Terminal Area Arrival PDF Metrics for the Modeling of the Safety - Throughput Trade-Off Analysis

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NEXTOR: Moving Metrics Workshop

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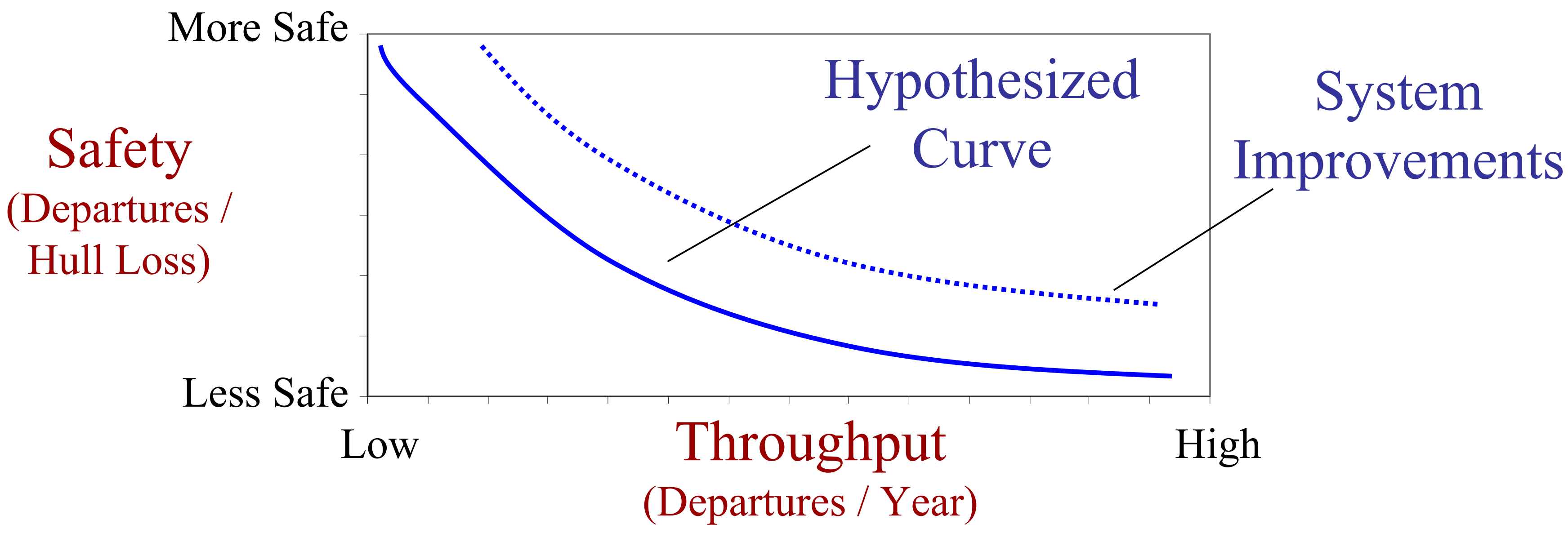
Safety / Throughput Trade-off

What is the trade-off between safety and throughput?



Key Safety Metrics

Ease of Predicting

Lower ↑ Easier

- **Airplane inter-arrival time**
- **Wake-normalized inter-arrival time**
- **Prob (simultaneous runway occupancy)**

} "Pseudo" Safety Metrics

- **Prob (collision), Prob (vortex accident)**

Higher ↓ Difficult

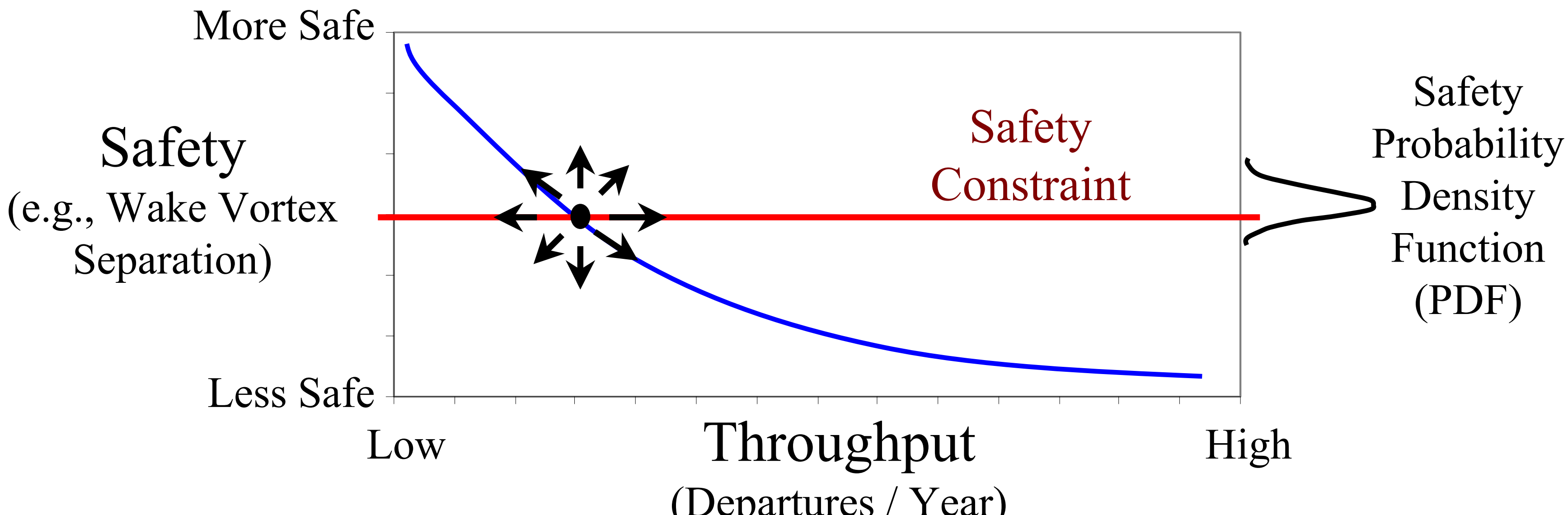
Metric Relevance

<u>Key Issues</u>

- **Metrics that matter the most are the most difficult to predict**
- **"Pseudo" metrics give *indication* of safety but not *proof* of safety**

Modeling Approach

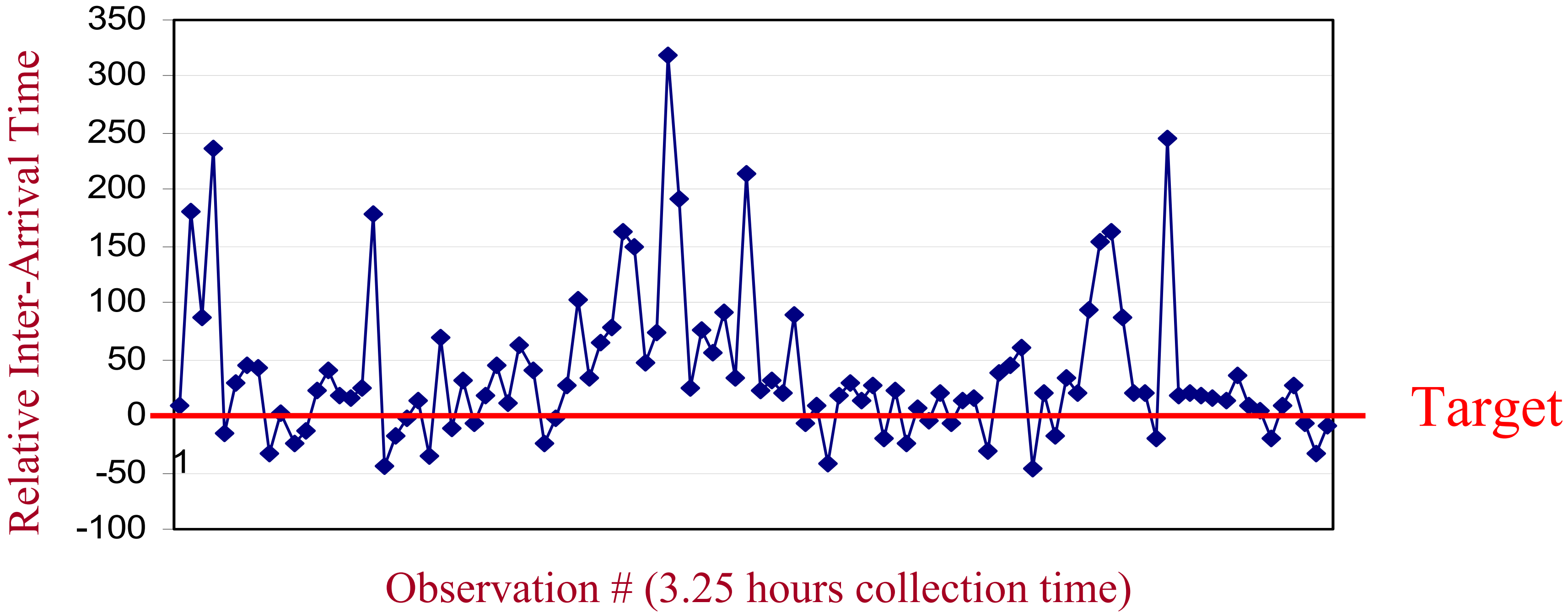
- **Common approach: Fix safety, maximize throughput**
- **Our approach:**
  - **Safety metrics are random**
  - **Safety / throughput are tightly coupled**



Observations

Atlanta Runway 27

March 5 2002, VMC



Total Observations: 102
# of Arrivals / Hr: 31

Representative velocity assumed for each class (S/L/757/H)

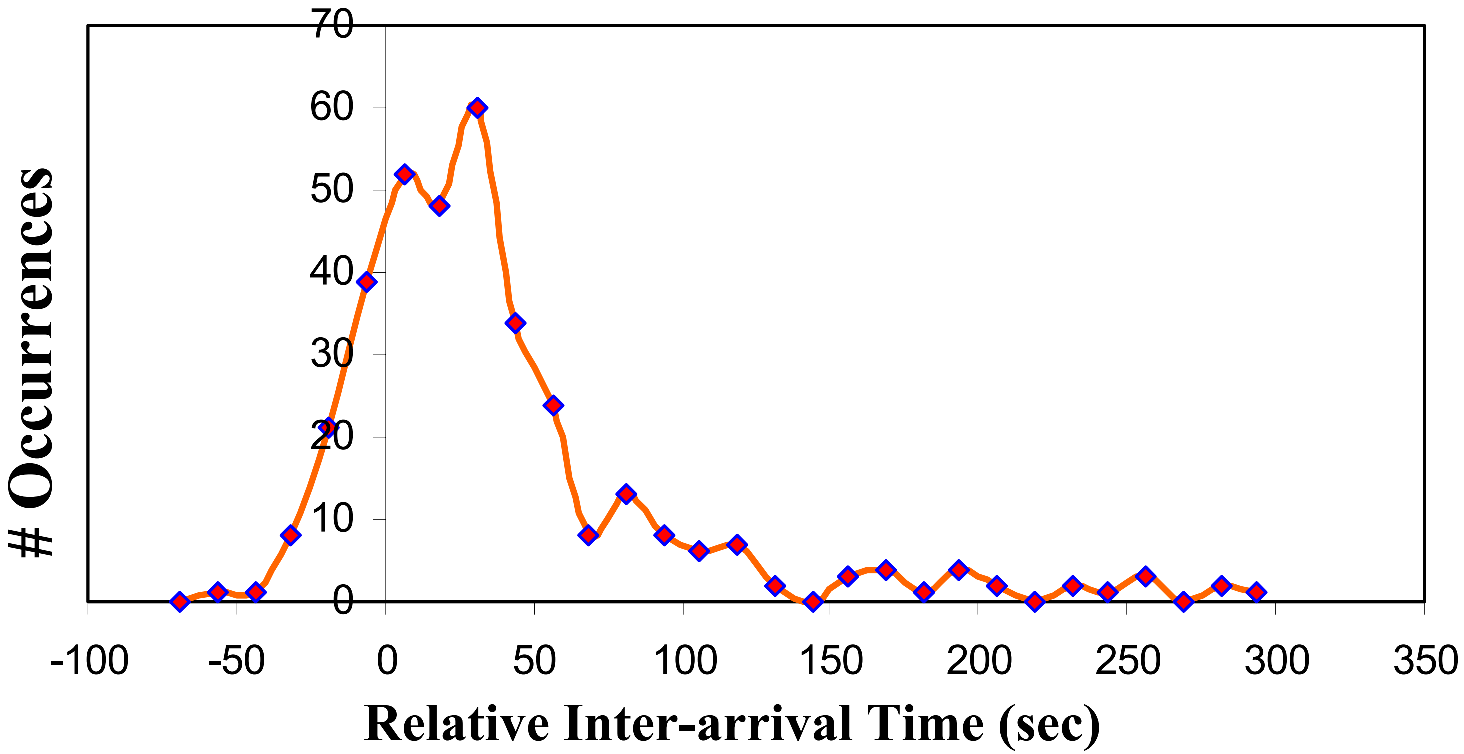
Haynie, R.C. 2002. Ph.D. Dissertation, George Mason University.

A Safety Metric PDF

Atlanta Runway 27

357 observations, VMC

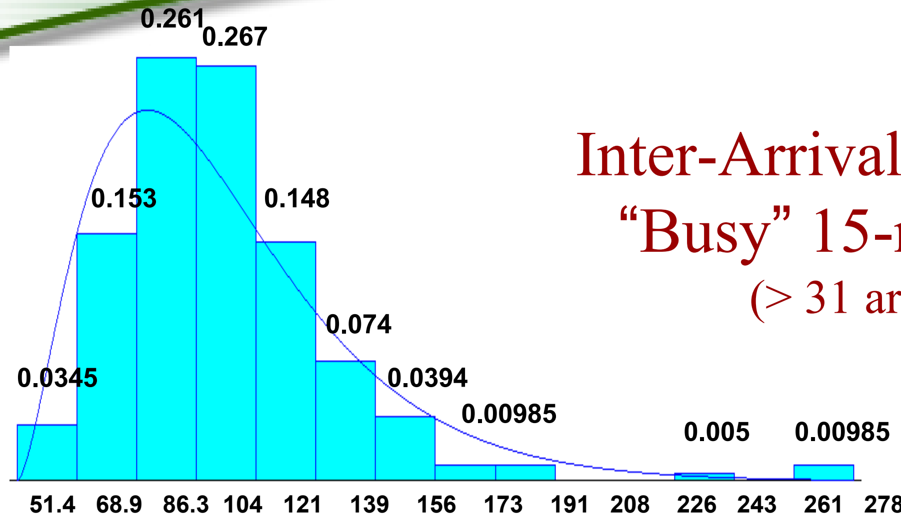
Lost Safety ? ⇦ ⇨ **Lost Capacity**



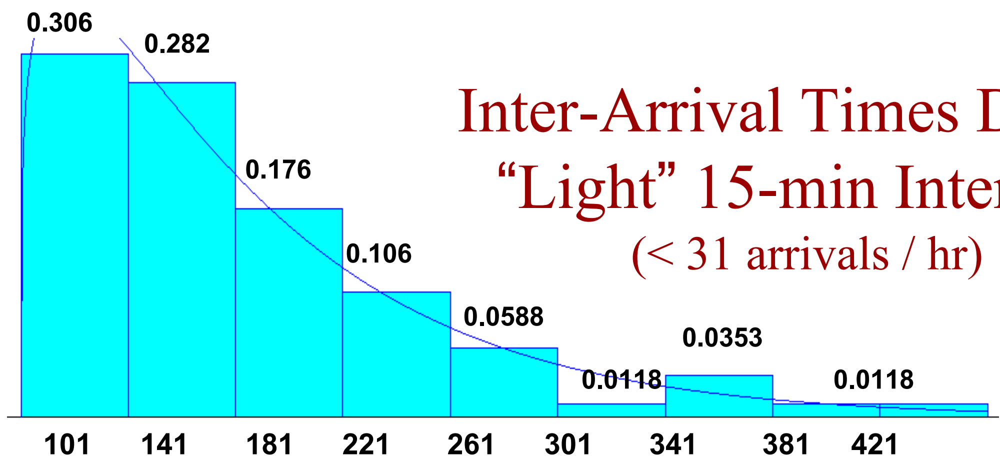
Relative inter-arrival time (sec) = Actual inter-arrival time – separation standard

Haynie, R.C. 2002. Ph.D. Dissertation, George Mason University.

Safety-Throughput Coupling



Inter-Arrival Times During
"Busy" 15-min Intervals
(> 31 arrivals / hr)



Inter-Arrival Times During
"Light" 15-min Intervals
(< 31 arrivals / hr)

Key Assumptions

<u>Key Assumptions</u>

- **Many safety metrics have associated PDF's**
  - **Possibly implies non-zero probability of constraint violation**
- **Mean and shape of PDF may shift as function of throughput**

<u>Objective</u>

- **Construct model to explain observed inter-arrival PDF**
- **Analyze safety / throughput trade-off with prev. assumptions**
- **Results are <u>qualitative</u> predictions**
  - **Insufficient current data to provide accurate quantitative predictions**

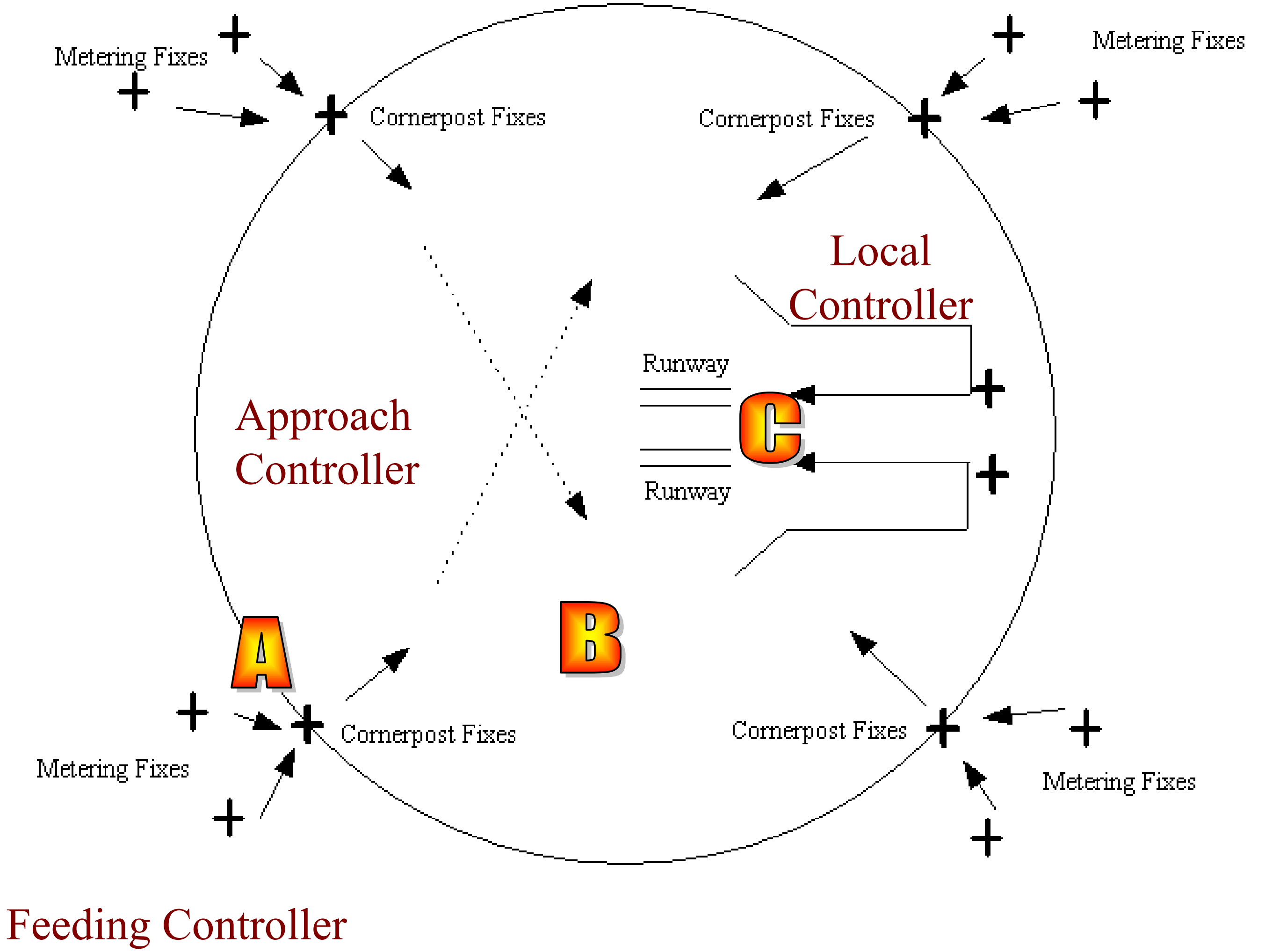
Model Outline

Steps

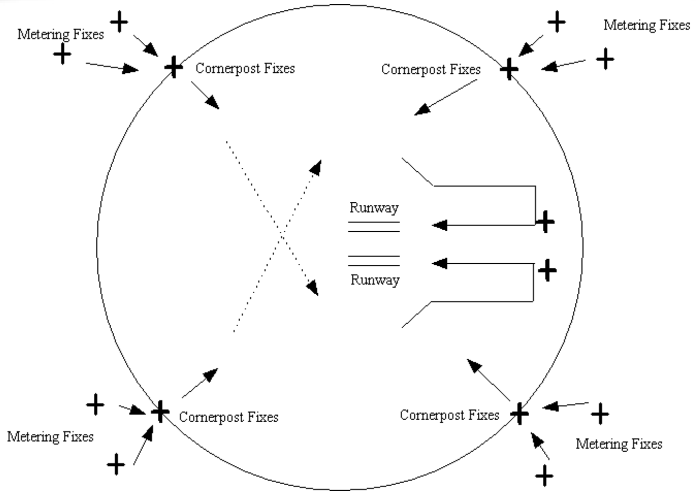
A. Aircraft Enter

B. Controller / Pilot Model

C. Threshhold



Controller / Pilot Model



- **Runway assignment**
  - **Assign runway to balance load**
- **Sequence aircraft**
  - **Compute expected time to reach final approach**
  - **Sequence aircraft based on first to final approach**
- **Space aircraft to pass final approach gate**
  - **Target arrival time (at final approach gate) =**

    Maximum (flight time, target arrival time of prev. plane + separation standard)
- **Airctaft at final approach gate**
  - **Actual arrival time = Target arrival time + noise**

Separation Matrix

Separation Standard at Threshhold

Time (sec) and Distance (nm)

Leader \ Trailer	Heavy	B757	Large	Small
Heavy	99 (4nm)	129 (5nm)	129 (5nm)	166 (6nm)
B757	99 (4nm)	103 (4nm)	103 (4nm)	138 (5nm)
Large	62 (2.5nm)	64 (2.5nm)	64 (2.5nm)	111 (4nm)
Small	62 (2.5nm)	64 (2.5nm)	64 (2.5nm)	69 (2.5nm)

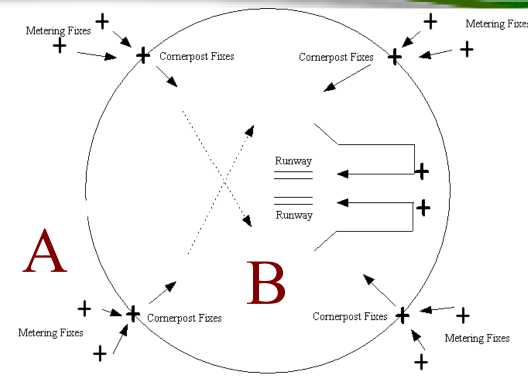
○ = Far - separated

others = Near - separated

Aircraft Speed Matrix (knots)

Speed(knots)\Category	Heavy		Large		B757		Small	
	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev
Final Approach Gate	175	7.8	155.5	7.8	169	5.8	152	4
Runway Threshold	145	5.8	140	5.8	140	3.8	130	4

Data Collection



Atlanta

A. Inter-arrival Time (sec)

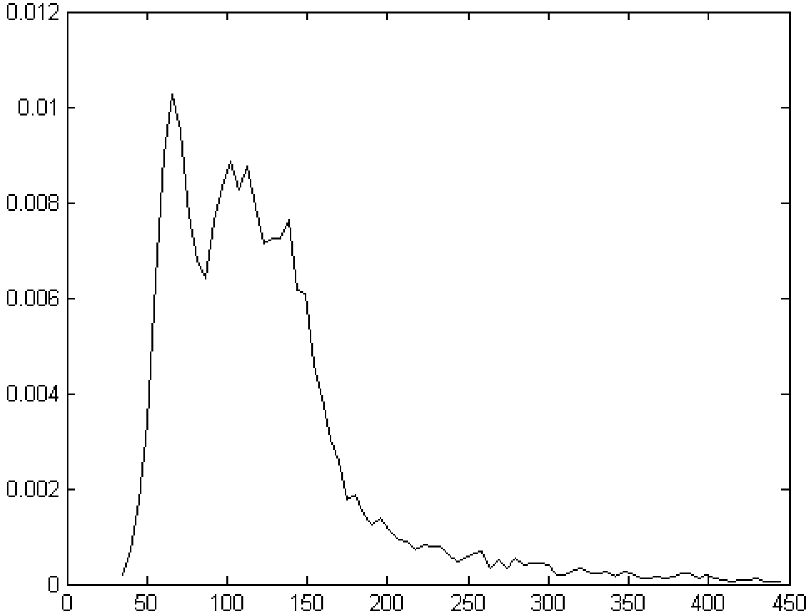
stream	mean	Std.dev	# of data points
Northeast	199	195	908
Northwest	232	269	818
Southwest	354	405	541
Southeast	252	256	721

B. Flight Time to Final Approach (sec)

stream	mean	Std.dev	# of data points
Northeast	563	79	911
Northwest	780	133	821
Southwest	673	95	544
Southeast	548	94	724

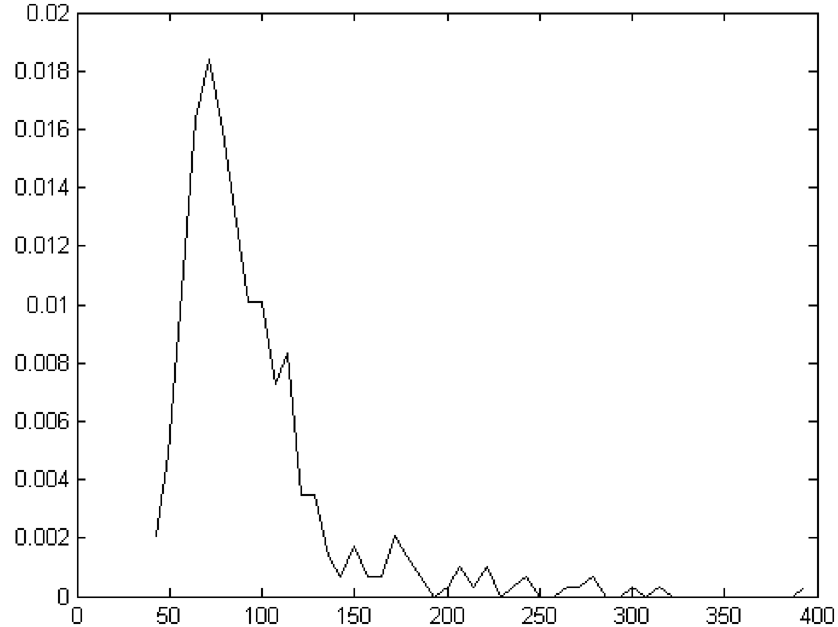
Simulation Results

Simulation Results with Standard Separation Matrix



Inter-arrival Time at Threshhold (sec)

Haynie's Observations, 2002



Inter-arrival Time at Threshhold (sec)

Haynie, R.C. 2002. Ph.D. Dissertation, George Mason University.

Hypothetical Matrix

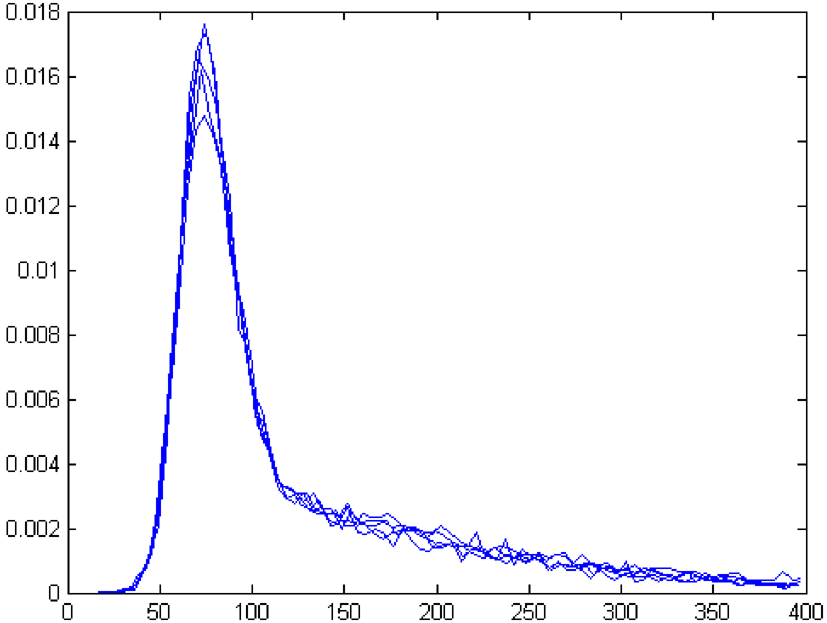
Table 5. Reduced Separation

Trailer / Leader	Heavy	B757	Large	Small
Heavy	83 (3.3nm)	83 (3.2nm)	83 (3.2nm)	83 (3nm)
B757	83 (3.3nm)	83 (3.2nm)	83 (3.2nm)	83 (3nm)
Large	67 (2.7nm)	70 (2.7nm)	83 (3.2nm)	83 (3nm)
Small	67 (2.7nm)	70 (2.7nm)	70 (2.7nm)	70 (2.5nm)

Basic change: Less difference between near and far separated aircraft

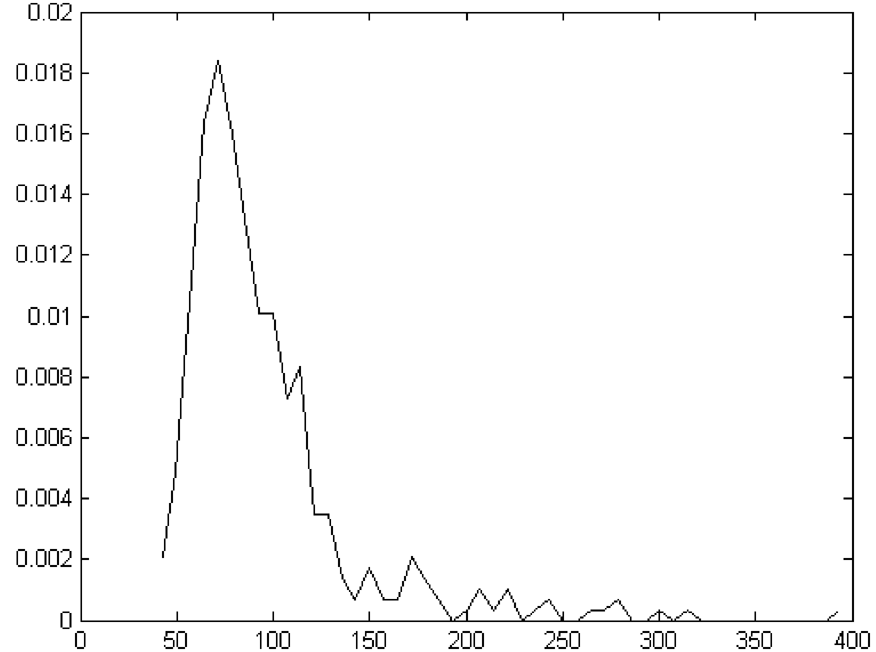
Model Output

Simulation Results
with Hypothetical Separation Matrix



Inter-arrival Time at Threshhold (sec)

Haynie's Observations, 2002



Inter-arrival Time at Threshhold (sec)

Traffic Volume Scenarios

- *Baseline*: 58 arrivals / hour (for two runways)
- *Lighter- than- baseline* cases:

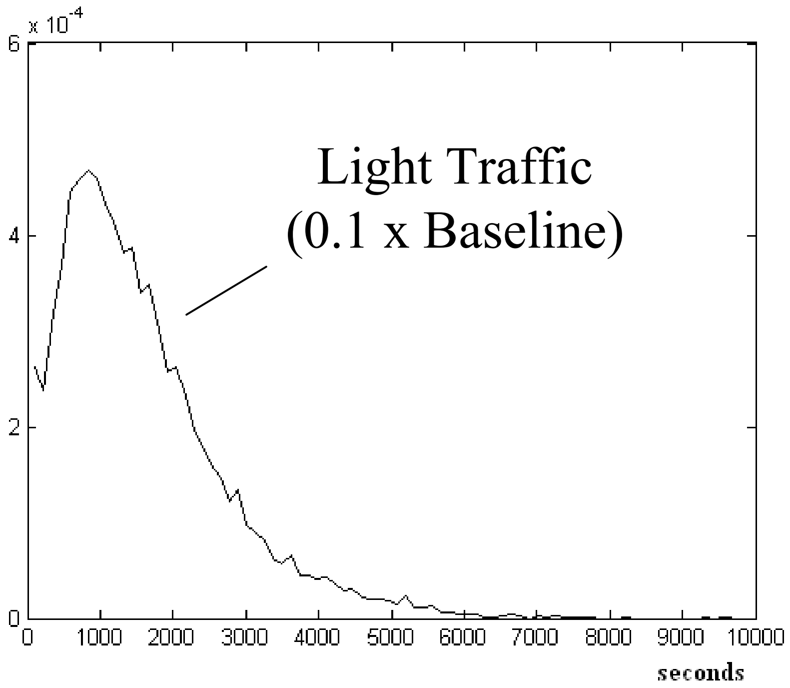
  - 0.1, 0.25, 0.5, and 0.75 times baseline level;

- *Heavier- than- baseline cases:*

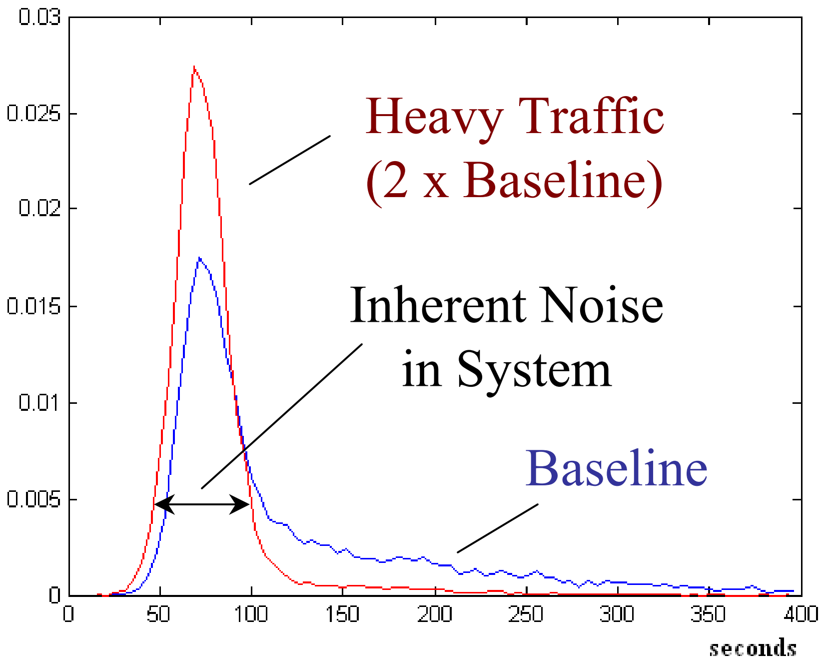
  - 1.25, 1.35, 1.45, 1.55, 1.75, 1.85, and 2 time baseline level

Light / Heavy Traffic

Comparison of Light and Heavy Traffic Volumes



Inter-Arrival Time

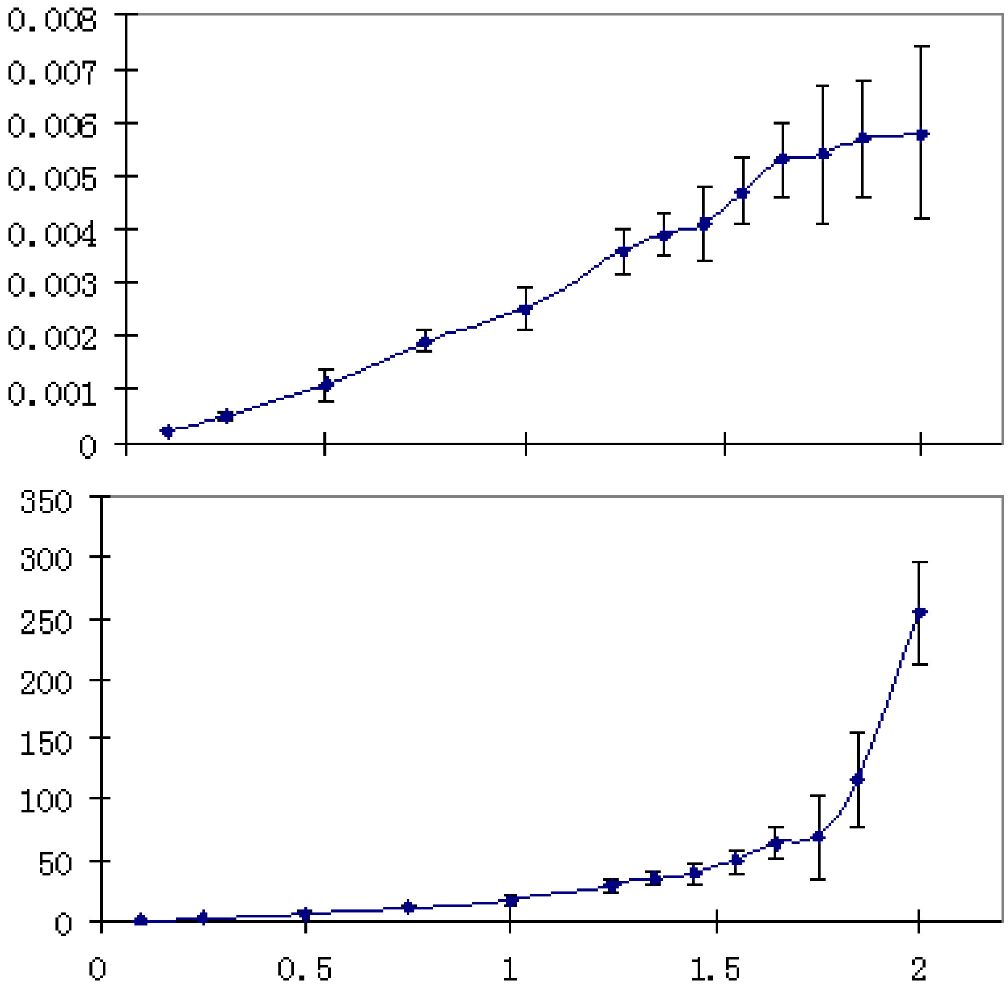


Inter-Arrival Time

Safety / Throughput

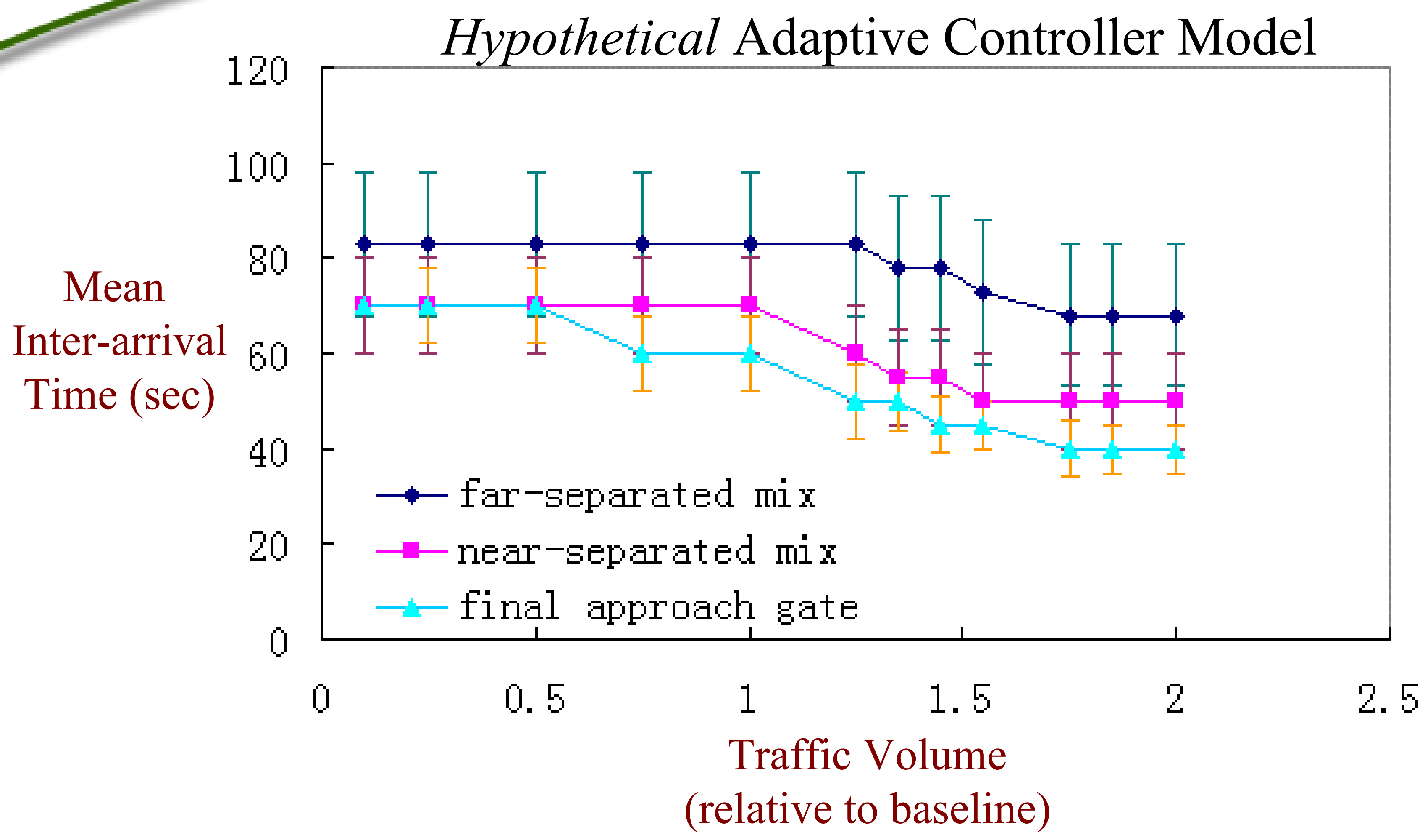
Prob (Simultaneous Runway Occupancy)

Delay (sec)



Normalized Arrival Rate (relative to baseline)

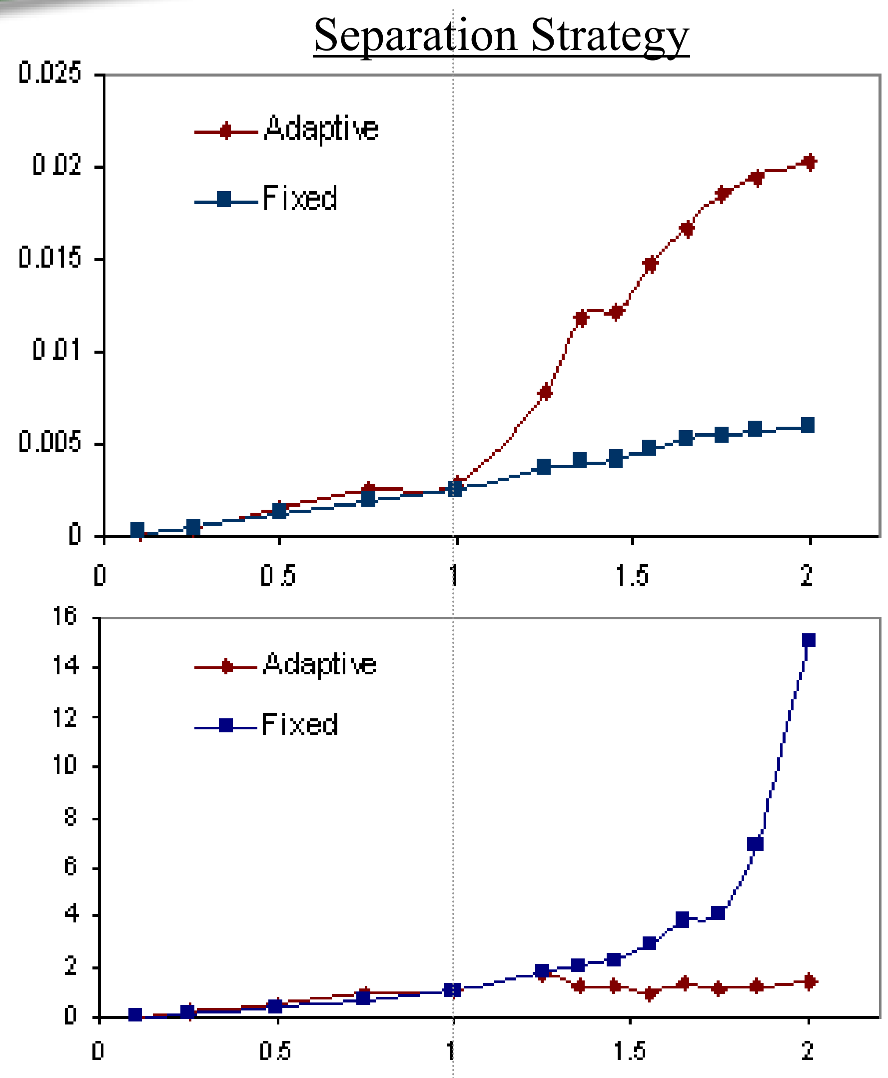
Adaptive Controller Model



Comparison of Controller Models

Prob (Simultaneous Runway Occupancy)

Delay (sec)



Normalized Arrival Rate (relative to baseline)

Error bars not shown

Conclusions

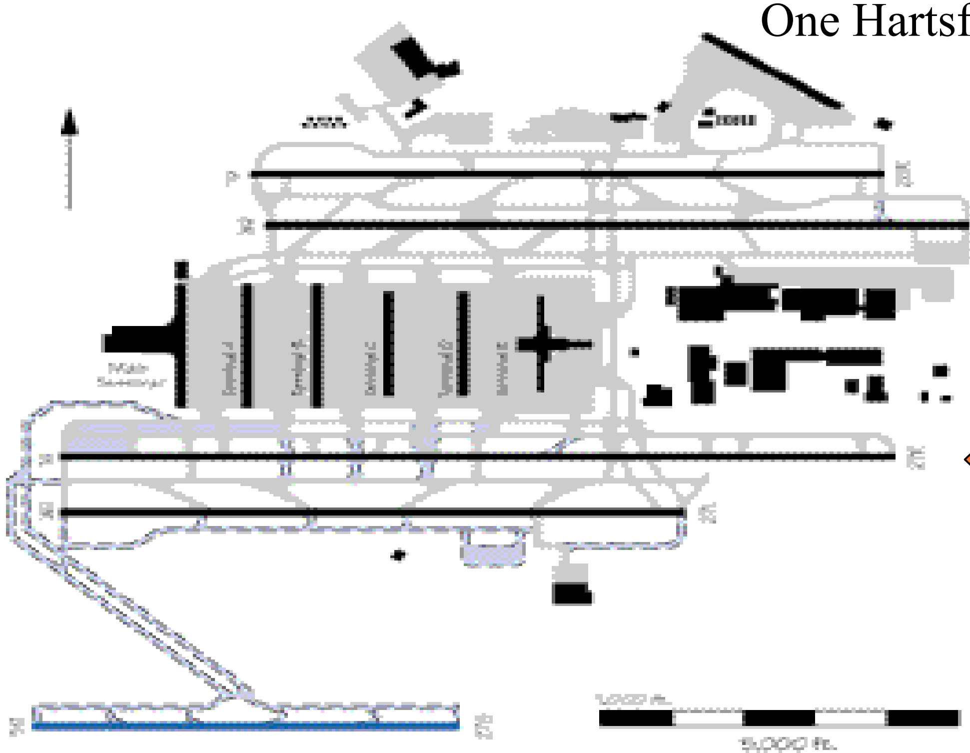
- Inter-arrival time PDF explained from two key dynamics:
  - Inherent noise in control system
  - Arrival process
- Left tail of PDF drives safety
- Safety / Throughput Model
  - Uses PDF's to model separation standards (vs. hard constraints)
  - Controller agents (can model safety / throughput coupling)
- Increasing throughput increases probability in left tail
  - In adaptive controller model, this effect is much worse
- Quantitative power of such models would greatly benefit from automated data collection:
  - Airplane threshhold arrival time, speed, type

Backup Slides

Where are the Airplanes?

Example Study: ATL

Observation Point
Renaissance Hotel
One Hartsfield Centre Parkway

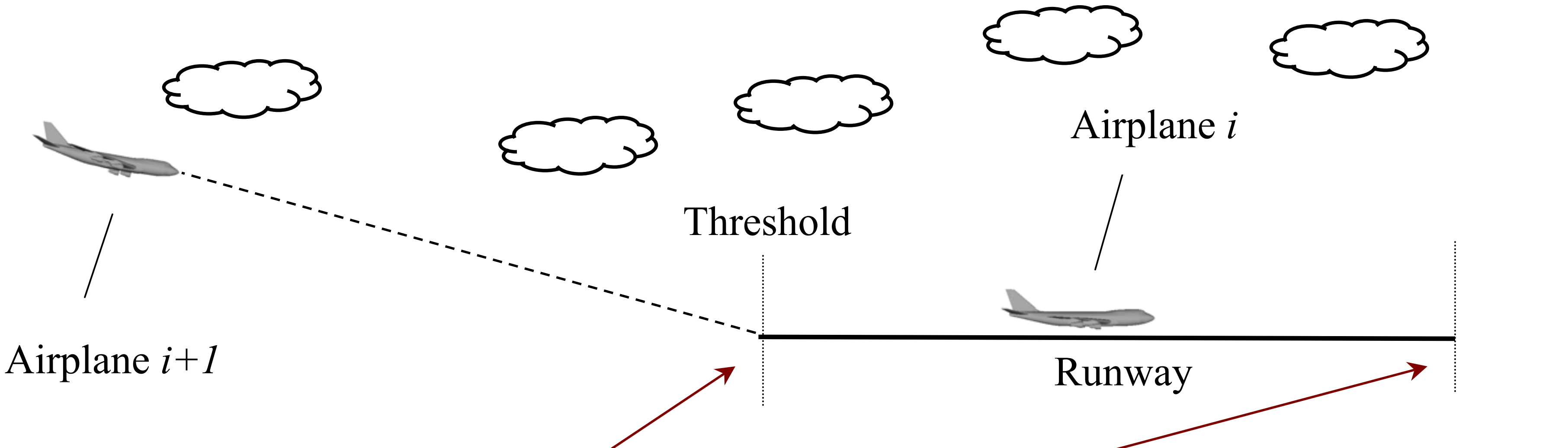


Runway 26

Runway 27

Haynie, R.C. 2002. Ph.D. Dissertation, George Mason University.

Data Collection Process



Aircraft Type	Threshold	Leave Runway
Heavy	10:23:14	10:24:04
Large	10:24:28	10:25:13
Large	10:26:16	10:27:12
Small	10:28:32	10:29:28
⋮	⋮	⋮

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Data Manipulation

Runway Occupancy Time (ROT) 45 sec

Aircraft Type	Threshold	Leave Runway
Heavy	10:23:14	10:24:04
Large	10:24:28	10:25:13
Large	10:26:16	10:27:12
Small	10:28:32	10:29:28

108 sec – 64 sec = +44 sec ***Relative*** **Inter-Arrival Time**

Inter-Arrival Time (IAT)

Wake Vortex Separation Standard
Large following Large (2.5 Nm)
(2.5 Nm / (140 knots / 3600 sec/hr))

Data Collection Summary

Airport	Days	Observations	Weather
Atlanta (ATL)	3	765	VMC
LaGuardia (LGA)	3	584	VMC / IMC
Baltimore (BWI)	2	135	IMC

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Observed Runway Incursions

One formal simultaneous runway occupancy

When	Where	Leader\Exit_time	Trailer\Thr_time
5,Mar,2002	ATL 26L	Large\8:27:31	B757\8:27:17

-14 sec

Several "near" simultaneous runway occupancies

When	Where	Leader\Exit_time	Trailer\Thr_time
5,Mar,2002	ATL 26L	Large\8:22:06	Large\8:22:06
5,Mar,2002	ATL 26L	Large\8:22:50	Large\8:22:50
5,Mar,2002	ATL 26L	Small\9:05:32	Large\9:05:30
5,Mar,2002	ATL 26L	Large\1:16:04	Large\1:16:04
6,Mar,2002	ATL 26L	Large\2:43:32	Heavy\2:43:32
6,Mar,2002	ATL 26L	B757\8:35:06	Large\8:35:06

Out of 364 valid data points