NEXTOR

Estimating Delay and Capacity Impacts of Airport Infrastructure Investments

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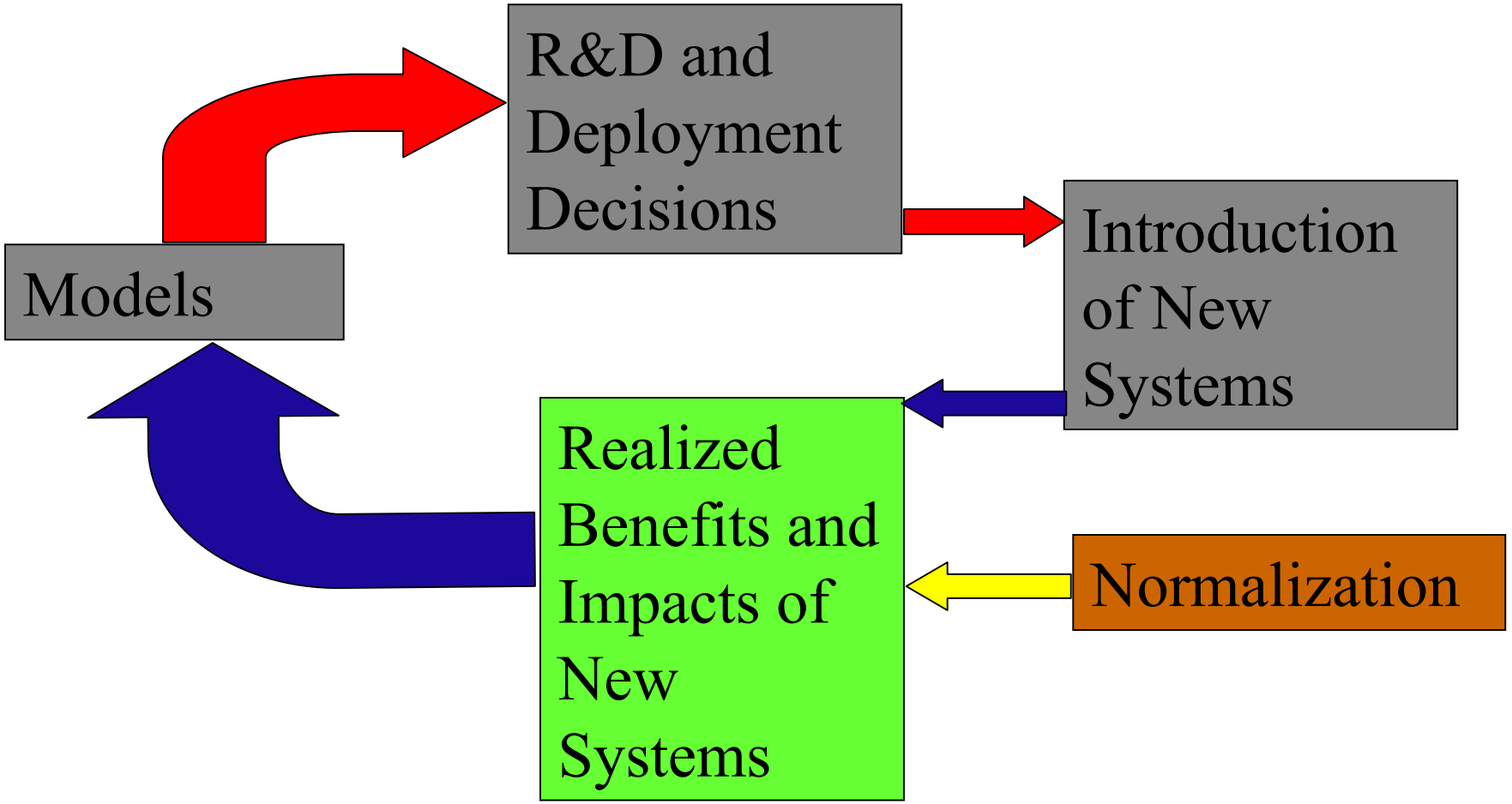
R&D Modeling Cycle



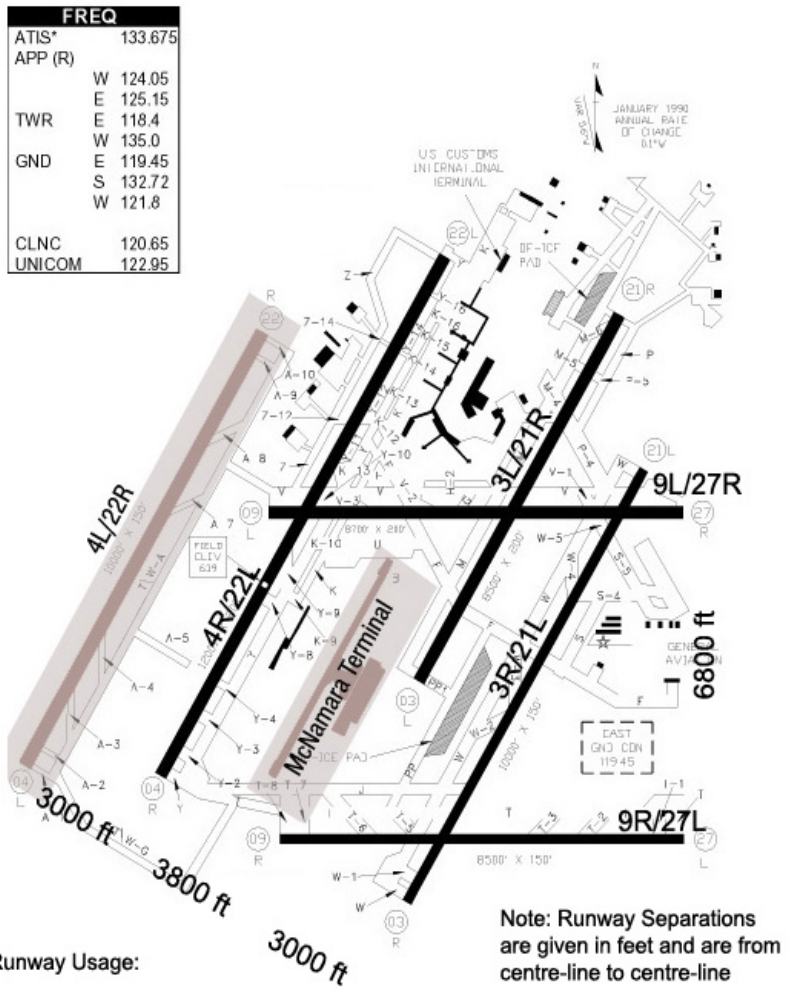
NEXTOR Metrics Research

- Effects of Investments and Technological Deployments on Terminal Area and En Route Performance
- Use Statistical Inference to Capture Impacts that may not be Directly Observable
- Consider both Throughput and Time-in-System Metrics

Background

- Runway 4L/22R Came On-line 12/11/01
- Simultaneous Arrival and Departure Streams Under IFR and VFR
- 4R/22L Dedicated to Departures Instead of Mixed Ops

Fig.1: Airfield Layout Plan of DTW showing the New Runway 4L/22R and McNamara Terminal for NWA



Runway Usage:

4L/22R & 3R/21L are normally used for arrivals
4R/22L & 3L/21R are normally used for departures

Runways 9L/27R & 9R/27L are used only during light cross-winds

Expected Impacts

- Benchmark Study: VFR and IFR capacity increases of 25% and 17% respectively (assuming “full use of runway”)
- Press Release
  - Overall capacity increase of 25%
  - 50% capacity increase during peak times
  - 3000 hrs of delay reduction

Motivation

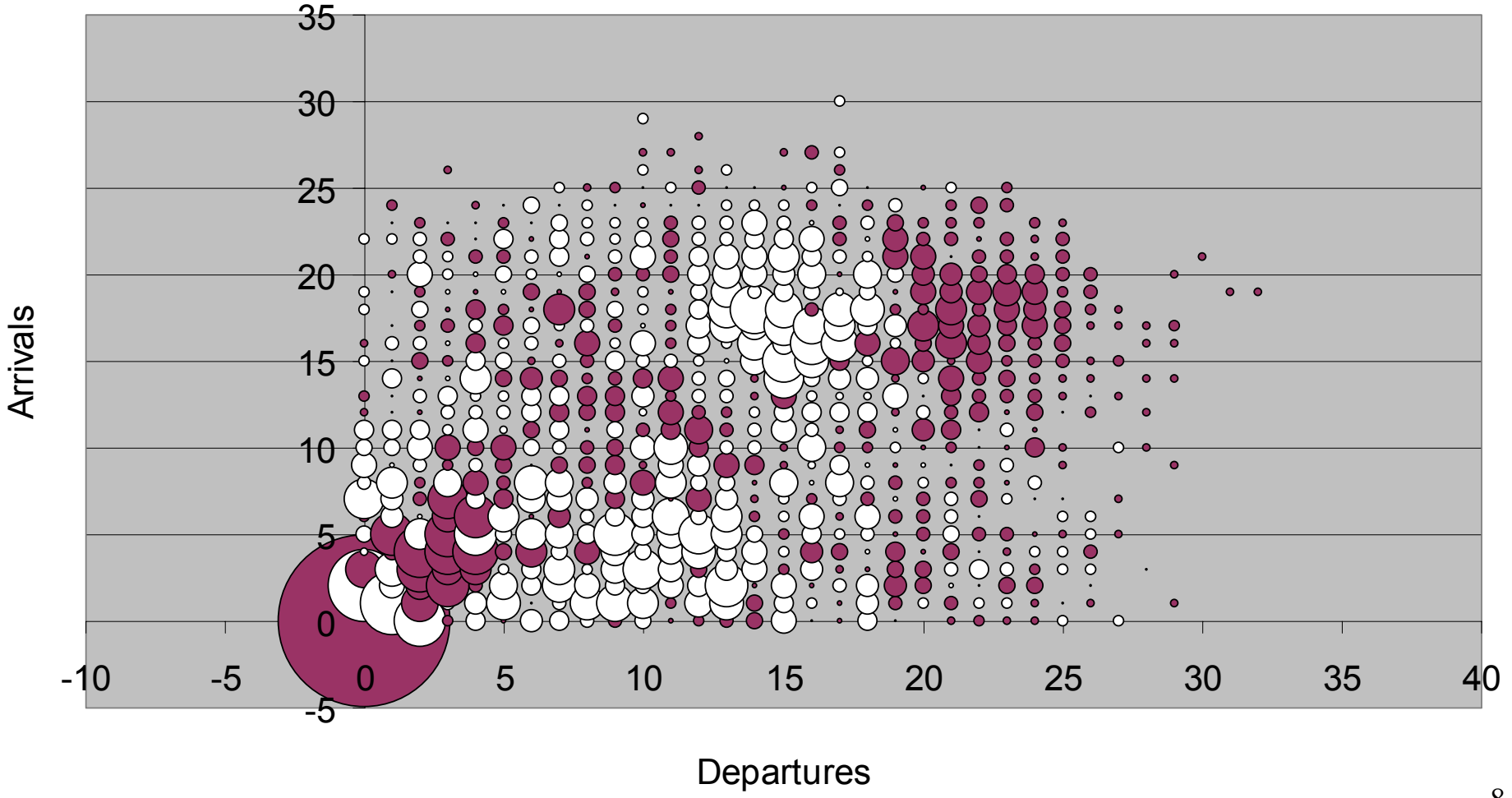
- Initial Free Flight Office analysis found little impact
- Implications for ability to measure impact of more incremental changes
- Confounding effects of 9/11

Data

- ASPM quarter-hour data for first six months of 2001 (before) and 2002 (after)
- Four metrics
  - Arrival counts and departure counts
  - Arrival demand and departure demand
    - Flight counted toward demand beginning in the quarter hour when it is expected to arrive/depart based on last filed flight plan before departure
    - If arrival/departure occurs earlier than planned then flight counted toward demand in the earlier period
    - Demand never exceeds count
    - Different between count and demand is queue length at end of period

Change in VMC Distribution of Arrival and Departure Counts, Jan-June 2001-2002

(purple is increase; light is decrease)



Change in IMC Distribution of Arrival and Departure Counts, Jan-June 2001-2002

(purple is increase; light is decrease)

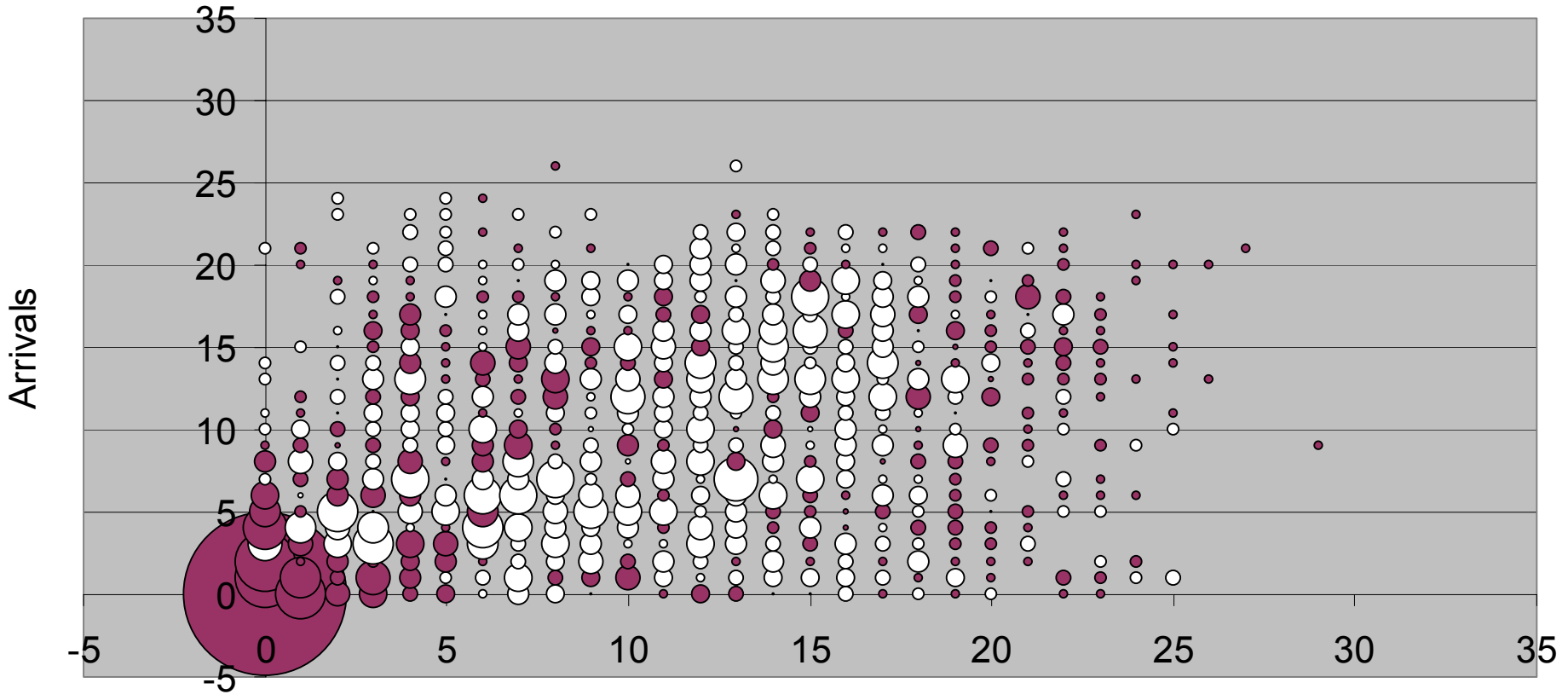


FIGURE 5
Departure Count Distribution for Jan-Jun 2001 & 2002 VFR Conditions.

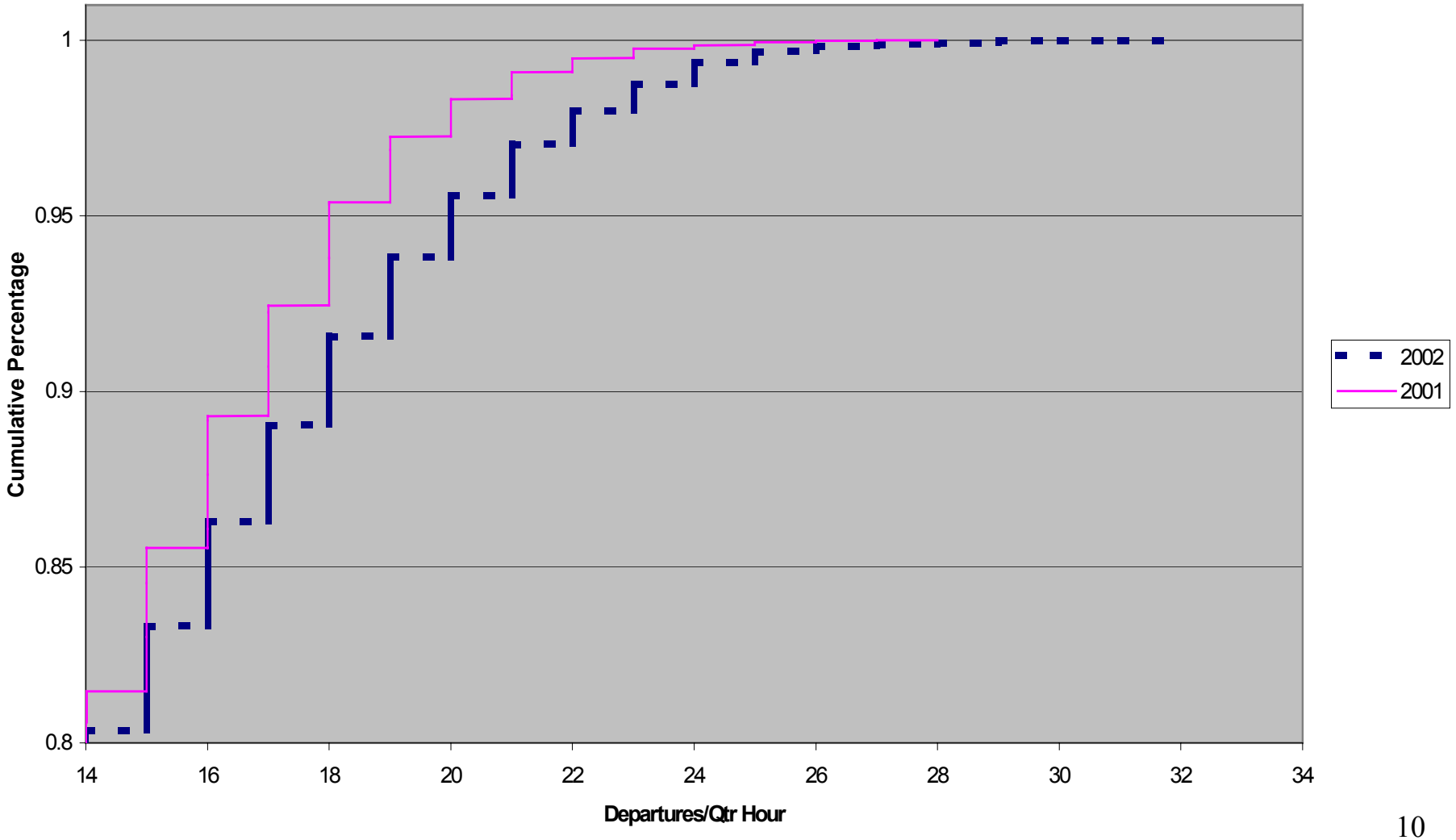


FIGURE 6
Departure Count Distribution for Jan - Jun 2001 & 2002 IFR Conditions.

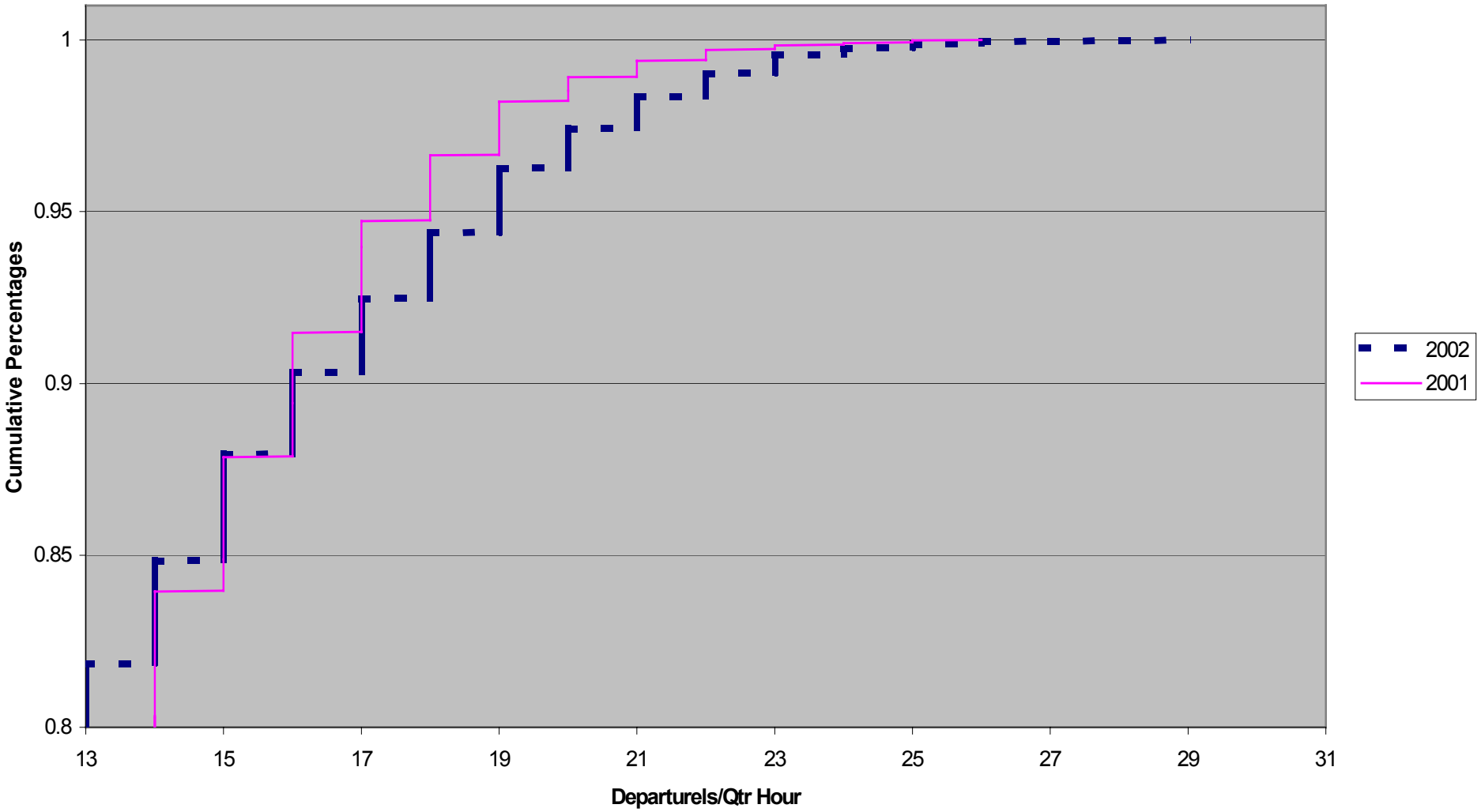


FIGURE 7

Arrival Count Distributions for Jan - Jun 2001 & 2002 VFR Conditions.

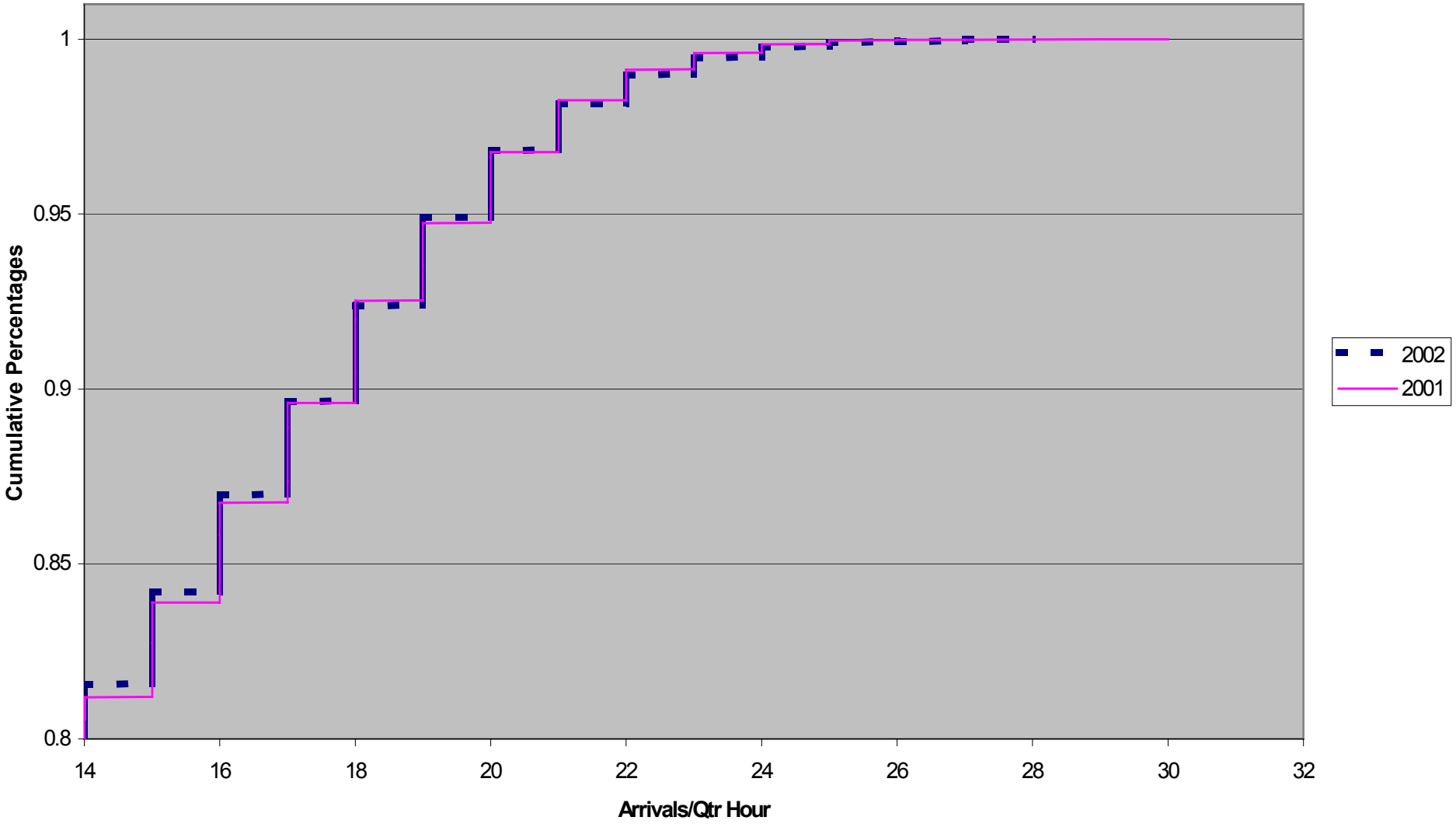


FIGURE 8
Arrival Count Distributions for Jan - Jun 2001 & 2002 IFR Conditions.

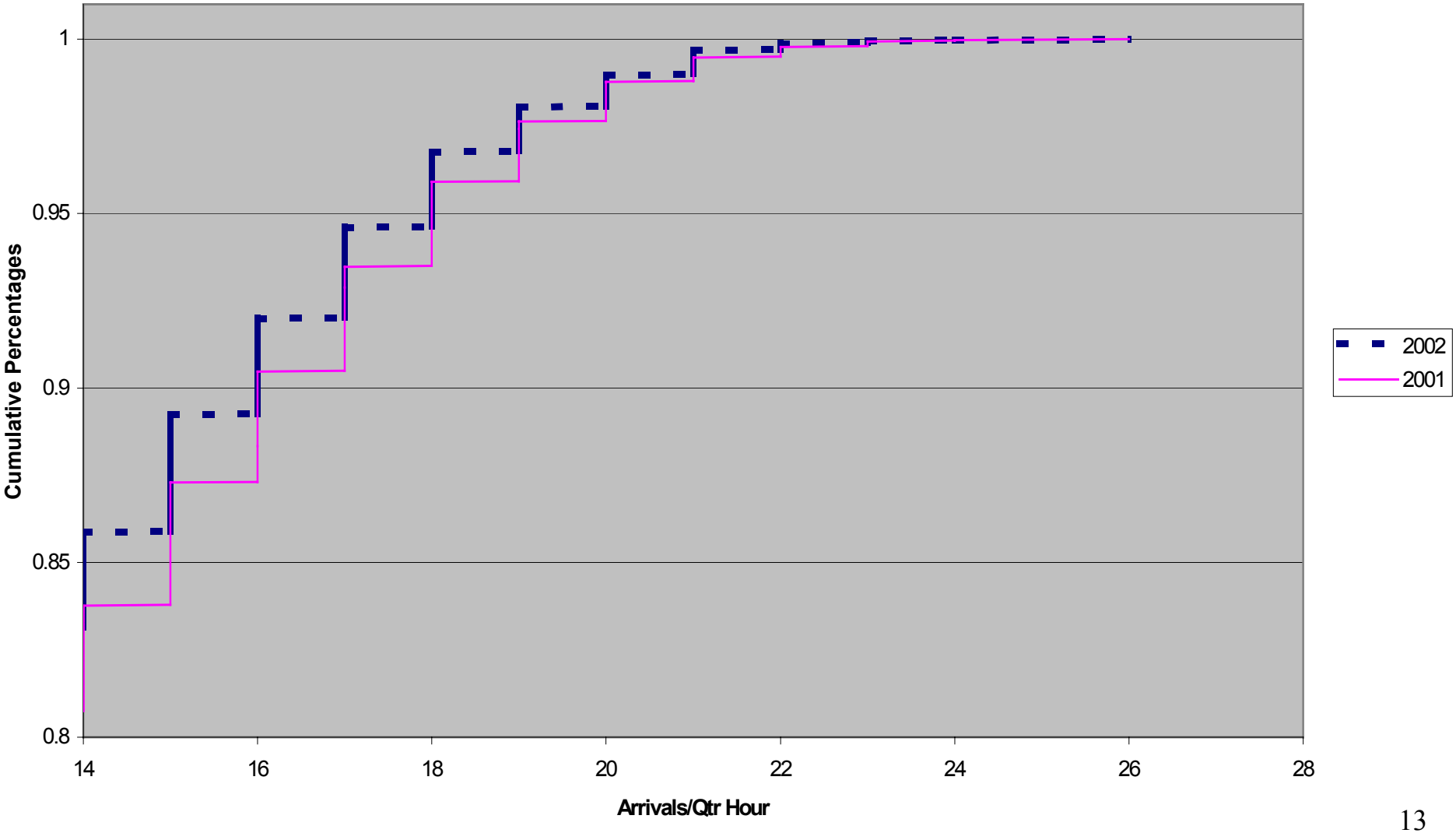


FIGURE 9

Mean Departure Count vs Departure Demand Jan-Jun 2001 & 2002 VFR Conditions.

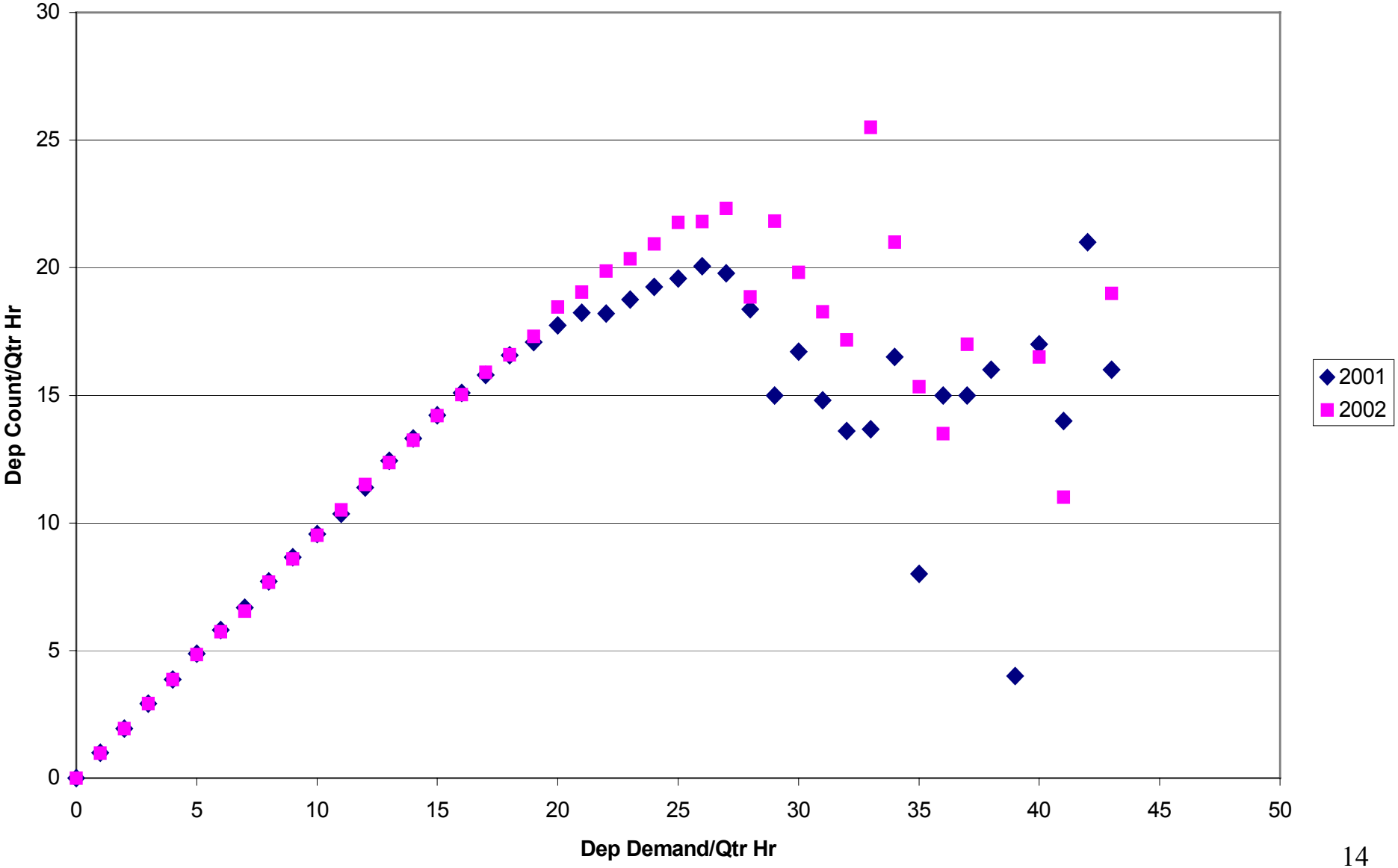


FIGURE 10

Mean Departure Count vs Departure Demand Jan-Jun 2001 & 2002 IFR Conditions.

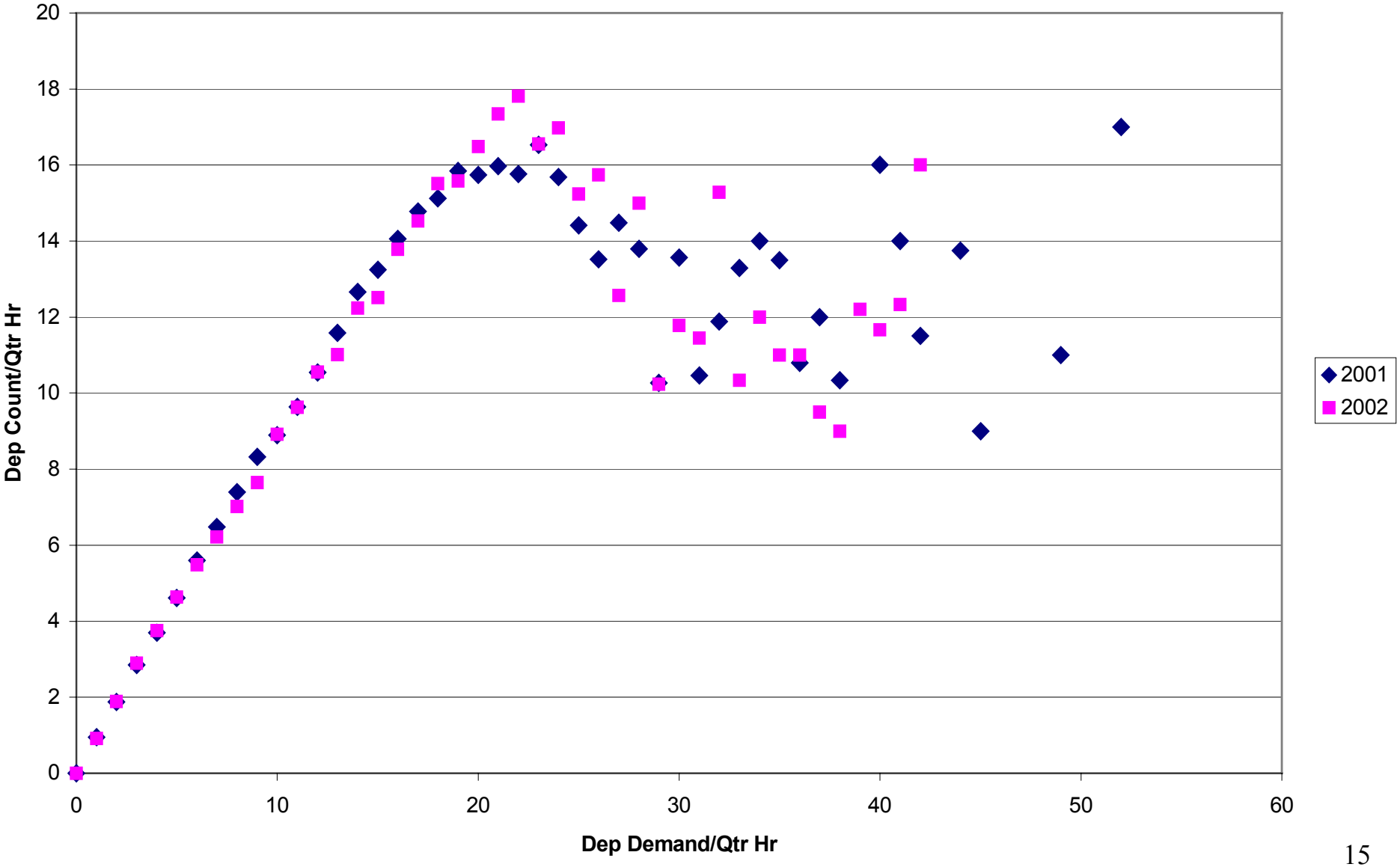


FIGURE 11
Mean Arrival Count vs Arrival Demand Jan-Jun 2001 & 2002 IFR Conditions.

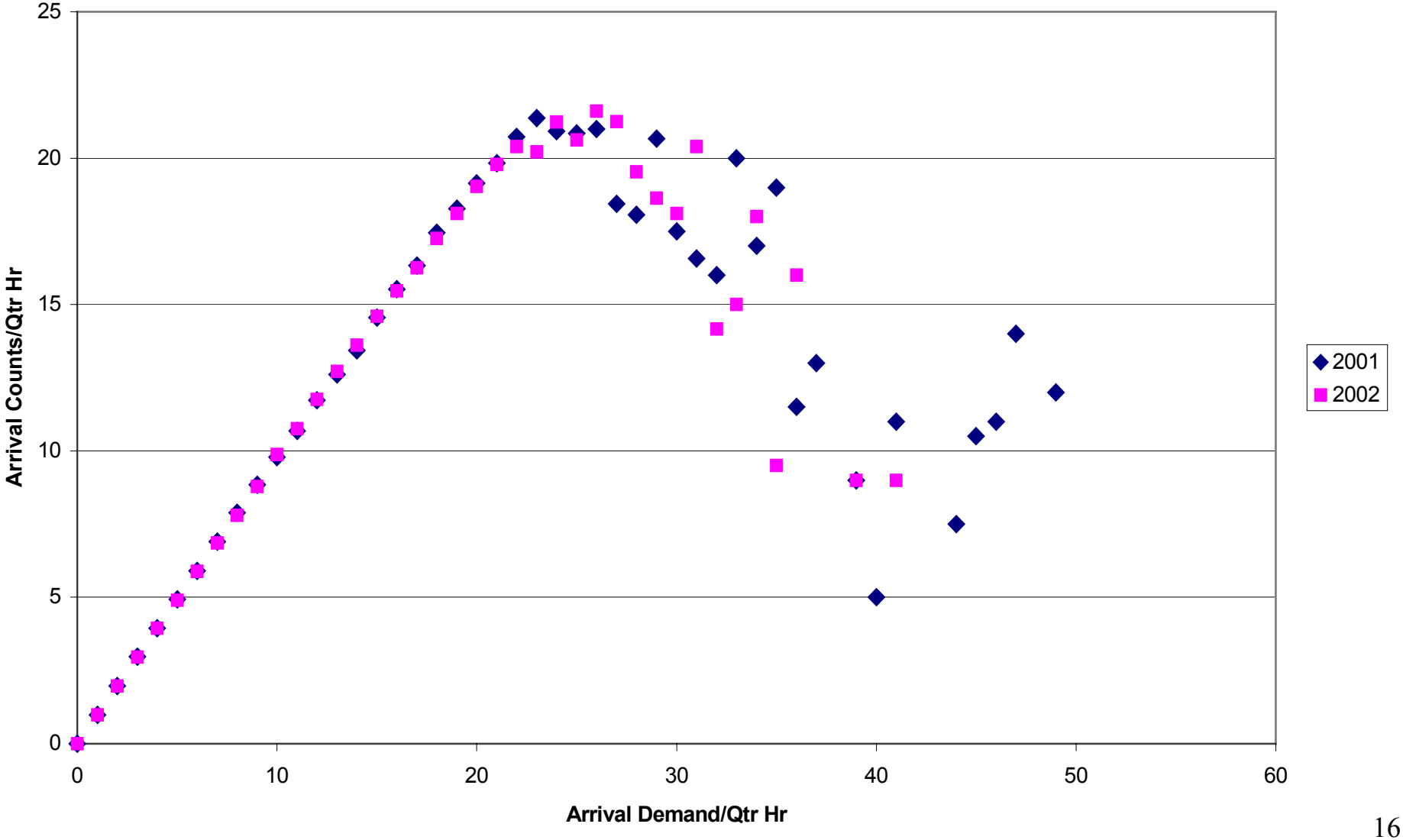
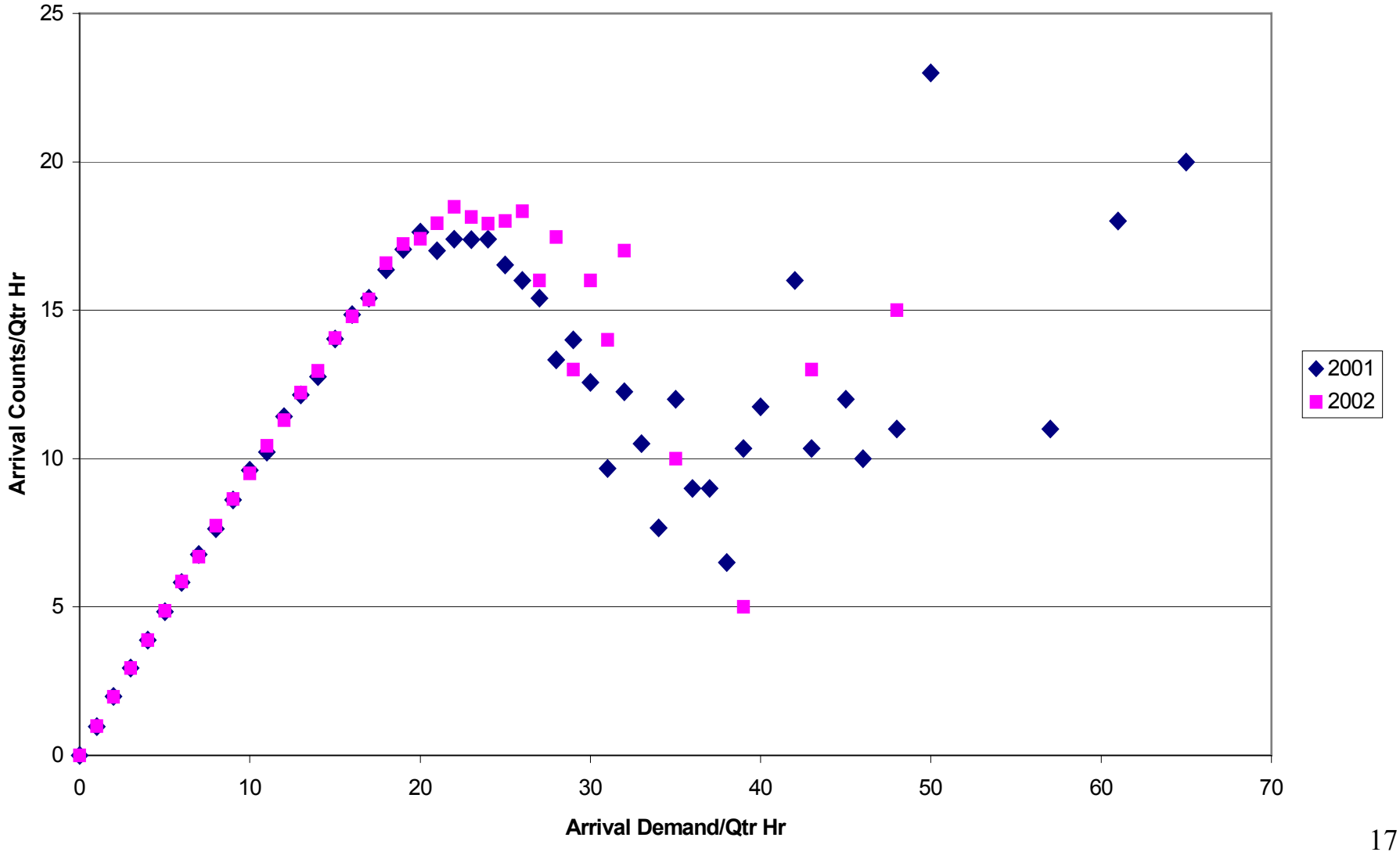
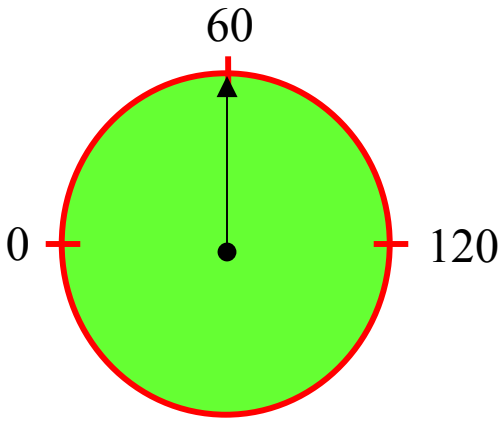


FIGURE 12
Mean Arrival Count vs Arrival Demand Jan-Jun 2001 & 2002 IFR Conditions.

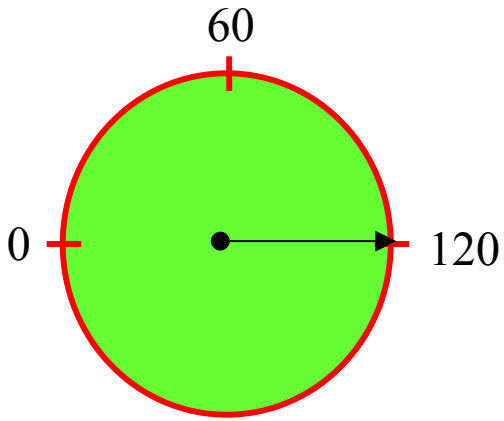


Censored Regression Analysis

- Data “saturates” measurement device
- Example: speedometer



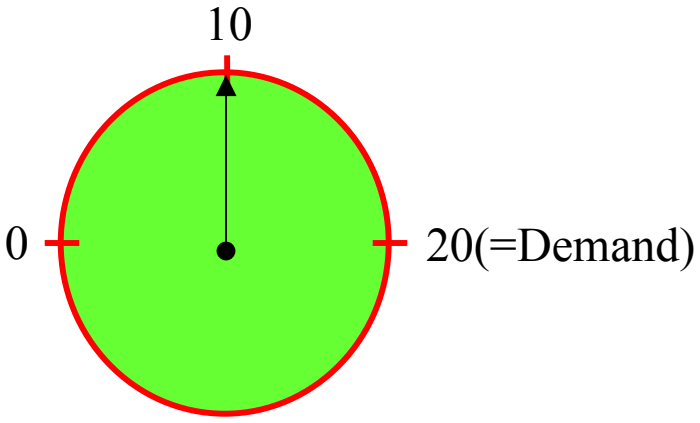
Speed=60 mph



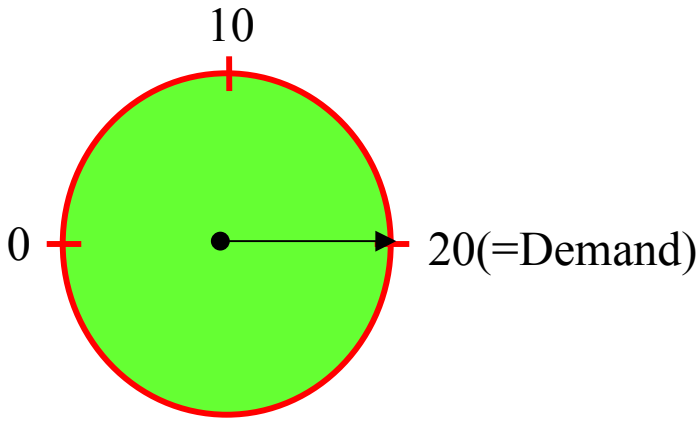
Speed>=120 mph

Application to Airport Capacity

- Actual Speed⇔Capacity
- Maximum Speed Measurement⇔Demand



Capacity=10 FPQH



Capacity≥20 FPQH

Censored Regression Model 1

$$COUNT_{op,t} = \min(CAP_{op,t}, DMD_{op,t})$$

$$CAP_{op,t} \sim NORM(\mu_{op,m(t),a(t)}, \sigma^2_{op,m(t)})$$

$COUNT_{op,t}$	ASPM count of operation *op*(arrs/deps) and 15-min time period *t*
$CAP_{op,t}$	Capacity for *op* in time period *t*
$DMD_{op,t}$	ASPM demand for *op* in time period *t*
$\mu_{op,m(t),a(t)}$	Mean capacity for *op,* meteorlogical condition *m* (VMC/IMC), before (a=0) and after (a=1) new runway
$\sigma^2_{op,m(t)}$	Capacity variance for *op,* meteorlogical condition *m* (VMC/IMC)

Problems with Model 1

- Flights counted toward demand may be unable to land/depart for reasons other than capacity constraint ("anomalously delayed" (AD) flights
- These can greatly distort capacity inferences
- Example
  - Demand=5
  - Capacity=20
  - No AD Flights $\Rightarrow$ Capacity $\geq$ 5
  - 1 AD Flight $\Rightarrow$ Capacity=4

Censored Regression Model 2

$$COUNT_{op,t} = \min(CAP_{op,t}, DMD^{*}_{op,t})$$

$$CAP_{op,t} \sim NORM(\mu_{op,m(t),a(t)}, \sigma^{2}_{op,m(t)})$$

$$DMD^{*}_{op,t} \sim BINOM(DMD_{op,t}, PNAD_{op,m(t)})$$

Where $PNAD_{op,m(t)}$ is the probability that a flight counted toward the demand for *op* is <u>not</u> anomalously delayed under meteorlogical condition *m*. It is calculated using count/demand ratios for under low demand conditions.

Rates of Anomalous Delays based on Count/Demand Ratios for Demand<5 FPQH

Meteorological Condition	Operation Type	Pre-deployment	Post-deployment	Overall
VMC	Arrivals	0.0132	0.0153	0.0142
	Departures	0.0285	0.0300	0.0293
IMC	Arrivals	0.0245	0.0214	0.0230
	Departures	0.0662	0.0603	0.0634

Table 2—Observed Rates of Anomalous Delays

Likelihood Function

$$LL(\alpha_{o,V},\beta_{o,V},\sigma_{o,V},\alpha_{o,I},\beta_{o,I},\sigma_{o,I}\,|\,Q_o(1)...Q_o(T),P_{o,V},P_{o,I}) =$$

$$\sum_{\substack{Q_o(t)<D_o(t)\\ Q_o(t)>0}} \log\left\{\left(\frac{D_o(t)!P_{o,m(t)}^{D_o(t)-Q_o(t)}(1-P_{o,m(t)})^{Q_o(t)}}{Q_o(t)!\left(D_o(t)-Q_o(t)\right)!}\right)\cdot\Phi\left(\frac{\alpha_{o,m(t)}+\beta_{o,m(t)}A(t)-Q_o(t)}{\sigma_{o,m}}\right)+\right.$$

$$\left.\sum_{n=1}^{D_o(t)-Q_o(t)-1}\left(\frac{D_o(t)!P_{o,m(t)}^{n}(1-P_{o,m(t)})^{D_o(t)-n}}{n!\left(D_o(t)-n\right)!}\cdot\frac{\phi\left(\left(Q_o(t)-\alpha_{o,m(t)}-\beta_{o,m(t)}A(t)\right)/\sigma_{o,m}\right)}{\sigma_{o,m}}\right)\right\}$$

$$+\sum_{\substack{D_o(t)>0\\ Q_o(t)=0}}\log\left\{P_{o,m(t)}^{D_o(t)}+\sum_{n=1}^{D_o(t)-1}\left(\frac{D_o(t)!P_{o,m(t)}^{n}(1-P_{o,m(t)})^{D_o(t)-n}}{n!\left(D_o(t)-n\right)!}\cdot\Phi\left(\frac{-\left(\alpha_{o,m(t)}+\beta_{o,m(t)}A(t)\right)}{\sigma_{o,m}}\right)\right)\right\}$$

$$+\sum_{Q_o(t)=D_o(t)}\log\left(\left(1-P_{o,m(t)}\right)^{D_o(t)}\cdot\Phi\left(\frac{\alpha_{o,m(t)}+\beta_{o,m(t)}A(t)-Q_o(t)}{\sigma_{o,m}}\right)\right)$$

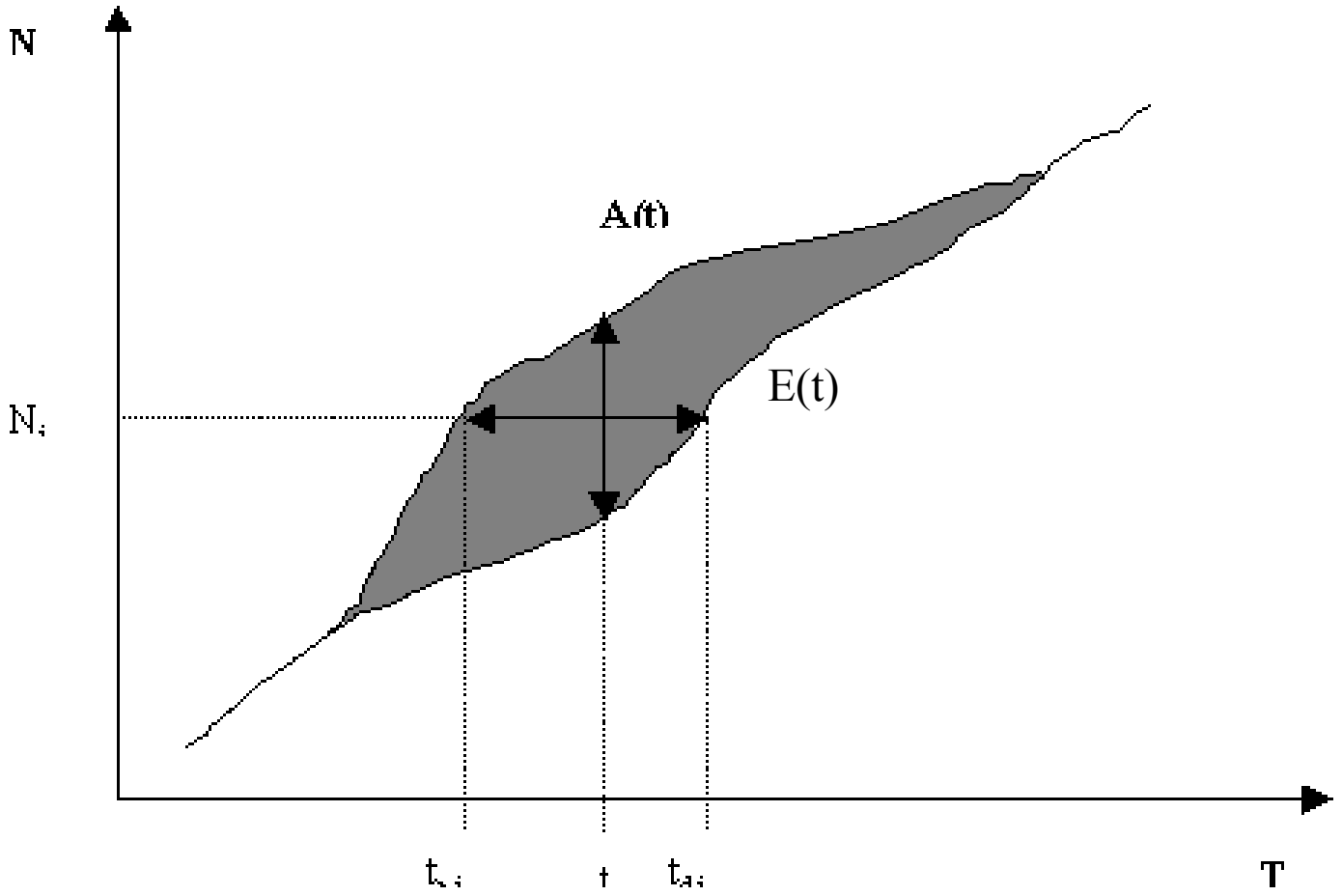
Estimation Results

- VMC departure capacity increased from 83 to 88 per hour
- No significant capacity increases for arrivals or IMC departures
- Interpretation
  - New runway replaced share-use runway with dedicated departure and arrival runways
  - Greatest impact on departures because arrivals given priority on shared-use runway
  - Greatest impact in VMC because IMC creates natural gaps in arrival stream that can be used for departures
  - Further changes expected when triple arrival stream procedure is implemented

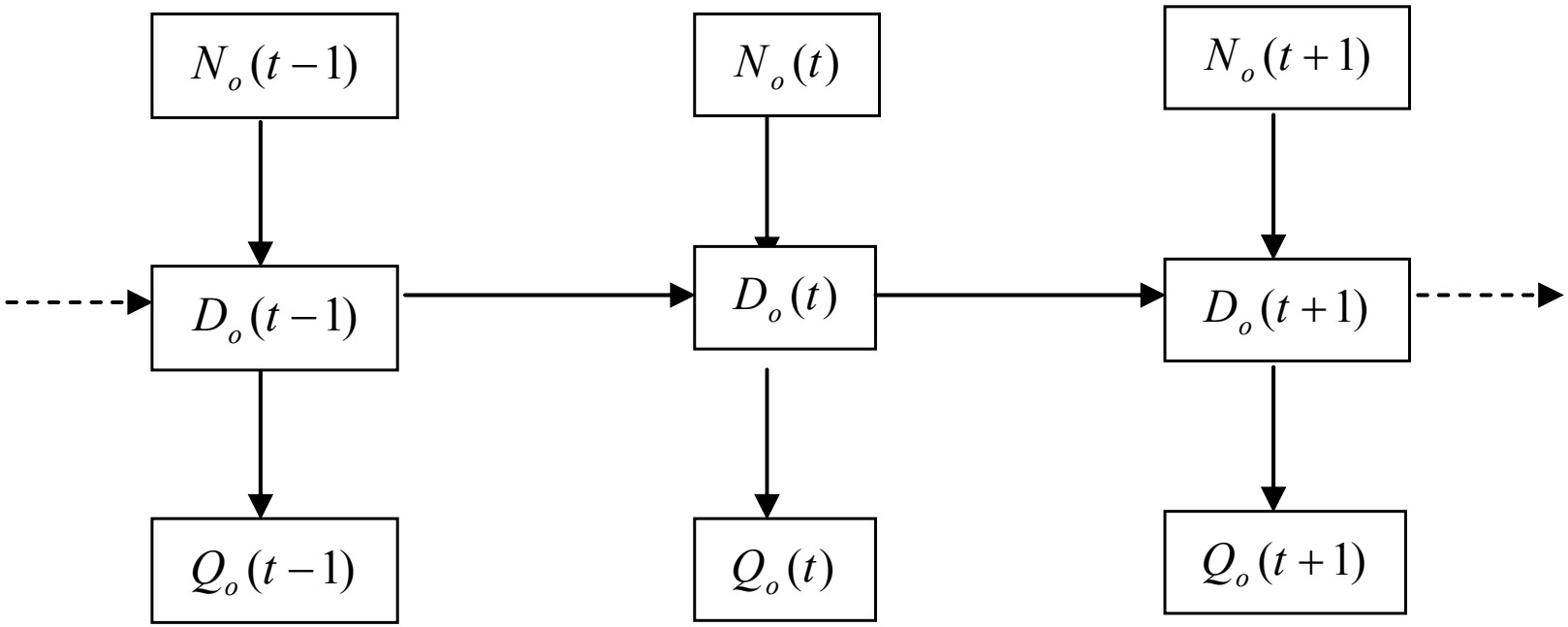
Delay Impact of Capacity Increase

- How much more delay would there have been if 2002 demand had been served by DTW without the new runway?
- Estimate using deterministic queuing diagram
- Consider departure delays only

Delay Impact Calculations



Relationship between New Demand, Total Demand, and Throughput



Delay Impact Estimates

		Jan.-June 2001		Jan.-June 2002	
		Mean	Std. Dev	Mean	Std. Dev
Departures	Observed	1.92		1.93	
	Simulated Baseline	2.00	0.060	1.92	0.032
	Simulated Counterfactual	1.77	0.052	2.26	0.070
	Difference	0.23		-0.34	
Arrivals	Observed	1.01		0.95	
	Simulated Baseline	0.89	0.026	0.93	0.029
	Simulated Counterfactual	0.92	0.027	0.90	0.041
	Difference	-0.03		0.03	

Table 5—Delay Comparisons, Simulated vs Observed, and Baseline vs Counterfactual

Conclusions

- Runway 4L/22R increased departure capacity but not departure capacity in post deployment period
- 7% capacity increase resulted in 15% departure delay decreased
- Impacts may change when additional procedures implemented
- Methodology shows promise for assessing capacity impacts of a large variety of events