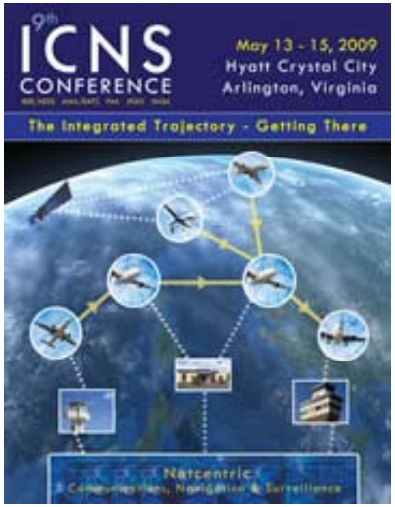
Queuing Analysis of Interdependencies in Airport Surface and Metroplex Operations

Husni Idris

L-3 Communications



ICNS Conference

Arlington, VA

May 13, 2009

Agenda

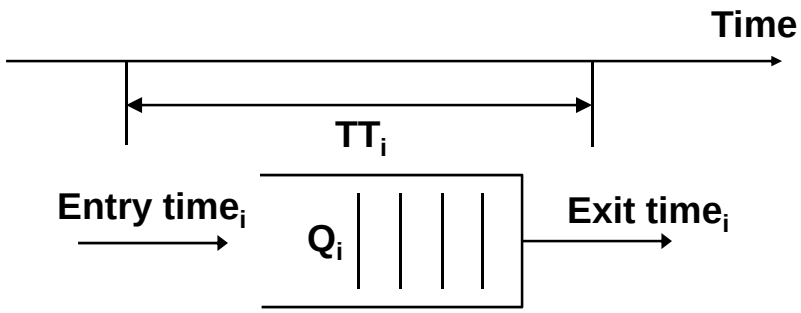
- **Research Question and Motivation**
- **Queuing Analysis: Model and Approach**
- **Analysis and Insights**
  - ***Queuing Analysis of Airport Surface Operations***
  - ***Queuing Analysis of Multi-Airport (Metroplex) Terminal Operations***
- **Summary and Future Research**

Research Question and Motivation

- **Air traffic is a queuing system**
- **Hypothesis: Interdependencies between airport flows manifest in queuing dynamics**
  - ***Namely, in correlation between travel time and queue size***
- **Demonstrate the queuing dynamics in known interdependency situations based on observations and documented procedures:**
  - ***Airport surface operations observed at Boston Logan***
  - ***Metroplex terminal operations observed in New York metroplex***
- **Apply insights in developing aggregate metrics that enable detecting behavior at environments with unknown interdependencies**

Queuing Model and Analysis Method

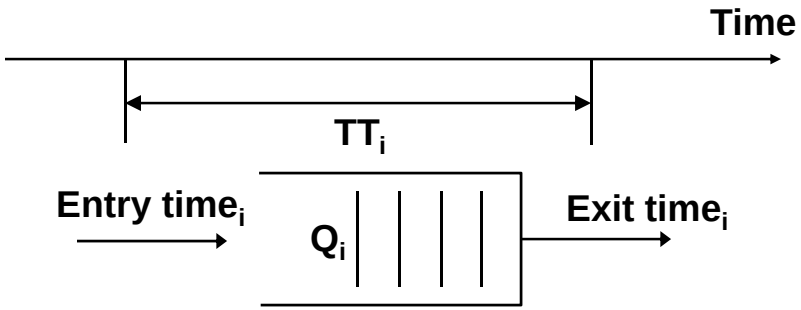
- **Analyze dependency between travel time TT and queue size Q for each aircraft i**

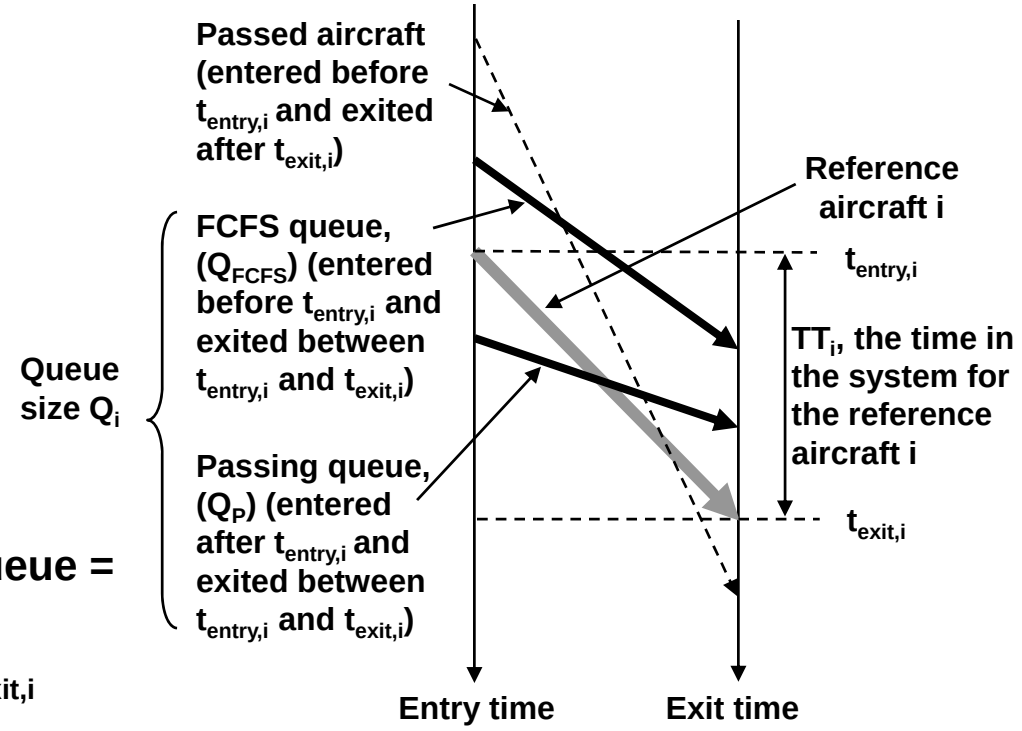


- **Analyze dynamics under specific conditions, for example:**
  - ***Runway configuration***
  - ***Downstream restrictions***
  - ***Different queue compositions***

Queuing Model and Analysis Method

- **Measure queue size Q_i for reference aircraft i taking passing into account**



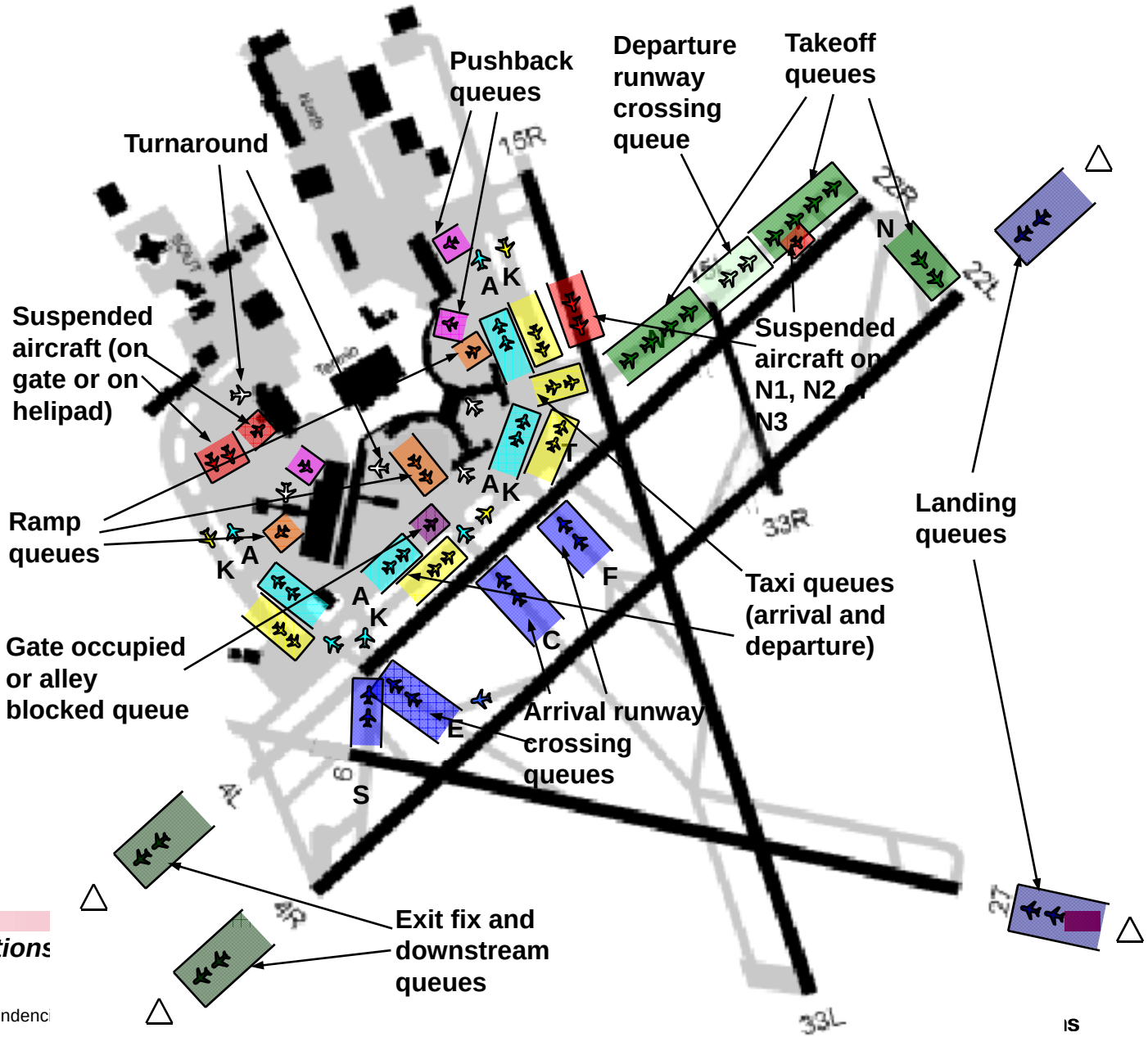


- **Travel time $TT_i = t_{exit,i} - t_{entry,i}$**
- **Queue size Q_i = FCFS queue + passing queue =**

  Number of flights j with: $t_{entry,i} < t_{exit,j} < t_{exit,i}$

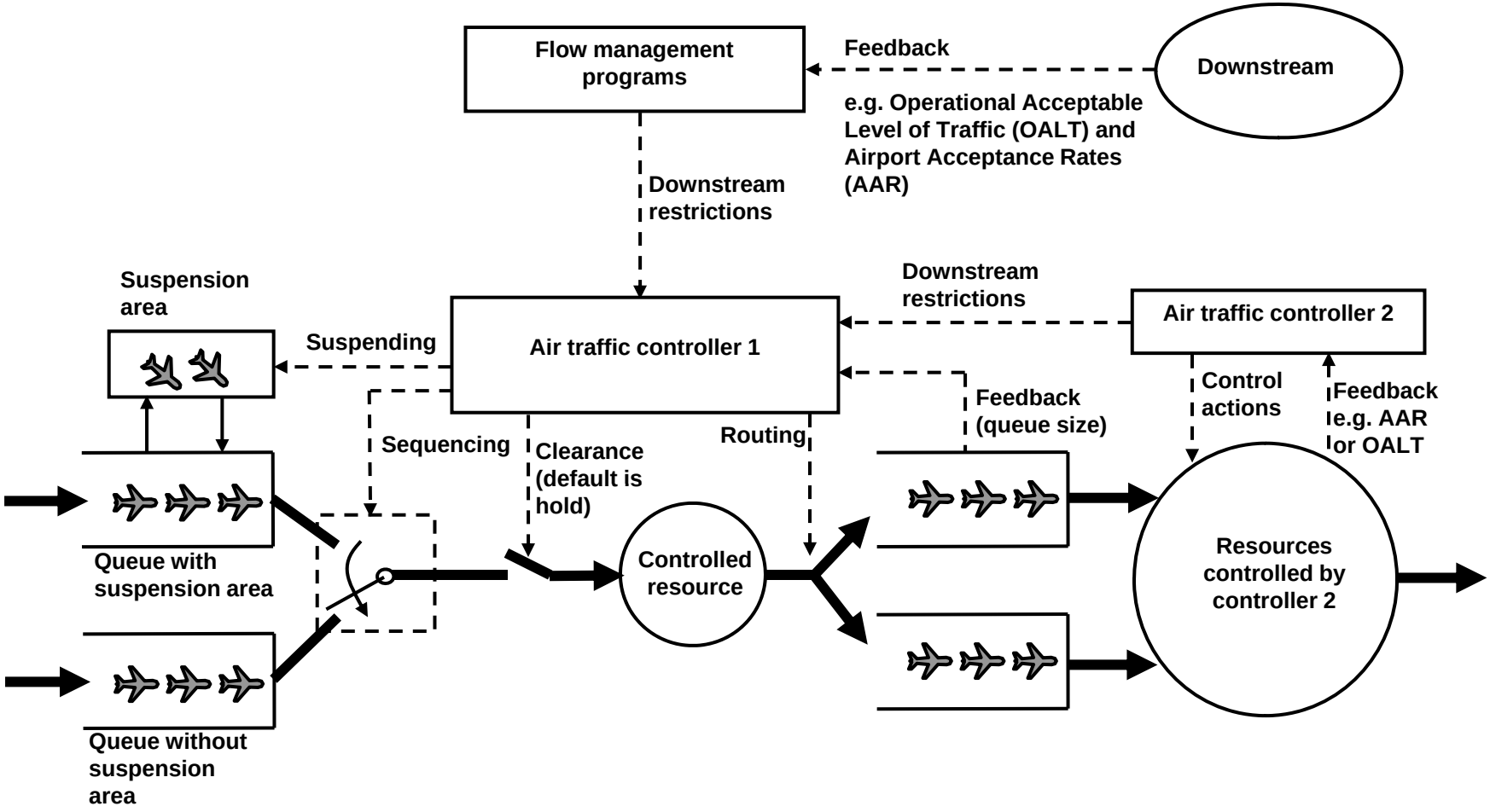
Analysis of Airport Surface Operations

- **Queuing network at Logan Airport**
  - ***Landing 27 & 22L***
  - ***Departing 22R & 22L***



Analysis of Airport Surface Operations

- **Queuing is also caused by waiting for controller services and downstream resources**



Analysis of Airport Surface Operations

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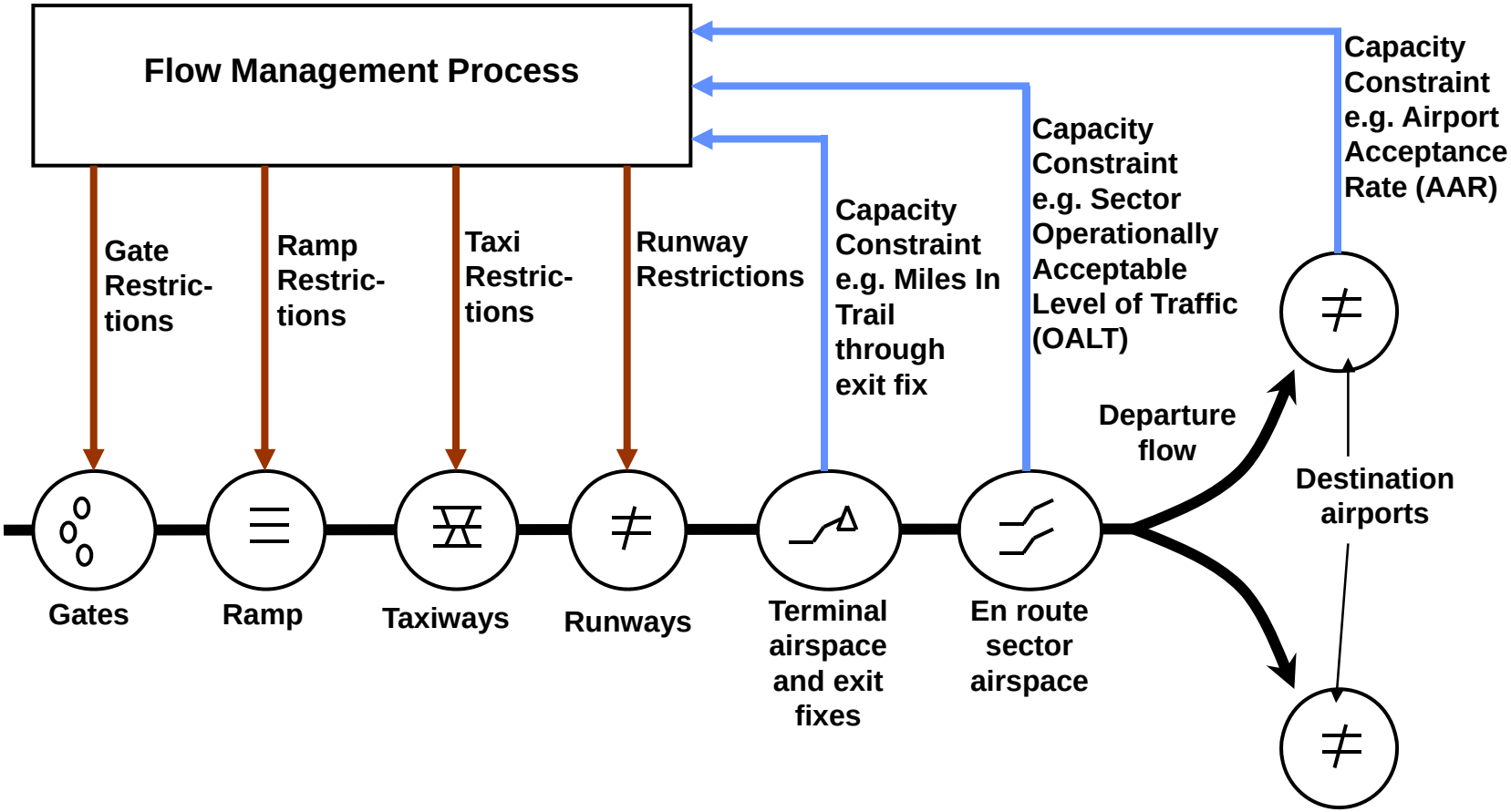
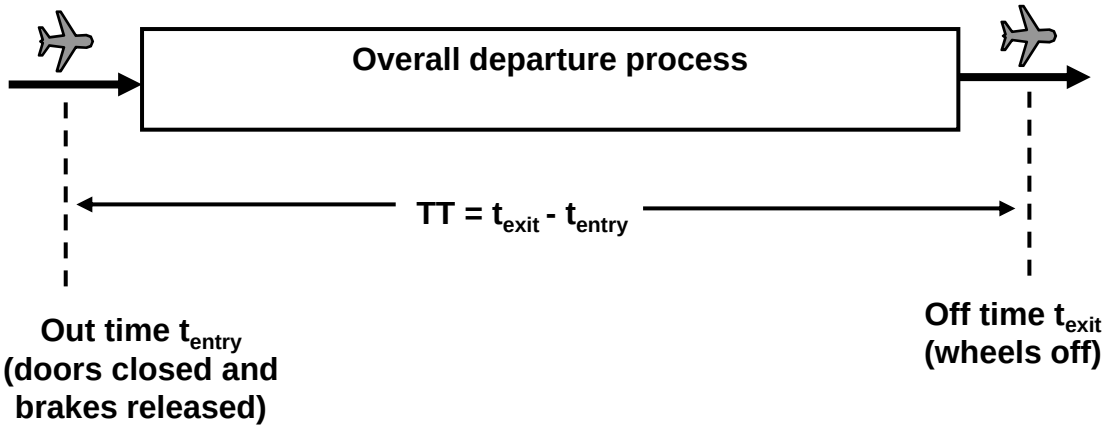


Analysis of Airport Surface Operations

- **Queuing dynamics of departures**
  - *Analyzed taxi out time versus queue size for a sample of one month of ASQP data - July 1998*

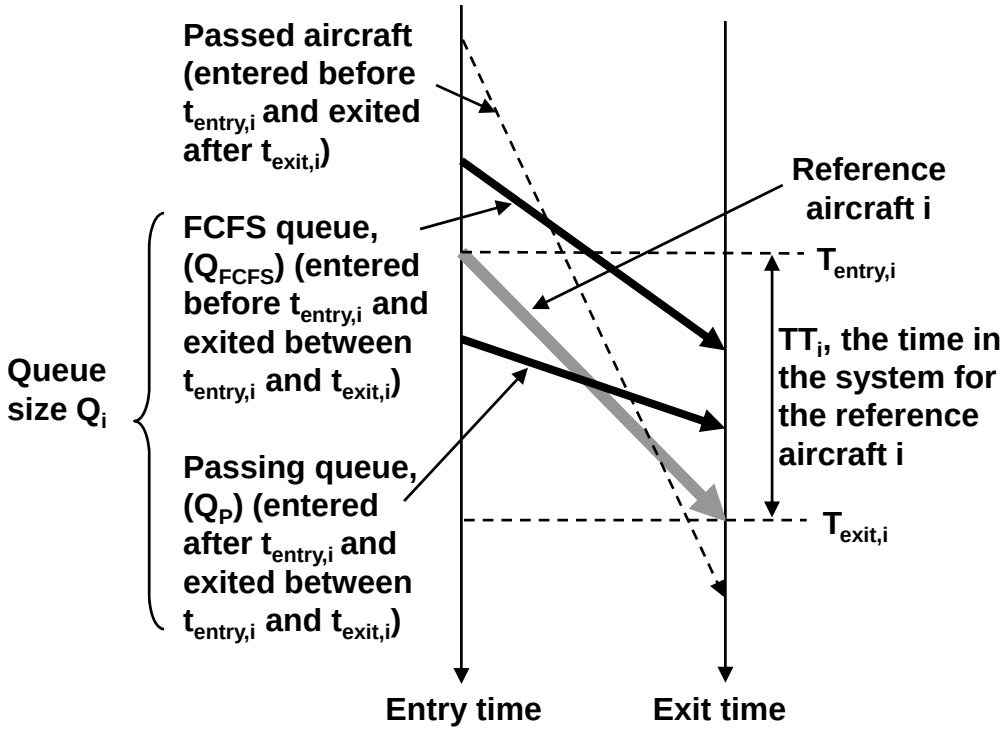


  - $T_{entry,i}$ = *Out time* = Out_i
  - $T_{exit,i}$ = *Takeoff time* = Off_i
  - *Travel time* $TT_i = t_{exit,i} - t_{entry,i} = Off_i - Out_i$
  - *Queue size* Q_i = *FCFS queue + passing queue =*

    Number of flights j with: $Out_i < Off_j < Off_i$

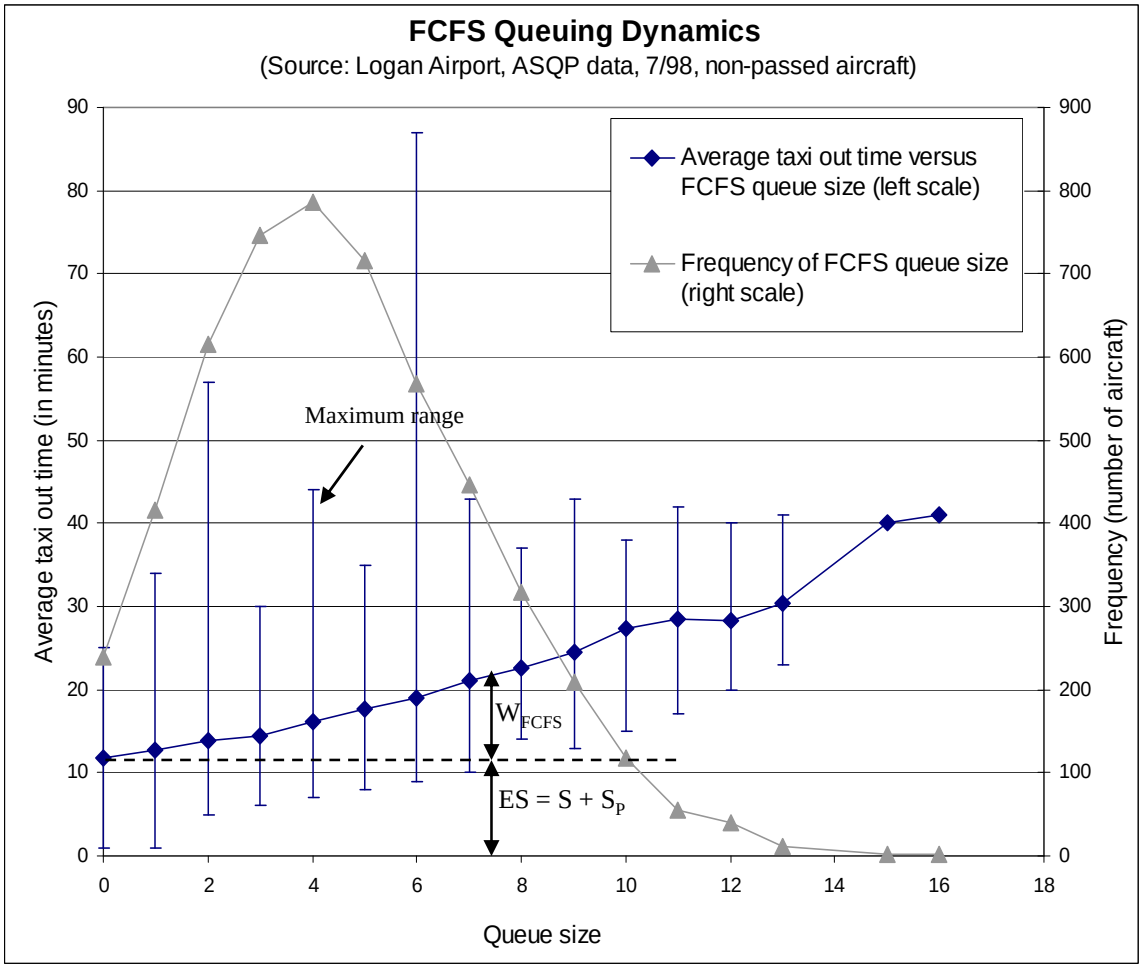
Analysis of Airport Surface Operations

- **Effect of control (sequencing, routing and holding) manifests through passing**
- **The sample was divided into two sub-samples:**
  - *Aircraft that were not passed ($Q = Q_{FCFS}$ and $Q_P = 0$), from which FCFS queuing was identified, and*
  - *Aircraft that were passed ($Q = Q_{FCFS} + Q_P$ and $Q_P > 0$), from which the waiting time due to passing was identified*



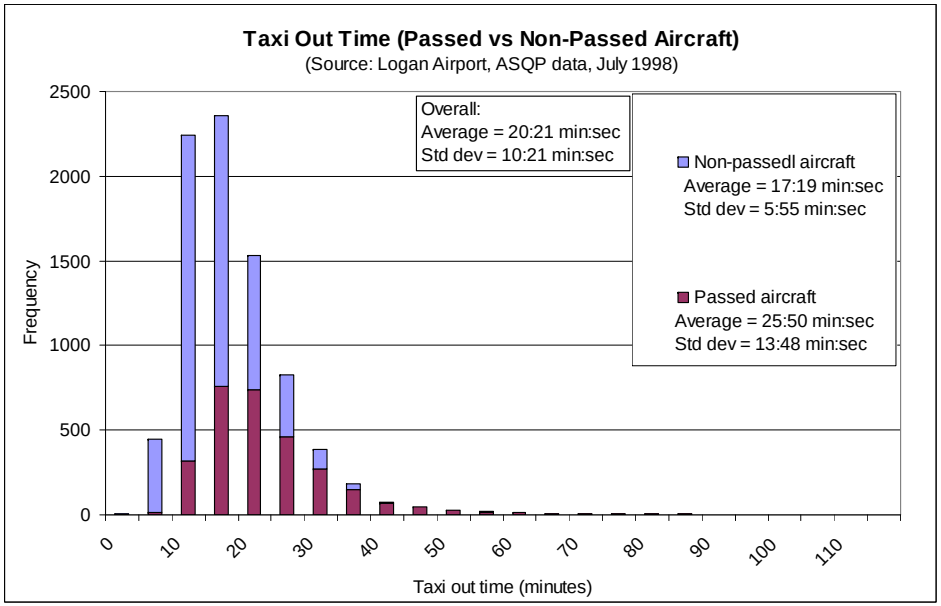
Analysis of Airport Surface Operations

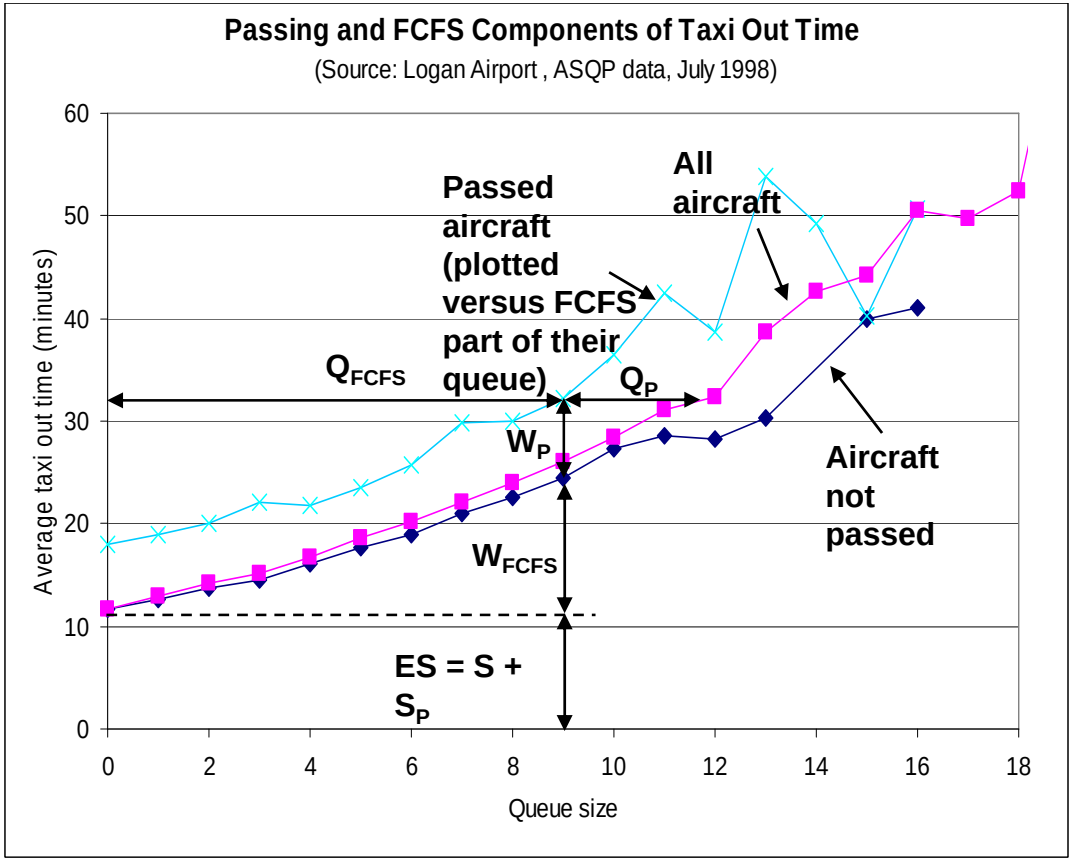
- **FCFS queuing dynamics**
  - *for aircraft with only FCFS queue ($Q = Q_{FCFS}$ and $Q_P = 0$))*
- **Two key parameters**
  - *Time intercept is unimpeded travel time = Service time ES*
  - *Slope is marginal waiting time due to queue = Waiting time W_{FCFS}*



Analysis of Airport Surface Operations

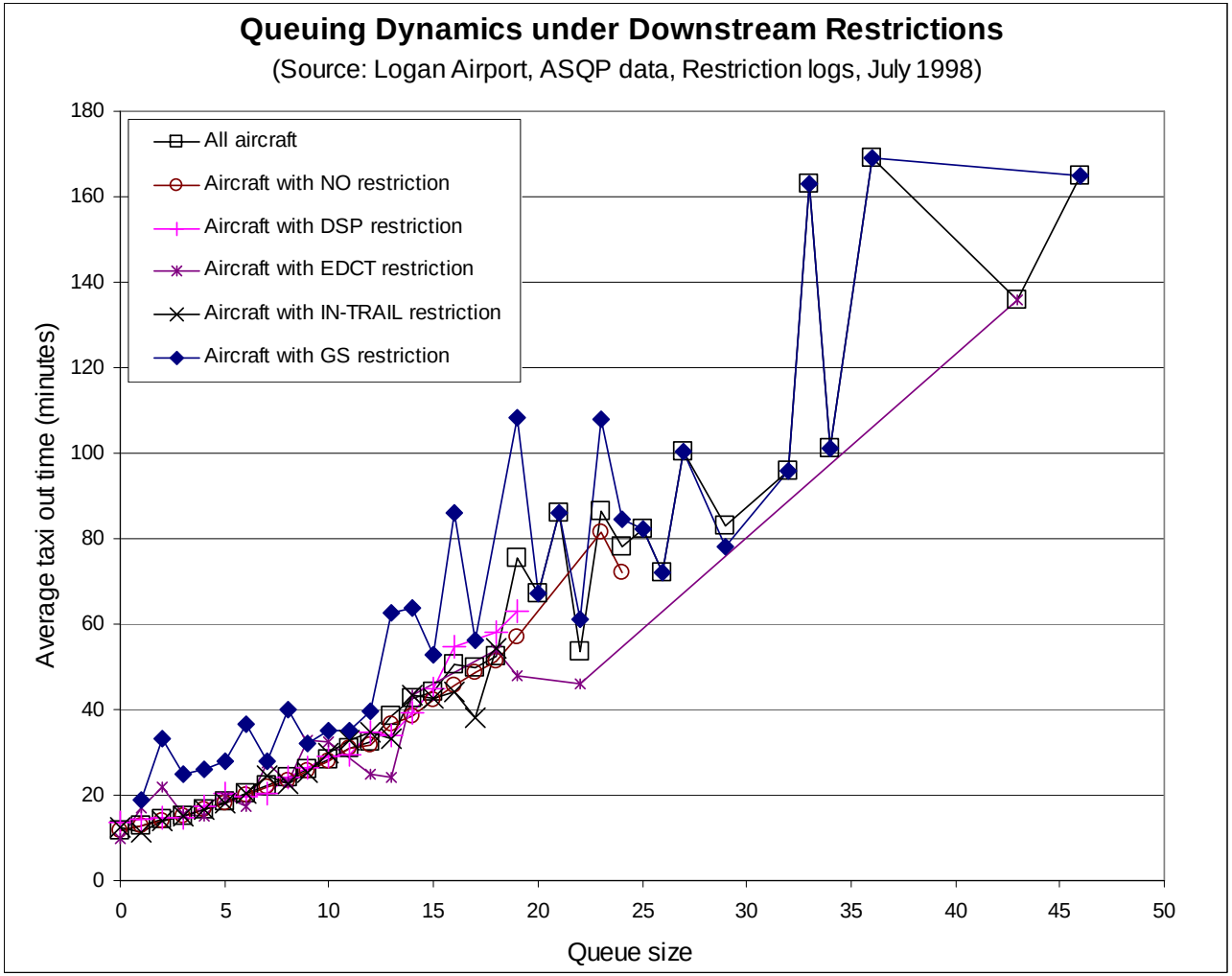
- **Waiting time due to passing versus FCFS**
  - $W = W_P + W_{FCFS}$
  - $TT = ES + W$





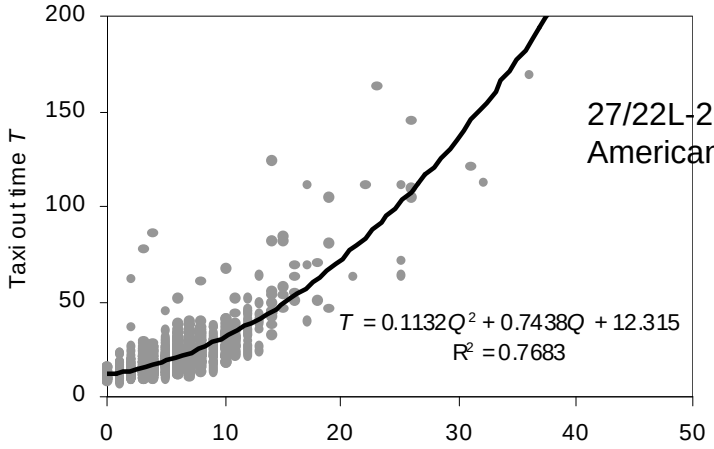
Analysis of Airport Surface Operations

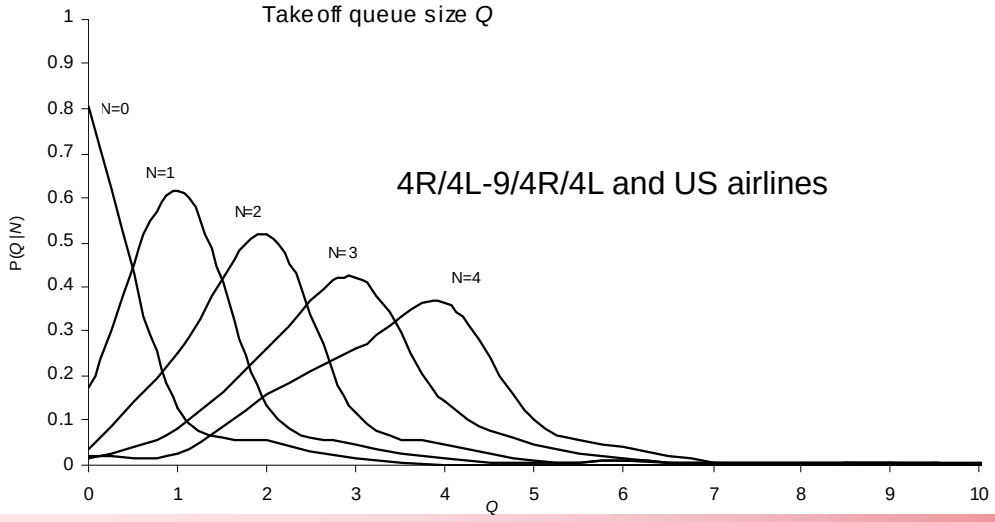
- **Queuing dynamics of departures under downstream restrictions**
  - ***Ground stop manifests through excessive passing due to suspension***
  - ***Time window or spacing restrictions met mainly through sequencing***



Analysis of Airport Surface Operations

- **Accounting for predicted passing improved taxi-out time estimation accuracy by 10% over 14-day-history-based estimate (Idris et al ATCQ 2002)**

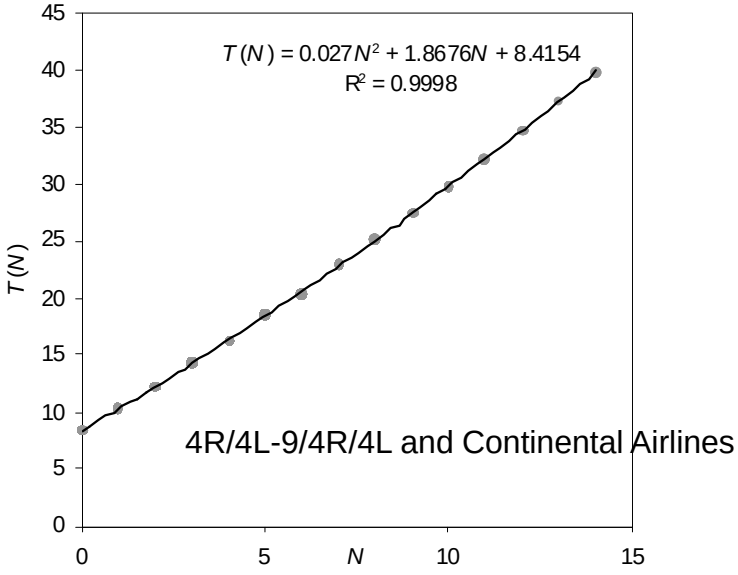




N = Observed number of departures on surface at pushback

Q = Queue size resulting at takeoff

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

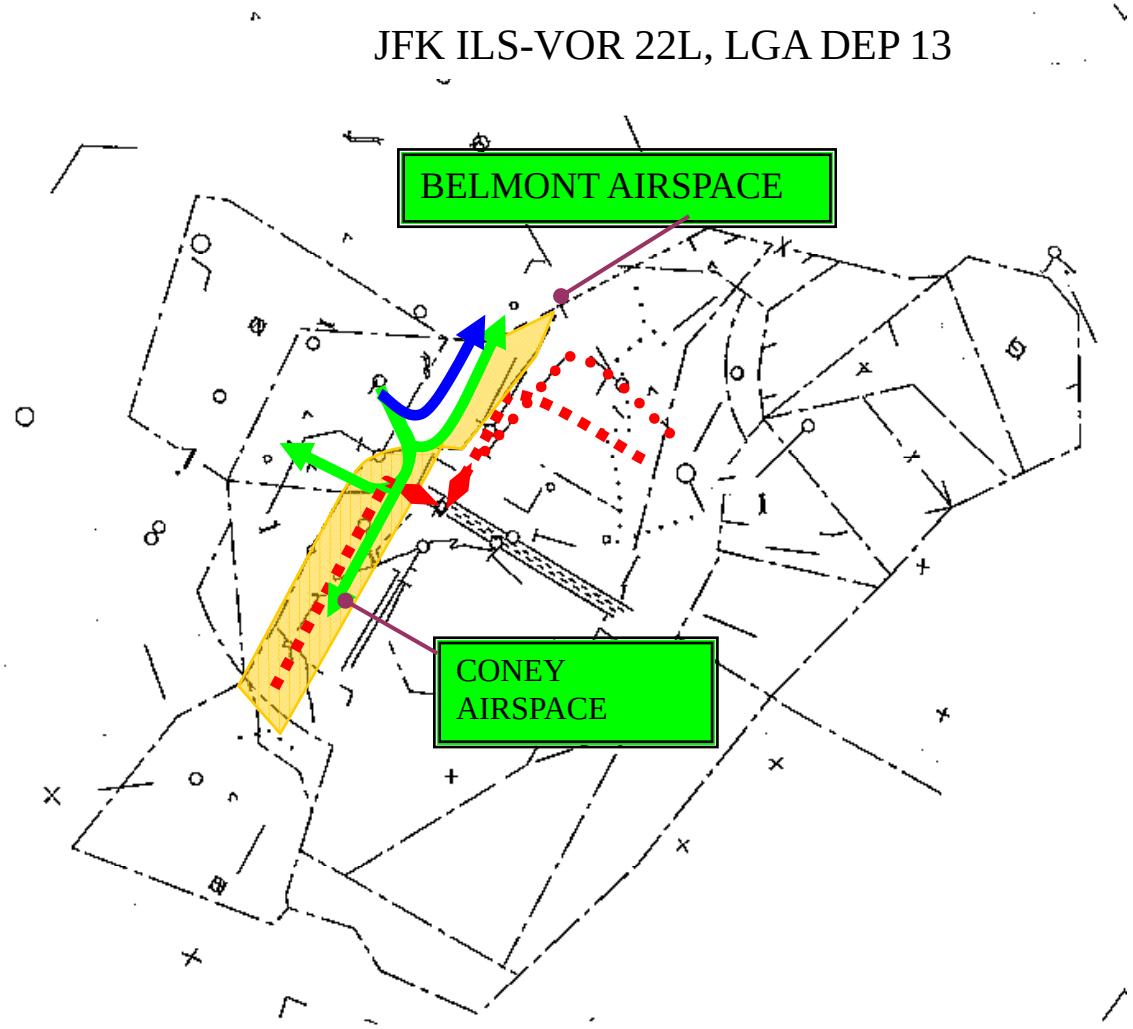


Analysis of Metroplex Operations

- **Two main types of interdependencies based on site observations**
  - ***Procedural segregation of traffic***
    - **Case 1: LGA departing runway 13 while JFK landing runways 22**
  - ***Merging of traffic***
    - **Case 2: TEB south departures merging with EWR south departures**

Analysis of Metroplex Operations

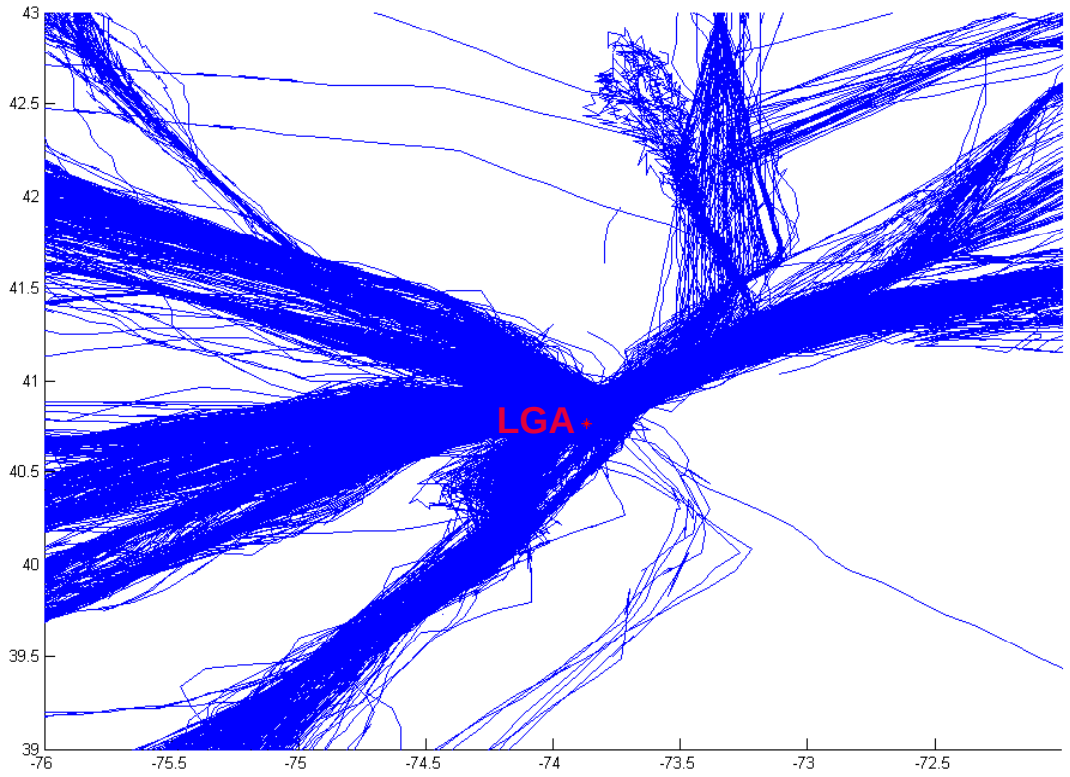
- **Case 1: Procedural segregation of traffic**
  - ***LGA 13 departures make immediate turns to avoid JFK***
  - ***JFK loses 22R arrivals***
  - ***Belmont airspace shared***
  - ***Communication between JFK and LGA local controllers to coordinate wide turns***



Analysis of Metroplex Operations

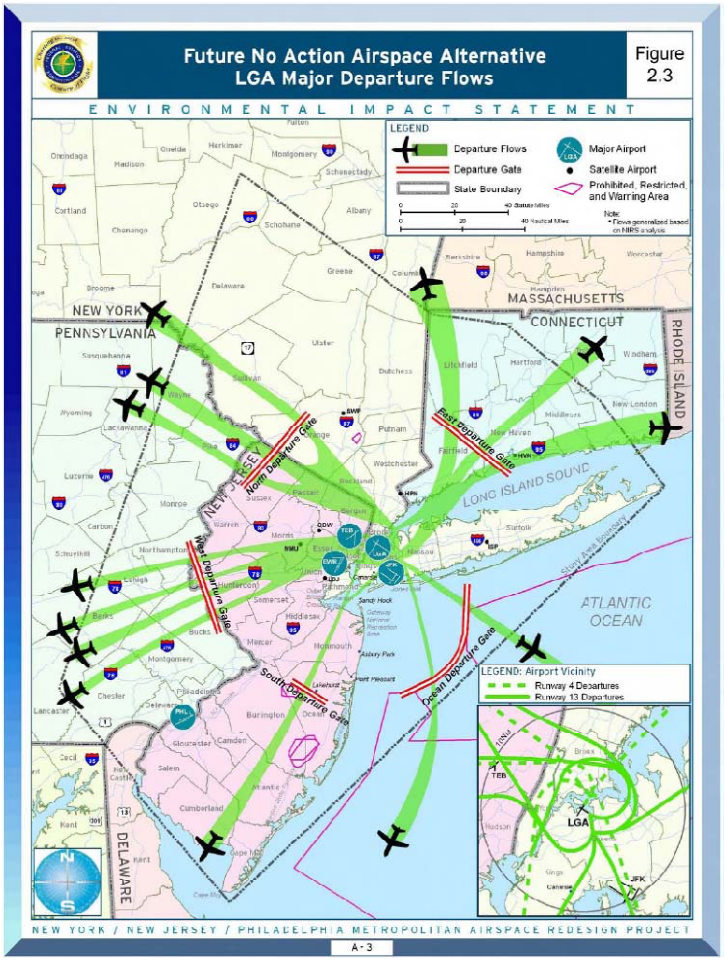
- **Case 1: Analyzed queuing dynamics of LGA departures**

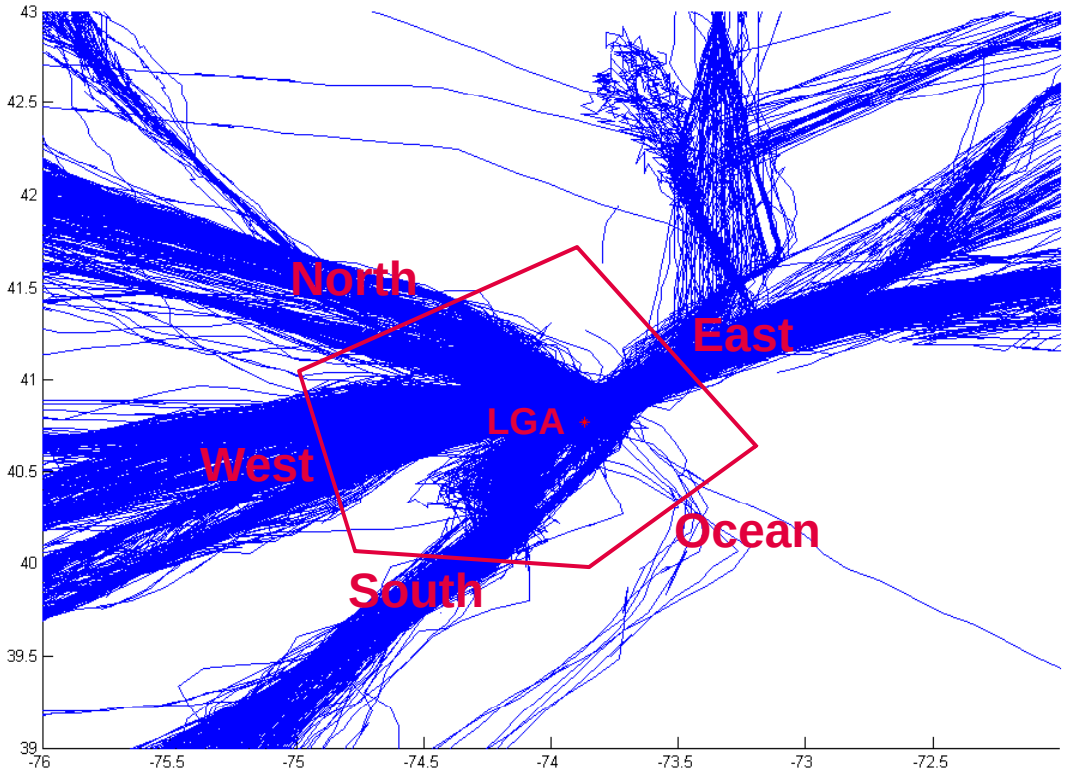
- **Data:**
  - ***ASDI May 3-23 2004 for traffic***
  - ***ASPM for runway configuration***
  - ***10356 flights (filtering bad data removed ~ 10 flights per day)***



Analysis of Metroplex Operations

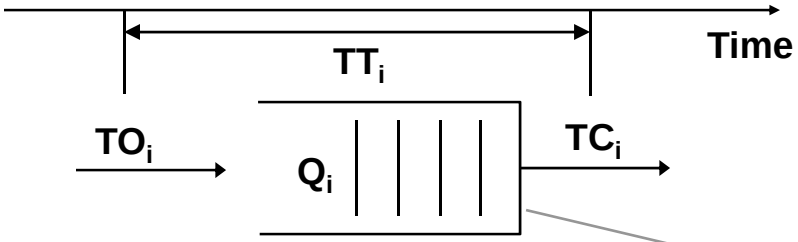
- **Classified flows by departure gate and departure runway (13, 31, 4, 22)**

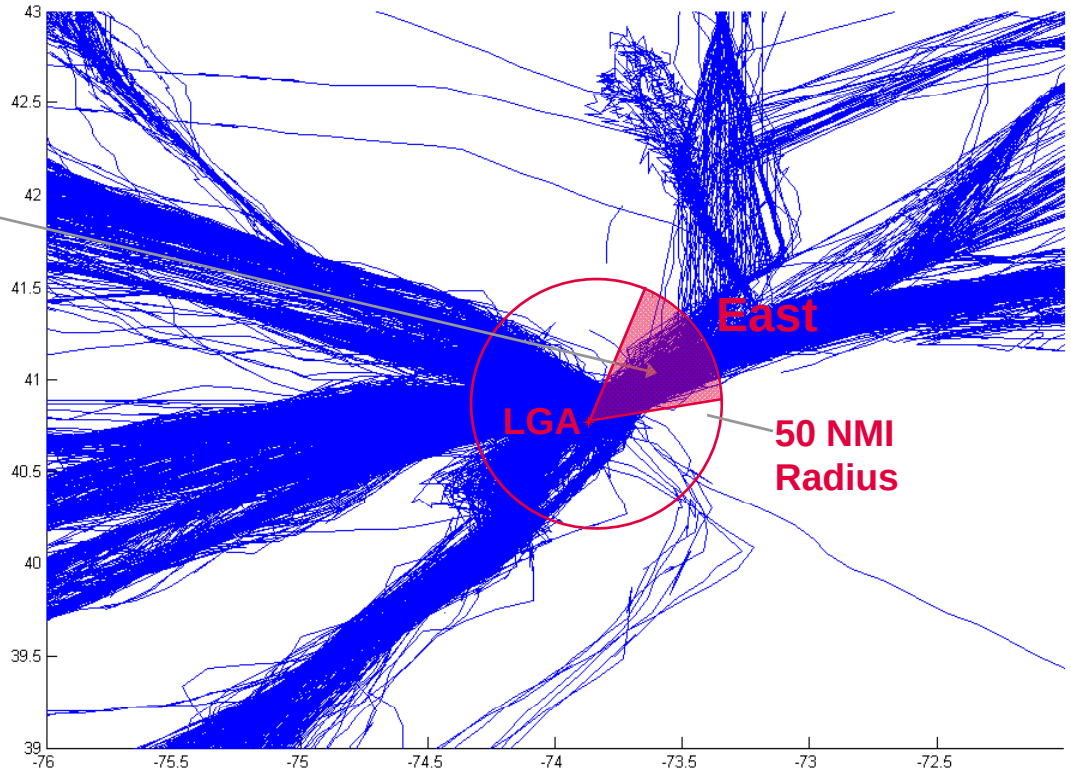




Analysis of Metroplex Operations

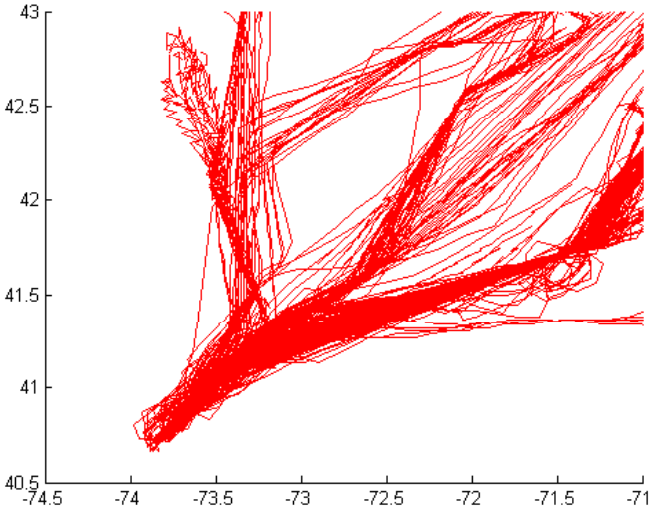
- **Analyzed East flow within 50 nautical miles from LGA**

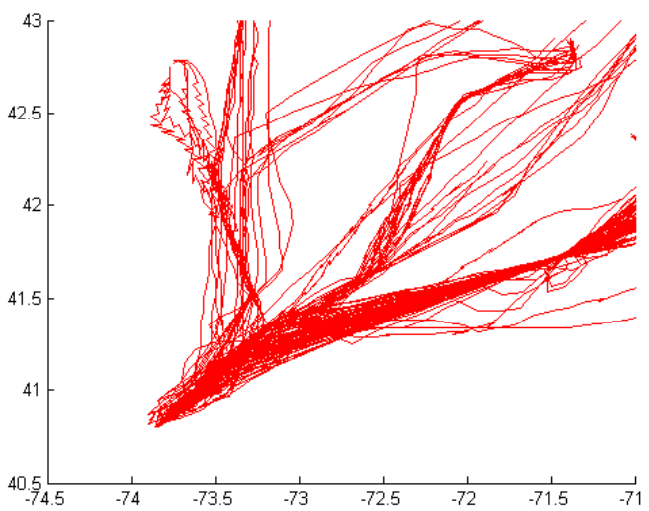


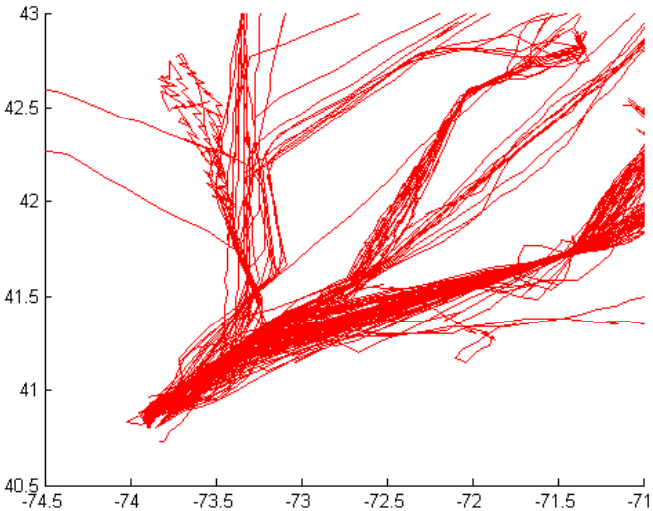


- **For each flight i**
  - *Entry = Takeoff time = TO_i*
  - *Exit = Time crossing 50 nmi arc = TC_i*
  - *Transition time $TT_i = TC_i - TO_i$*
  - *(a) Queue size Q_i = Number of LGA flights j with TC_j: $TO_i < TC_j < TC_i$*
  - *(b) Queue size = Q_i + Number of JFK arrivals j with landing time TL_j: $TO_i < TL_j < TC_i$*

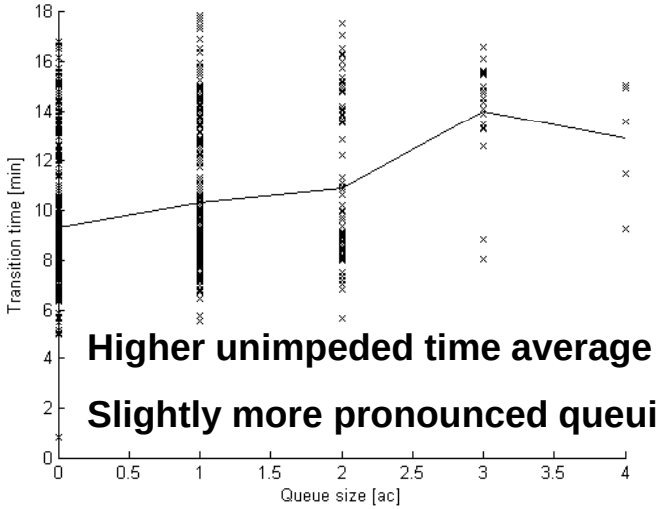
Analysis of Metroplex Operations







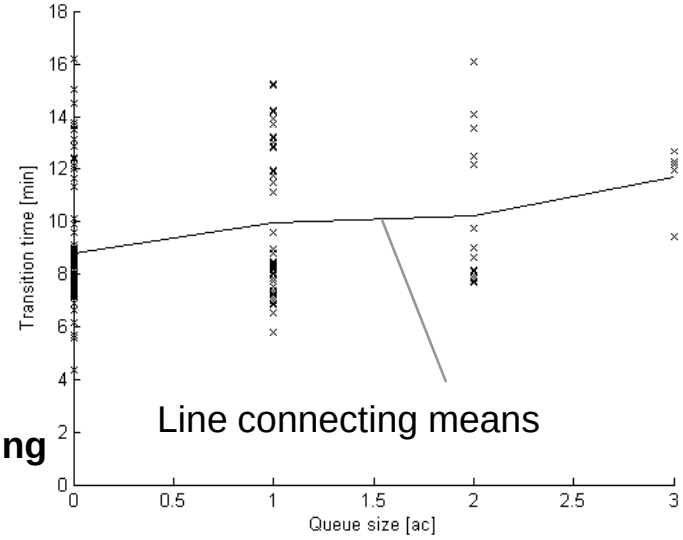
13 – Departure



Higher unimpeded time average

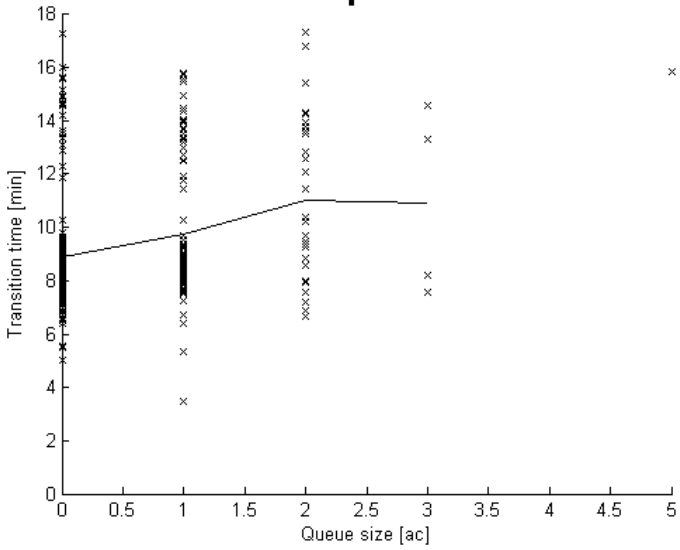
Slightly more pronounced queuing

4 – Departure



Line connecting means

31 – Departure



Global Security and Engineering Solutions

L3 communications

Analysis of Metroplex Operations

- **13 – Departures have higher average unimpeded transition time (at zero queue size), particularly when JFK landing 22**
  - ***Indicating procedural increase in unimpeded travel time***
- **No significant difference in marginal transition time with queue size**
  - ***Indicating that procedural segregation did not increase queuing effect***

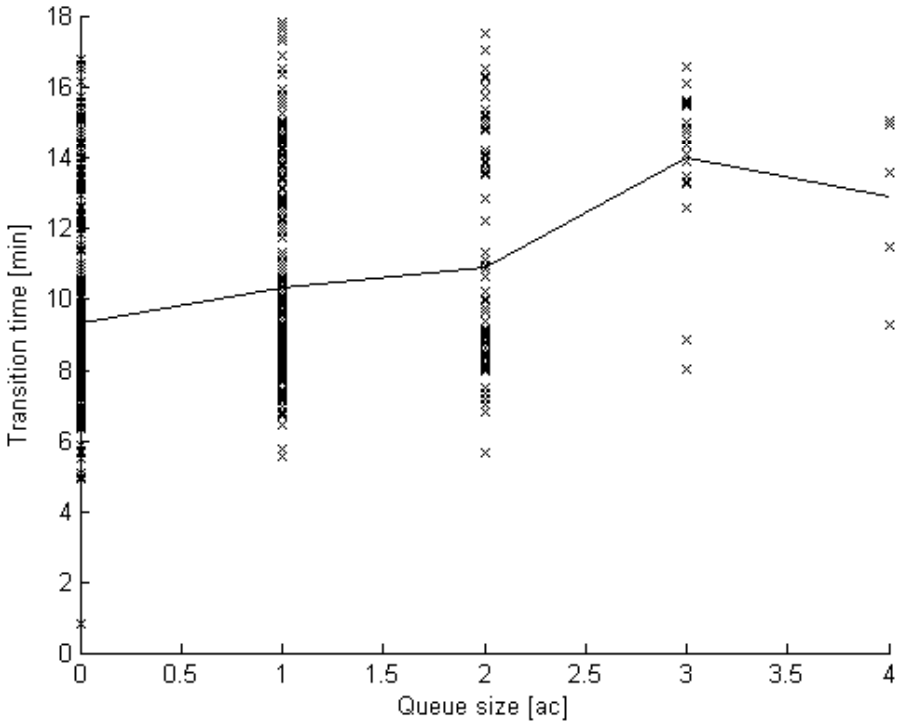
Flow	Unimpeded Transition Time Average (min)	Marginal Transition Time Average (min/aircraft)
13 – departures (JFK land 22)	9.65	0.96
13 – departures (JFK other than 22)	9.23	1.06
4 – departures	8.84	0.90
31 – departures	8.87	0.97

- **Further investigation is ongoing**

Analysis of Metroplex Operations

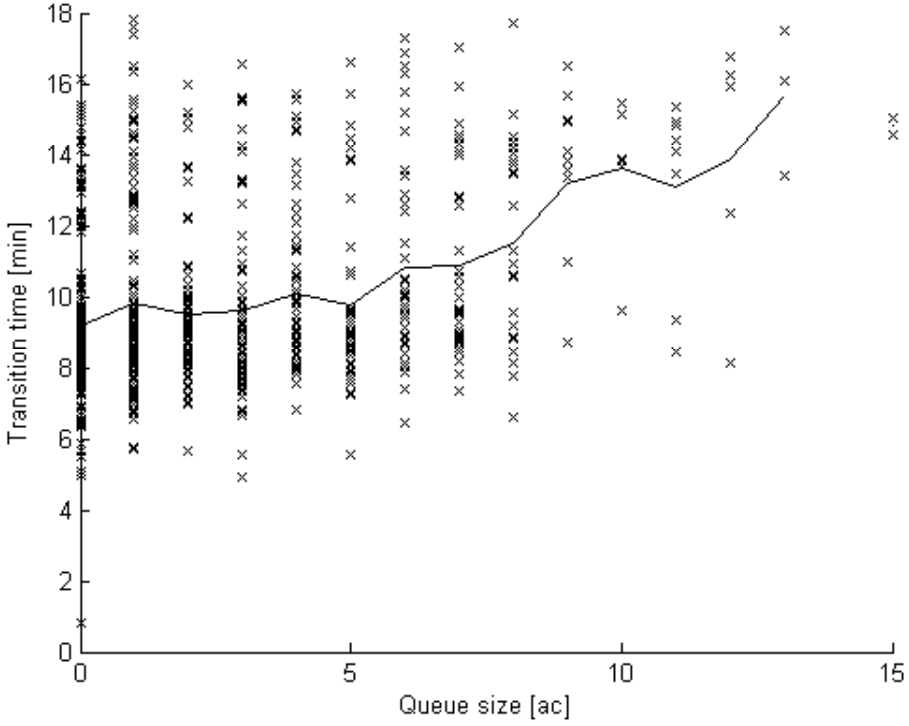
- **(2) Investigated if correlation of transition time with queue size increases if JFK arrivals are added to LGA departures in queue size**

(a) Without JFK arrivals in queue size



(b) With JFK arrivals added to queue size

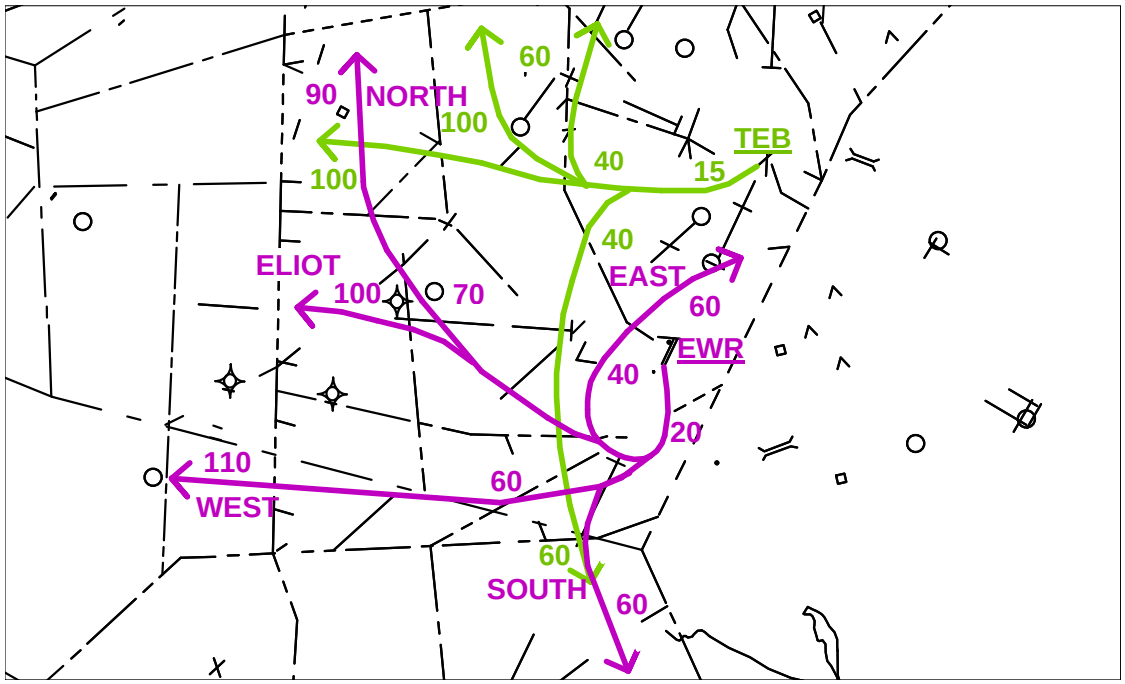
No clear improvement



Analysis of Metroplex Operations

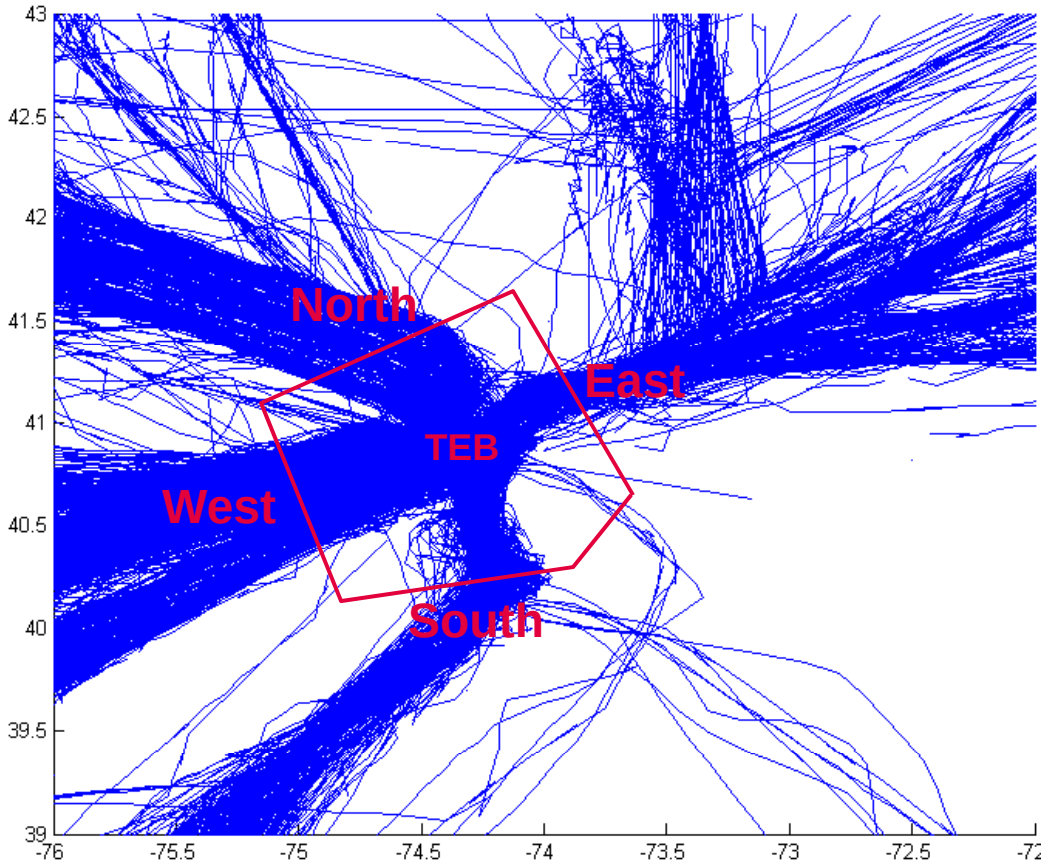
- **Case 2: Merging of traffic**
  - ***TEB South departures are merged with EWR South departures***
  - ***ASDI May 3-23 2004 for traffic***
  - ***ASPM for runway configuration***
  - ***4178 flights***

TEB and EWR Departures



Analysis of Metroplex Operations

- **Classified flows by departure gate and departure runway (19, 1, 6, 24)**



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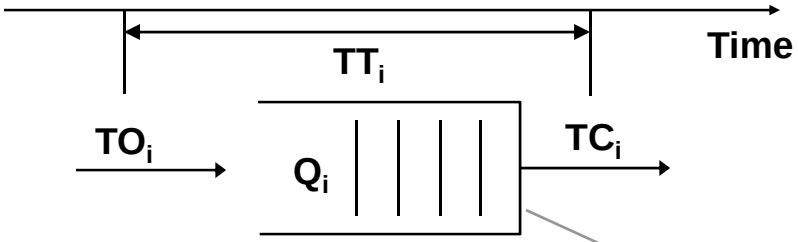
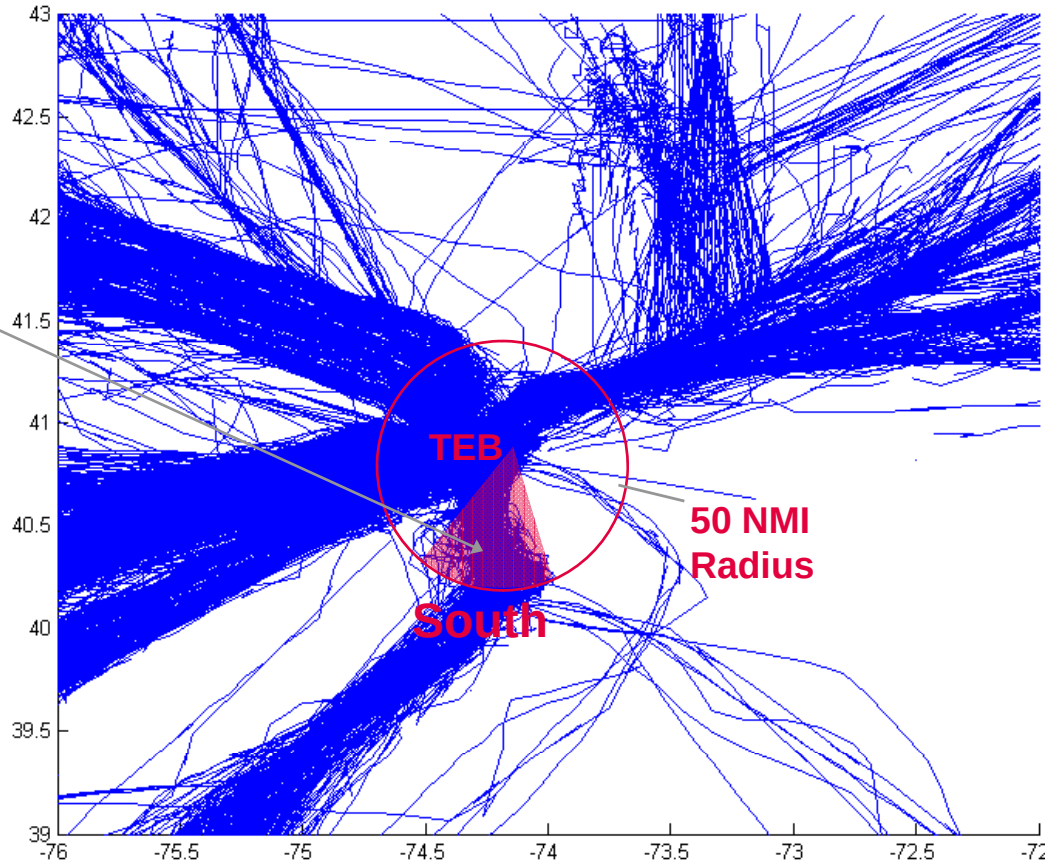
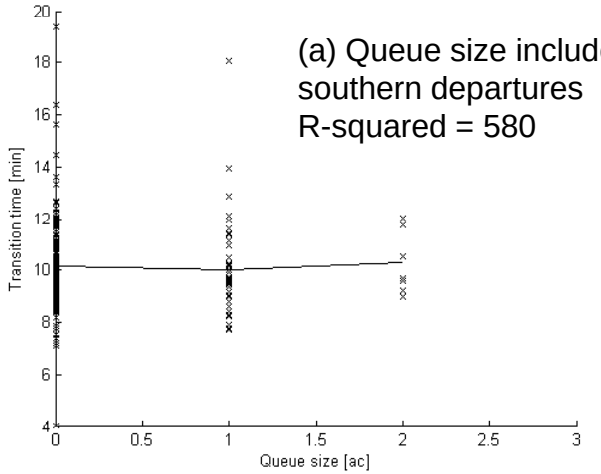




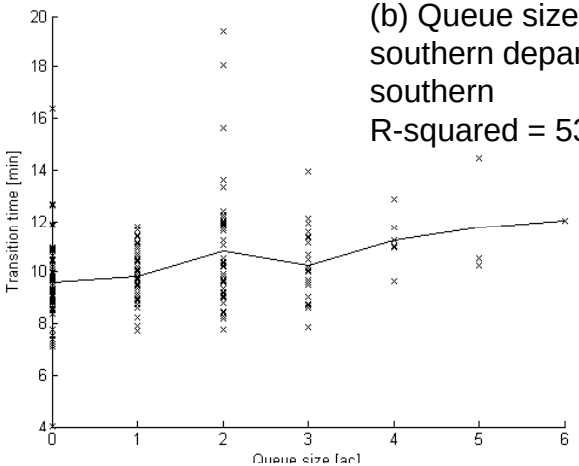
- **For each flight i**
  - ***Entry = Takeoff time = TO_i***
  - ***Exit = Time crossing 50 nmi arc = TC_i***
  - ***Transition time $TT_i = TC_i$ -- TO_i***
  - ***(a) Queue size = Q_i = Number of TEB flights j with: $TO_i < TC_j < TC_i$***
  - ***(b, c, d) Queue size = Q_i + Number of EWR departures j with: $TO_i < TC_j < TC_i$***

Analysis of Metroplex Operations

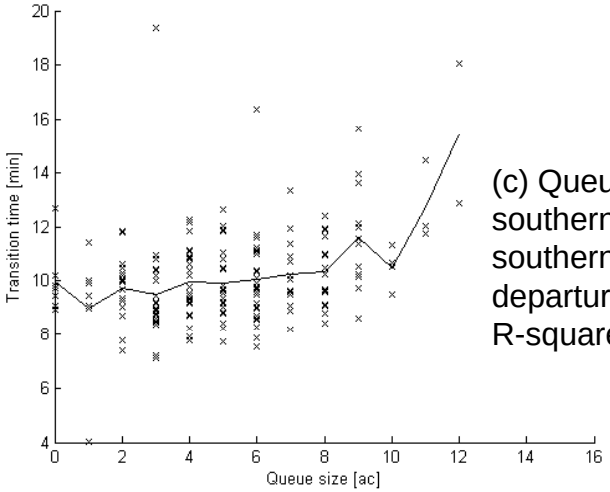
- **Queuing dynamics of TEB runway 24/SOUTH Departures**



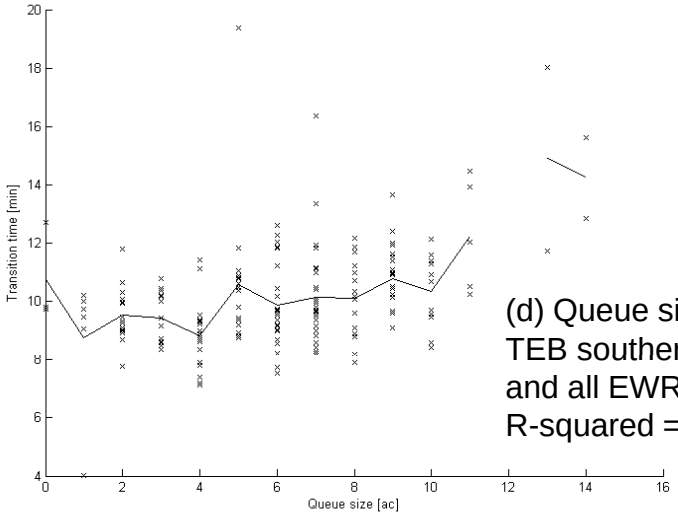
(a) Queue size includes Only TEB southern departures
R-squared = 580



(b) Queue size includes TEB southern departures and EWR southern
R-squared = 536



(c) Queue size includes TEB southern departures and EWR southern, western and northern departures
R-squared = 487



(d) Queue size includes TEB southern departures and all EWR departures
R-squared = 467

Summary and Future Work

- Queuing analysis captures interdependencies between flows in surface and metroplex environments
- Useful for system diagnosis and estimation of travel time
- Future work: Analyze more anecdotal situations with known interdependencies to gain more insights
- Future work: Automate the analysis process to analyze situation with unknown interdependencies