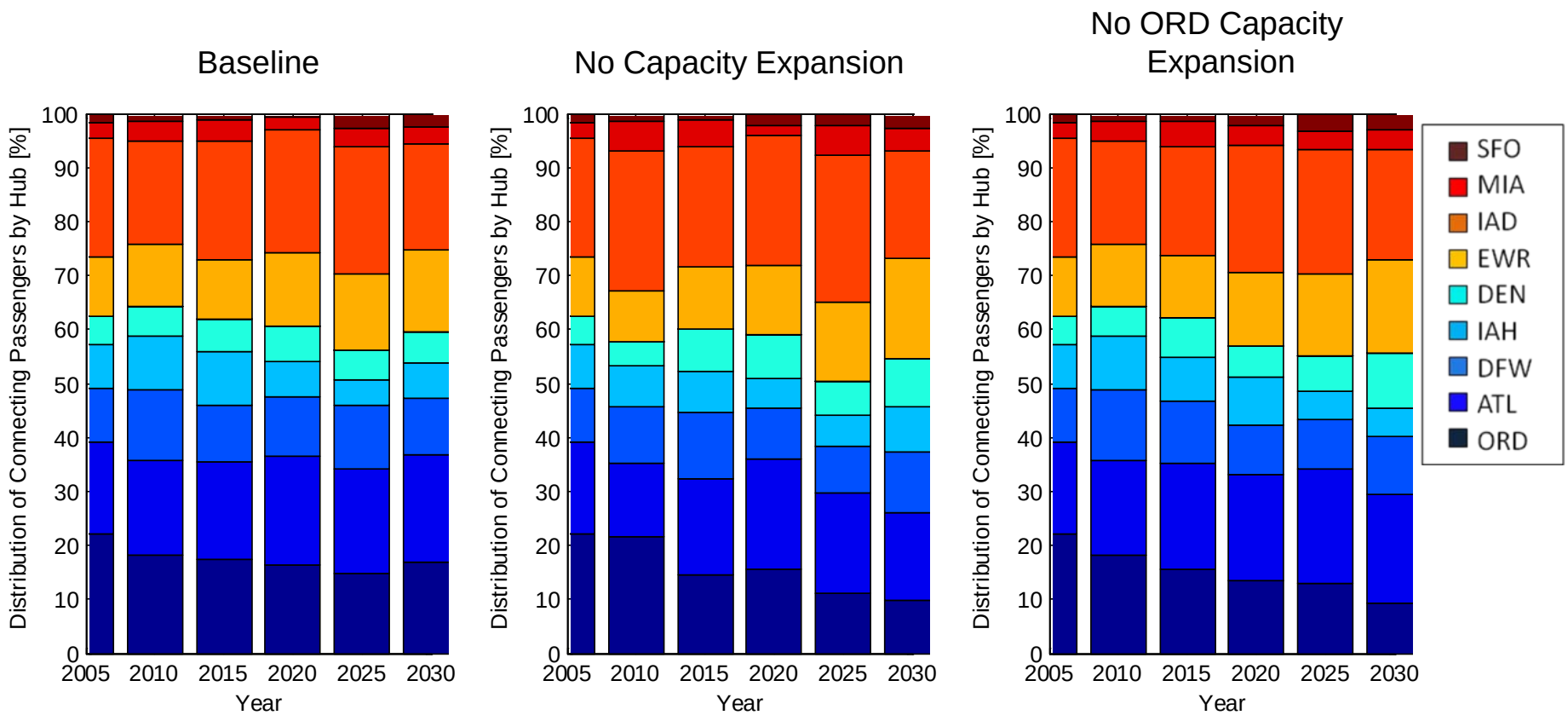






Simulating to 2030: Hubs

- Population, income, oil price based on MIT CCSP (2007) IGSM scenario



Conclusions

- A model was developed that simulates airline flight network routing responses to airport capacity constraints
- The model was validated by applying it to a network of 22 airports and 14 cities in the United States in 2005
  - Passenger demand, average fares, and segment flight frequencies predicted within a 10-12% range compared to observed values
- The model was applied to simulate operations in the US through 2030 under alternative airport capacity scenarios
  - Airport capacity constraints may have a significant impact on flight delay
  - The impact on system-wide passenger demand, air traffic growth, and CO_2 emissions is relatively small
  - The impact on congested hub airport traffic growth and local airport emissions is more significant because of redistribution of connecting passengers to less congested hubs
- The model may be applied to simulate airline network routing responses to other constraints