

A vertical strip on the left side of the slide shows a silhouette of an air traffic control tower against a bright, hazy sky. A small airplane is visible in the distance, flying towards the right.

# Stochastic Models for Estimating Congestion in the En-route Airspace

*Bala Chandran*

*David Lovell*

*Michael Ball*

NEXTOR

University of Maryland, College Park

A vertical image on the left side of the slide shows an air traffic control tower in the foreground, partially obscured by a dark vertical bar. In the background, a silhouette of an airplane is visible against a bright, hazy sky, possibly during sunrise or sunset.

# 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

A vertical decorative image on the left side of the slide. It shows a silhouette of an air traffic control tower in the foreground on the left, and a silhouette of an airplane flying in the sky in the background. The sky is a warm, golden-yellow color, suggesting a sunset or sunrise.

# 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

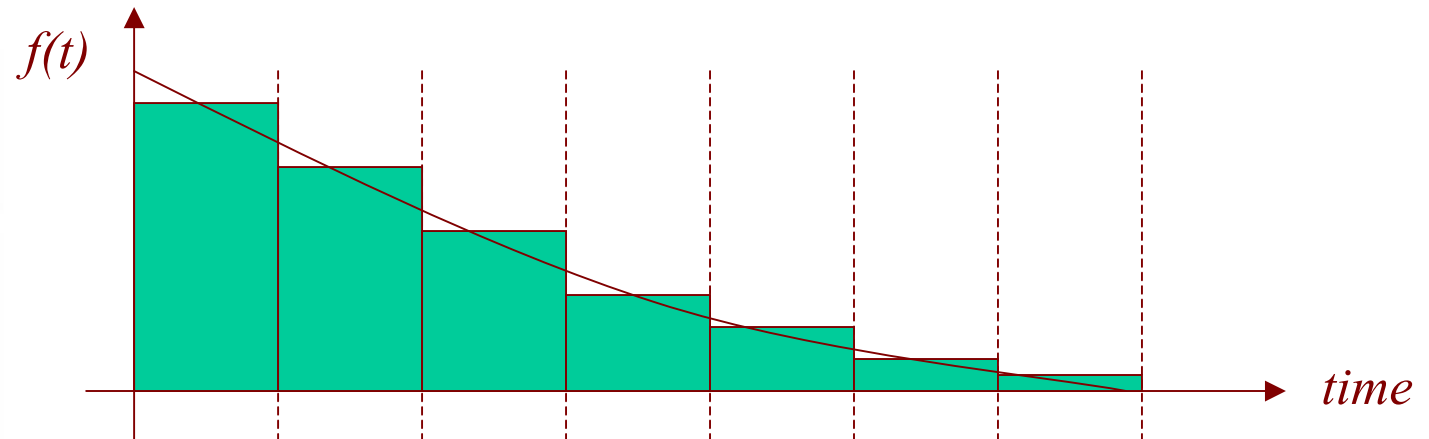
A vertical image on the left side of the slide shows an air traffic control tower in the foreground, partially obscured by a bright, hazy sky. In the background, a small airplane is visible in flight against the same bright sky.

# 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

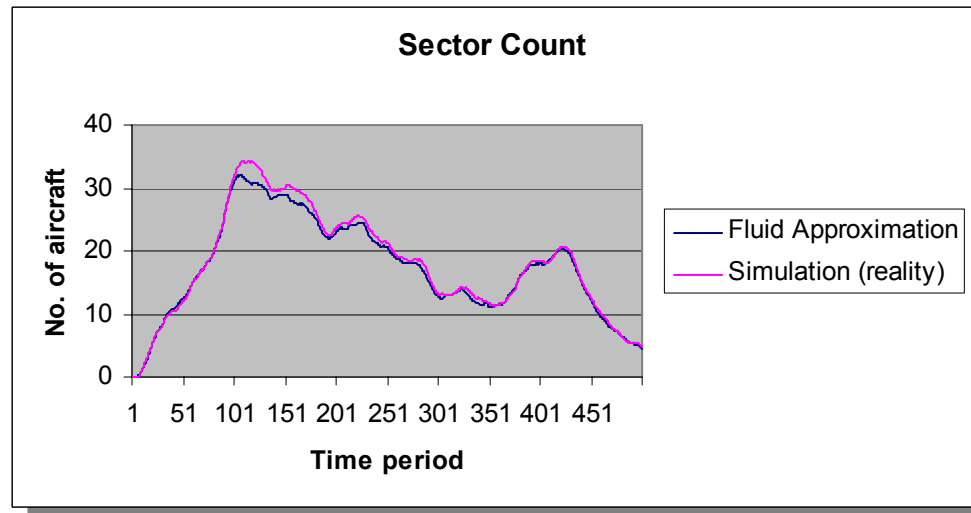
# Modeling Stochastic Departure Times


- 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.)



A vertical image on the left side of the slide shows an air traffic control tower in the foreground, partially obscured by a bright, hazy sky. In the background, a silhouette of an aircraft is visible flying across the sky.

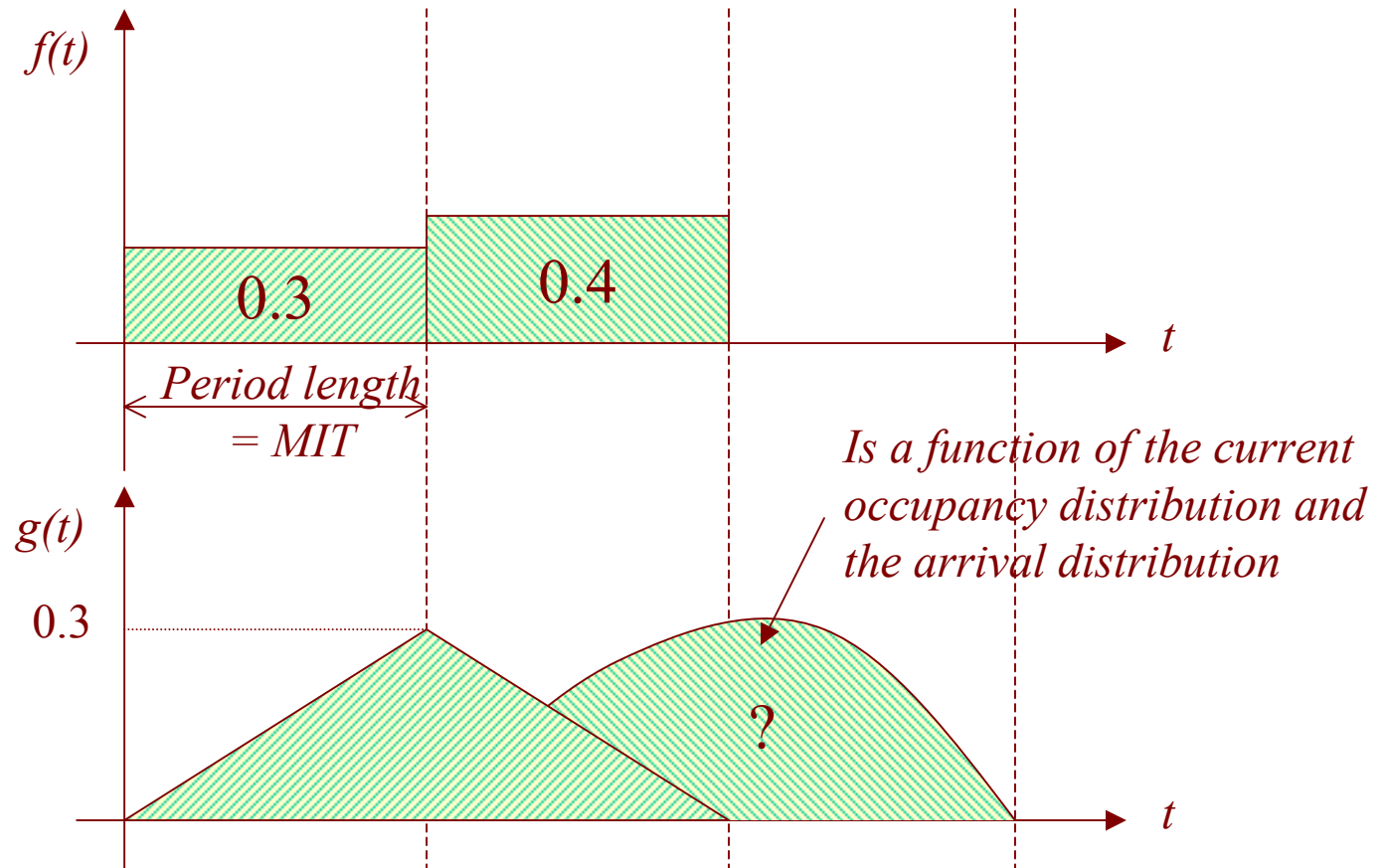
# Key Concept (1)

## “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.





A vertical image on the left side of the slide shows an air traffic control tower in the foreground, partially obscured by a bright, hazy sky. In the background, a silhouette of an aircraft is visible against the light sky.

## Key Concept (2)

### “Weak Interactions”

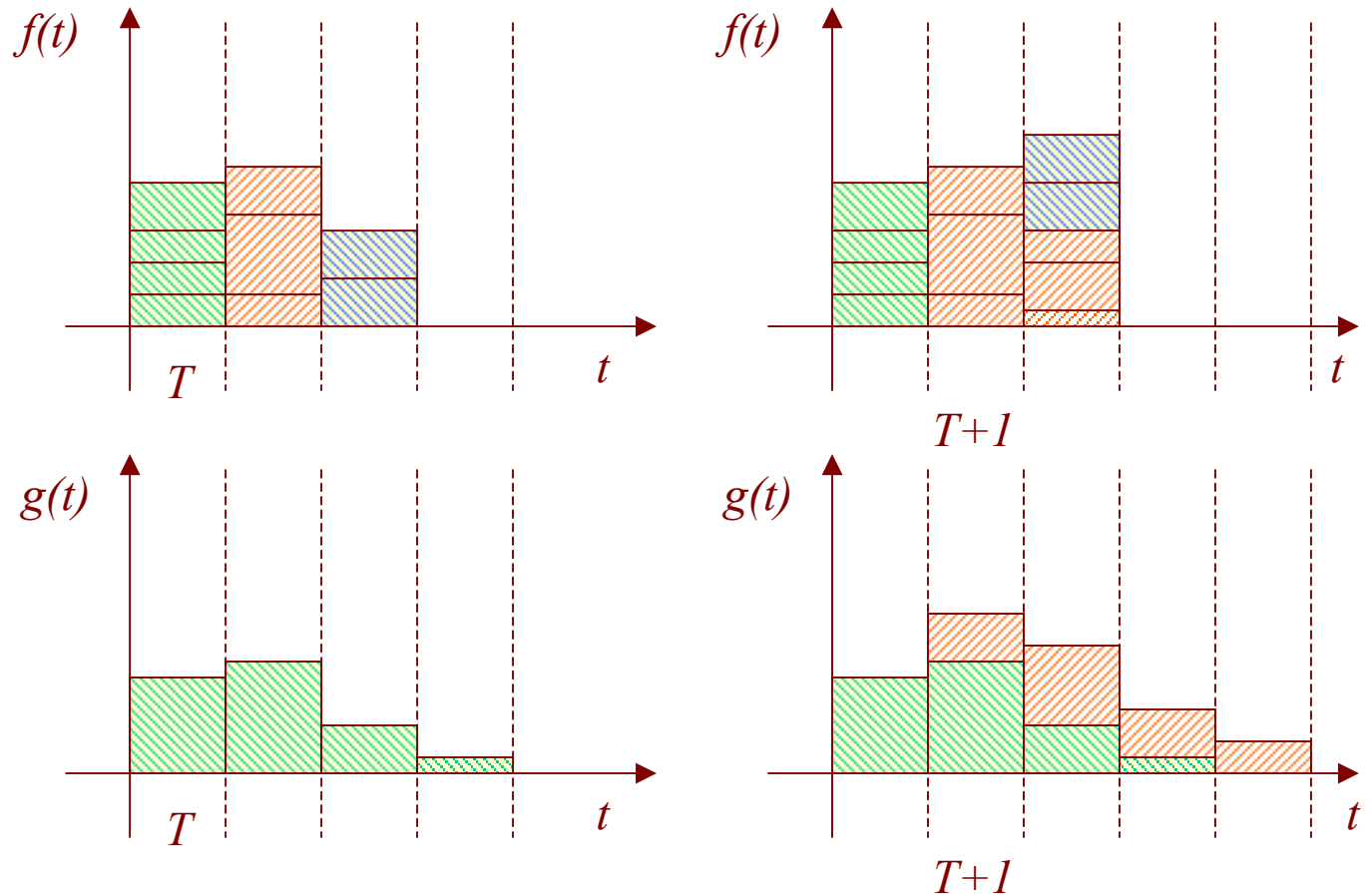
- Interactions between aircraft are not explicitly considered to estimate delays. Instead, sets of aircraft have occupancy distributions independent of other sets of aircraft. The constraint is that for a feasible set of flows, the probability of occupancy cannot exceed 1 at any time
- This approach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

A vertical image on the left side of the slide shows an air traffic control tower in the foreground, partially obscured by a dark vertical bar. In the background, a silhouette of an aircraft is visible against a bright, hazy sky, possibly during sunrise or sunset.

# Algorithm Philosophy

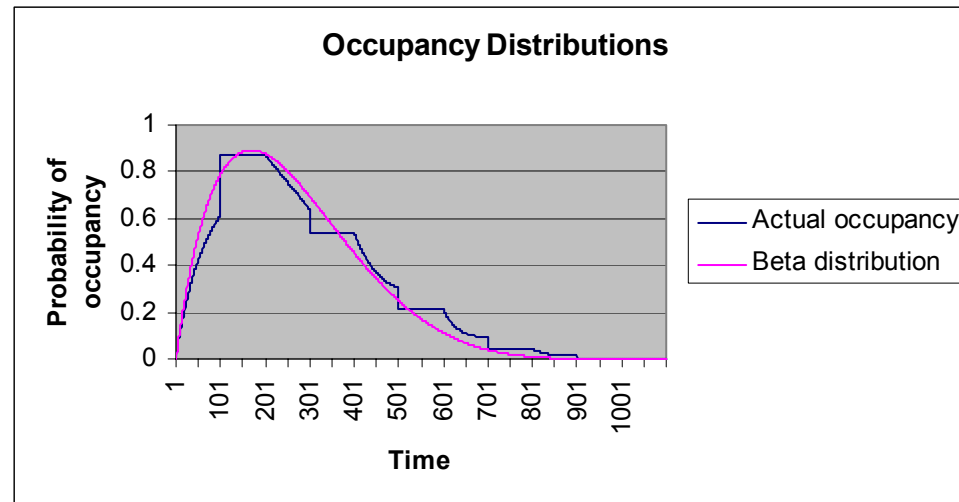
- Not possible to use only strong interactions to generate delay because
  - Computation of delay is highly combinatorial
  - An aircraft should not be allowed to strongly interact with itself
- The algorithm uses a hybrid of strong and weak interactions to generate feasible probability flows in the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

# Algorithm Description



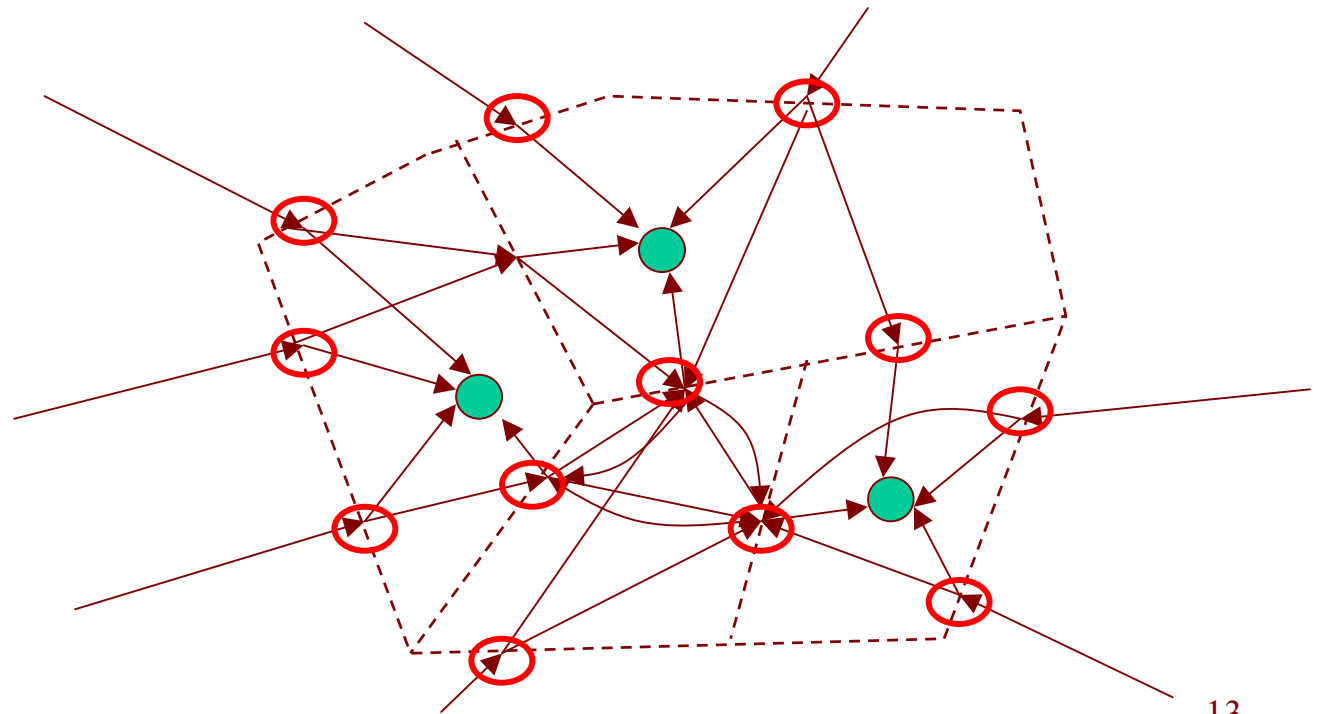
# Generating Occupancy Distributions

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



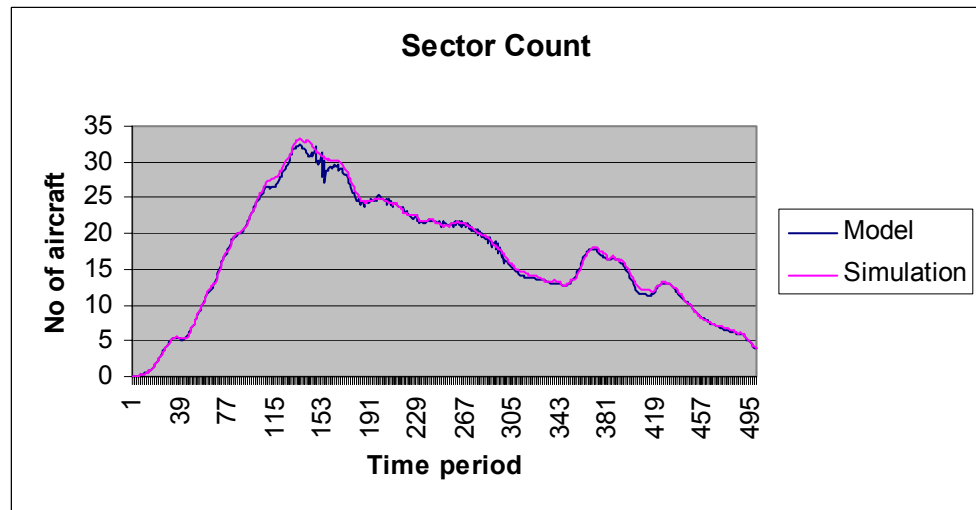
# Experiments

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



# Experimental Results

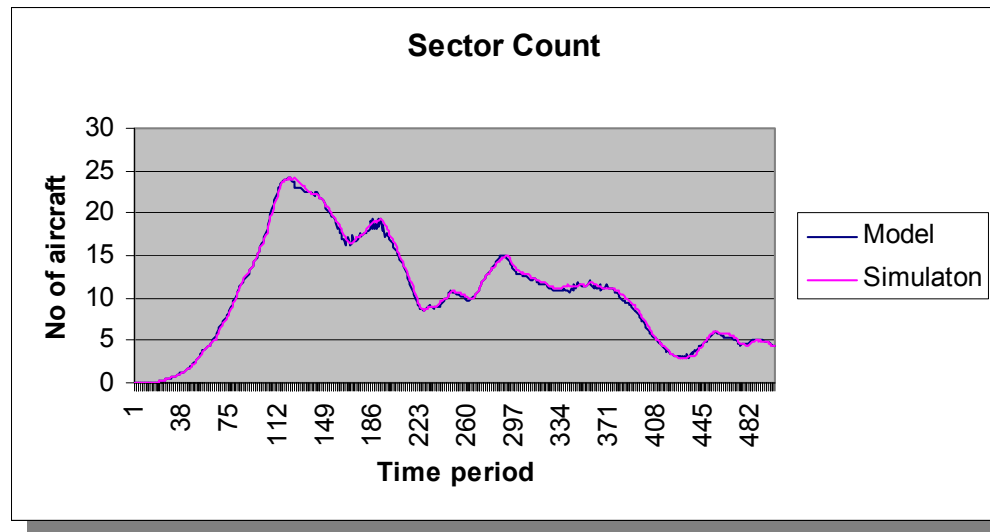
## Time-varying arrivals and constant capacity



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

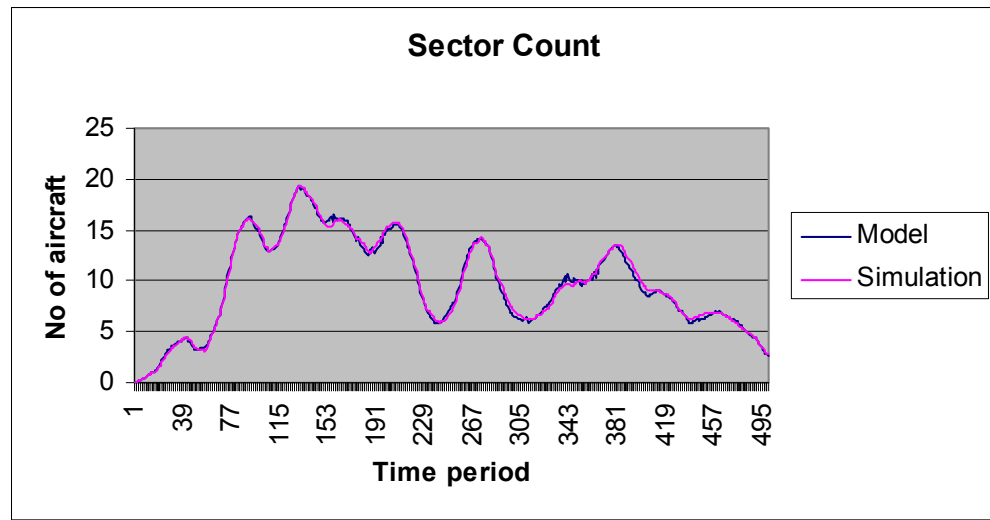
## Time-varying arrivals and capacity



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



A vertical decorative image on the left side of the slide. It shows a silhouette of an air traffic control tower in the foreground on the left. In the background, a sunset sky is visible with a silhouette of an airplane flying across it.

# Future Work

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