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Briefing on AirNets Project

(Project initiated in November 2007)

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AirNets Participants

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  - Cynthia Barnhart (CEE, MIT)
  - Álvaro Costa (FEUP)
  - Rosario Macario (IST)
  - Amedeo Odoni (Aero/Astro, MIT)
- Students:
  - Shubham Gupta (OR Center, MIT)
  - Sandra Melo (FEUP)
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  - Joao Pita (FCTUC)
  - Nikolas Pyrgiotis (Aero/Astro, MIT)
  - Vasco Reis (IST)
  - Miguel Santos (FCTUC)
  - Antony Evans (Cambridge, UK)

Objectives

- How do airport-related costs, constraints, and policies affect the evolution of airline networks and of aviation infrastructure?
- Develop models of air transportation networks that are sensitive to the costs of airport development, congestion, and access (e.g., landing fees, passenger taxes, environmental taxes and constraints).
- Using these models, explore the impacts of alternative policies on the distribution of traffic among different types of airports, as well as on the incidence of delays on airlines.
- Ambitious!

Operational Objectives

- <u>Develop a model of an airport network</u> that captures how the network expands in response to demand growth, capacity constraints, environmental constraints and traffic-allocation policies (WP1, WP4).
- <u>Develop a model of an airline network</u> that captures potential airline responses to airport-related congestion and airport-related costs (WP1, WP4).
- <u>Develop a stochastic and dynamic queuing model of an airport network</u> to compute delay profiles at each airport and the propagation of delays across airports (WP2).
- <u>Apply the models to networks consisting of the major airports in the E.U. and U.S.</u> air transportation systems (WP3, WP5, WP6).

Project Structure by Work Package

WP	Relation to Operational Objectives	Description of the Work	Duration (months)	Start Month	End Month
0	All	Detailed specification of operational objectives and expected outcomes for the different work packages	2	Nov. 01, 2007	Dec. 31, 2007
1	Development of airport and airline network models	Conceptual design of the airport and airline network models	6	Jan. 01, 2008	June 30, 2008
2	Development of stochastic and dynamic queuing model	Design, formulation and testing of the stochastic and dynamic queuing model	18	Jan. 01, 2008	June 30, 2009
3	Application of the models to the E.U. and U.S.	Assembly and analysis of relevant data for the E.U. and U.S. air transportation systems	30	July 01, 2008	June 30, 2010
4	Development of airport and airline network models	Formulation and testing of the airport and airline network models	18	July 01, 2008	Dec. 31, 2009
5	Application of the models to the E.U. and U.S.	Development of scenarios regarding the evolution of air transportation systems	18	April 01, 2008	June 30, 2010
6	Application of the models to the E.U. and U.S.	Application of the models to the E.U. and U.S. air transportation systems	12	Jan. 01, 2010	Dec. 31, 2010

Summary of Activities on Ongoing WPs

- WP1: Conceptual design of the airport and airline network models; formulation and testing of the models. Leader: FCTUC; support: MIT, FEUP, IST.
- WP2: Development of stochastic and dynamic queuing network model: formulation and testing of the stochastic and dynamic queuing model. Leader: MIT.
- WP3: Application of the models to the EU and U.S.: assembly and analysis of relevant data for the EU and U.S. air transportation systems. Leader: FEUP; support: MIT, IST.
- WP5: Application of the models to the EU and U.S.: development of scenarios regarding the evolution of air transportation systems. Leader: IST; support: MIT, FEUP.

Major Accomplishments

- Initial formulation and testing of airport network development and expansion model; second pass through the model (FCTUC).
- Design, development and testing of stochastic and dynamic queuing network model – AND; already includes 12 of the busiest airports in U.S. (MIT).
- Trove of data on U.S. from NASA and FAA (MIT); more limited data, so far, from EU (FEUP).
- Preparation of draft of air transport development scenarios (IST).

Major Future Challenges

- Availability of European data (individual airport schedules, aircraft itineraries).
- Development of airline network model.
- Integrating work (using models in concert).

Events

- First planning meeting: MIT, September 2007.
- Project launched in November 2007.
- Visit by Barnhart (to IST) and Odoni (to IST and U. of Coimbra), February 2008.
- 1st Workshop: Lisbon, February 25, 2008.
- Frequent communications; appointment of Odoni as co-supervisor (with Prof. Antunes) of Santos and Pita theses.
- 2nd Workshop: MIT, September 8, 2008.
- Participation from Portugal may be expanded.

Steps Completed to Date at MIT on WP2

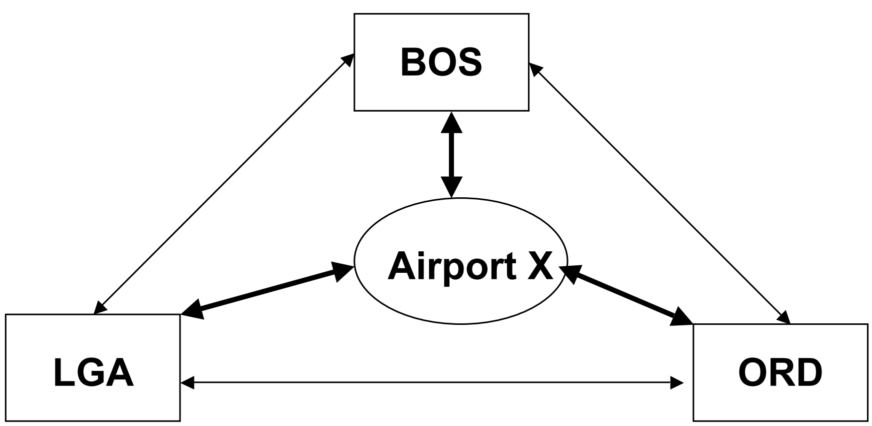
- Re-programmed DELAYS model in Java; tested extensively the model and verified it is performing correctly.
- Obtained data on demand (every arrival and departure during a 24-hour period) at 35 busiest airports in United States.
- Obtained data on most common daily capacity profiles at several major airports in the United States, with associated probabilities. *All 35 busiest airports are available.*
- Tested DELAYS model extensively at several airports.
- Programmed the Approximate Network Delays (AND) model (delay propagation in a network of airports) in Java.
- Verified availability of data on aircraft itineraries from NASA (necessary to operate AND model).
- De-bugged and tested AND in a test case involving Chicago O'Hare, New York LaGuardia and Boston Logan airports.
- Have now included 12 major US airports into AND (out of eventual 25).

Overall Assessment: **Significantly ahead of schedule!**

Outline of AND

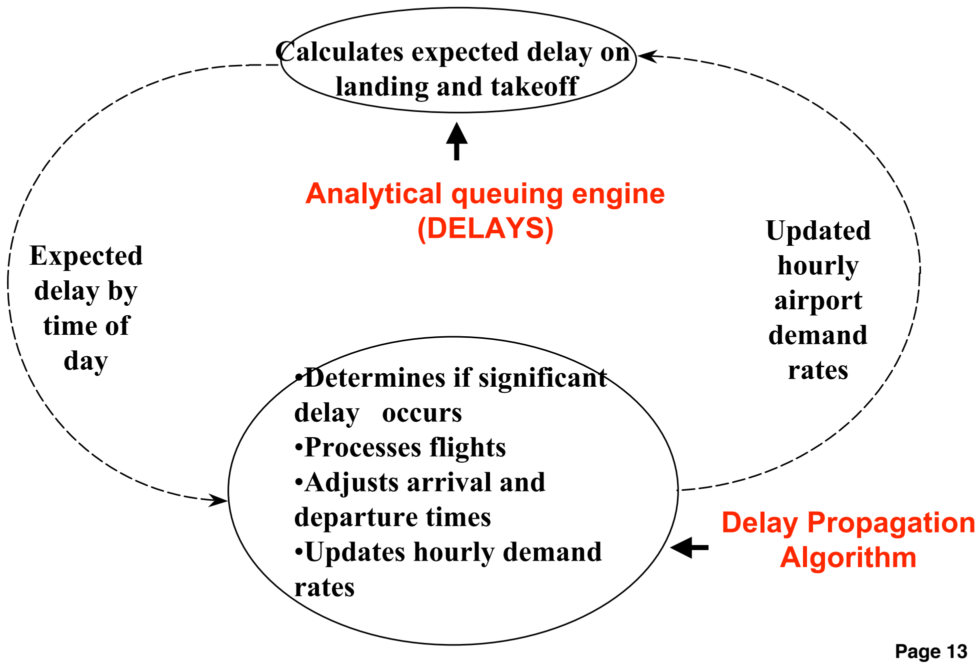
- Models US (national scale) or EU (continent scale) airport system as a dynamic and stochastic queuing network
- Each individual airport is viewed as an individual queuing system; uses a decomposition approach to analyze delays at each airport separately
- Uses a delay-propagation and demand updating algorithm to capture the interactions between each individual airport and all other airports in network
- Initial conceptual design due to Malone and Odoni (1996)
- Model is being developed *ab initio* in java, incorporates major improvements over initial concept and is designed to accommodate data structure and massive database associated with aircraft itineraries

A Three-Airport Network



Airport X represents all the "external airports"; it acts as an un-capacitated source and sink of traffic

The Iterative Logic of AND



A macroscopic, stochastic and dynamic single airport model: DELAYS

Modeling Dynamic Queuing Systems

- The behavior of a class of dynamic queuing systems over time can be computed through the numerical solution of a set of first-order ordinary differential equations, the "Chapman-Kolmogorov equations"
- A particularly powerful model is the one with:
  – demands which are Poisson with time-varying rates
  – service times which are k-th order Erlang with time-varying service rates
- This model (the $M(t)/E_k(t)/n$ model) is important because:
  – its numerical solution can be obtained efficiently
  – it approximates well most M(t)/G(t)/n systems
- The MIT DELAYS model does precisely that: it approximates M(t)/G(t)/n systems

Model of Each Airport

- Each airport is viewed as a queuing system with capacity equal to that of the runway system: modeled through DELAYS
- Aircraft requesting permission to land or take off are the demands
- The times of demands for arrivals and departures are modeled as time-varying Poisson processes
- Service times are modeled as k-th order Erlang; k is determined by ratio of σ_S to $E[S]$
- Queuing discipline is FCFS
- Infinite waiting line capacity

The DELAYS Model

- Approximates, with high precision, the $M(t)/E_k(t)/n$ queue (and (by implication also approximates $M(t)/G(t)/n$ systems)
- Inputs: *Dynamic demand profile* (typically specified via hourly demand rates); *dynamic capacity profile* (typically hourly capacity)
- Approach: Starting with initial conditions at time t=0, solves equations describing the evolution of queues by computing the probabilities, $P_n(t)$, of having n= 0, 1, 2, 3, … aircraft in queue at times $t = \Delta t, 2\Delta t, 3\Delta t, \ldots$.. up to end of the time period of interest (typically 24 hours)
- Outputs: Statistics about queues (average queue length, average waiting time, fraction of flights delayed more than *X* minutes, etc.)

The DELAYS model [2]

- Analytical; approximate; single airport
- Requires few data (demand profile, capacity profile, estimate of variance of service times)
- Time-horizon can be subdivided into intervals as small as 10 minutes
- Demand may exceed capacity during any number of intervals (no '$\rho < 1$' restriction)
- Very fast and easy-to-use: updated to java in Fall 2007 and Winter 2008;, less than 1 sec for estimation of all $P_n(t)$ for a 24-hour period at a major airport
- Especially useful for parametric studies and sensitivity analyses

A macroscopic, stochastic and dynamic model of a network of airports: The Approximate Network Delays Model (AND)

AND Data Requirements

- Detailed demand data (schedule of arrivals and of departures) for entire day for every airport
- Detailed capacity data (number of arrivals and of departures that can be accommodated per hour or other unit of time) for every airport
  - Preferably capacity data will be provided for good and bad weather conditions, with associated probabilities
- Detailed aircraft itineraries: routing and schedule of every aircraft flying through the system