The Airside Departure Process:
Observations & Queuing Models

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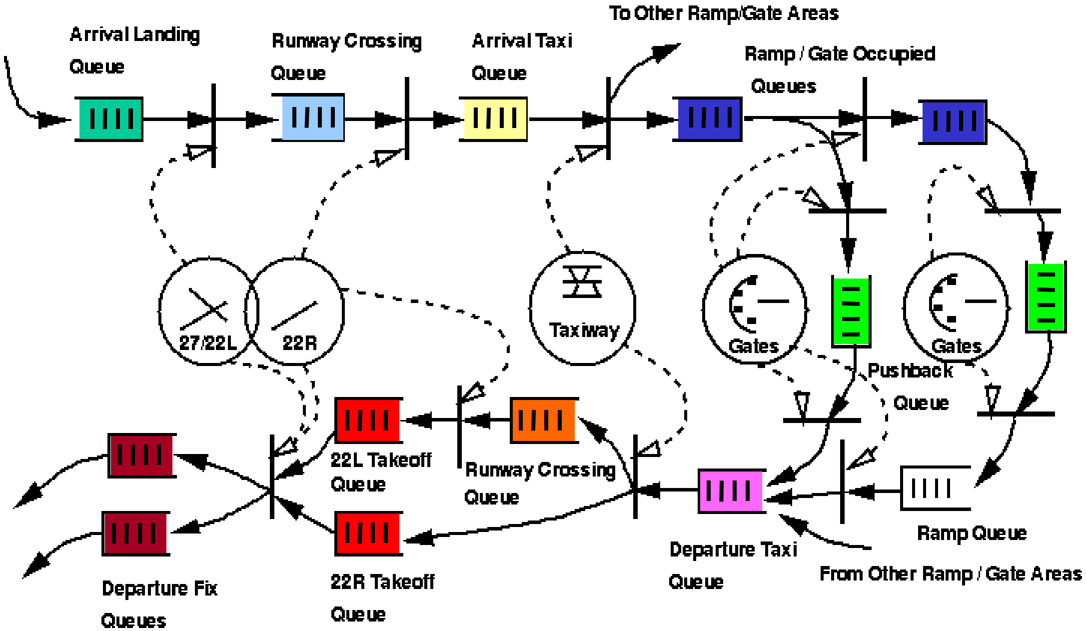
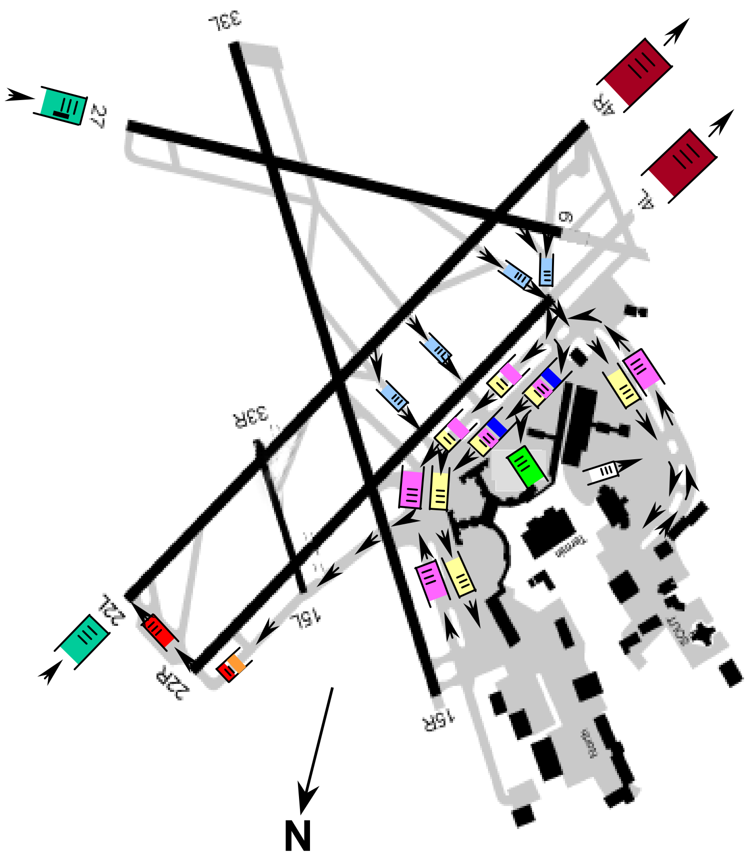
Overview

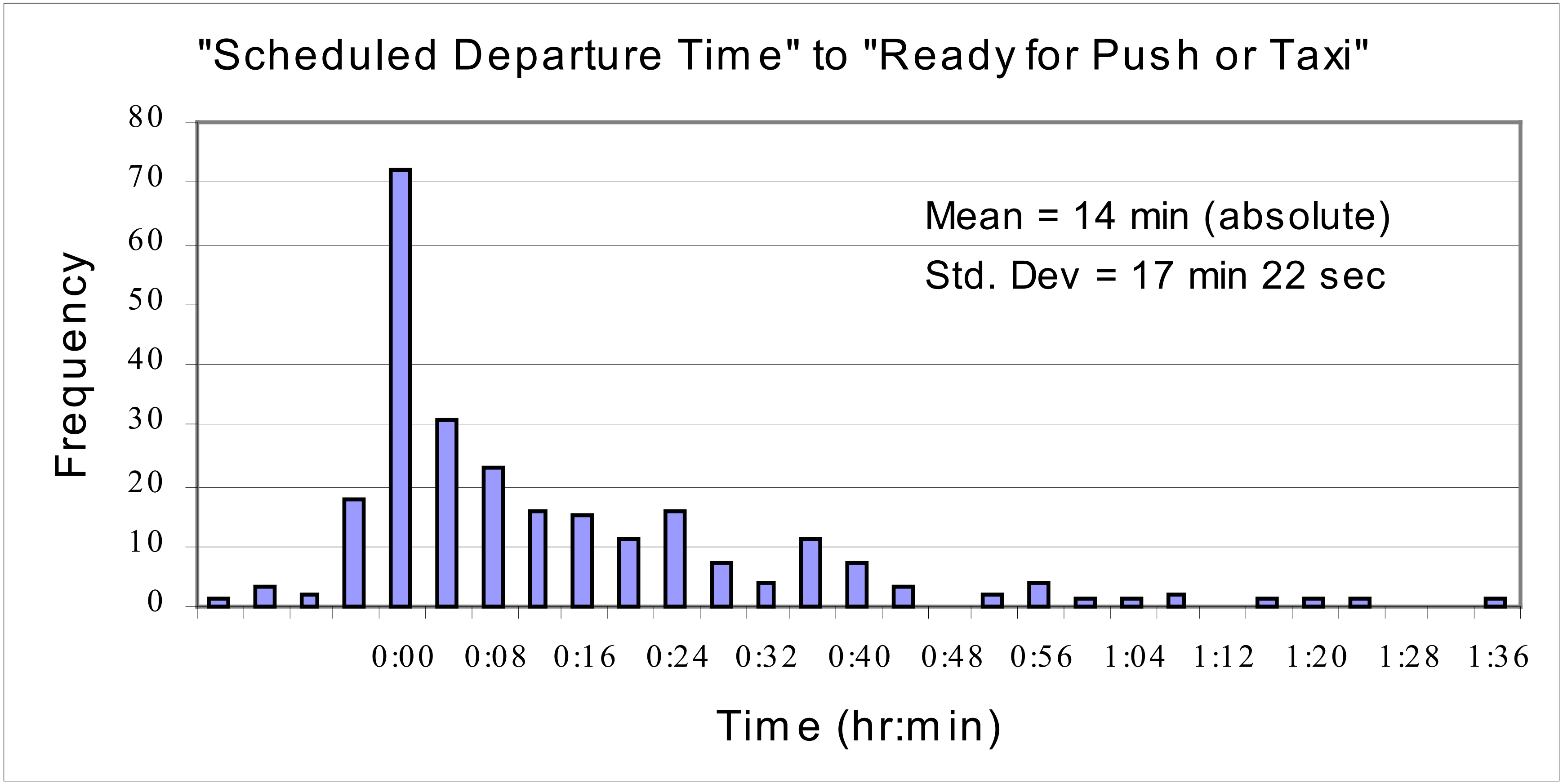
- Observations at BOS
- Queuing Model of Taxi Out Process with Aircraft Passing
- Observations at EWR
- Queuing Model of Departure Flow with Downstream Constraints

Interactive Queuing System

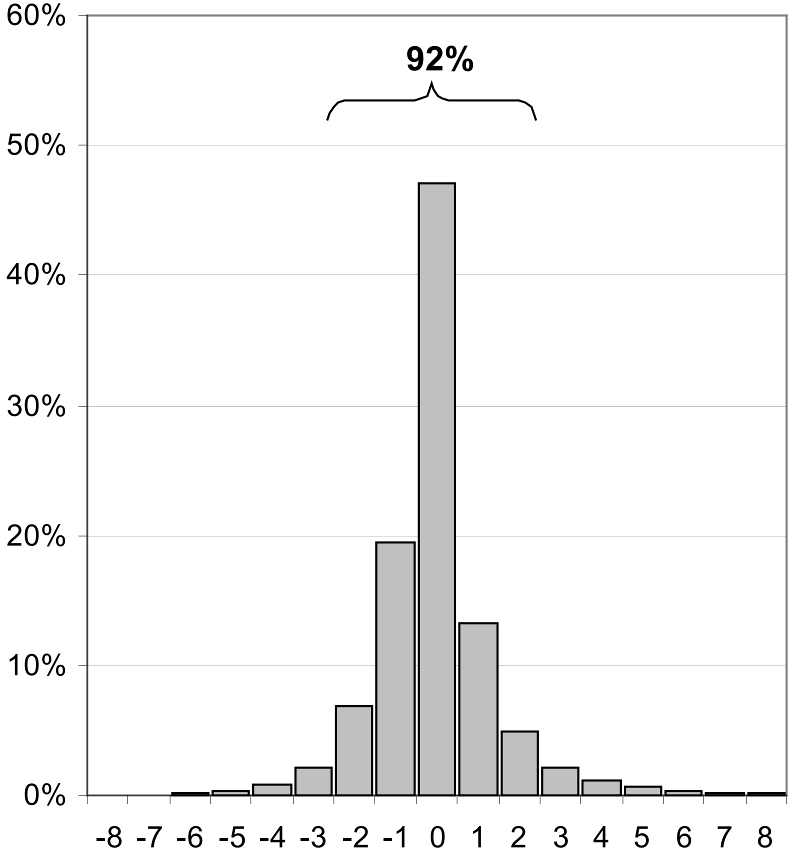




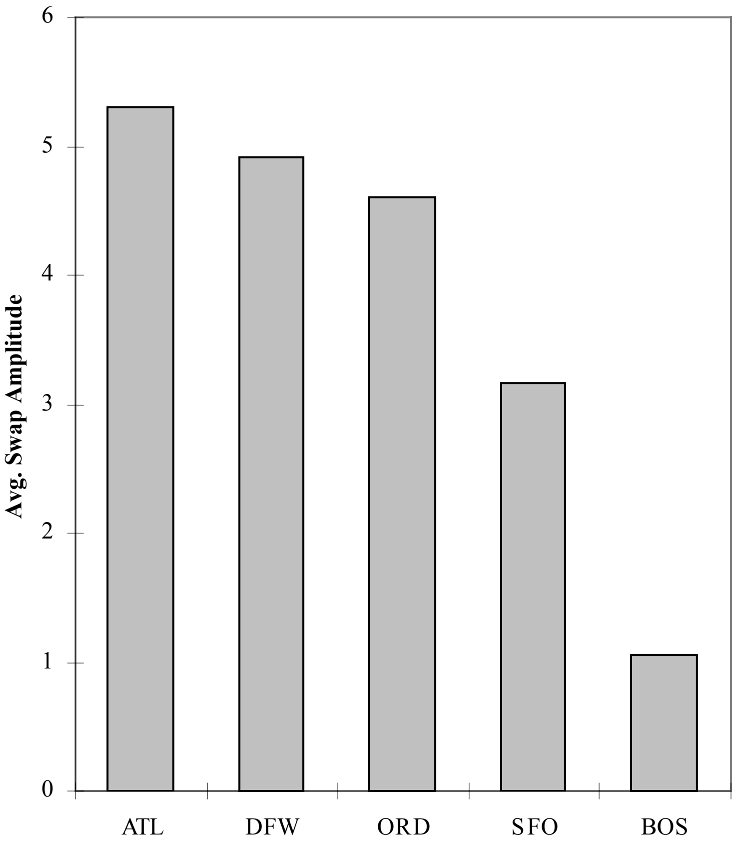
Uncertainty in Pushback Time



Passing During Taxi-Out



Histogram of swap magnitude at Logan airport



Comparison of 5 U.S. airports

Key Observations

- Airport is an interactive queuing system.
- Runway is the key flow constraint.
- Gates, Ramps and Taxiways are secondary flow constraints.
- Downstream constraints manifest at different points in the system such as at the runways and at the gates.
- High uncertainty in pushback time.
- Significant passing during taxi-out.
- ATC workload can be a flow constraint.

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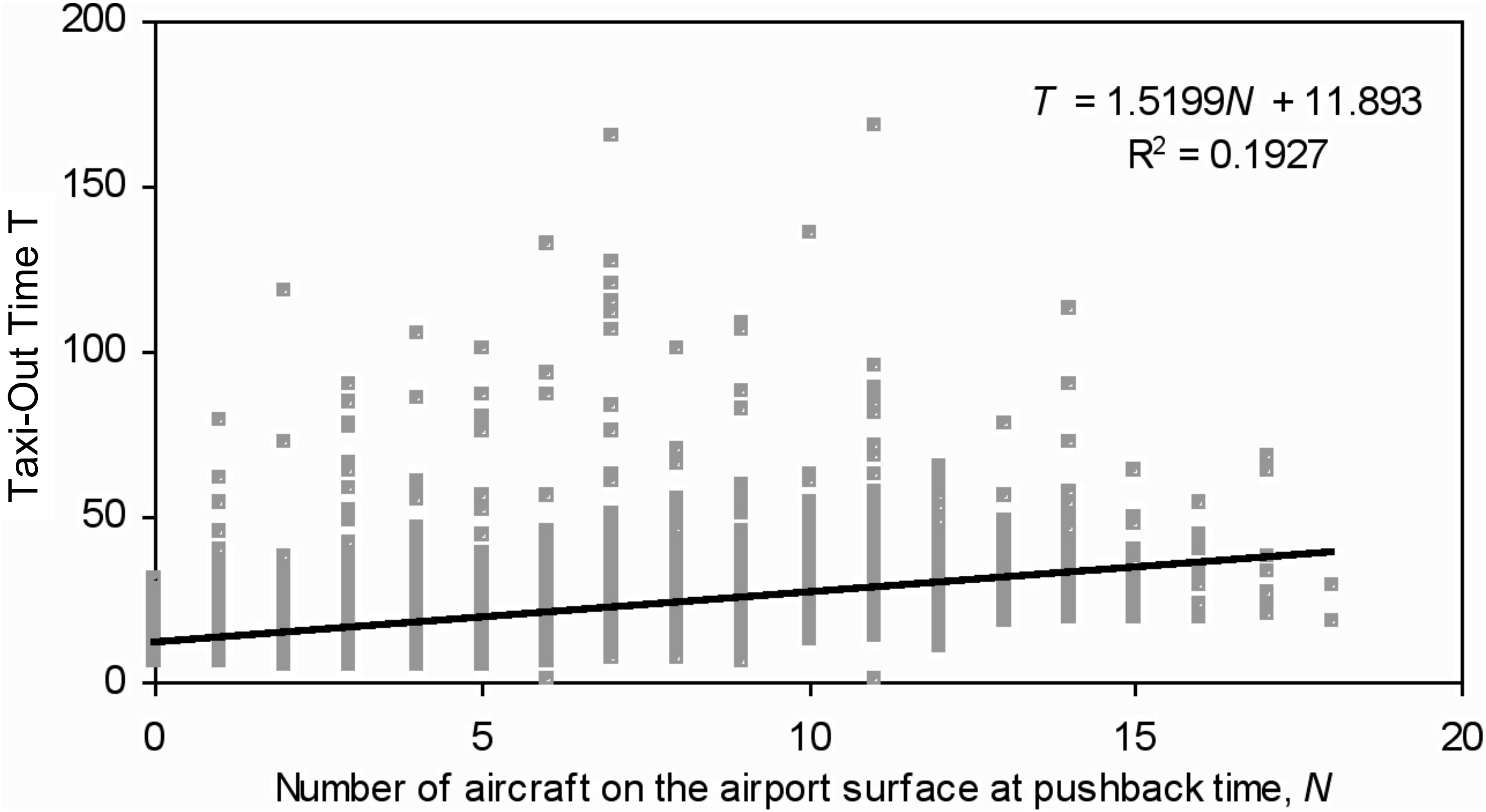
Queuing Model of Taxi Out Process with Aircraft Passing

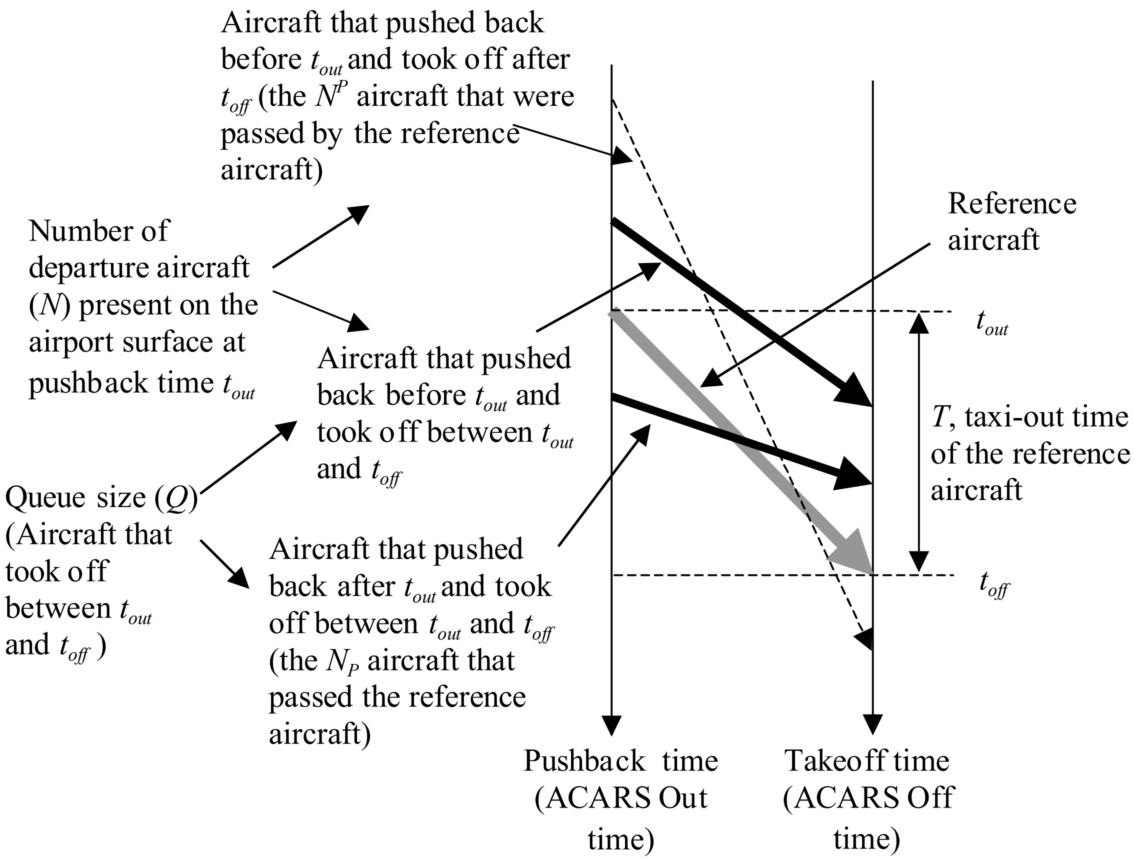
- Motivation:
  - Current queuing models for taxi out time are based on the ***number of aircraft*** taxiing out when aircraft being considered is pushed back from the gate.
  - Field observations and interviews at BOS indicate that there is significant ***passing*** that occurs ***during taxi out*** and that the taxi time is most strongly correlated with ***configuration, airline*** (surrogate for terminal) and ***queue at runway***.
- Modeling Approach:
  - Divide data based on configuration and airline
  - Quantify passing behavior as ***P(Q|N)***
  - Use passing behavior to map N to Q and then to T

$$\overline{T}(N) = \sum_{Q} [T(Q) * P(Q \mid N)]$$

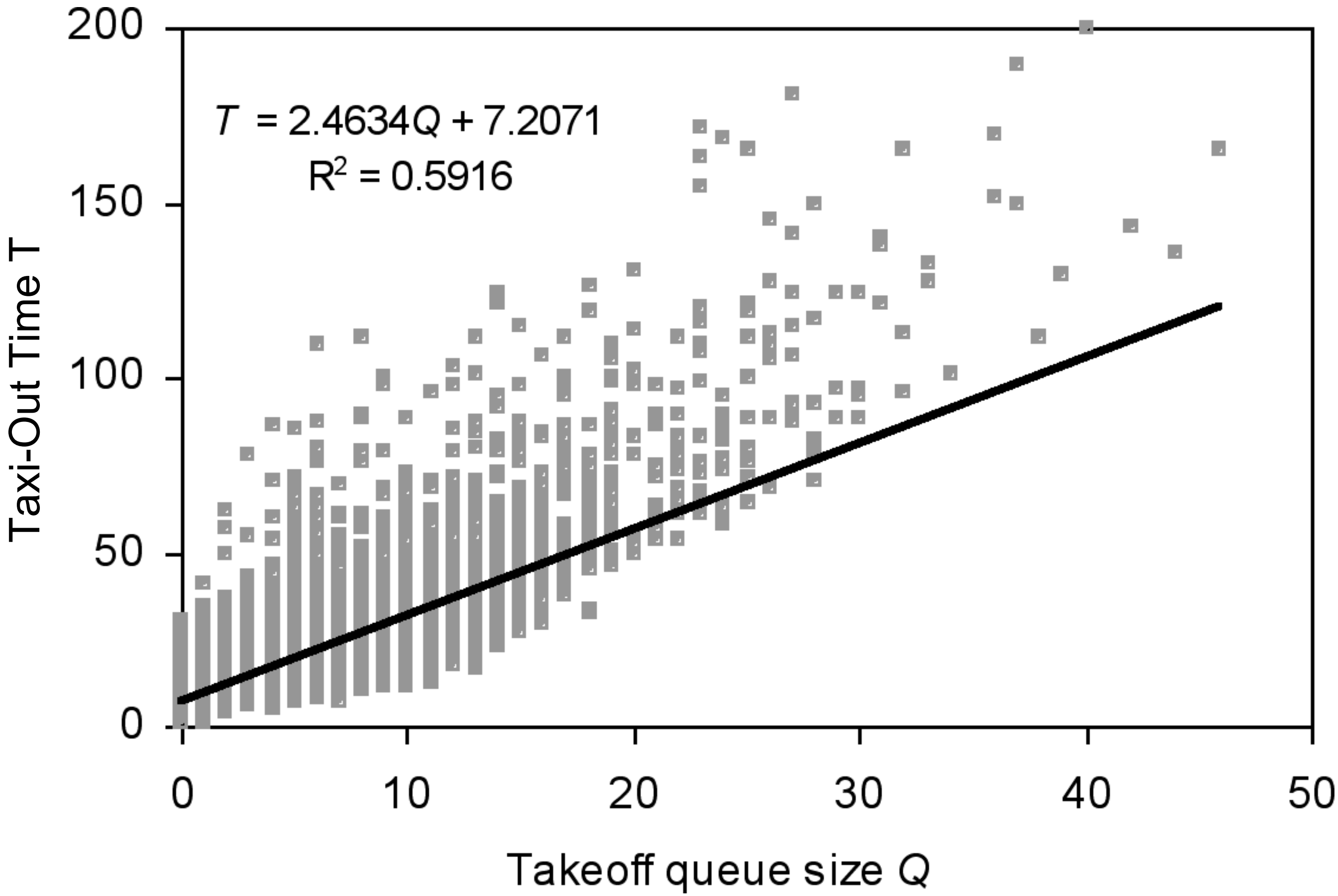
Taxi-Out Time vs. N Aircraft@Pushback



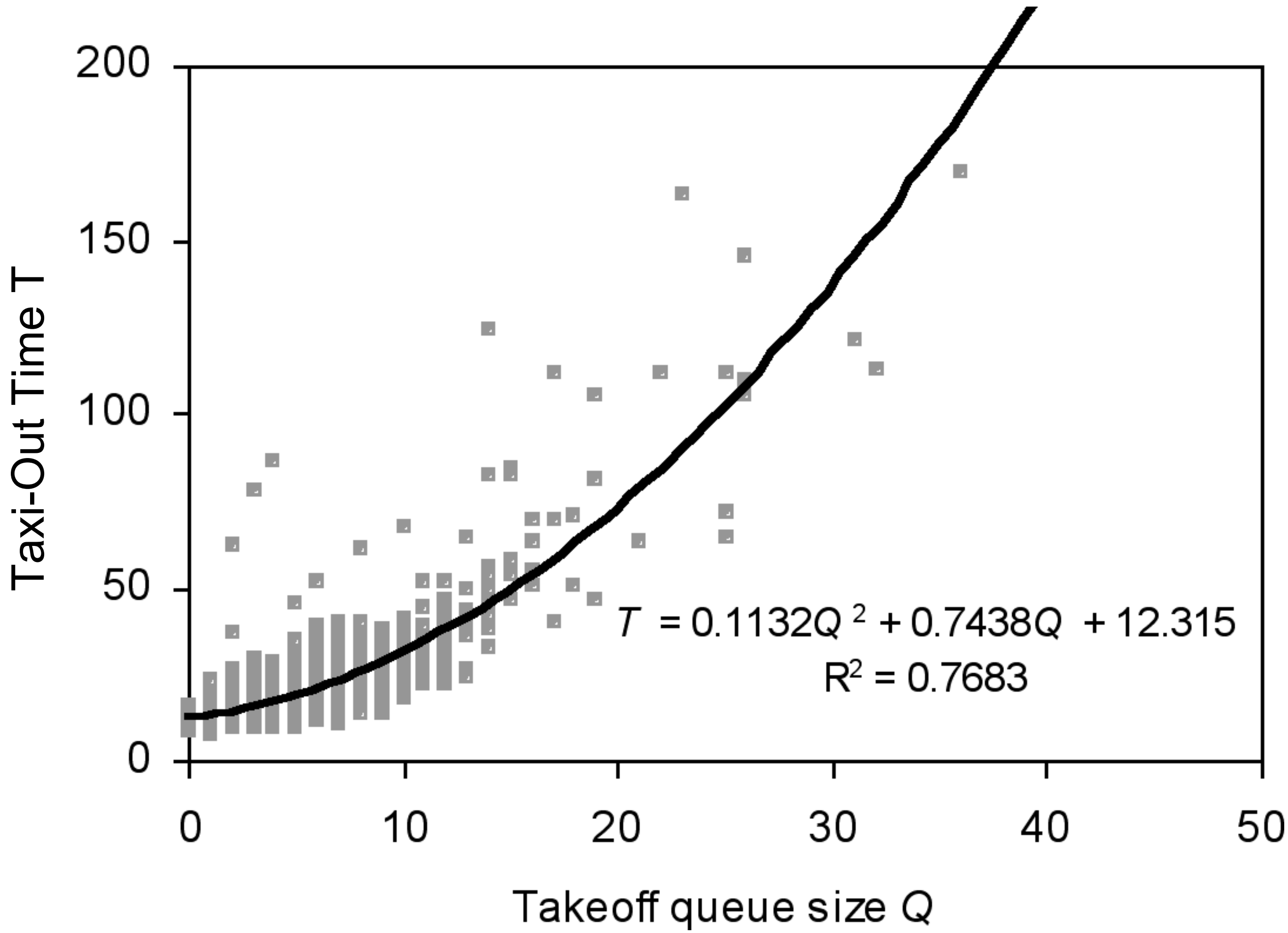
Passing Behavior



Taxi-Out Time vs. Takeoff Queue Size

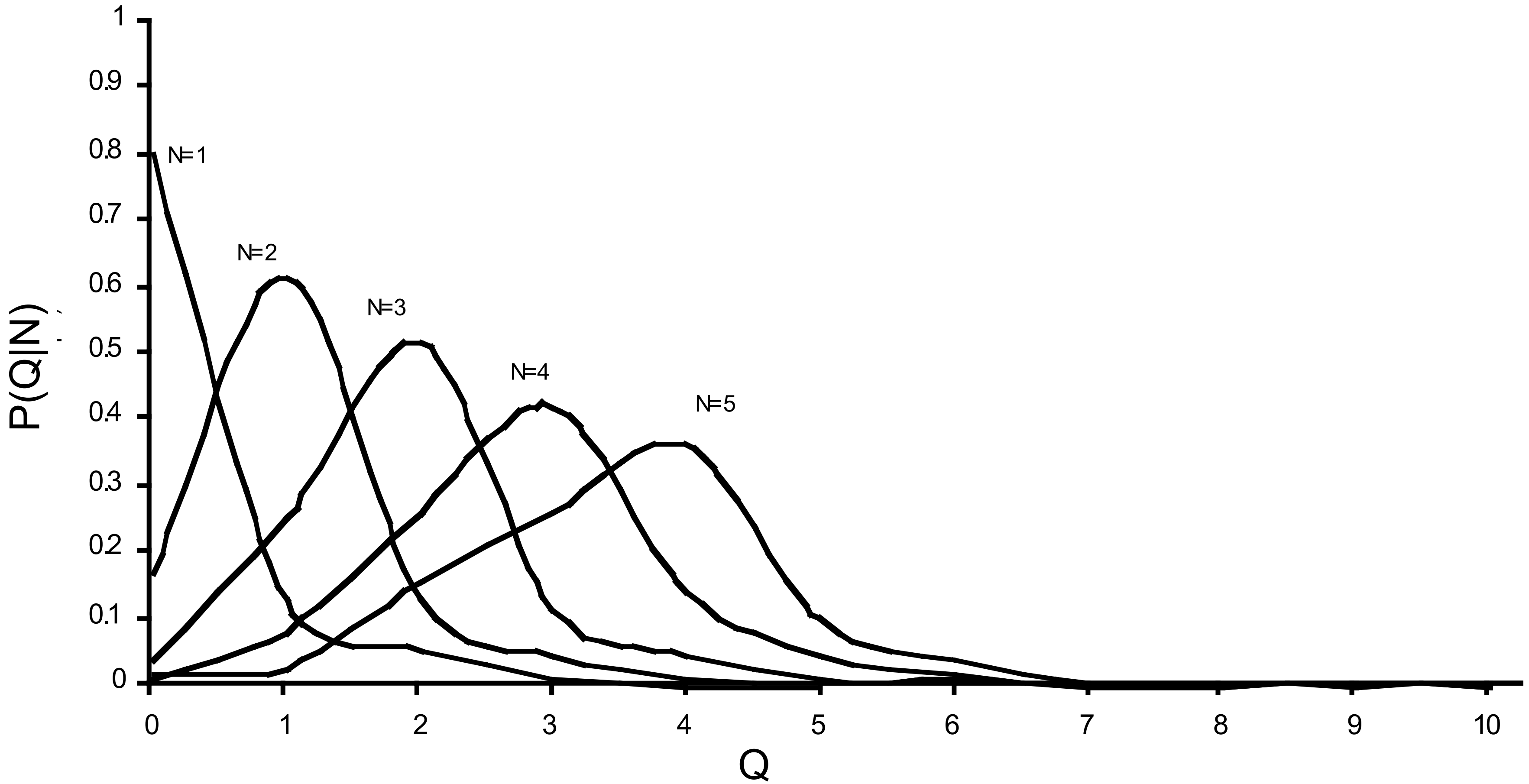


Taxi-Out Time vs. Takeoff Queue Size (given Configuration and Airline)



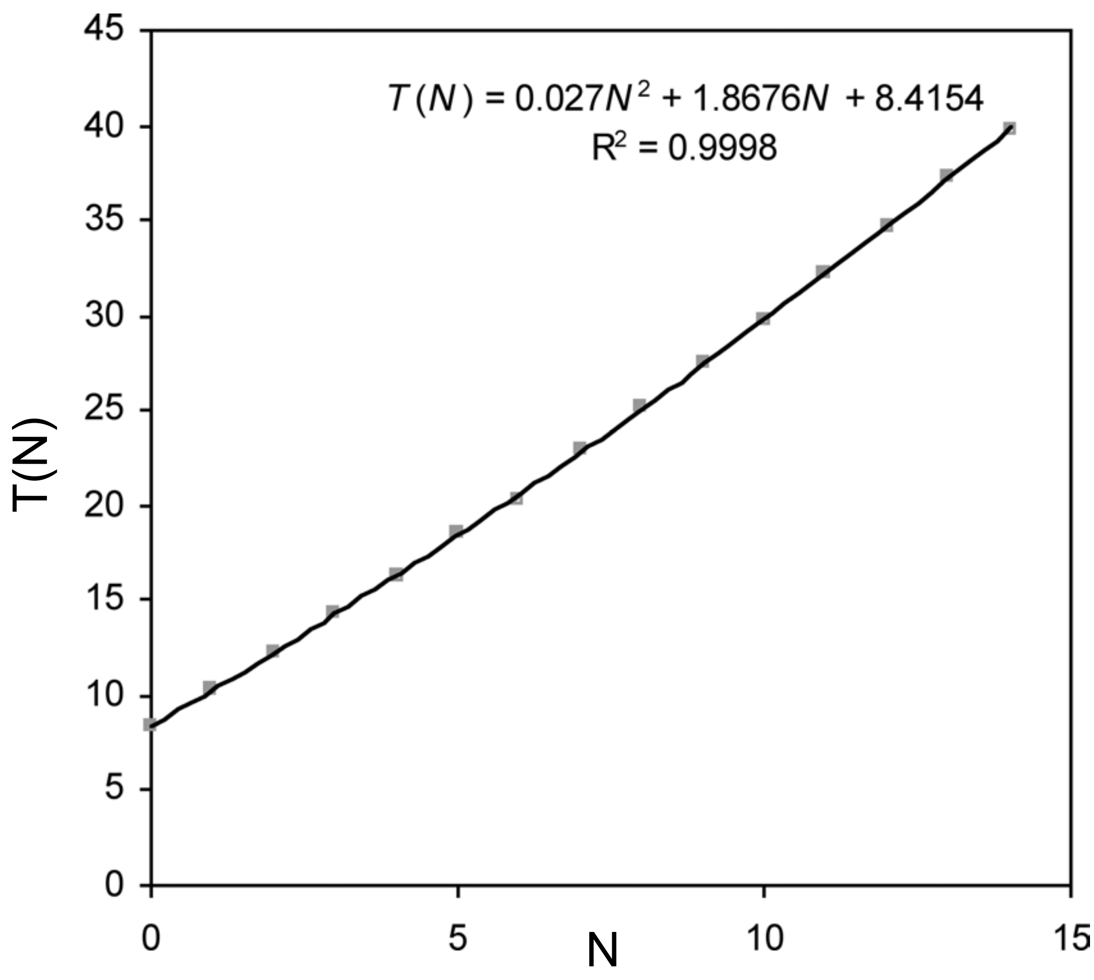
T(*Q*) for BOS configuration 27/22L-22R/22L and American Airlines

P(Queue Size Q | N Aircraft@Pushback)



Distributions P(*Q* | *N*) for BOS configuration 4R/4L-9/4R/4L and US airlines

Taxi-Out Time vs. N Aircraft@Pushback (with Passing Behavior Included)



T(N) for BOS configuration 4R/4L-9/4R/4L and Continental Airlines

Model Performance

	Running Average	Queuing Model
Mean absolute difference between actual and predicted taxi	5.69 minutes	4.56 minutes
% predicted within 5 minutes of actual taxi	53.74%	65.63%

			95% Confidence Interval for Difference of Means	
Group	t Value	Prob > t	Lower Limit	Upper Limit
Actual - Running Avg	-10.66	<.0001	-1.46	-1.00
Actual - Queuing Model	-0.848	0.3966	-0.30	0.12
Running Avg - Queueing Model	-14.21	<.0001	-1.30	-1.00

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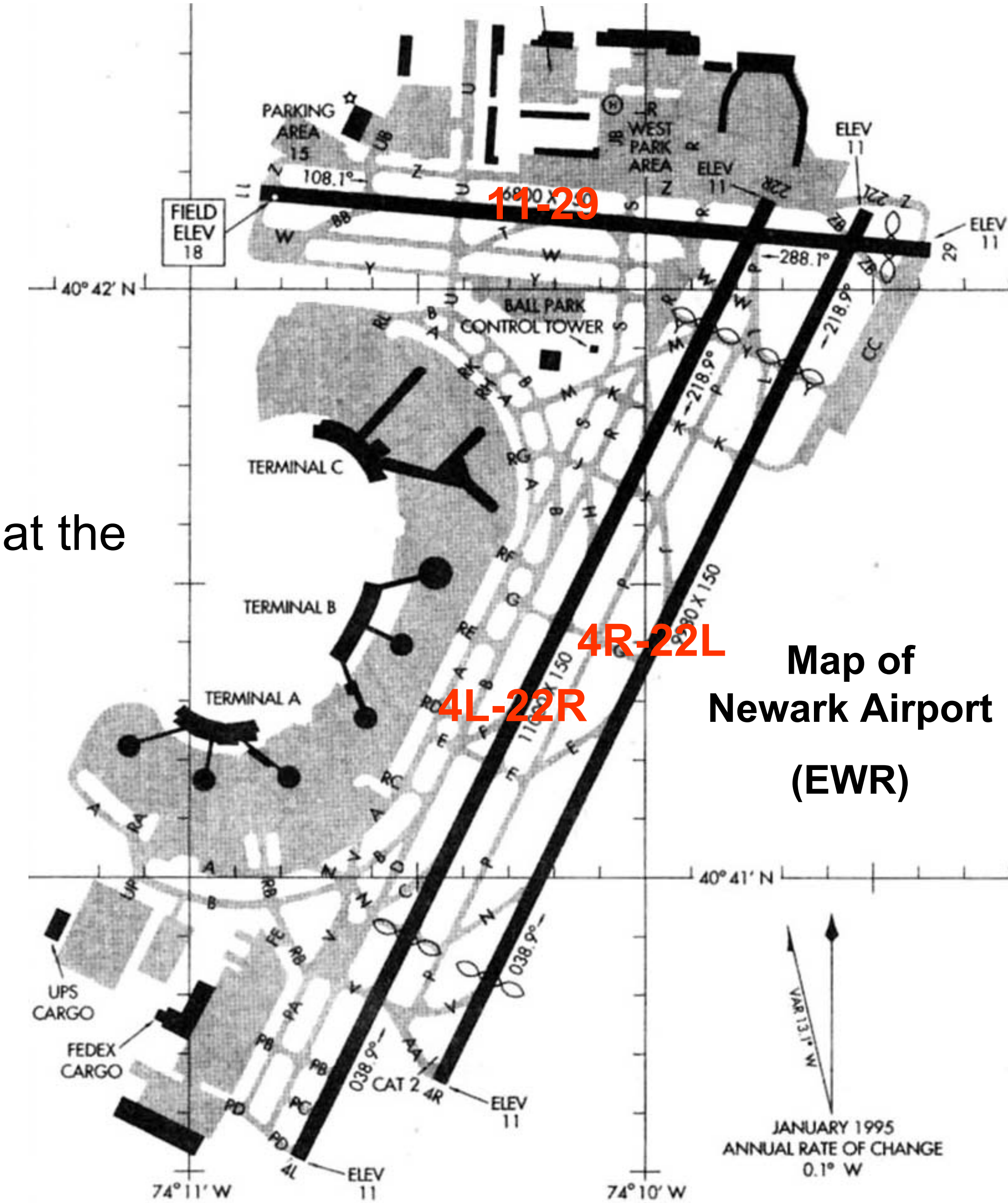
Cause of Weather Delays: EWR

- Sensitivity to weather
  - Runway limitations
  - Limited gate space
- Frequency of adverse weather
- The schedule operated at the airport
- New York airspace congestion



Map of Newark Airport

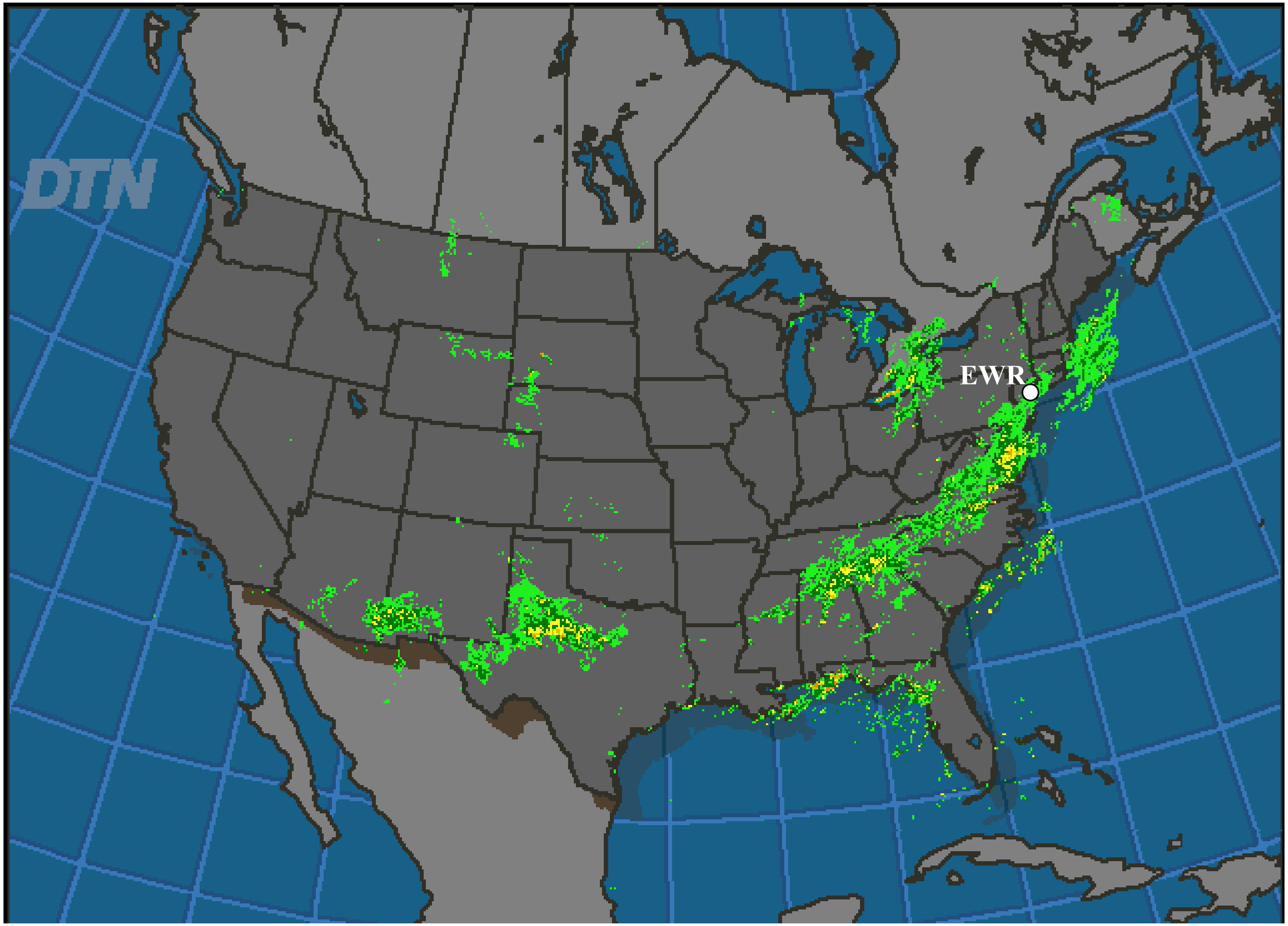
(EWR)

EWR System Study

- Site visit Thursday, June 29, 2000
  - Observations at NY TRACON, EWR Tower, CO Ramp Tower
  - "Worst summer ever"
  - Just before July 4th weekend
  - Large delays the previous day
  - Severe Weather Avoidance Program (SWAP) active, 1pm – 10:30pm EDT
  - Data collected focuses on departures

June 29, 2000 – National Weather

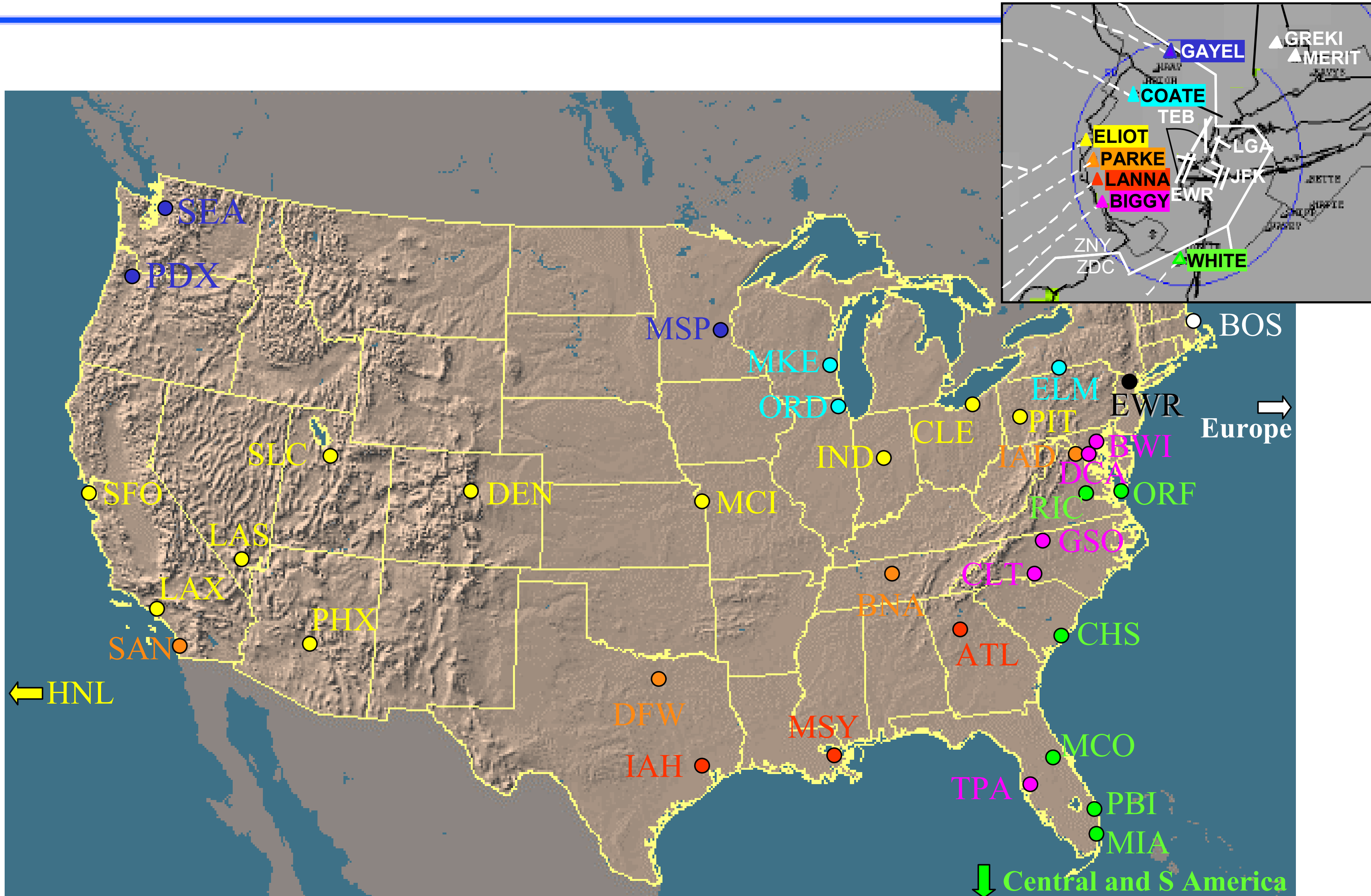
National Doppler Radar Map



9:30:00 EDT (13:30:00 Zulu)

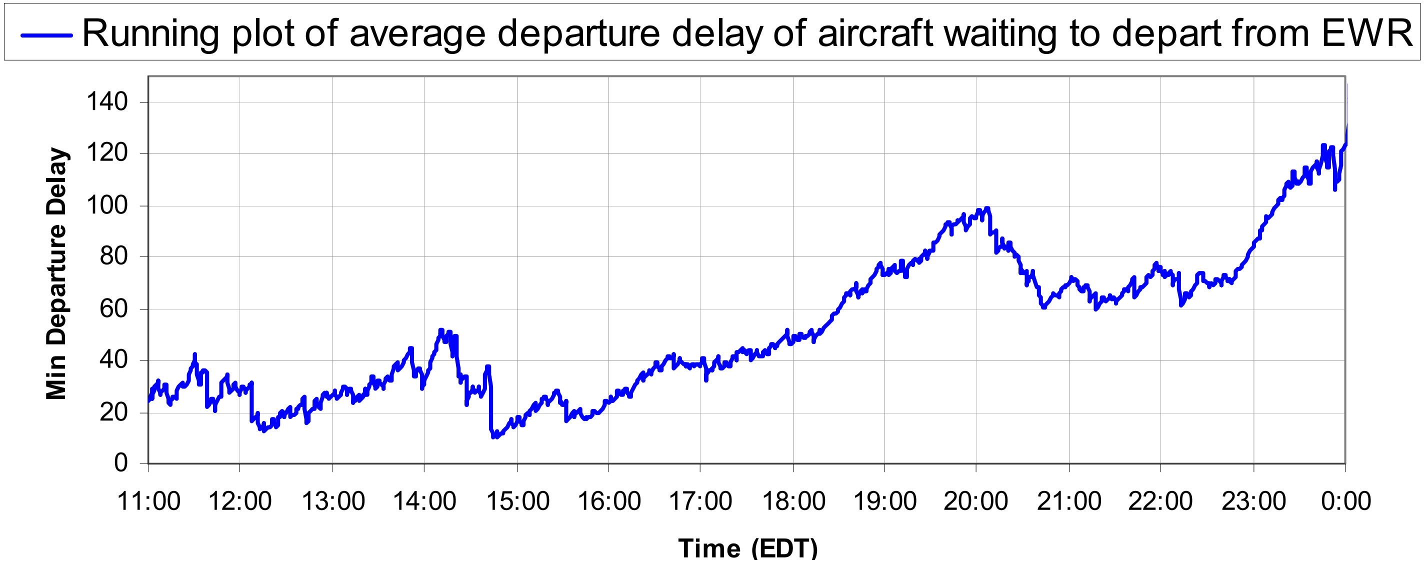
Source: Data Transmission Network

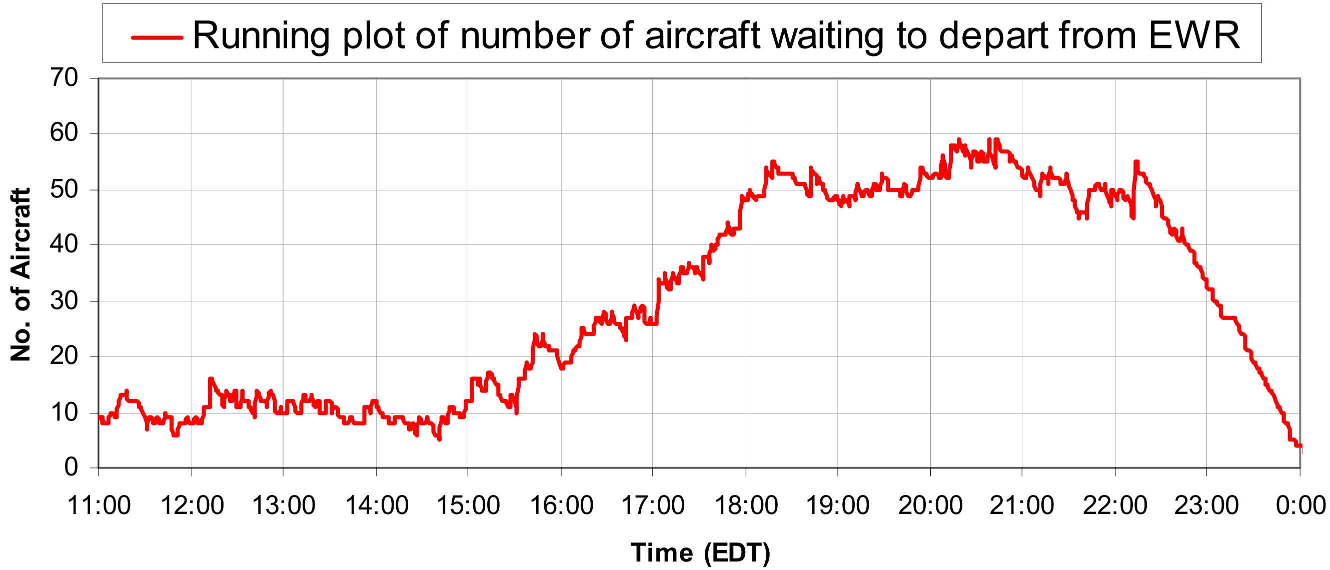
EWR Fix-Destination Mapping



According to preferred routings

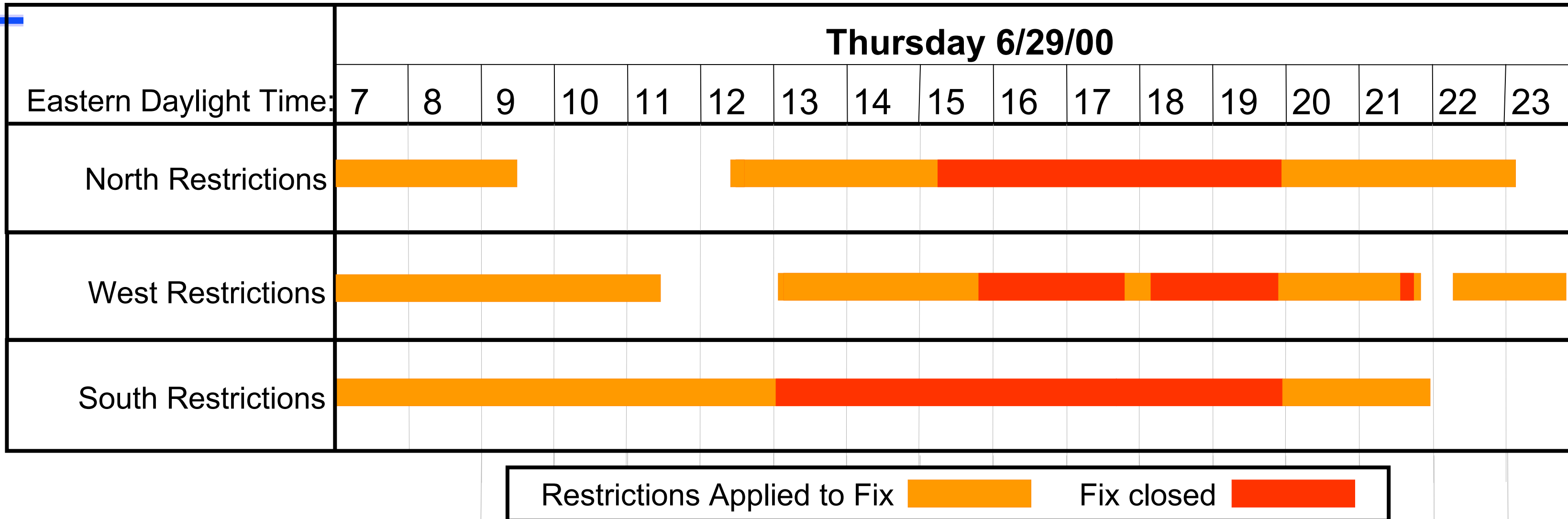
Impact on Delays

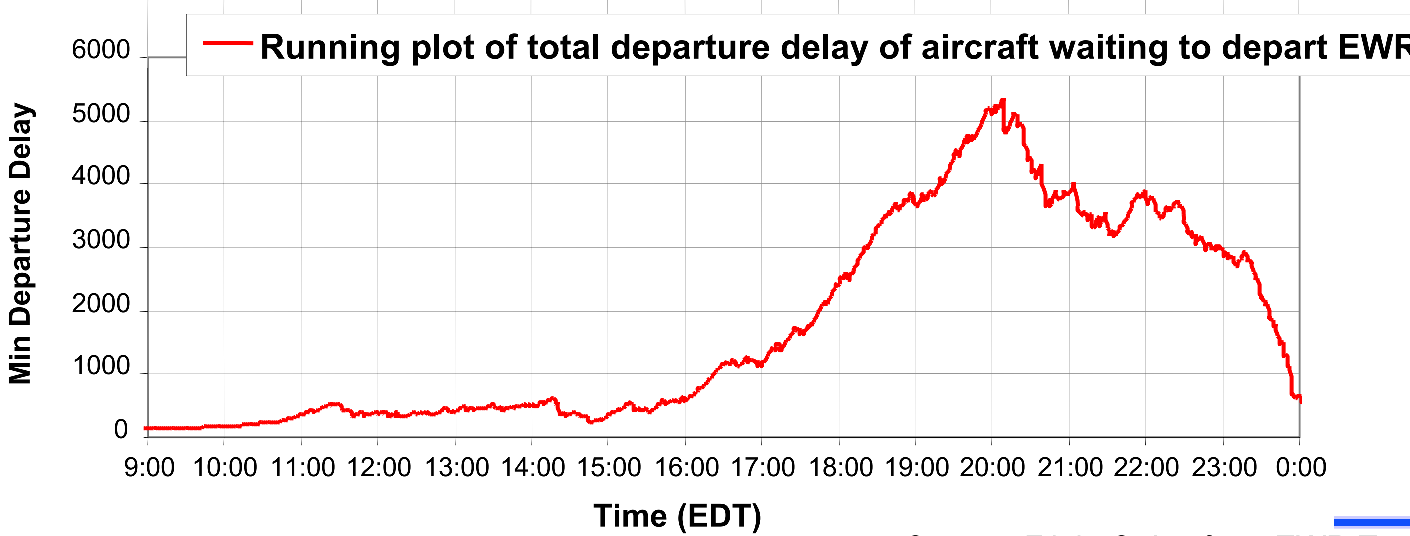




Source: Flight Strips from EWR Tower

Impact on Delays

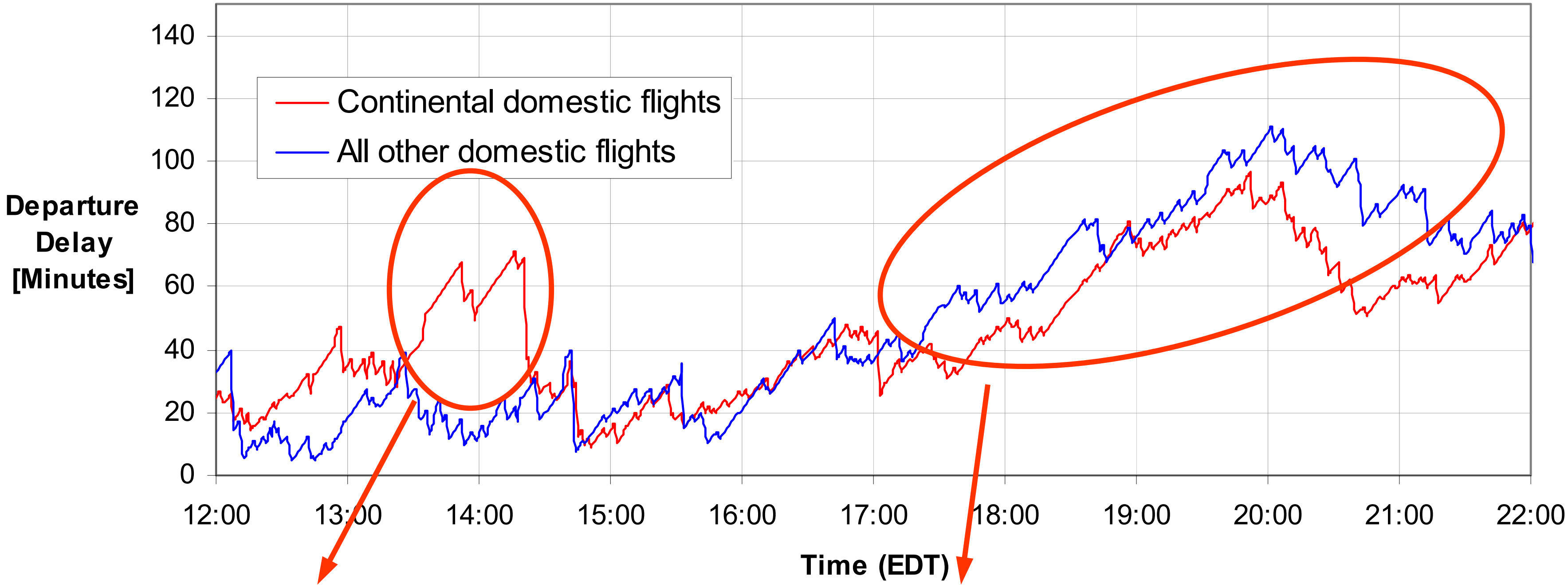




Source: Flight Strips from EWR Tower

Pre-Sequencing

Running plot of average departure delay of aircraft waiting to depart EWR



High CO arrival delays

Effect of pre-sequencing

Source: Flight Strips from EWR Tower

Key Observations

- Non-local restrictions (e.g. arrival restrictions at destination) and time-windowing (e.g. DSP or EDCT) has less airport-wide impact than flow-restrictions (e.g. MIT metering) at local fixes.
  - ⇨ Large impact per flight but only a few flights are affected.
- Controllers can impose minor MIT or MINIT restrictions over departure fix (e.g. stretching 3-mile takeoff minimum to 5 MIT) in TRACON airspace without impacting throughput.
  - ⇨ This flexibility is limited by workload involved in necessary sequencing, and traffic distribution among fixes.

Key Observations

- Restrictions caused by coupling of local weather, downstream weather and traffic demand.
  - Some fixes impacted by local weather but unrestricted because of light traffic.
  - Some fixes not impacted by local weather but restricted because of downstream weather.
- Opportunities for reroutes not utilized because of inter-facility coordination required.
  - Gap in weather to south not utilized for west reroutes because of coordination required with Washington Center & Cleveland Center.
- Airline planning (e.g. pre-sequencing) can reduce delays.

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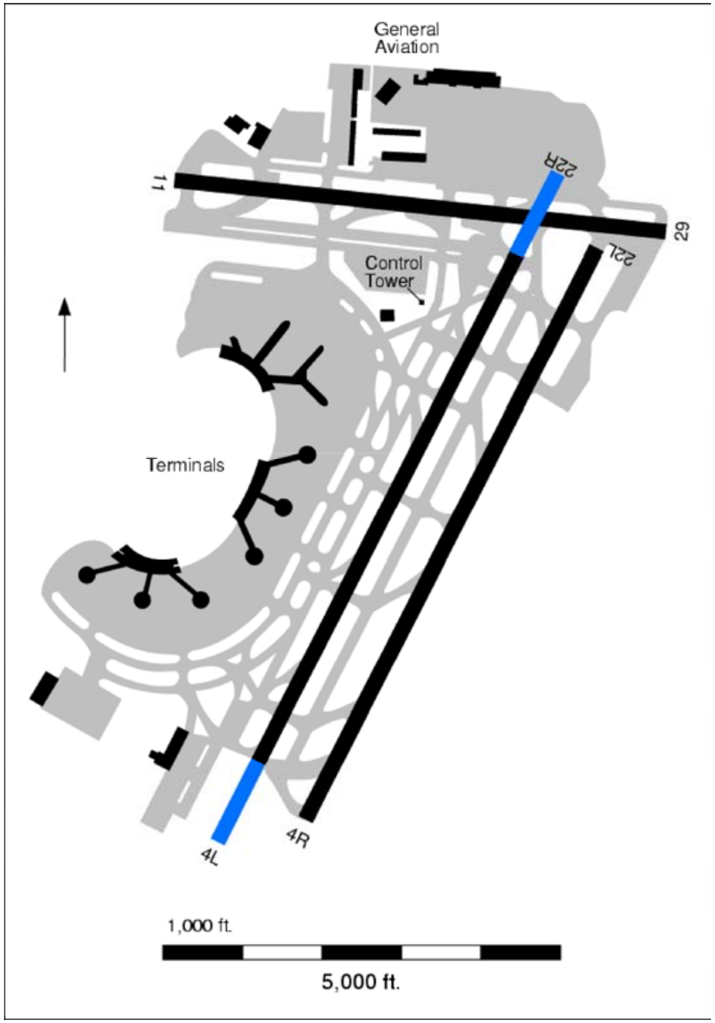
Queuing Model of Departure Flow with Downstream Constraints

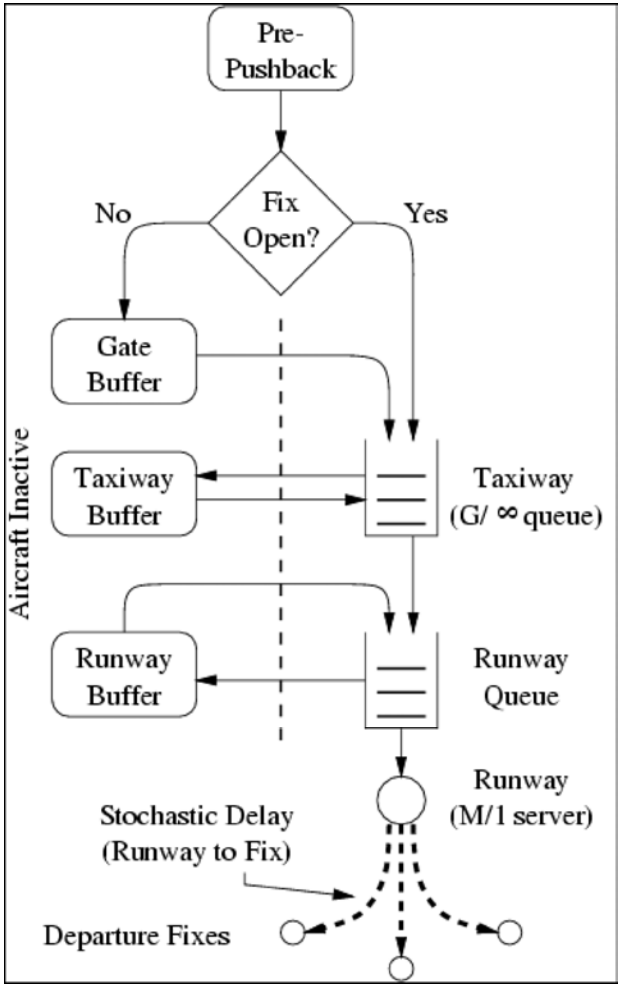
- **Motivation:**
  - Current queuing models for airport surface traffic focus on ***runways*** as major bottleneck.
  - Field observations and interviews at BOS and EWR indicate that ***downstream flow constraints*** as a major source of delay and that the closure of **departure fixes** are the most severe class of flow constraints.
- **Modeling Approach:**
  - Use observations at BOS and EWR to extend queuing model to include the effects of fix closures.
  - Test extended model via Monte Carlo simulation with EWR operations data collected on 2000-06-29.

Extending the Queuing Model (I)

- Many aircraft were pushed back on-time, only to be held in parking areas or "penalty boxes" during fix closures.
  - ⇨ Parking areas did not impede normal surface traffic.
  - ⇨ Parking capacity was not a limiting factor.
- Runway 11/29 was used for less than 4% of flights.
  - ⇨ Queuing model only requires a single runway queue.



Extending the Queuing Model (II)



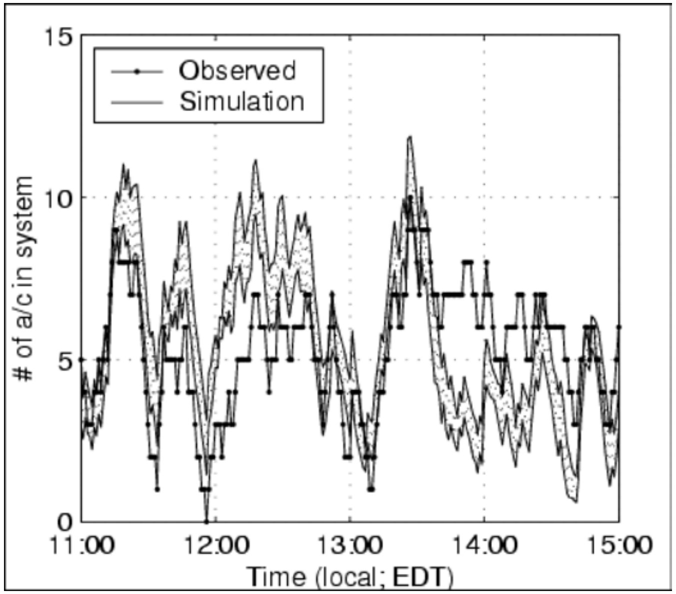
- Right side of figure:
  - Original queuing model
- Left side of figure:
  - Fix-closure effects
- When fix closes, A/C move to "buffers", and stop making progress toward takeoff.
- When fix opens, A/C start making progress again.
- A/C which leave runway queue must re-enter at end of the queue (i.e. they lose their spot in line).

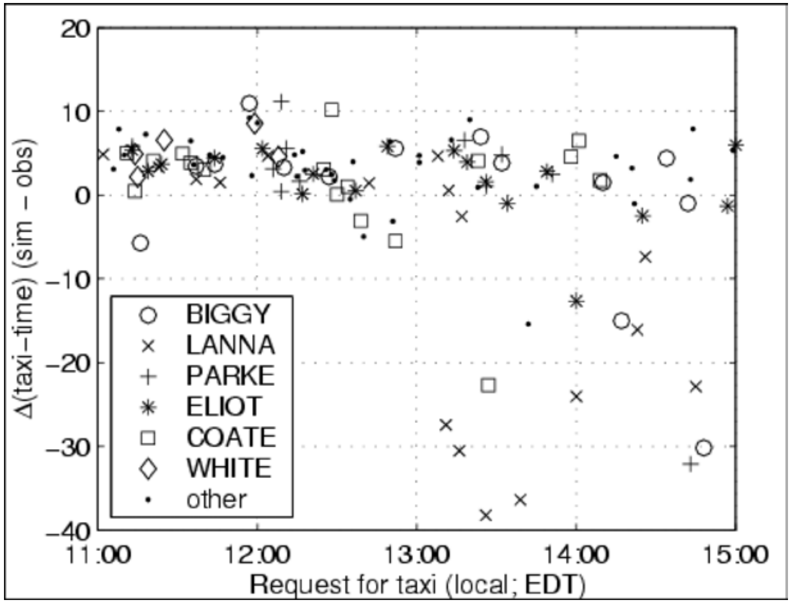
Calibration and Testing

- Operations data:
  - ⇨ Taken from CATER system and TRACON logs.
  - ⇨ Data set for 11:00 to 19:00 EDT on July 29, 2000.
- Stochastic runway service time:
  - ⇨ Estimated from 09:00 to 11:00 period (very light restrictions).
  - ⇨ Triangular density (mode of 1 minute, range of 0 to 2 minutes).
- Stochastic unimpeded taxi-out times:
  - ⇨ Estimated for major passenger carriers from 1998 ASQP data.
  - ⇨ Same distribution (9.75±2.75 min.) assumed for other carriers.
- Testing Procedure:
  - ⇨ Run Monte Carlo simulation of traffic over 11:00 to 19:00.
  - ⇨ Compute average results over 40 Monte Carlo runs.

Monte Carlo Results: Early Period (11:00 to 15:00 EDT)

- Simulation accurately tracks observed number of departing A/C.
- 88% of flights (107 out of 122) have taxi-time error‡ of 10min or less. Of the 15 outliers, 8 used LANNA fix, with 40MIT from 13:05 to 15:50.
- In contrast, original queuing model gives errors of up to 3 hours for flights hit by fix closures, and wider distribution of errors for other flights.

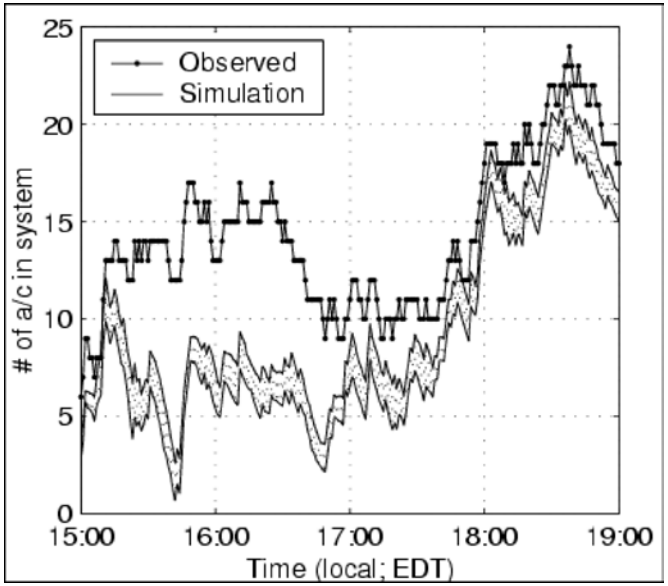


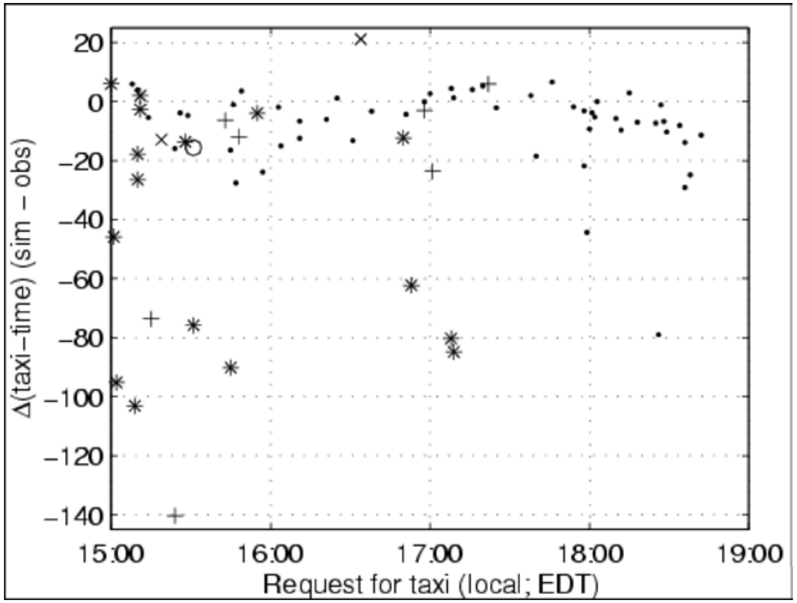


‡: Def'n of taxi-time "error": Difference between actual taxi-time and average simulated taxi-time.

Monte Carlo Results: Late Period (15:00 to 19:00 EDT)

- Much larger number of restrictions during this period. Simulation tracks poorly until 17:00 when it starts to recover.
- Flights through ELIOT and PARKE account for most of the extreme errors. Both fixes closed from 16:00 to 16:30 and again from 18:10 to 19:00, but had only 20MIT during remaining period; hence large delays must be due to some other cause.





Research Questions

- *Question:* After a fix closure is lifted, what is the expected response-time for fix throughput to reach capacity? Can this response-time be minimized by buffering A/C in different parts of the system?
- *Question:* At many airports, departure fixes are clustered, e.g. the West fixes at EWR. Are there workable re-routing procedures which could switch fixes (and thus avoid closures) in response to local weather?
- *Question:* What is the utility of lead-time information on upcoming changes to fix restrictions?
- *Question:* What level of MIT/MINIT spacing effectively closes a fix?

Further Extensions to the Model

- Severe spacing restrictions can combine with high traffic levels, overloading the flexibility to meet such restrictions via re-sequencing before takeoff or vectoring after takeoff. To correctly model effects of spacing restrictions, need to capture sequencing logic of controllers.
- Airspace buffering for departures is not currently observed. However, may be worth extending model in that direction, to evaluate potential benefits (setting aside workload and procedural issues for the moment).