Estimating Delay and Capacity Impacts of Airport Infrastructure Investments

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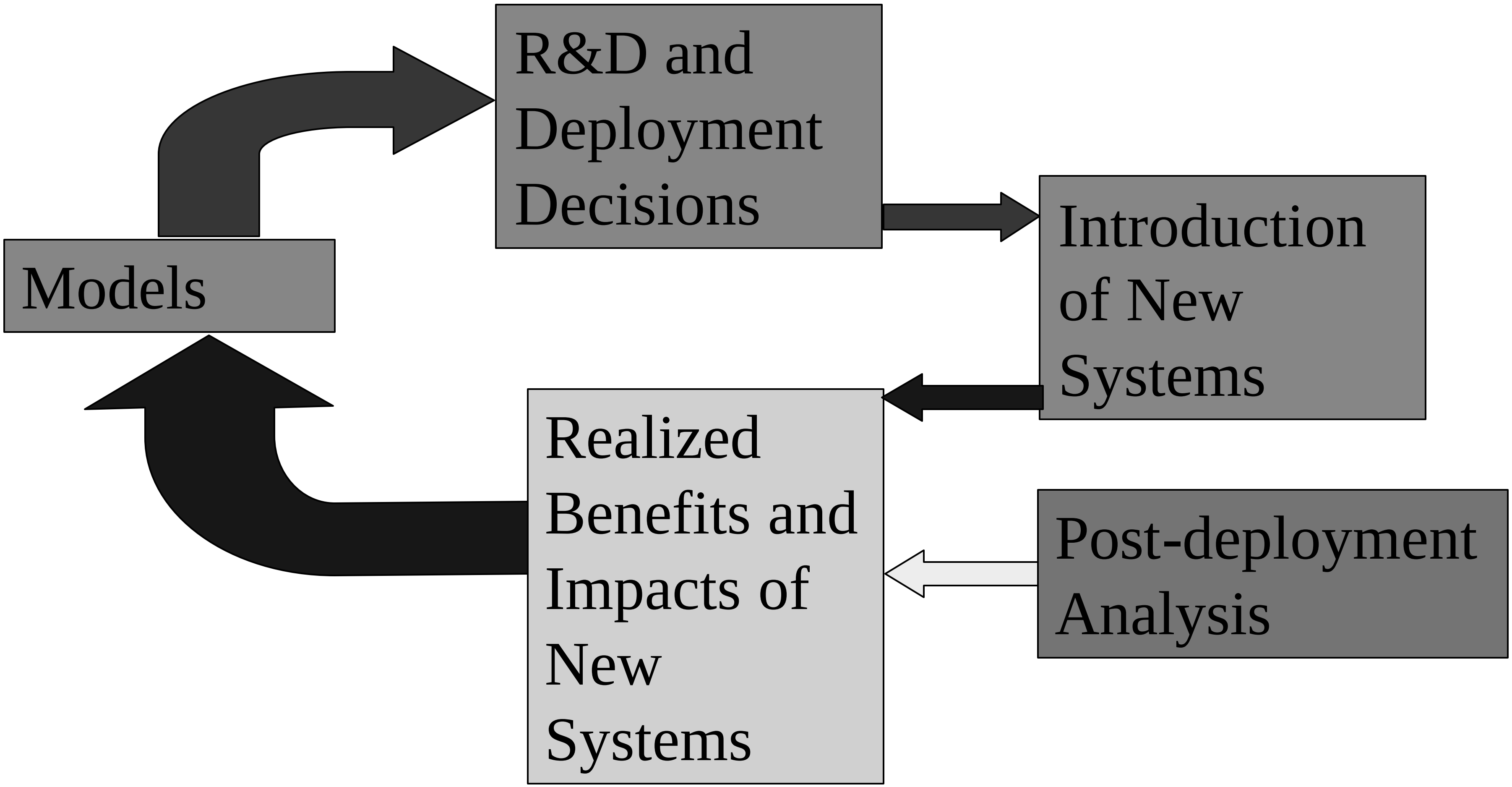
Systems Analysis in Aviation



Post-Deployment Analysis

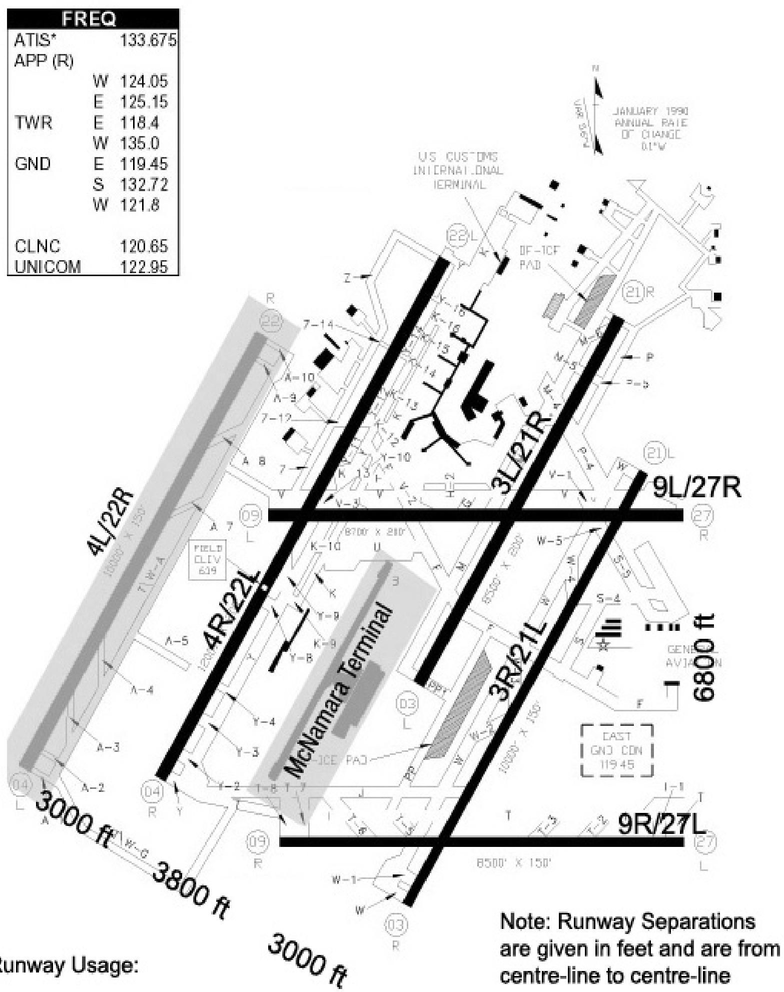
- Study actual effects of infrastructure and technology deployments on NAS behavior and performance
- Close the systems analysis loop and allow learning from experience
- Two schools of thought on PDA
  - Counting school—how deployments effect capacity and throughtput
  - Timing school—how deployments effect delays and times-in-system

This Study

- Achieve “best of both worlds” from counting school and timing school
- Overcome methodological problems in both schools
- Use censorer regression to estimate capacity impacts
- Extract delay directy from capacity impacts

Background

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

- 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

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

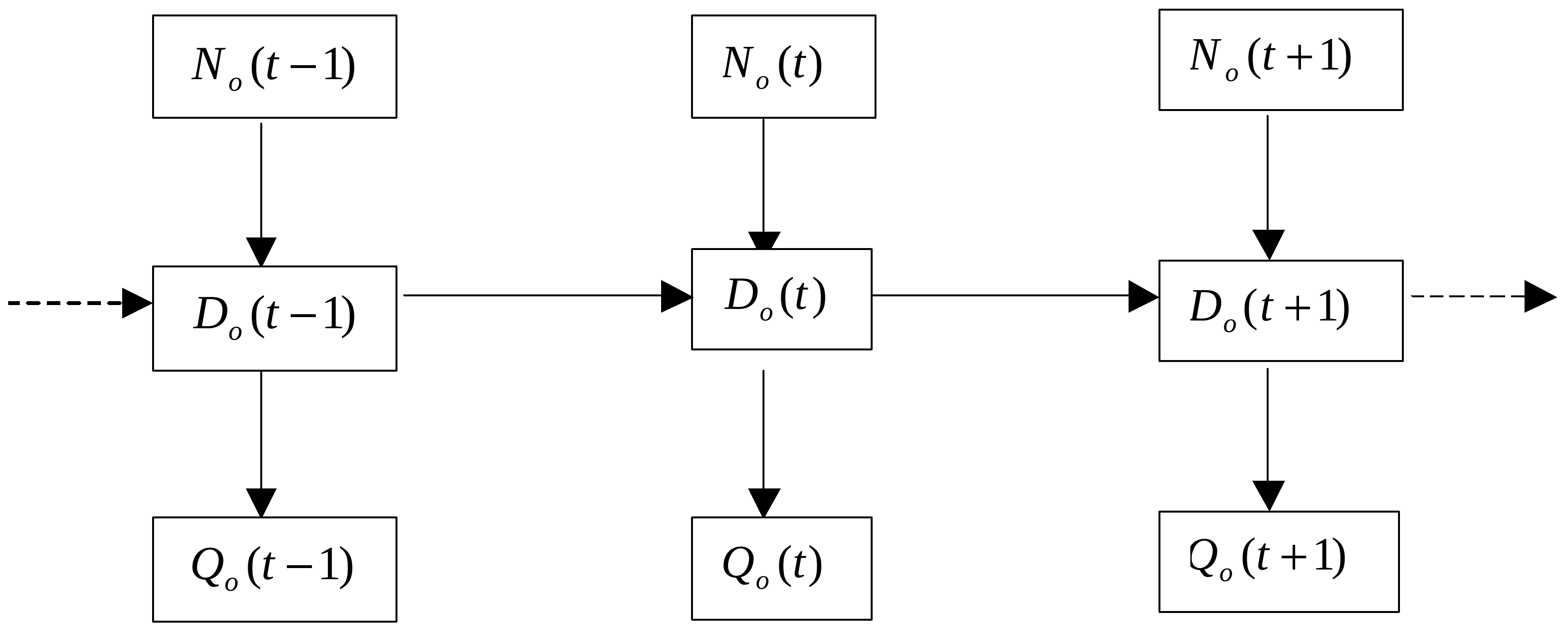
Motivation

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

Data

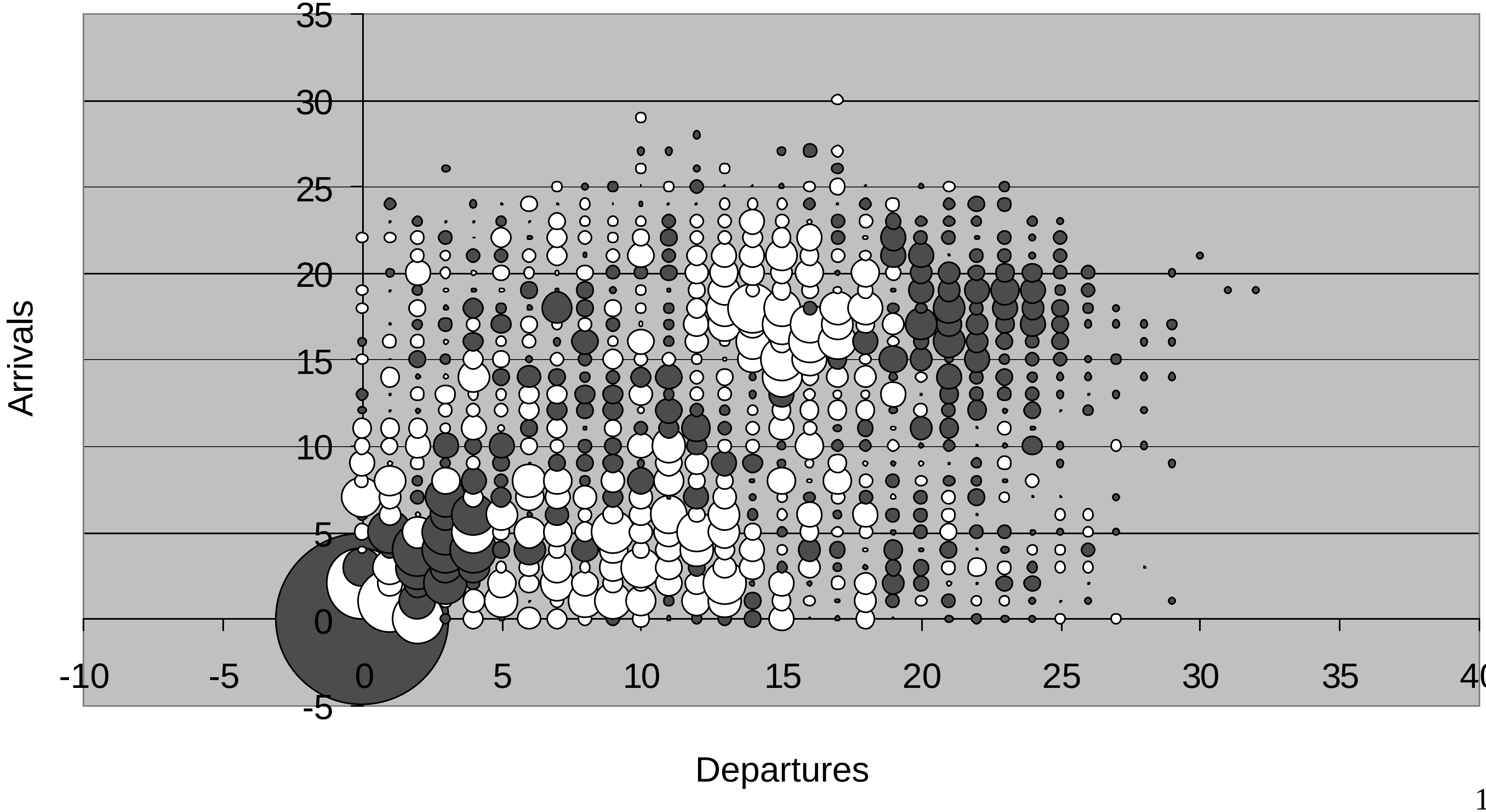
- ASPM quarter-hour data for first six months of 2001 (before) and 2002 (after)
- Four metrics
  - Arrival counts and departure counts
  - Arrival demand and departure demand
    - Flight counted toward demand beginning in the quarter hour when it is expected to arrive/depart based on last filed flight plan before departure/time of gate 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

Relationship between Demand (D), Count (Q), and New Demand (N)



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

(purple is increase; light is decrease)



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

(purple is increase; light is decrease)

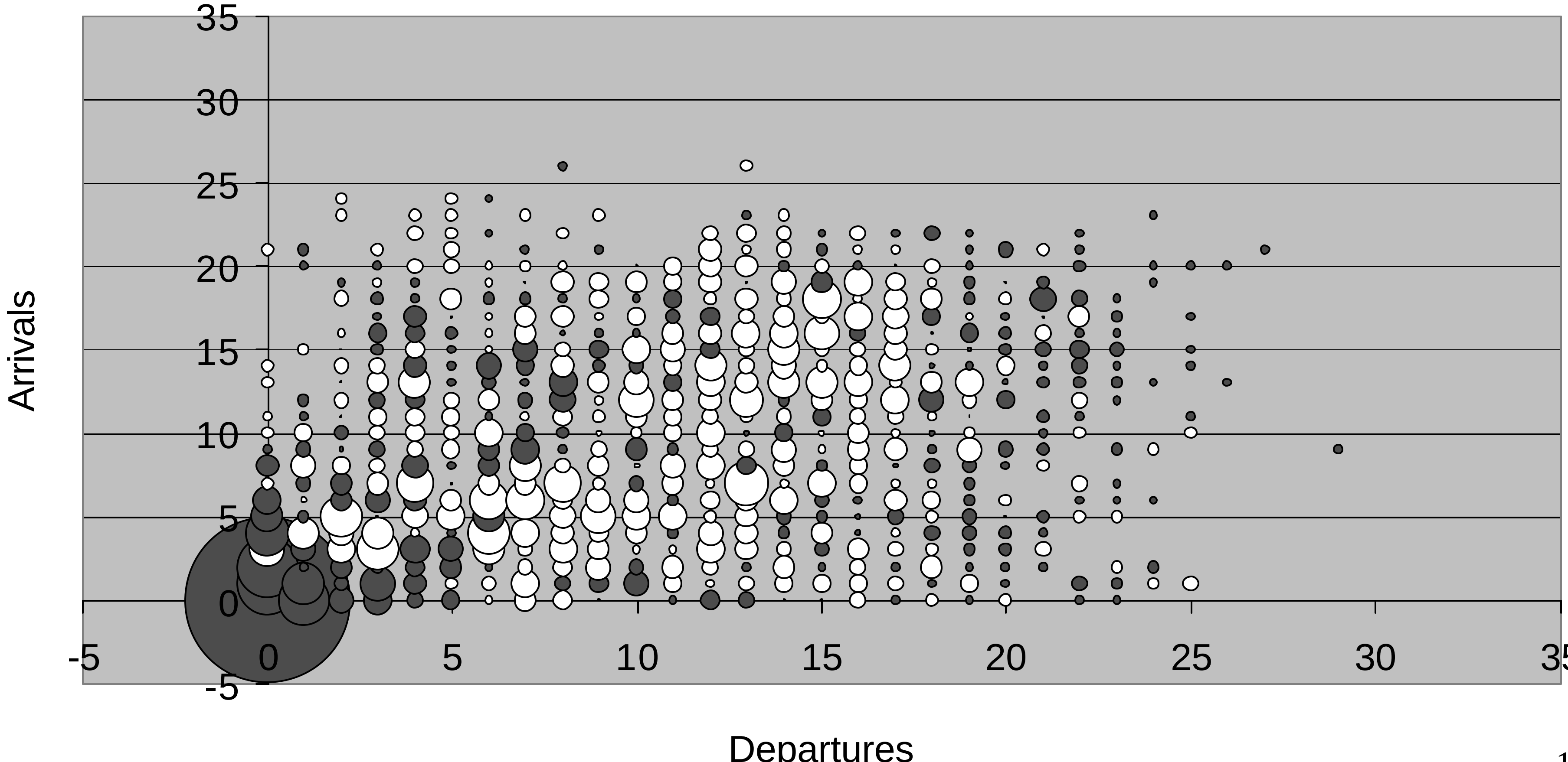


FIGURE 9
Mean Departure Count vs Departure Demand Jan-Jun 2001 & 2002 VFR Conditions.

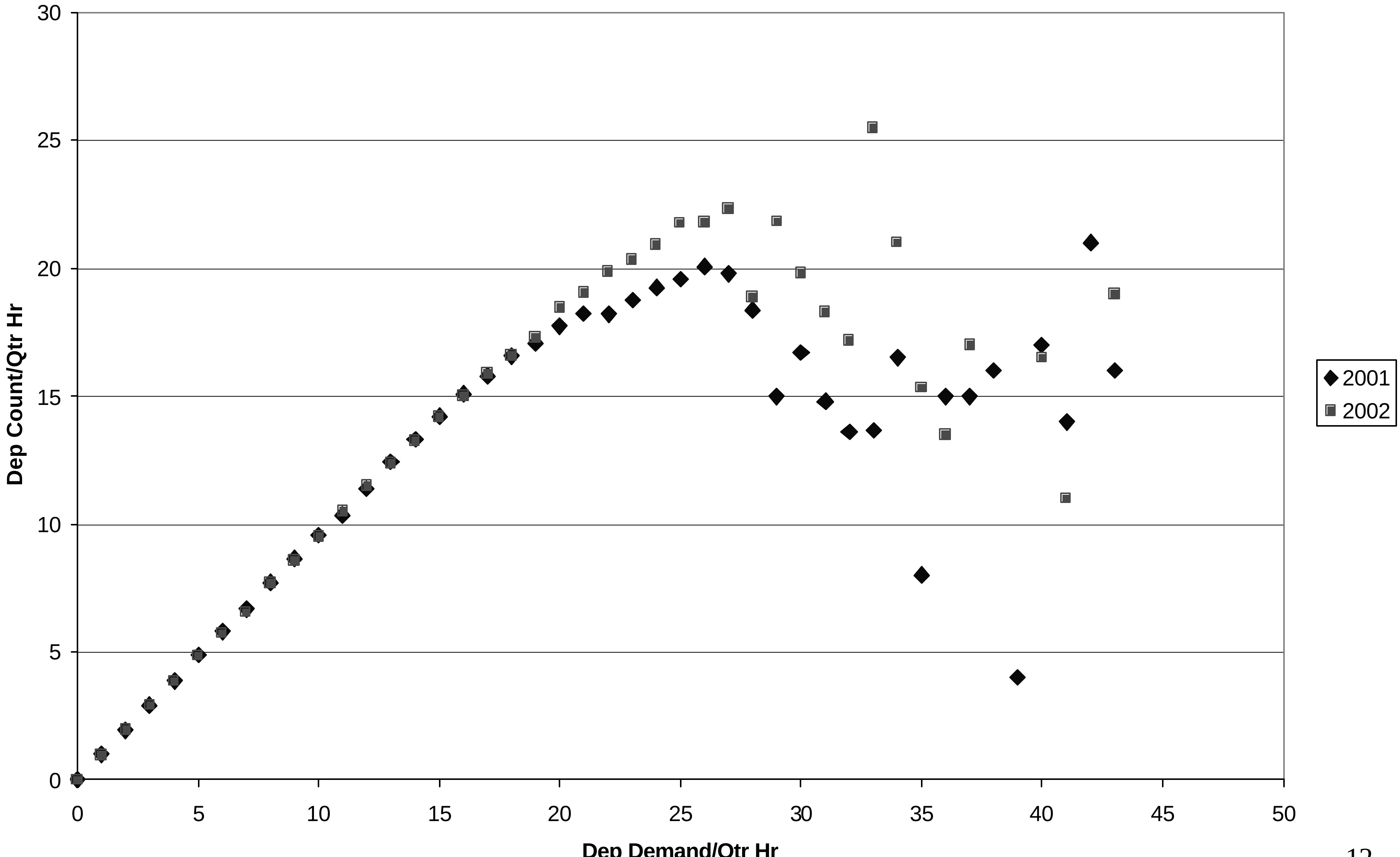


FIGURE 10
Mean Departure Count vs Departure Demand Jan-Jun 2001 & 2002 IFR Conditions.

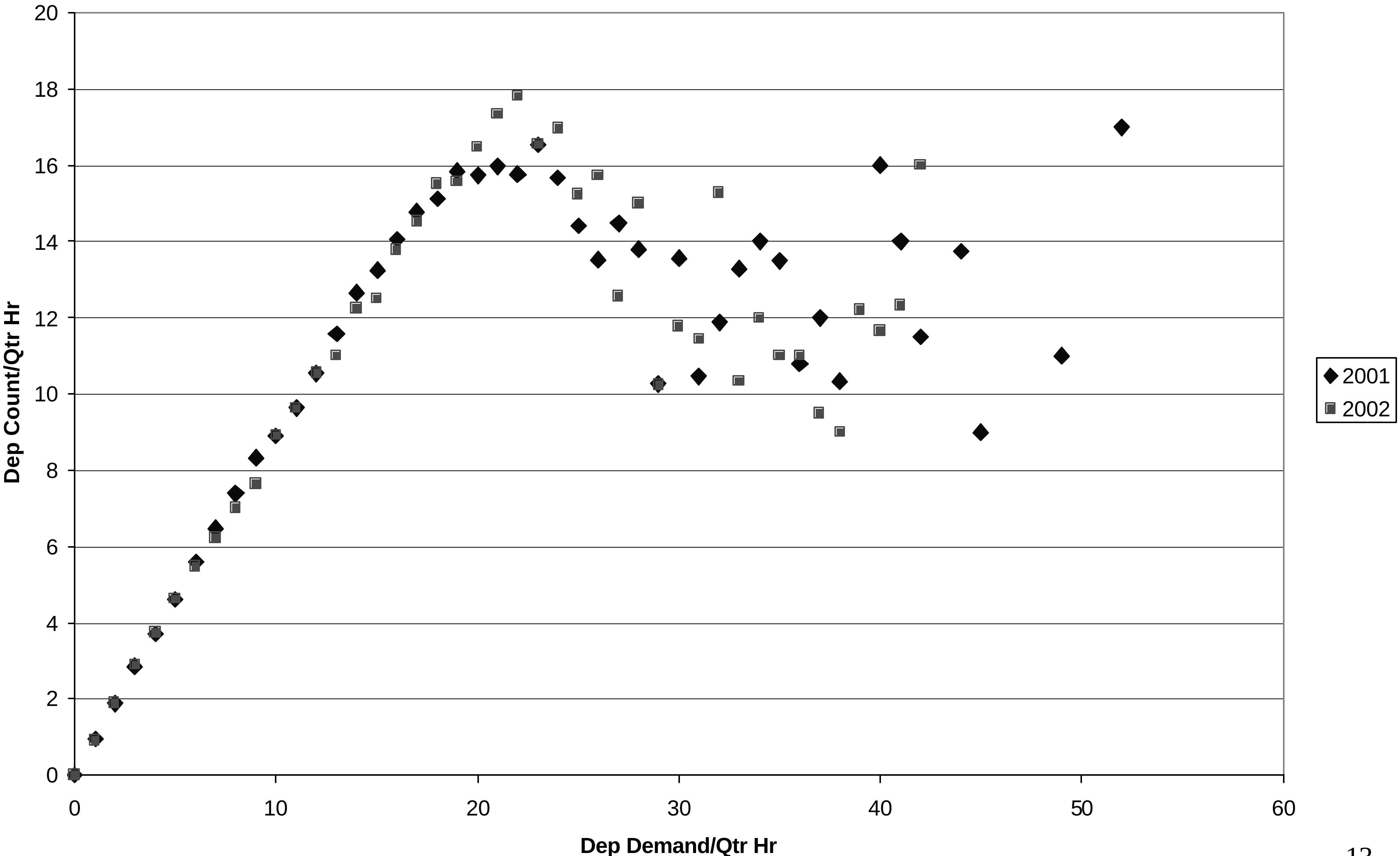


FIGURE 11
Mean Arrival Count vs Arrival Demand Jan-Jun 2001 & 2002 IFR Conditions.

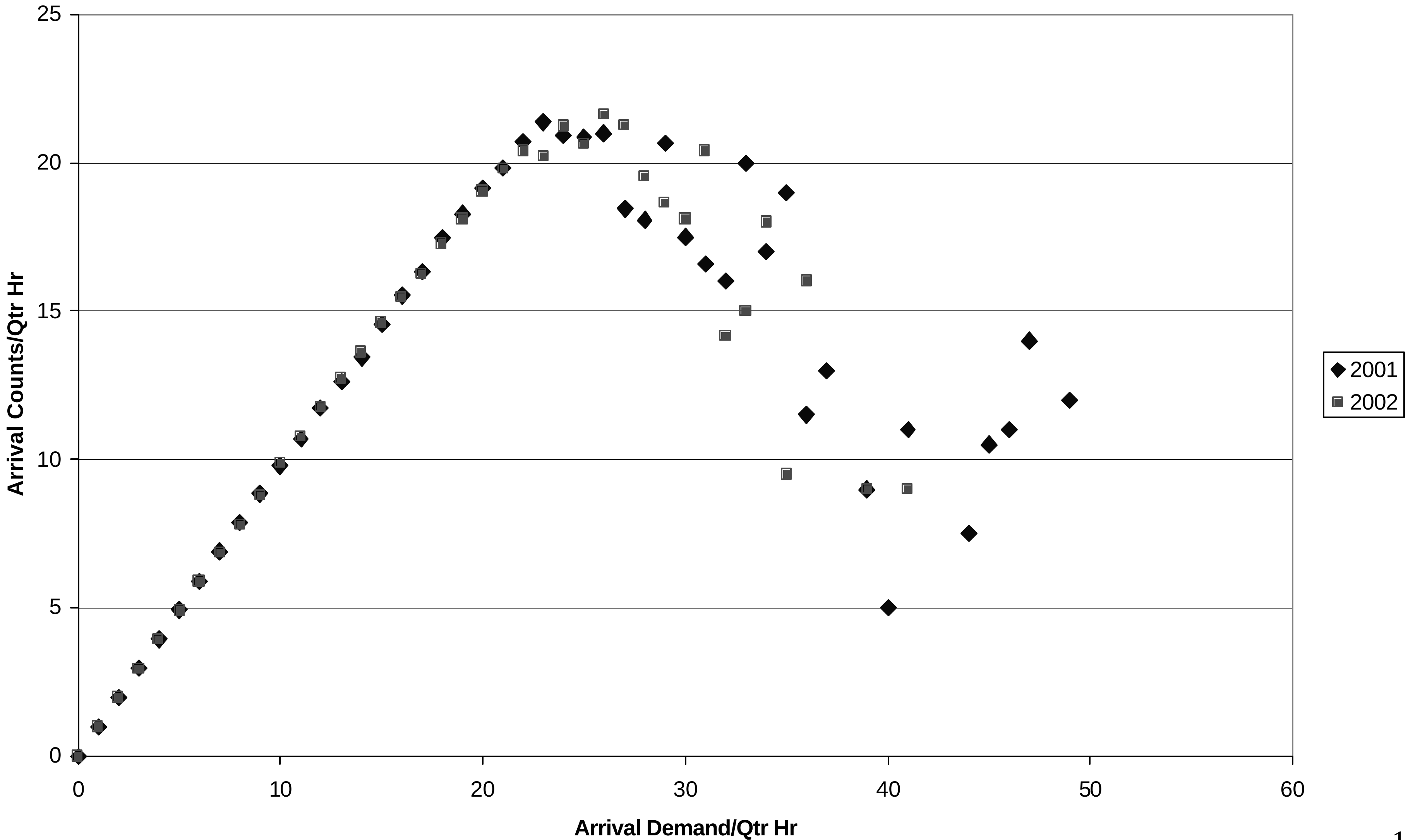
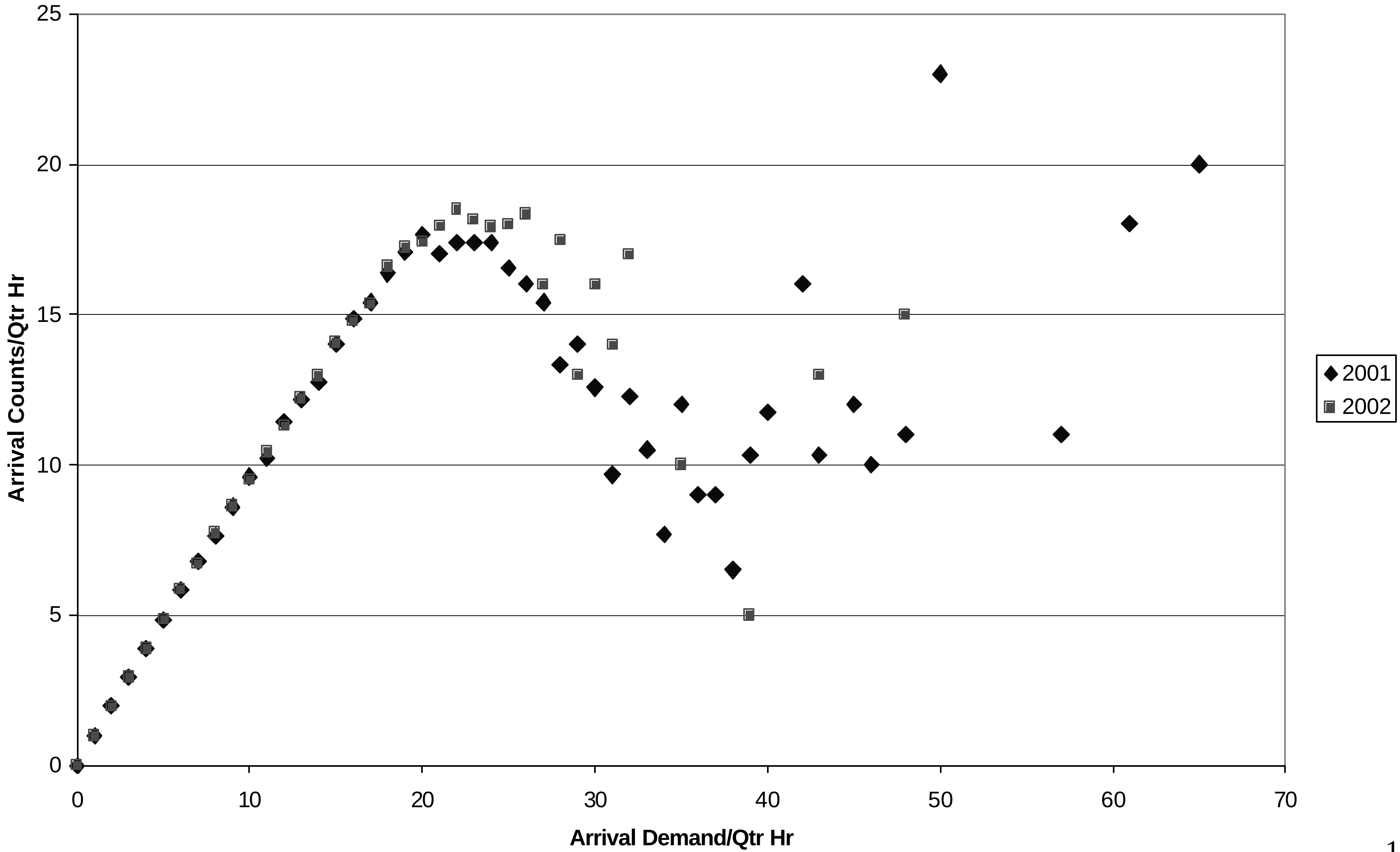


FIGURE 12
Mean Arrival Count vs Arrival Demand Jan-Jun 2001 & 2002 IFR Conditions.



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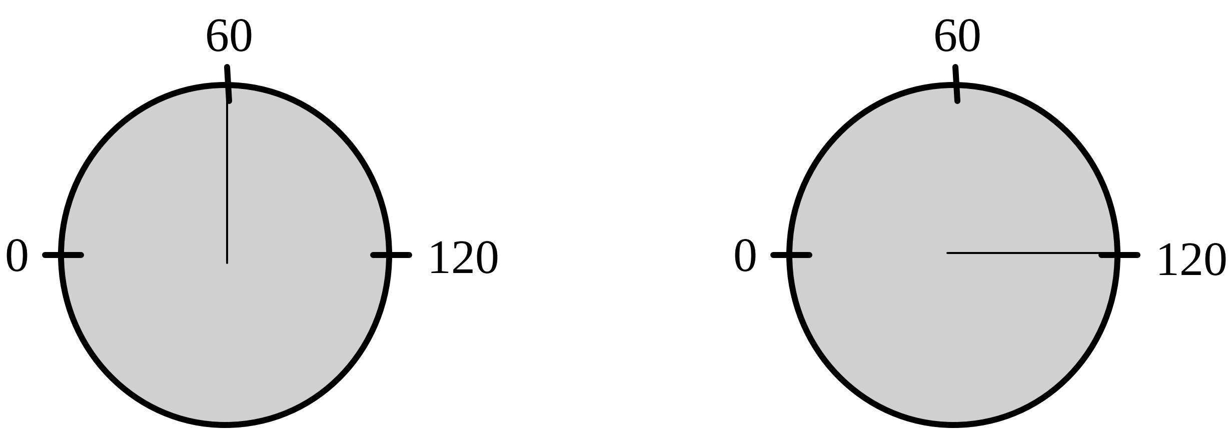
Censored Regression Analysis

- Data “saturates” measurement device
- Example: speedometer

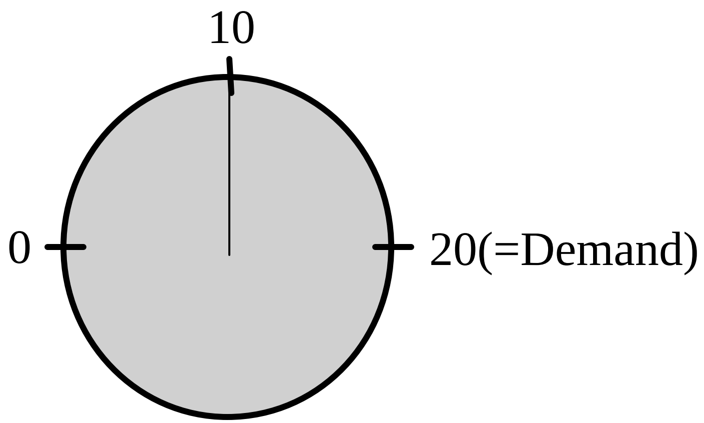


Speed=60 mph

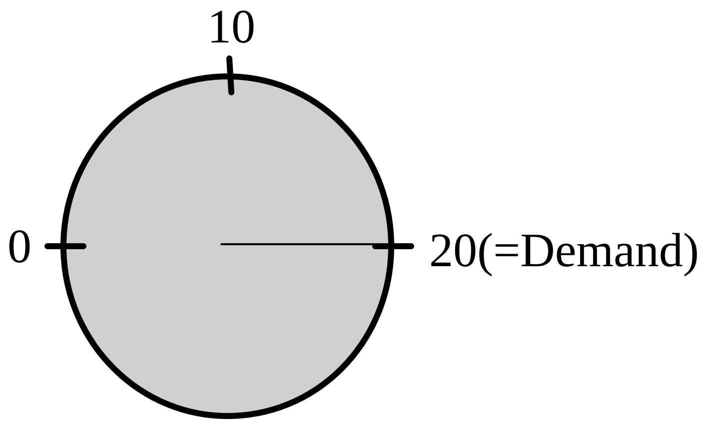
Speed>=120 mph

Application to Airport Capacity

- Actual Speed⇔Capacity
- Maximum Speed Measurement⇔Demand



Capacity=10 FPQH



Capacity≥20 FPQH

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Censored Regression Model 1

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

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

$COUNT_{op,t}$	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*
$m_{op,m(t),a(t)}$	Mean capacity for *op,* meteorlogical condition *m* (VMC/IMC), before (a=0) and after (a=1) new runway
$s^{2}_{op,m(t)}$	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=5

NEXTOR

Censored Regression Model 2

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

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

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

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

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Likelihood Function

$$LL(a_{o,V}, b_{o,V}, s_{o,V}, a_{o,I}, b_{o,I}, s_{o,I} \mid Q_o(1) \ldots Q_o(T), P_{o,V}, P_{o,I}) =$$

$$\sum_{\substack{Q_o(t)<D_o(t)\\ Q_o(t)>0}} \log\left\{ \left(\frac{D_o(t)!\, P_{o,m(t)}^{D_o(t)-Q_o(t)} (1-P_{o,m(t)})^{Q_o(t)}}{Q_o(t)!\big(D_o(t)-Q_o(t)\big)!} \right) \cdot \Phi\left(\frac{a_{o,m(t)} + b_{o,m(t)} A(t) - Q_o(t)}{s_{o,m}} \right) + \sum_{n=1}^{D_o(t)-Q_o(t)-1} \left(\frac{D_o(t)!\, P_{o,m(t)}^{n} (1-P_{o,m(t)})^{D_o(t)-n}}{n!\big(D_o(t)-n\big)!} \cdot \frac{f\Big(\big(Q_o(t) - a_{o,m(t)} - b_{o,m(t)} A(t)\big)/s_{o,m}\Big)}{s_{o,m}} \right) \right\}$$

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

$$+ \sum_{Q_o(t)=D_o(t)} \log\left(\big(1 - P_{o,m(t)}\big)^{D_o(t)} \cdot \Phi\left(\frac{a_{o,m(t)} + b_{o,m(t)} A(t) - Q_o(t)}{s_{o,m}} \right) \right)$$

Meteorological Condition	Coefficient	Operation Type: Arrivals	Operation Type: Departures
VMC	$a_{o,v}$	24.578	20.667
		(0.263)*	(0.167)
	$b_{o,v}$	-0.611	1.569
		(0.254)	(0.194)
	$s_{o,v}$	6.535	6.039
		(0.142)	(0.092)
IMC	$a_{o,i}$	18.524	18.129
		(0.228)	(0.245)
	$b_{o,i}$	0.403	-0.274
		(0.293)	(0.309)
	$s_{o,i}$	5.584	7.196
		(0.140)	(0.160)

Capacity change after new runway

*Standard errors in parentheses.

Table 3—Estimation Results, Truncated Capacity Models with Anomalous Delays

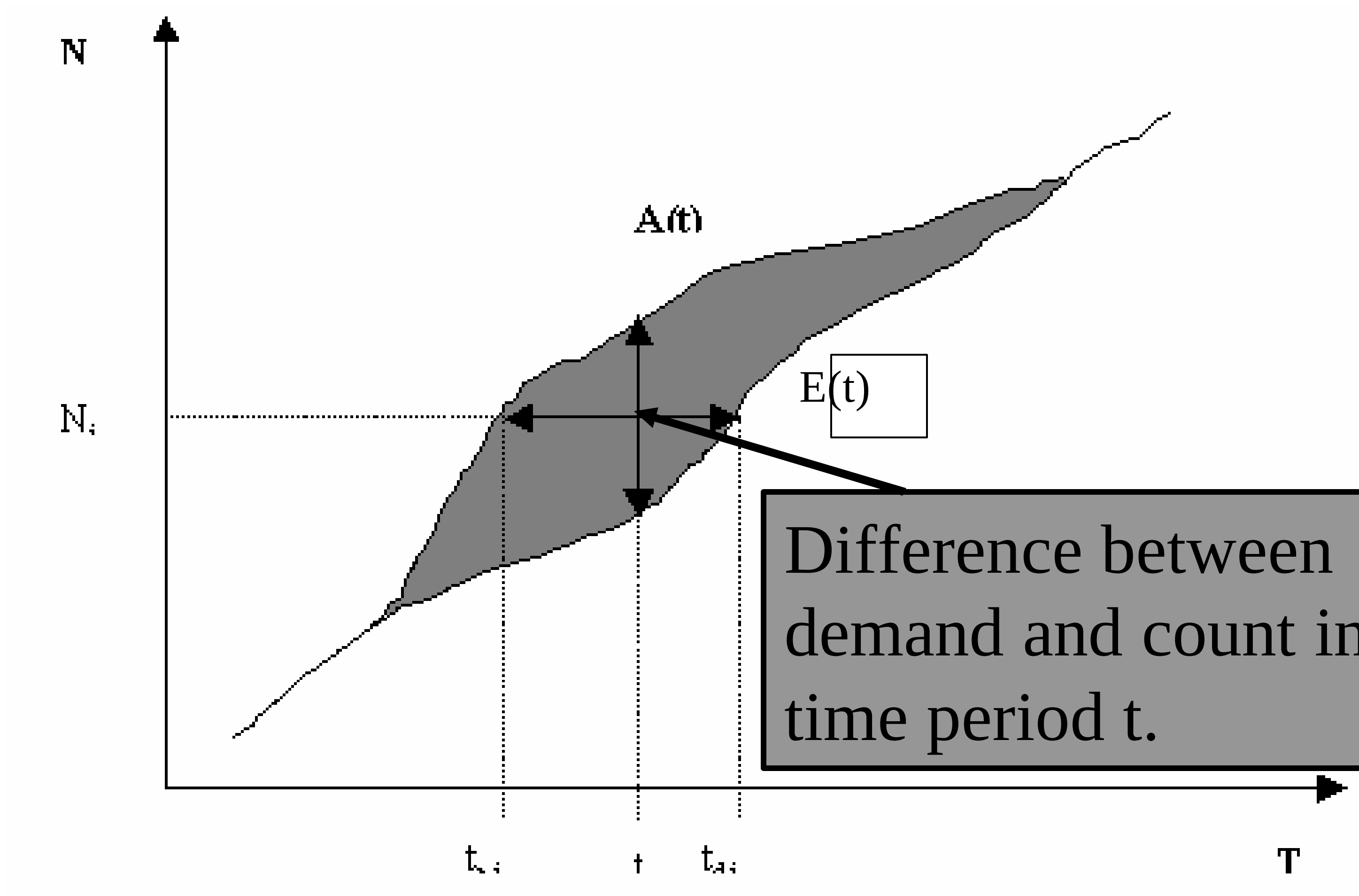
Key Estimation Results

- Significant increase in VMC arrival capacity after new runway
- Small but significant decrease in VMC departure capacity after new runway
- No significant changes in IMC capacity
- Large variability in capacities

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?
- How much less delay would there have been in 2001 demand had been served by DTW with the new runway.
- Deterministic queuing analysis.

Delay Impact Calculations



Delay Impact Calculations

1. Set $t=1$ and initiate the demand using $\tilde{D}_o(1) = N_o(1)$.
2. Draw the number of anomalously delayed flights in time period t, $\tilde{A}_o(t)$, from the binomial distribution with success probability $P_{o,m(t)}$ and number of trials $\tilde{D}_o(t)$.
3. Draw the capacity in time period t, $\tilde{C}_o(t)$, from the normal distribution for the appropriate deployment scenario, operation type, and meteorological condition.
4. Calculate the throughput in time period t as $\tilde{Q}_o(t) = \text{nint}\left(\min(\tilde{C}_o(t), \tilde{D}_o(t) - \tilde{A}_o(t))\right)$ where the $\text{nint}(\cdot)$ function rounds its argument to the nearest integer.
5. If $t=T$, go to 6. Otherwise set $\tilde{D}_o(t+1) = N_o(t+1) + (\tilde{D}_o(t) - \tilde{Q}_o(t))$, $t=t+1$, and go to step 2.
6. Calculate delay by summing unsatisfied demand at end of each time period.

		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

Key Delay Analysis Results

- Average departure delays decreased 15-20 seconds per flight as result of new runway
- This translates into 1000-1300 hrs of annual delay savings for departures
- Arrival delay impact neglible (2 second increase)

Caveats

- Delays that are incorporated into flight plan gate departure time ignored
- Demand impact ignored
- Assume that before/after change is consequence of new runway
- Analysis based on early post-deployment experience when procedures not fully adjusted

Conclusions

- New post-deployment analysis method that should please both the counters and the timers
- Also useful for many other applications (e.g. capacity impact of facility outages)
- Further refinements to consider serial autocorrelation in capacities and explain throughput loss in high demand conditions