Stochastic Models for Estimating Congestion in the En-route Airspace

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Motivation

- Accurate congestion prediction helps improve efficiency through tactical and operational reactions
- FAA currently uses Monitor Alert which has two major drawbacks. It does not account for
  - stochastic departure times
  - queueing effects
  - re-routing

Objective

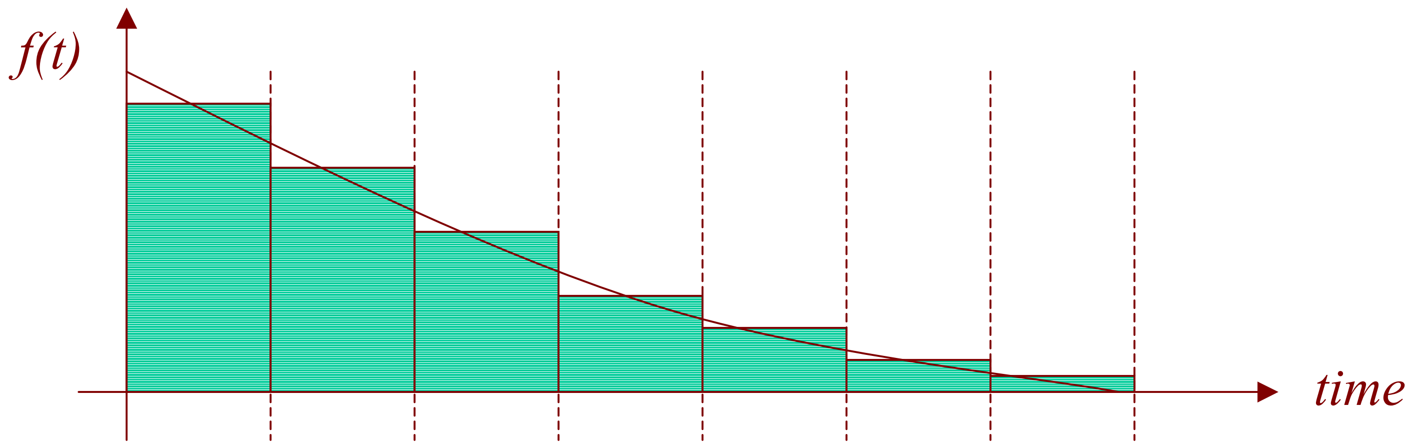
- To develop a model that analyzes queueing delays in networks with stochastic schedule-based arrivals and time-varying service times
- Functionality
  - Congestion prediction
  - Schedule evaluation
  - Airspace capacity design

Why Is This So Hard?

- Queueing networks under time-varying and state-dependent conditions are extremely difficult to analyze
- Arrival / service time distributions are not mathematically tractable
- Network is highly dynamic - time during congestion is shorter than time required to attain congestion

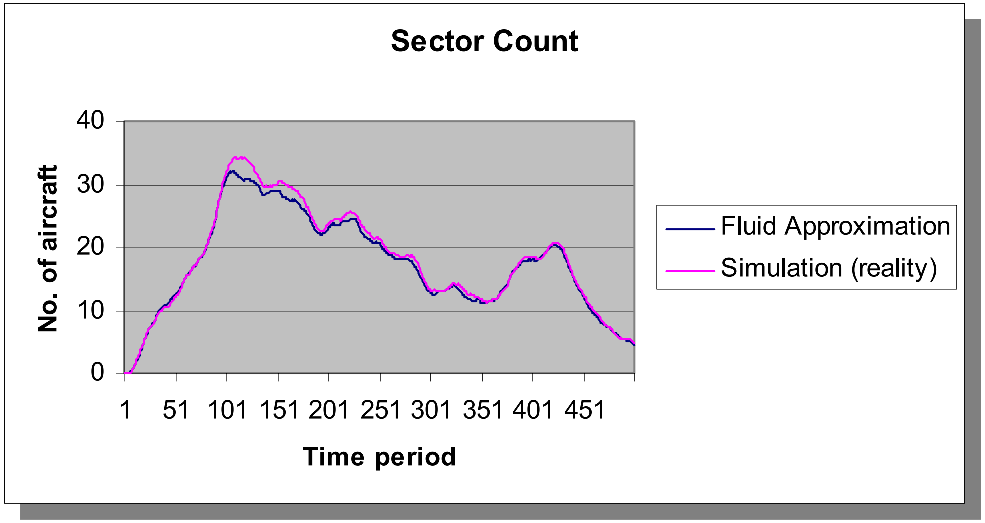
Modeling Stochastic Departure Times

- Impose discrete time slices on the time horizon
- Focus on "probability flows" rather than flows of discrete aircraft



Fluid Approximation

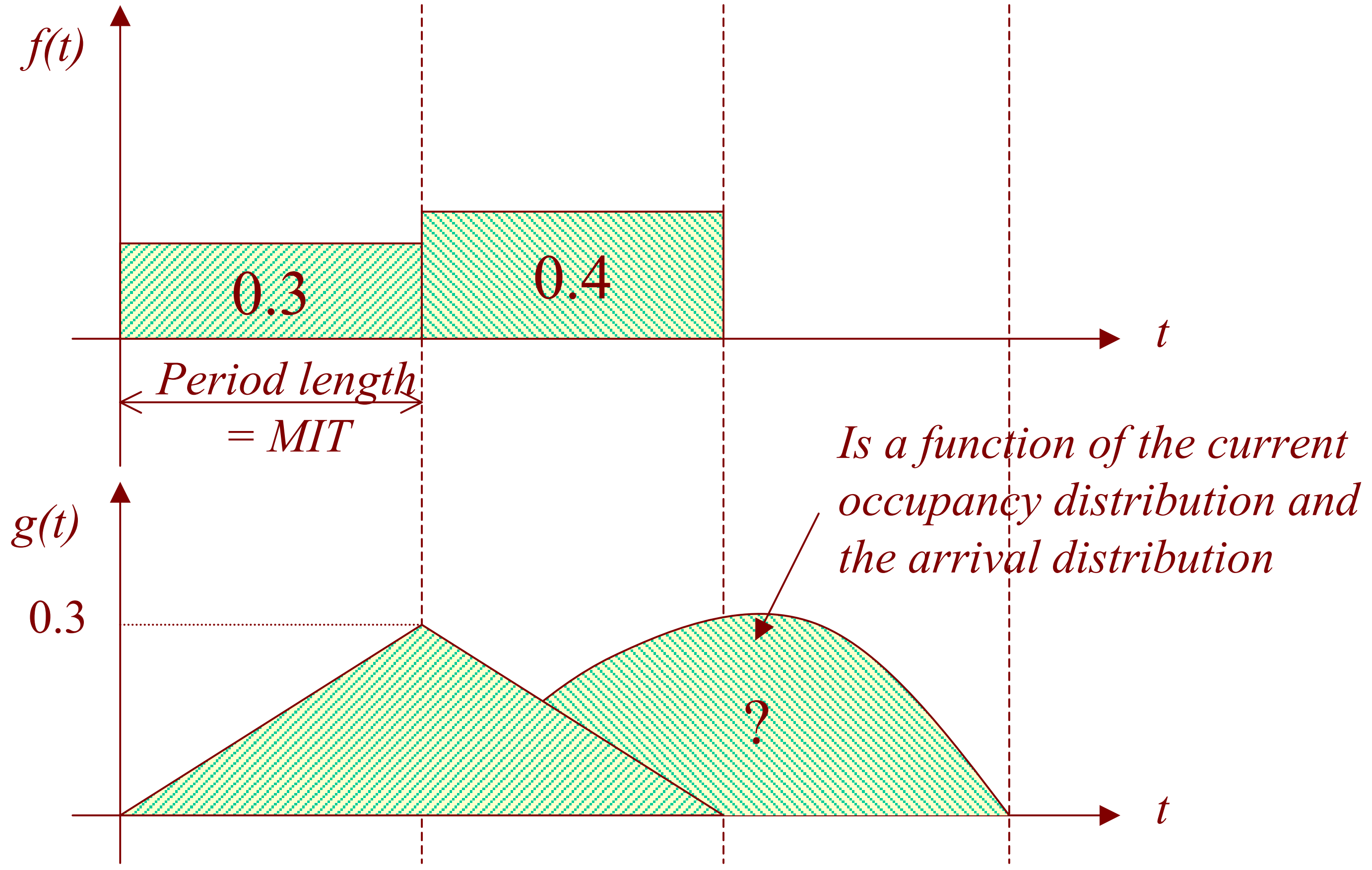
- Push probability flows through the network using aggregate capacities (capacity of 5 aircraft in a 10 minute time interval implies a MIT of 2 min.)



Key Concept (1) "Strong Interactions"

- A set of aircraft passing through a waypoint create an "occupancy distribution" over time, defined as the probability that the waypoint is "busy" serving this set of aircraft
- The delay experienced by an aircraft arriving at a waypoint depends on the occupancy distribution of that waypoint

Key Concept (1) "Strong Interactions"- Contd.



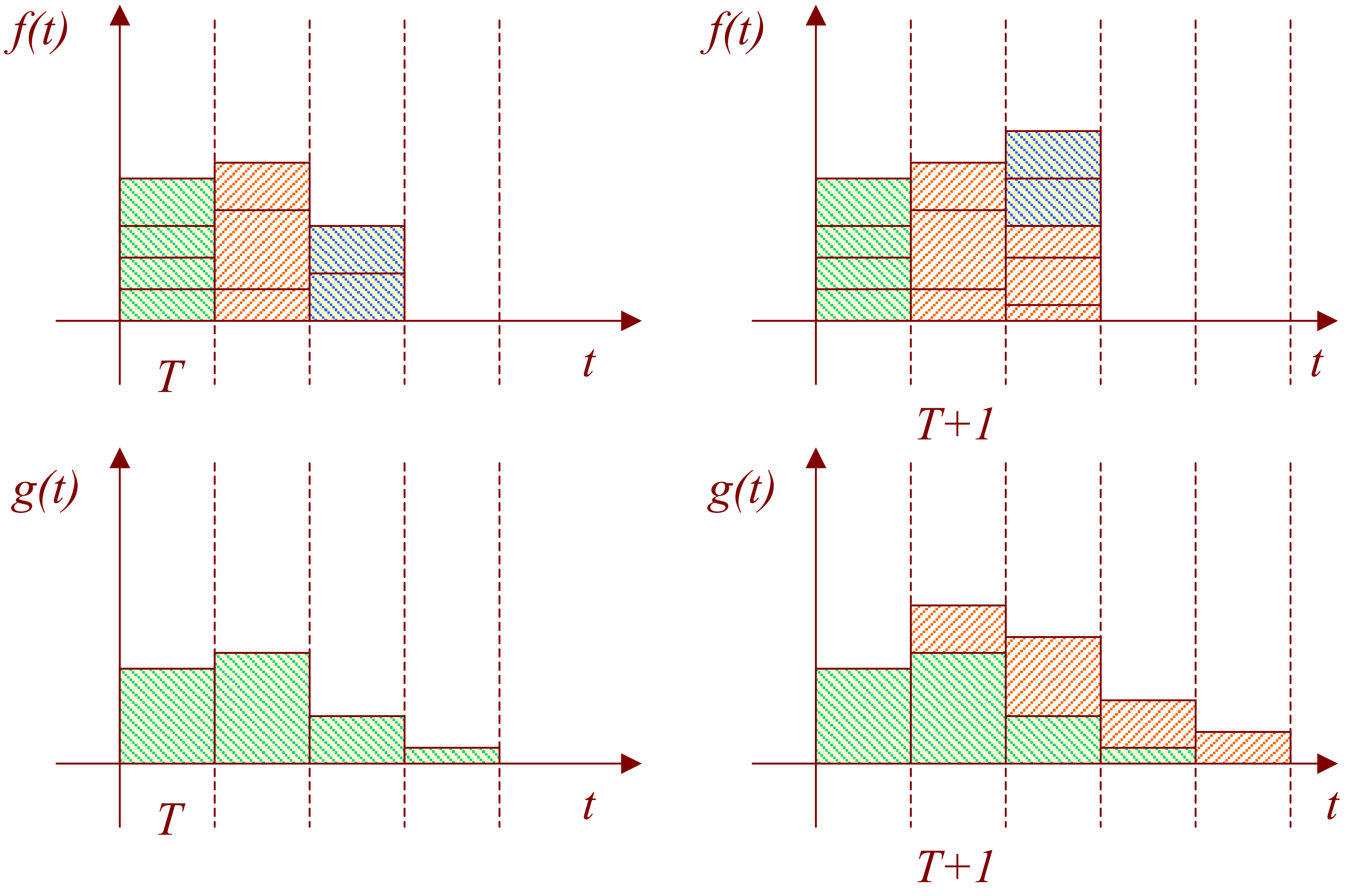
Key Concept (2)
"Weak Interactions"

- Interactions between aircraft are not explicitly considered to estimate delays. Instead, sets of aircraft have occupancy distributions independent of other sets of aircraft. The constraint is that for a feasible set of flows, the probability of occupancy cannot exceed 1 at any time
- This approach underestimates queueing

Algorithm Philosophy

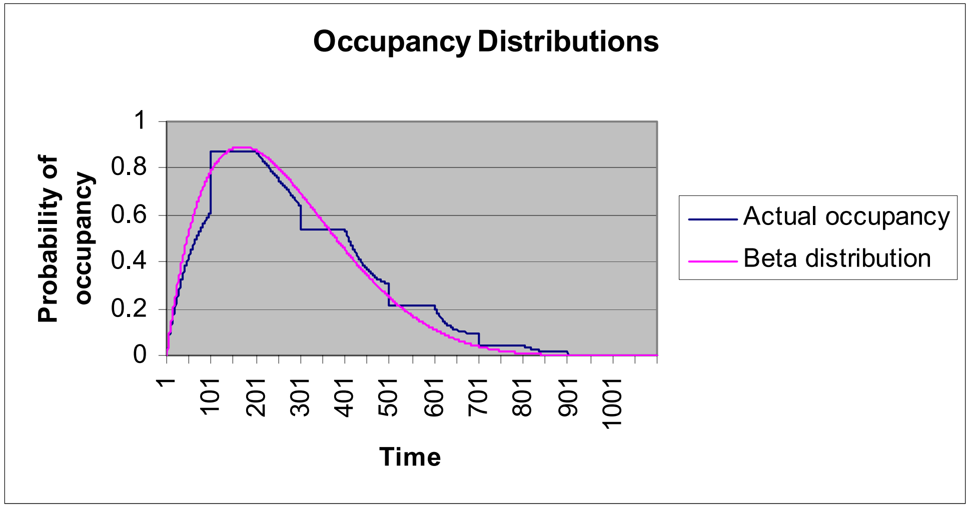
- Not possible to use only strong interactions to generate delay because
  - Computation of delay is highly combinatorial
  - An aircraft should not be allowed to strongly interact with itself
- The algorithm uses a hybrid of strong and weak interactions to generate feasible probability flows in the network

Algorithm Description



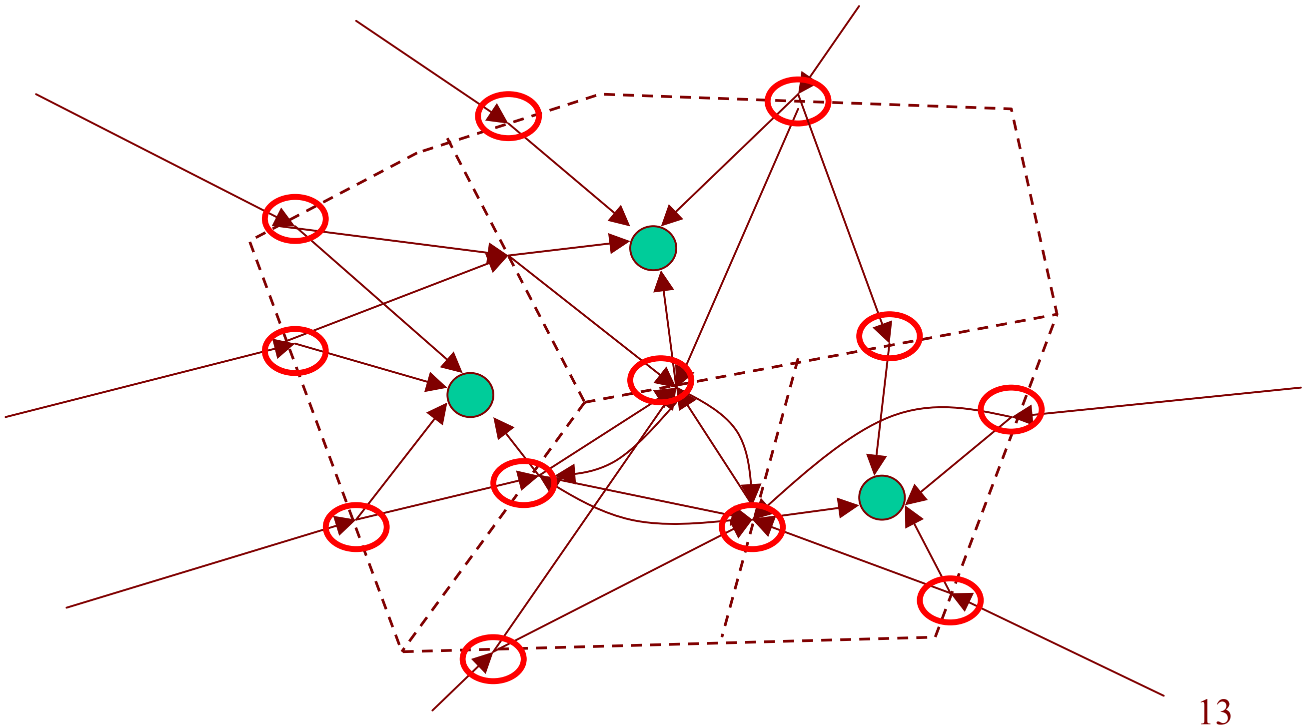
Generating Occupancy Distributions

- Being able to generate occupancy distributions as functions of capacity, previous occupancy, and the arrival distribution is central to the algorithm

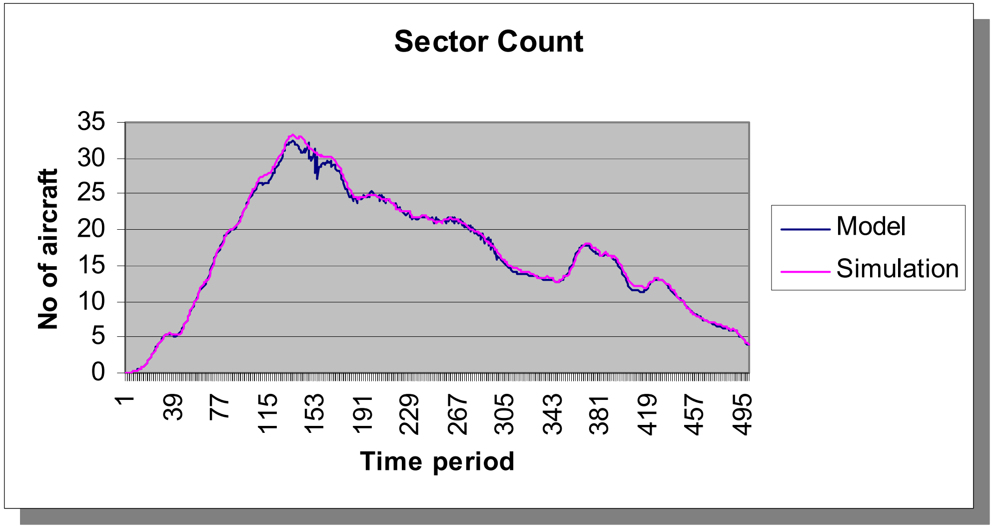


Experiments

- Compared sector counts generated by the model to that of a simulation

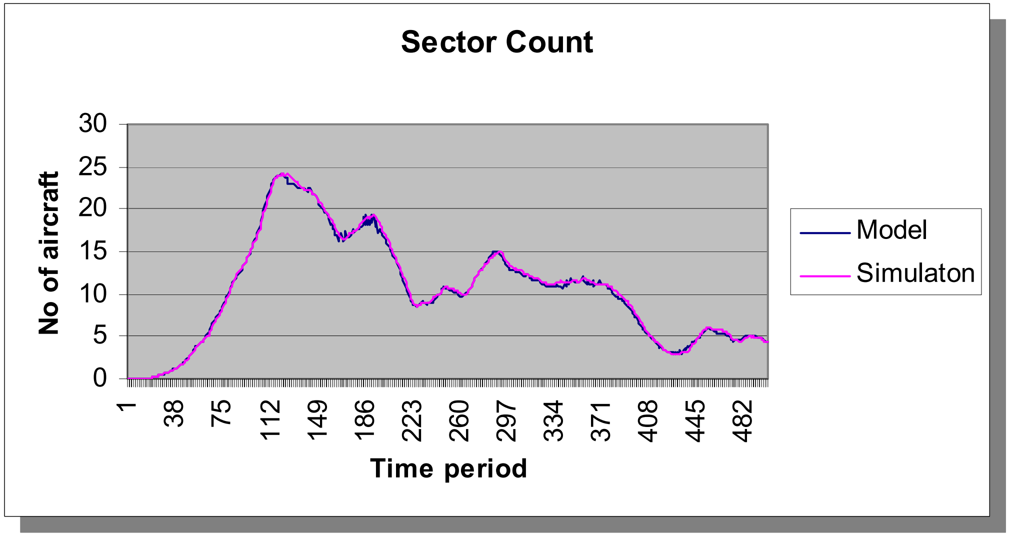


Experimental Results
Time-varying arrivals and constant capacity



Flight No	Predicted Travel Time	Actual Travel Time
119	161.293	163.059
540	232.260	232.445
872	169.828	168.639

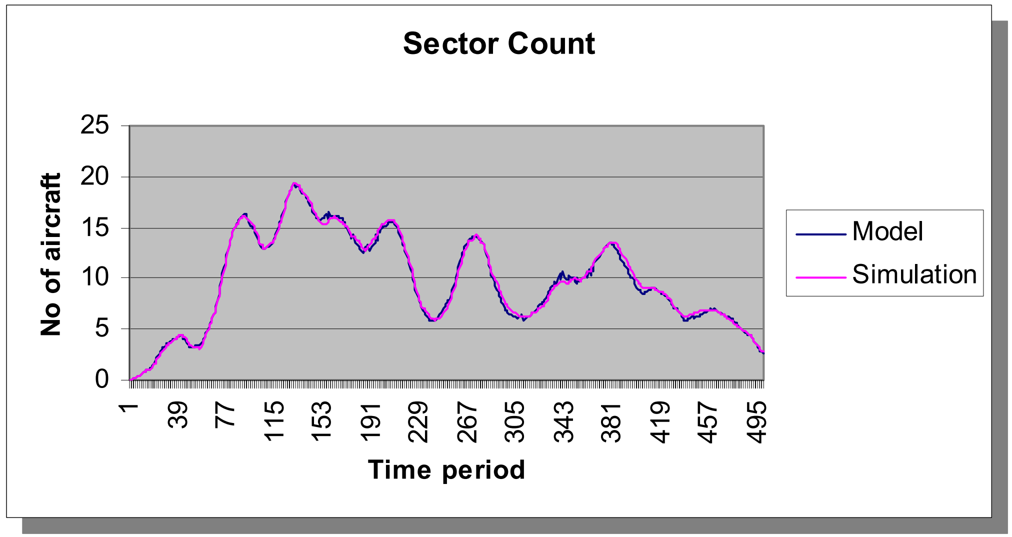
Experimental Results
Time-varying arrivals and capacity



Flight No	Predicted Travel Time	Actual Travel Time
119	113.506	115.528
340	460.265	457.877
954	290.506	291.927

Experimental Results

Time-varying arrivals, capacity, and cancellation probabilities



Flight No	Predicted Travel Time	Actual Travel Time
119	119.555	116.199
340	111.755	114.744
954	356.743	364.500

Future Work

- Better estimation of occupancy distributions
- Compare results to a “real” scenario (?)
- Incorporate network connectivity constraints
- Confidence intervals on prediction
- Pop-ups (?)