NextGen and Safety

A Case for Automation

Federal Aviation Administration

Presented to: NAS Performance Workshop

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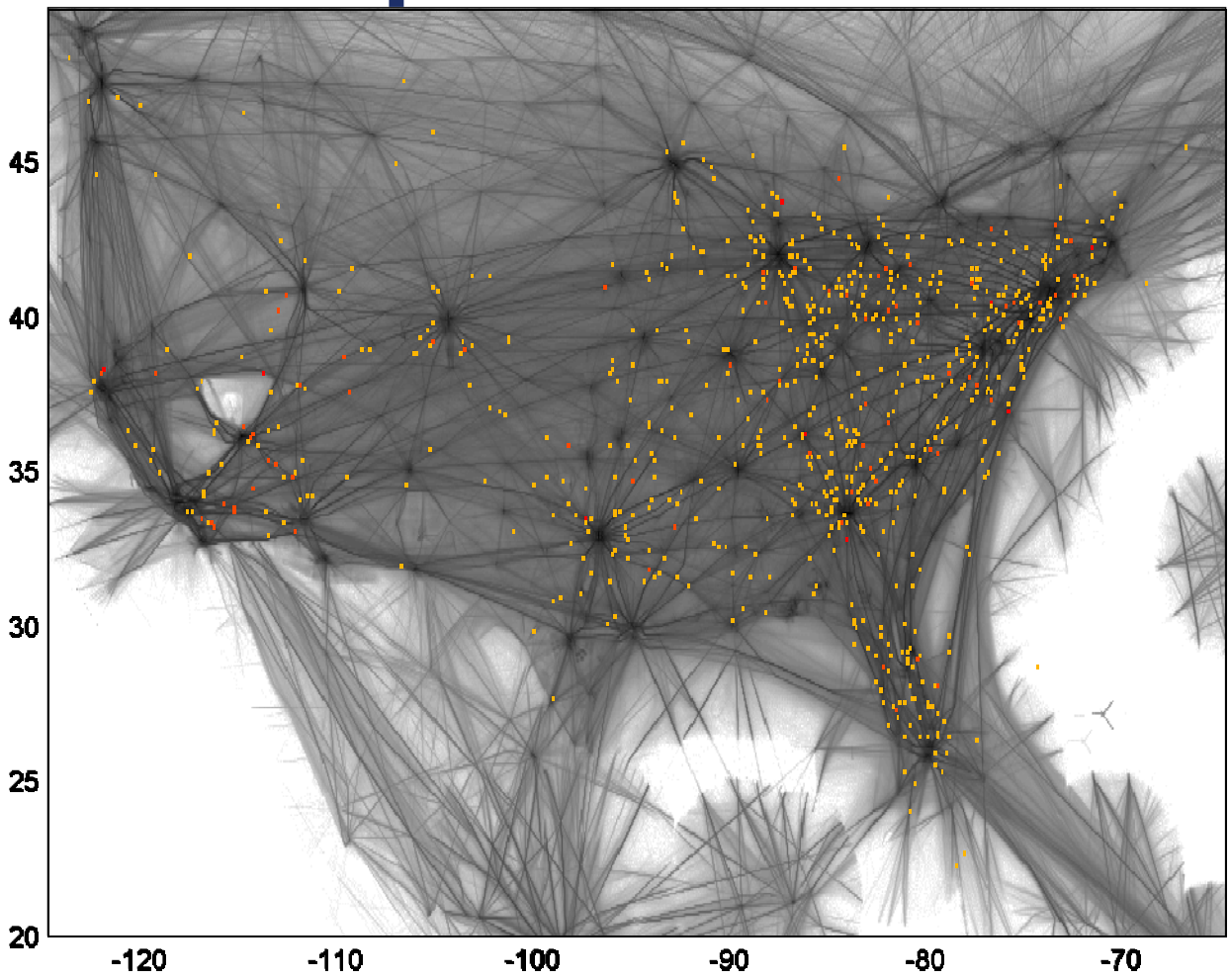
Date: September 5, 2007

Acknowledgments

- **Gerald Shapiro, the CNA Corporation**

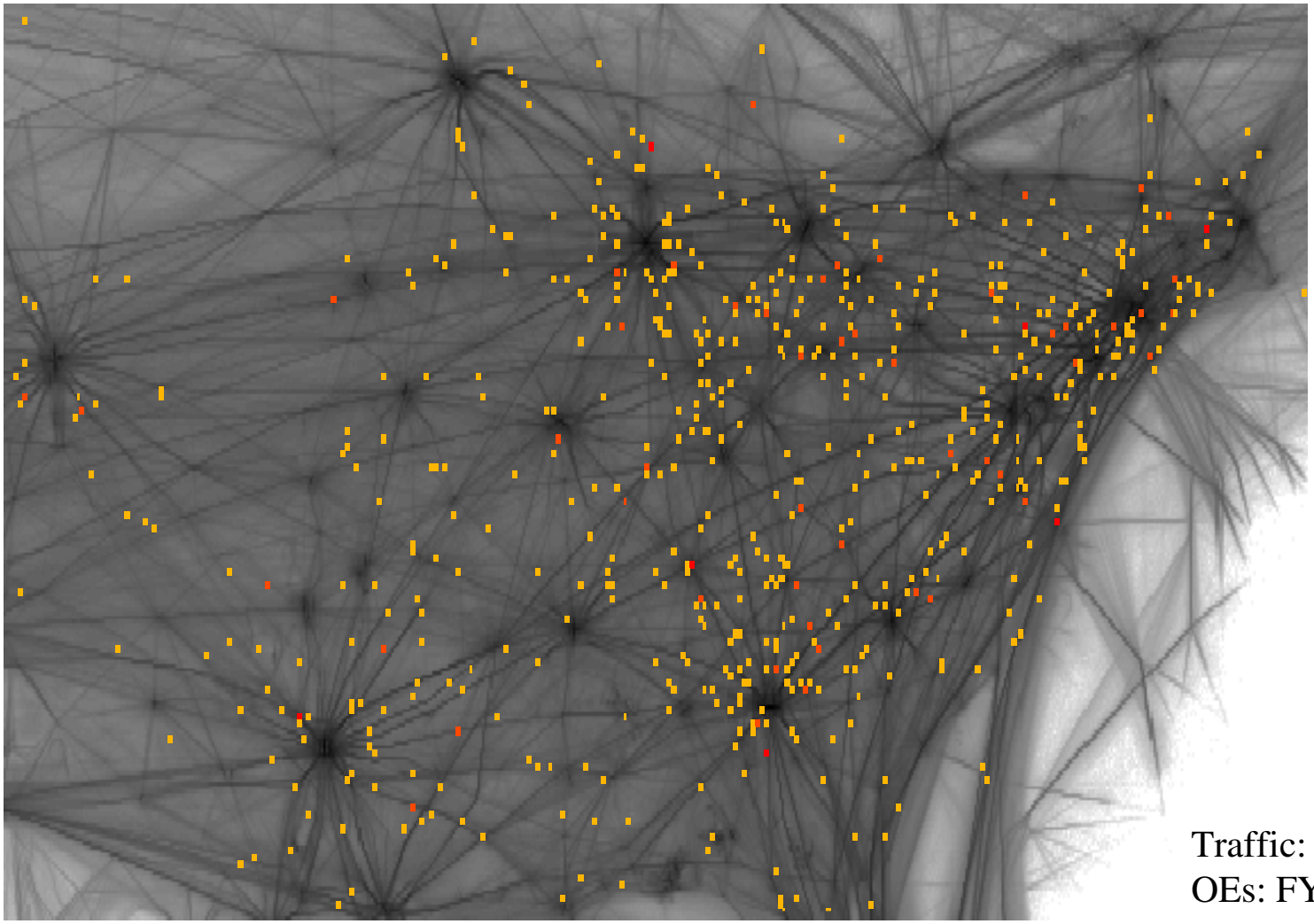
- **Similar results presented at ATM 2007**
  - FAA/EUROCONTROL ATM R&D Seminar, Barcelona 2007

En-route Operational Errors



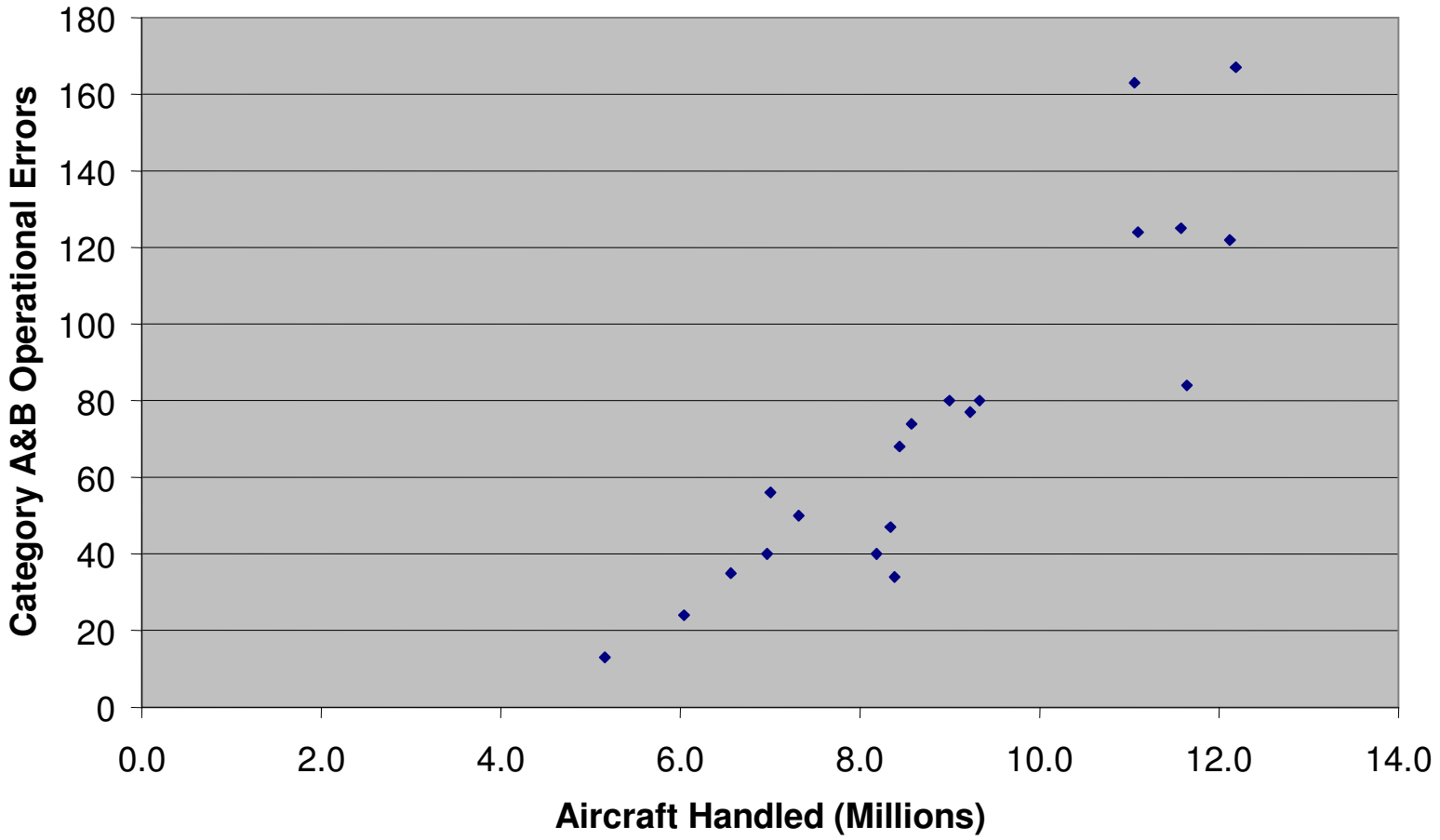
Traffic: FY05
OEs: FY02-FY05

En-route Operational Errors



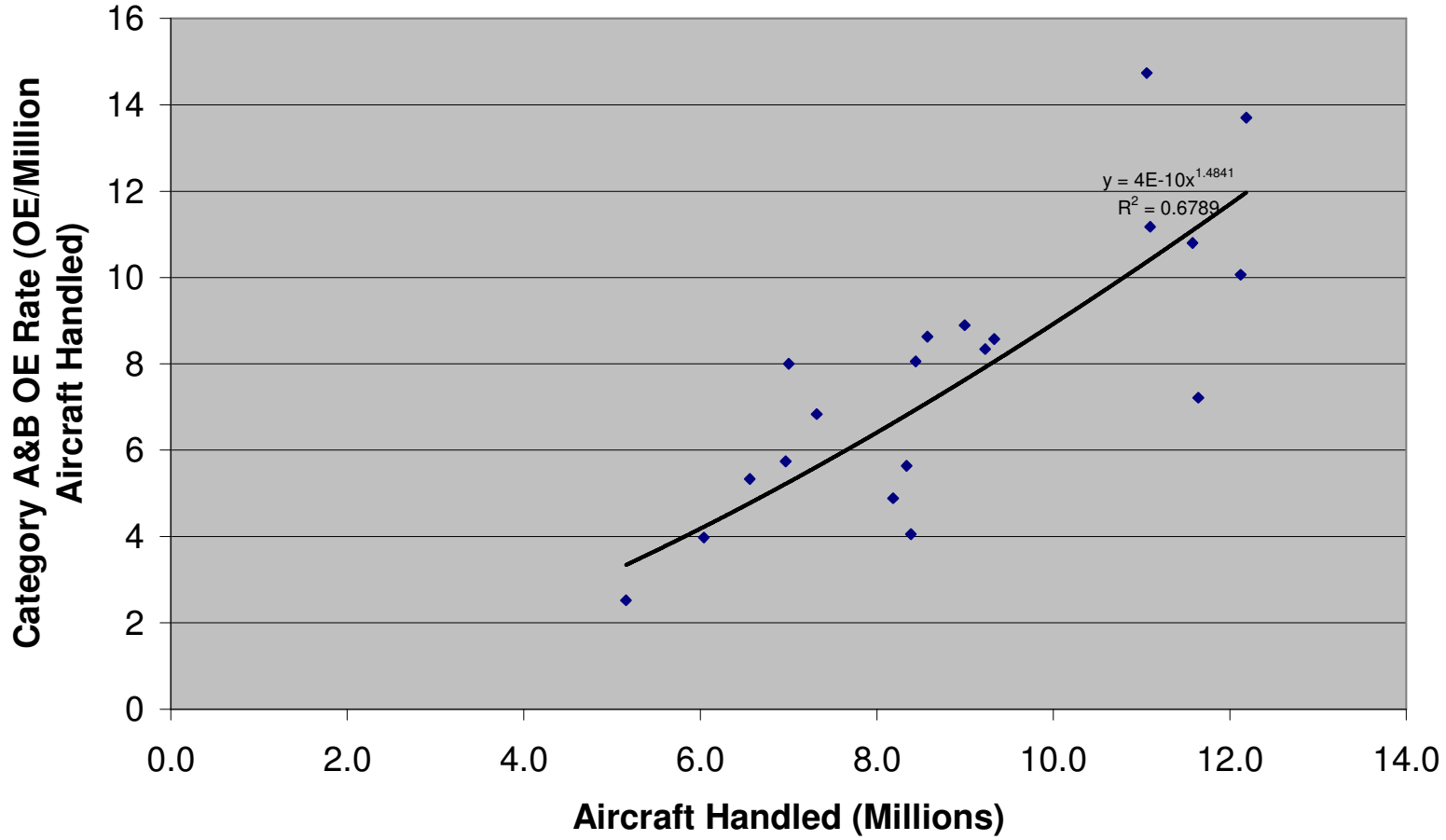
Traffic: FY05
OEs: FY02-FY05

Operational Errors vs. Annual Traffic (by ARTCC)



FY02-FY05

Operational Error Rate by ARTCC



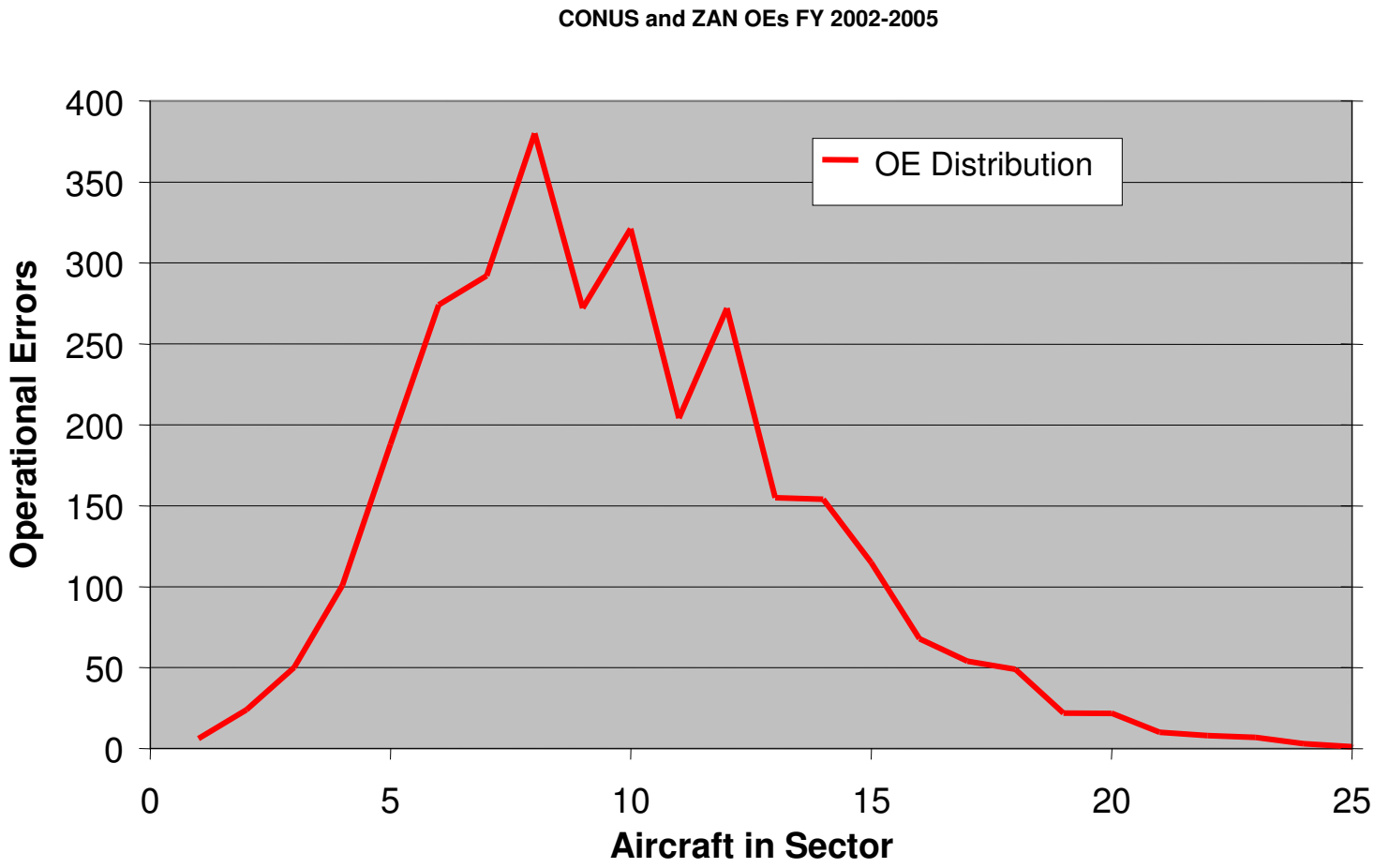
FY02-FY05

OE Rate and Center Traffic

- **Operational Error rate increases with ARTCC traffic***
- **Data suggest underlying mechanism linking occurrence of operational errors and number of aircraft handled**
  - Not all agree that there is a linkage
    - "Post-peak" or "light traffic" hypothesis

*Similar results noted by Gosling (TRB 2002)

Errors and Sector Traffic

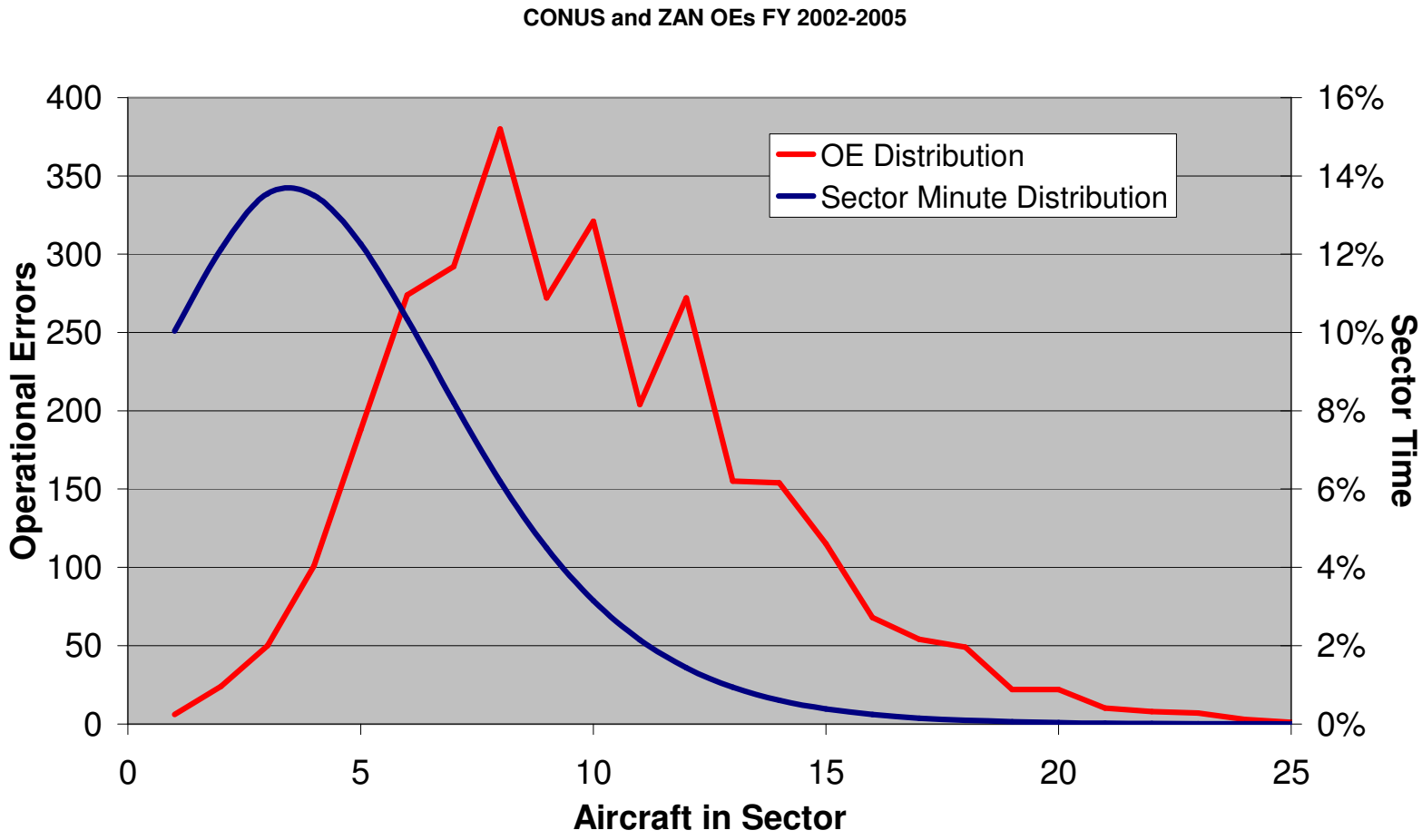


All OEs
FY02-FY05

Counts may be misleading

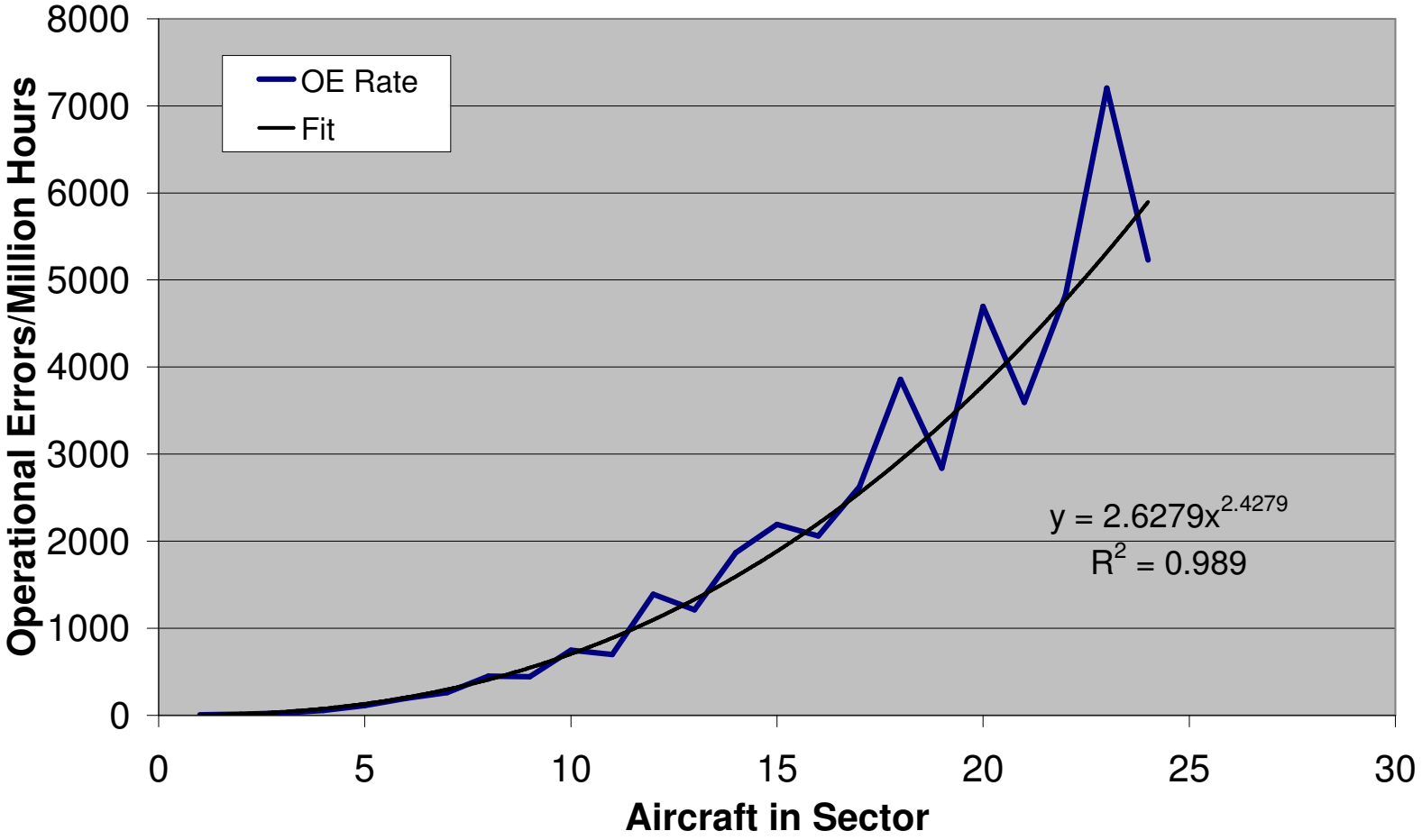
- **Number occurrence must be related to number of opportunities**
- **Instantaneous sector traffic count can be computed from HAME (Host Aircraft Management Execs) data**

Errors and Sector Traffic



FY02-FY05

Error Rates and Sector Traffic



FY02-FY05

Summary

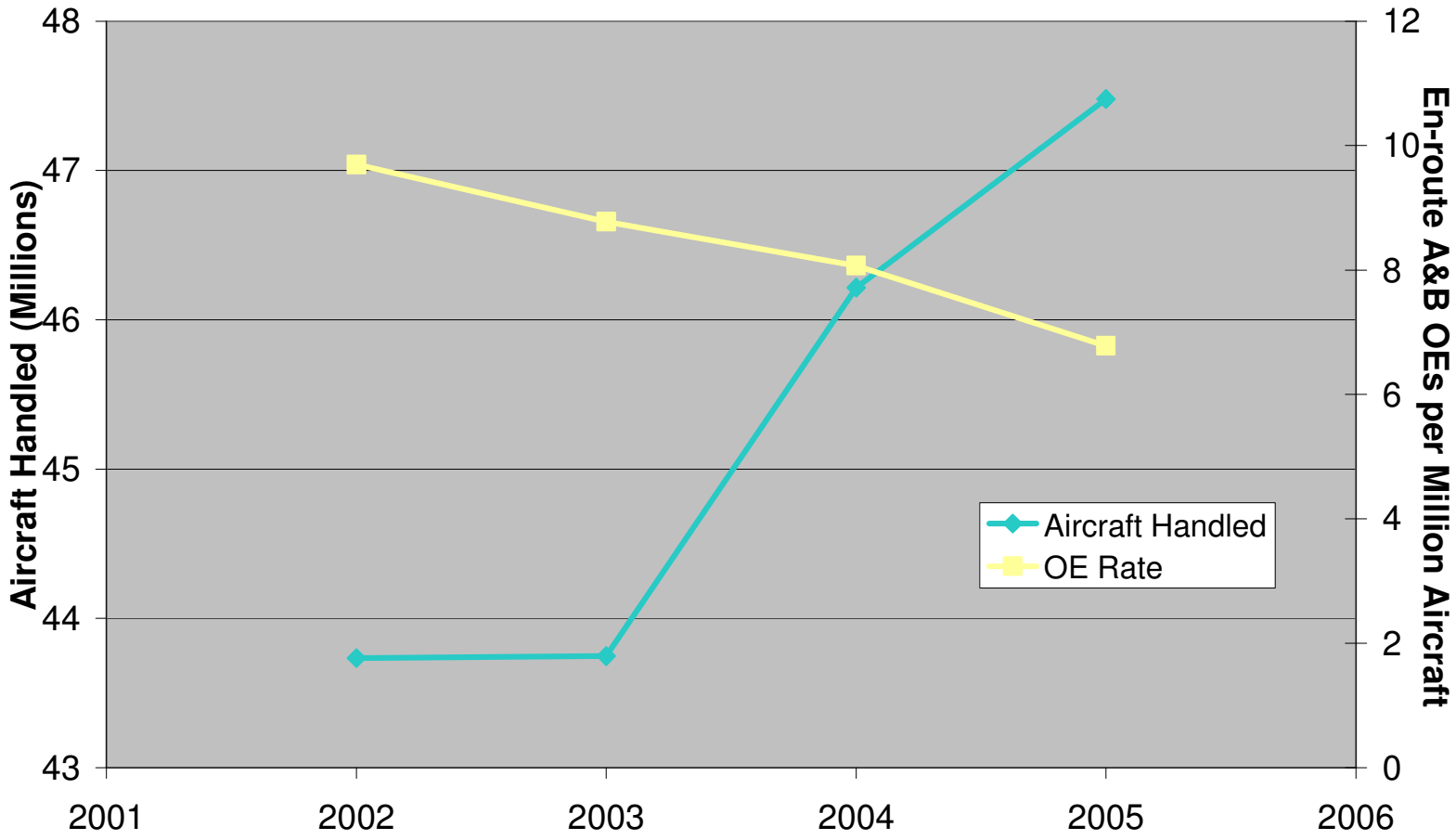
- **Operational errors happen most often when controllers are handling 8-10 aircraft***
- **Sectors most often handle 4 aircraft***
- **Sectors rarely handle more than 10 aircraft**
- **En-route operational error rate increases faster than the square of the traffic**

*Results consistent with Rodgers et al., DOT/FAA/AM-98/14, May 1998

Predictions of Model

- **Operational Errors will grow faster than traffic**
  - 27% traffic increase could mean 60% increase in operational errors
- **Safety concerns may limit traffic growth**

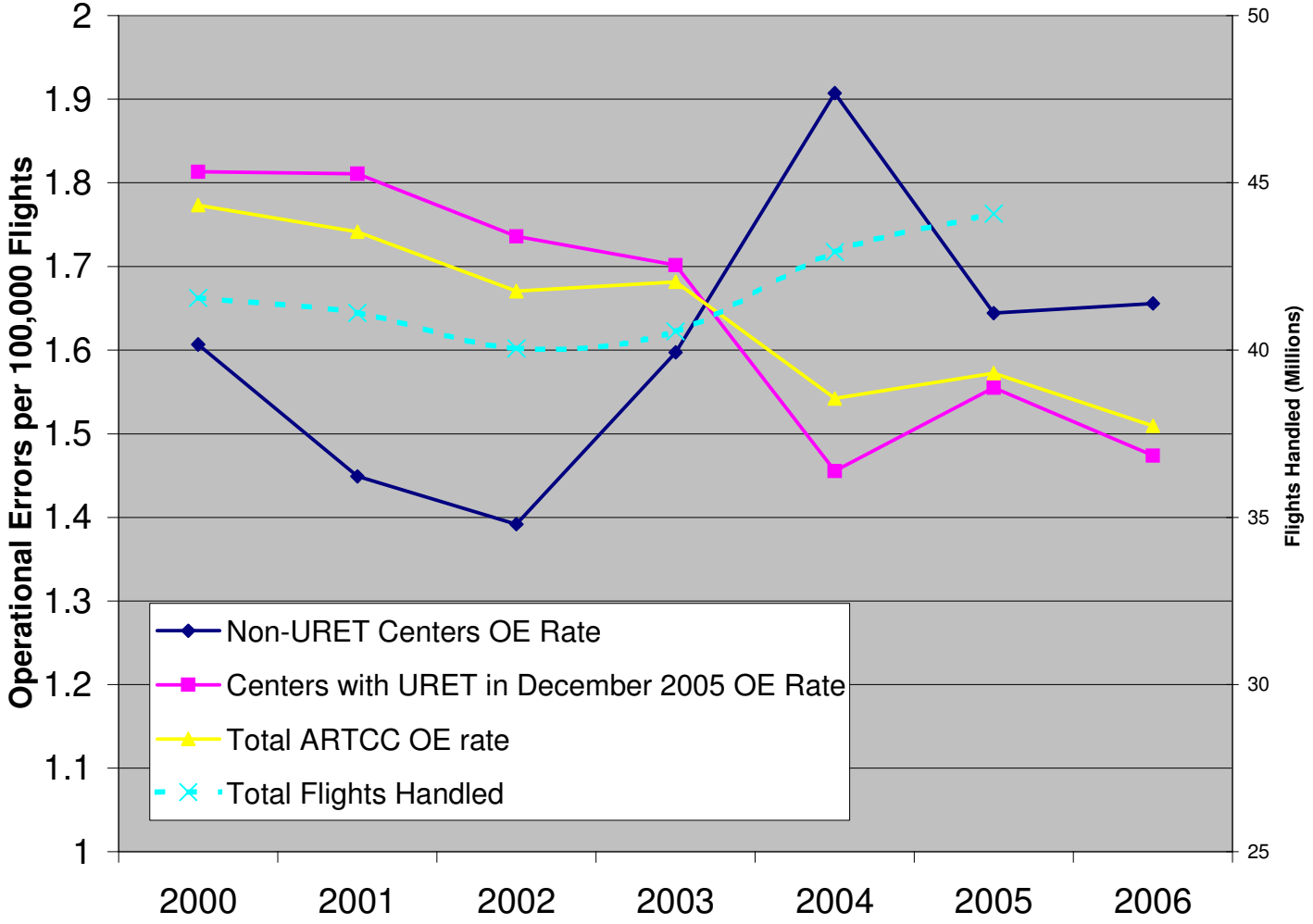
En-route OE Rate is Decreasing!



FY02-FY05

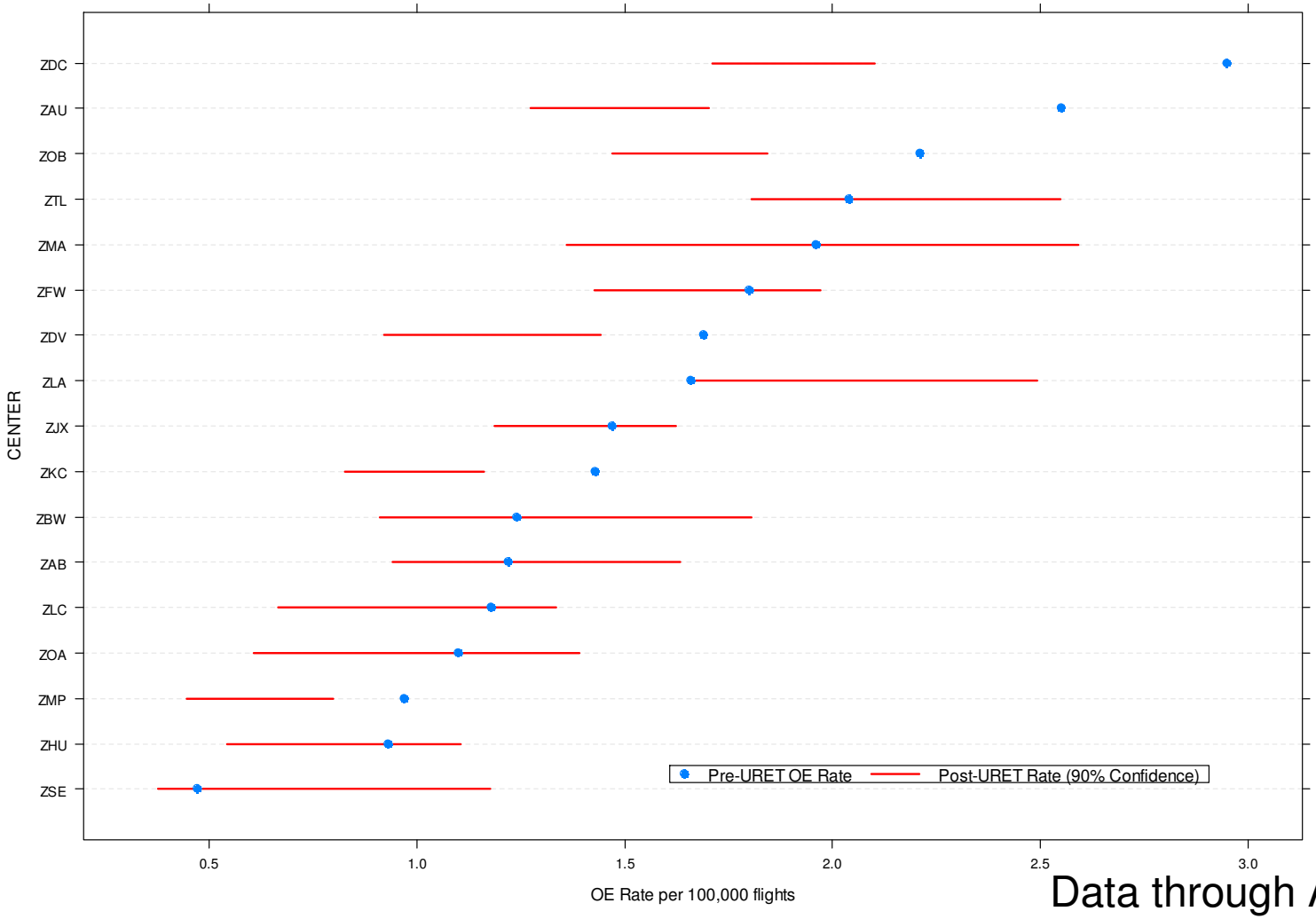
User Request Evaluation Tool

OE Rate Comparison by FY



Data through August 2006

Pre- vs. Post-URET OE Rates



Data through April 2007

URET Impact by ARTCC

- **OE rate has shown statistically significant(*) decrease in six ARTCCs post-URET**
  - Three ARTCCs with highest OE rates all show statistically significant decrease post-URET
    - ZDC, ZAU, ZOB
- **No ARTCCs show statistically significant increase in OE rate post-URET**

(*) – 90% two-sided confidence level

Statistical Significance of URET

Estimated exponents and significance

Center	Pre-URET *q*	Post-URET *q*	p
Chicago	1.4	1.7	0.0007
Washington	2.2	1.3	0.000006
Denver	1.7	1.0	0.036
Kansas City	3.0	1.7	0.002
Minneapolis	1.5	1.1	0.010

Estimated URET Safety Impact

Center	Months Post-URET (Through March 2006)	Sector Loads	Actual OEs Post-URET(*)	Modelled OEs Post-URET(*)	Modelled OEs with Pre-URET parameters(*)	Annual OEs Avoided Post-URET(*)
ZAU	27	3..14	95	97.5	163.8	29.5
ZDC	39	3..19	174	190.4	331.0	43.3
ZDV	22	4..17	28	28.4	48.6	11.0
ZKC	47	3..19	102	105.4	173.1	17.3
ZMP	24	3..19	21	20.0	42.9	11.5
			420	441.7	759.4	112.5
			(*) OEs during periods with modeled sector loads			

By what mechanism is the benefit achieved?

Workload

- **Time observing and planning vs. time engaged in making the system work**

Strip Bay

Conclusions

- **OE rate increases with workload**
- **URET caused recent decrease in en-route OE rate**
  - URET is fully deployed
- **En-route OE rate will begin to increase**
- **Workload-reducing automation is needed to decrease OE rate**

Questions

- **Are safety improvements of NextGen cost-beneficial?**
  - Operational error is not a mid-air
  - Current quantification of safety based on loss of life
- **Should aviation safety goals be exempted from traditional cost-benefit analysis?**
  - Decreased safety margin is unacceptable

49 U.S.C. VII

… the Secretary of Transportation shall consider the following matters … as being in the public interest and consistent with public convenience and necessity:

(1) assigning and maintaining safety as the highest priority in air commerce.

(3) preventing deterioration in established safety procedures, recognizing the clear intent … of Congress to further the highest degree of safety in air transportation and air commerce, and to maintain the safety vigilance that has evolved in air transportation….

OEP Solution Sets

1. Initiate Trajectory Based Operations
2. Increase Operations at High-Density Airports
3. Increase Flexibility in the Terminal Environment
4. Improved Collaborative ATM
5. Reduce Weather Impact
6. Security, Safety, Environment
7. Transform Facilities

Questions and Discussion

Likelihood Ratio Test

- **Assume model** $\rho_n = P(OE \mid n) = \gamma n^{1+q}$
  - Parameters determined separately for each ARTCC
- **Compare likelihood function using**
  - One set of model parameters
  - Separate model parameters for pre- and post-URET observations (two additional degrees of freedom)
- **First model is a special case of the second**
  - Nested model likelihood ratio comparison for significance testing
  - -2*ln(likelihood ratio) is test statistic
  - Chi-square distribution with two degrees of freedom gives distribution of test statistic under null hypothesis (no difference)

Parameter Estimation

- **Non-linear least squares**
  - Weighted to account for number of observations at each value of *n*
  - Exclude *n<3, n>19* in parameter estimation
    - Additional extreme values excluded for Denver and Chicago ARTCCs, due to solver instability
- **Time periods when there was partial implementation of URET were excluded**

Linking Sector and ARTCC Level Observations

Little's Law for Sector-Minutes

- $\overline{S}$ **the average time for an aircraft to transit the sector**
- $N(T)$ **aircraft handled during time** T
- $\overline{S} \times N(T)$ **expected sector minutes during** T

- $\overline{n}$ **average number in sector**
- $\overline{n}T$ **expected sector minutes during** T

- $\lambda = N(T)/T$ **traffic intensity (definition)**
- **Equate both sector minute expressions**

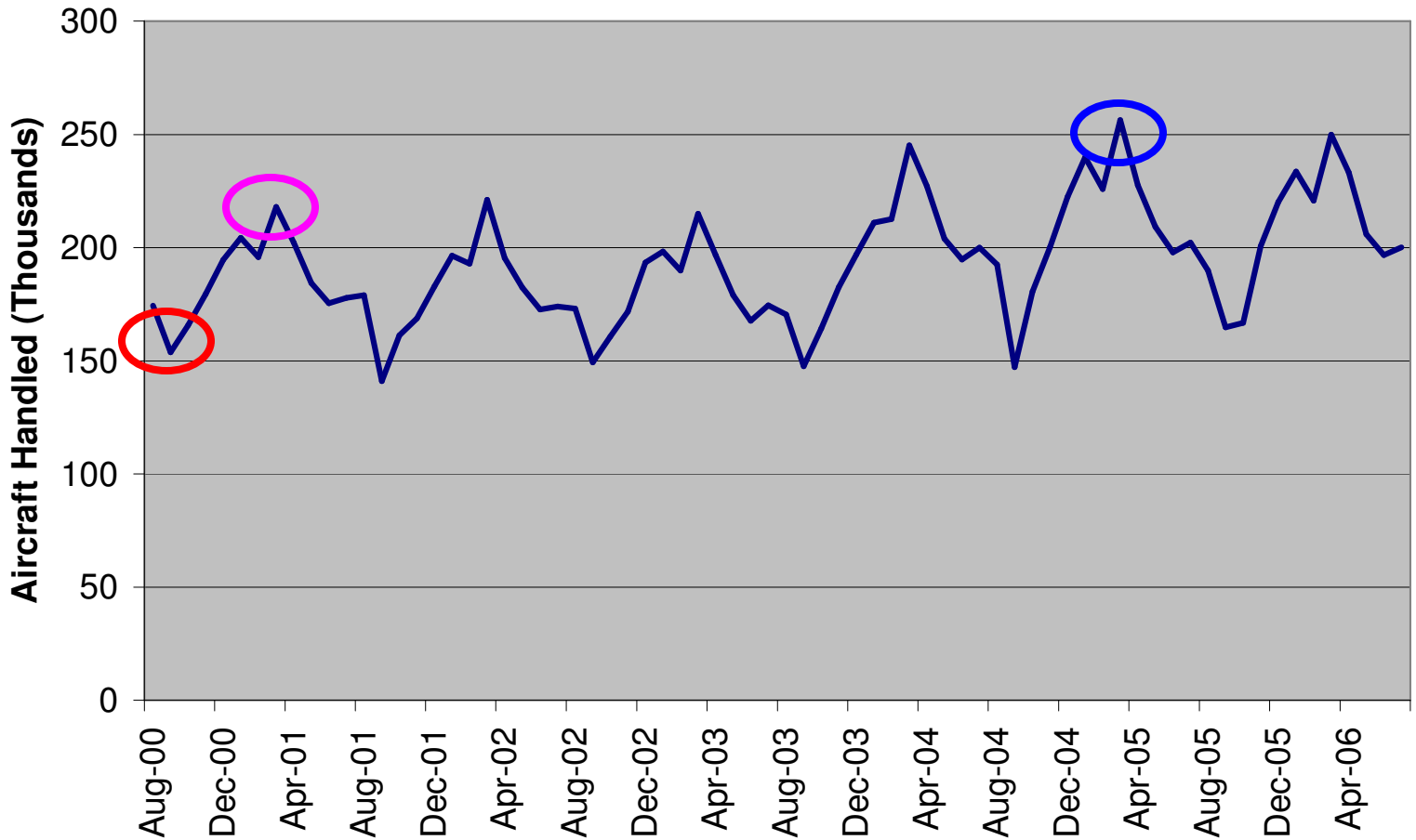
$$\overline{n} = \lambda \overline{S}$$

Little's Law Consequences

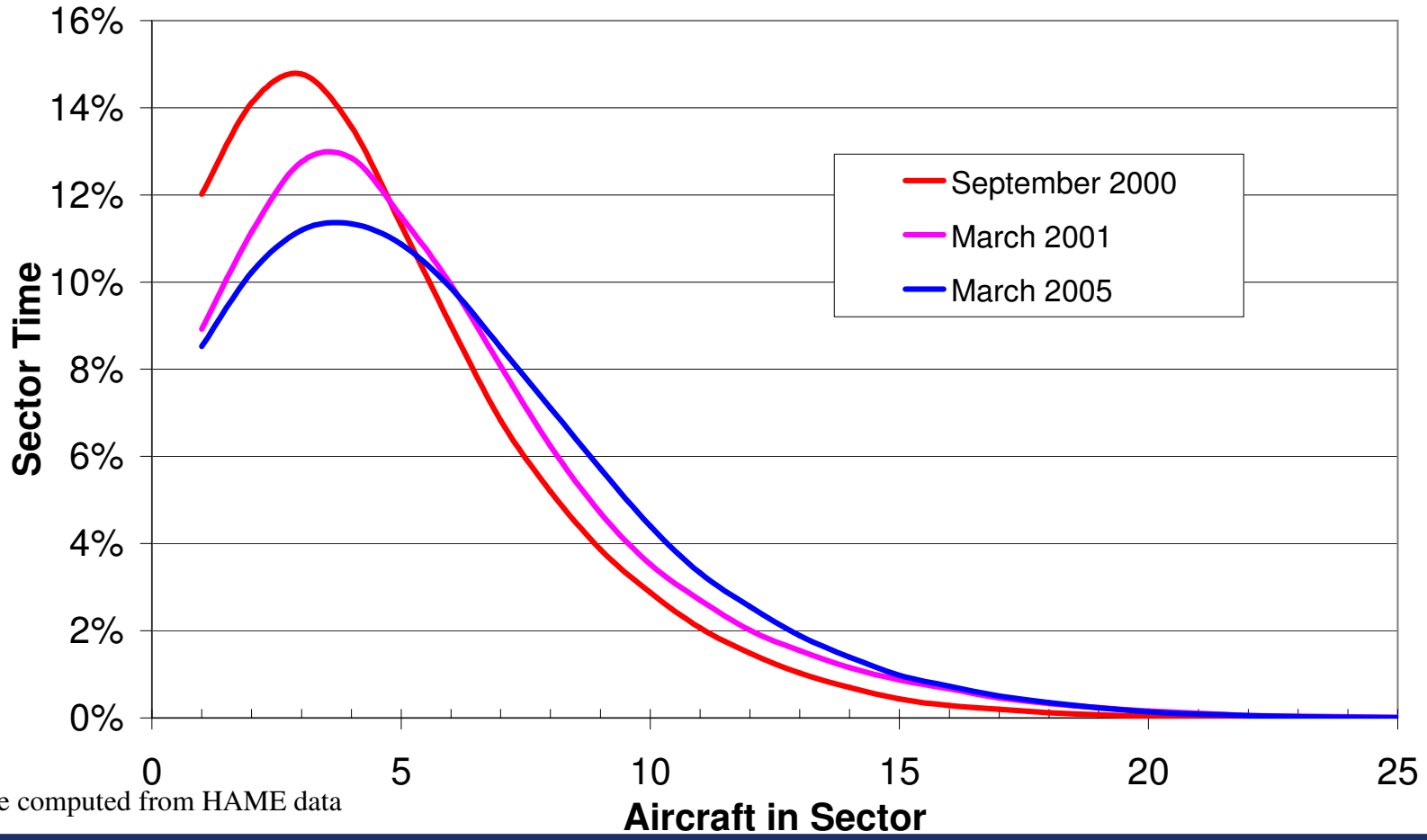
- **For a given sector, we would not expect average transit time to change**
- **Implies average sector load is proportional to total sector traffic**
- **Thus,**
  - Increase in total traffic =>
  - Increase in average count => (OE rate model)
  - Increase in OE rate

Observations Confirm Hypothesis

ZMA Monthly Traffic



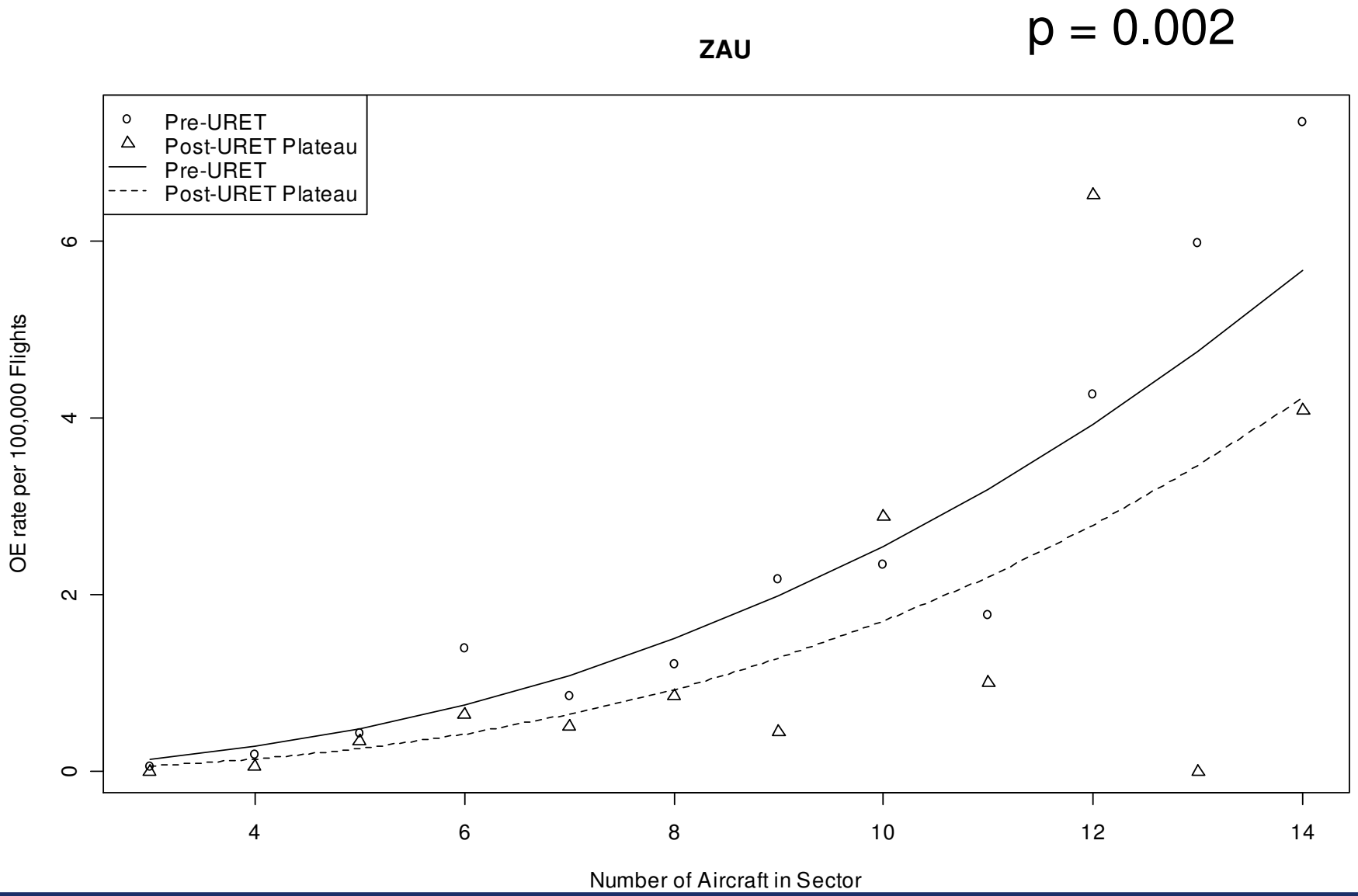
ZMA Traffic Distribution

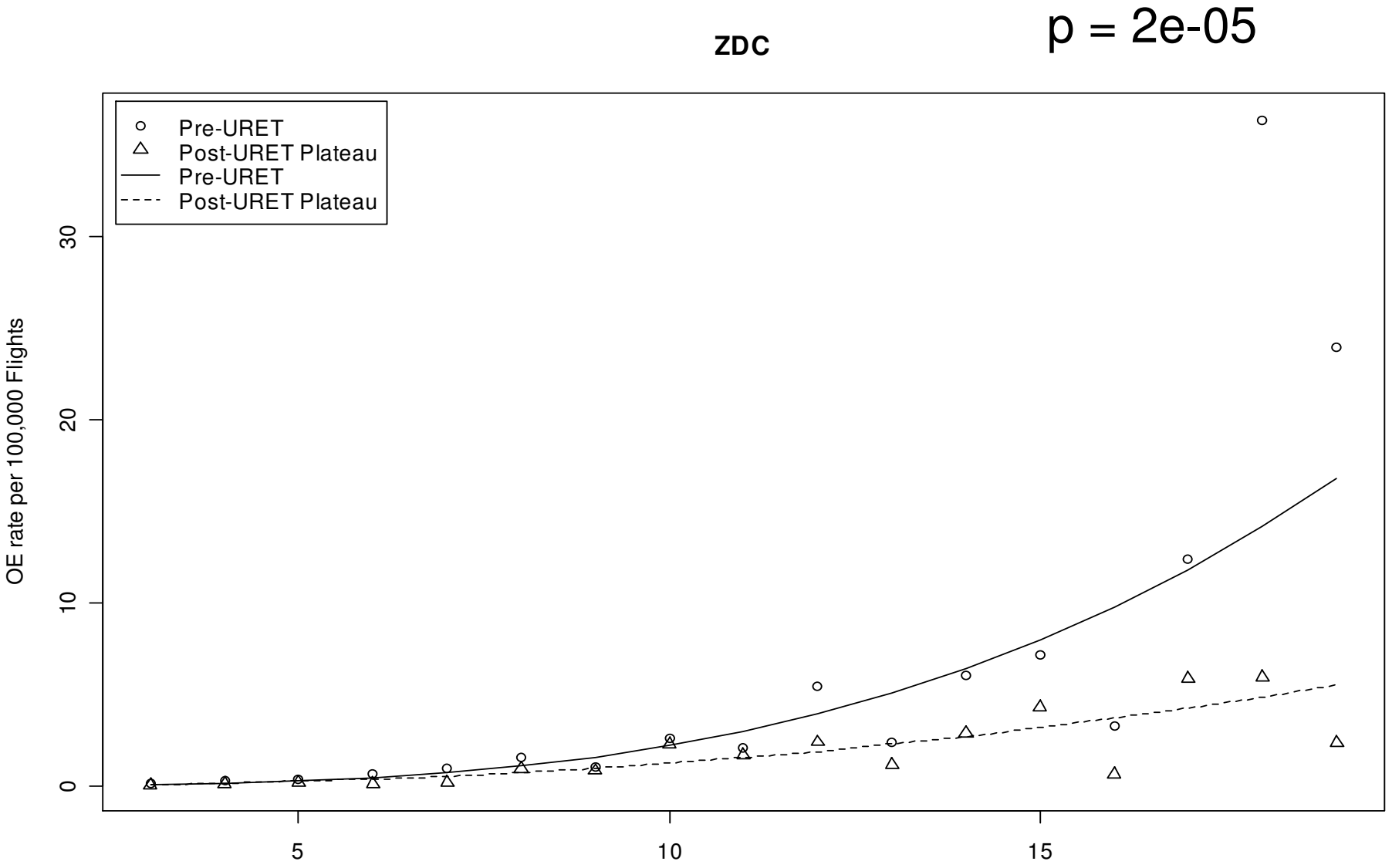


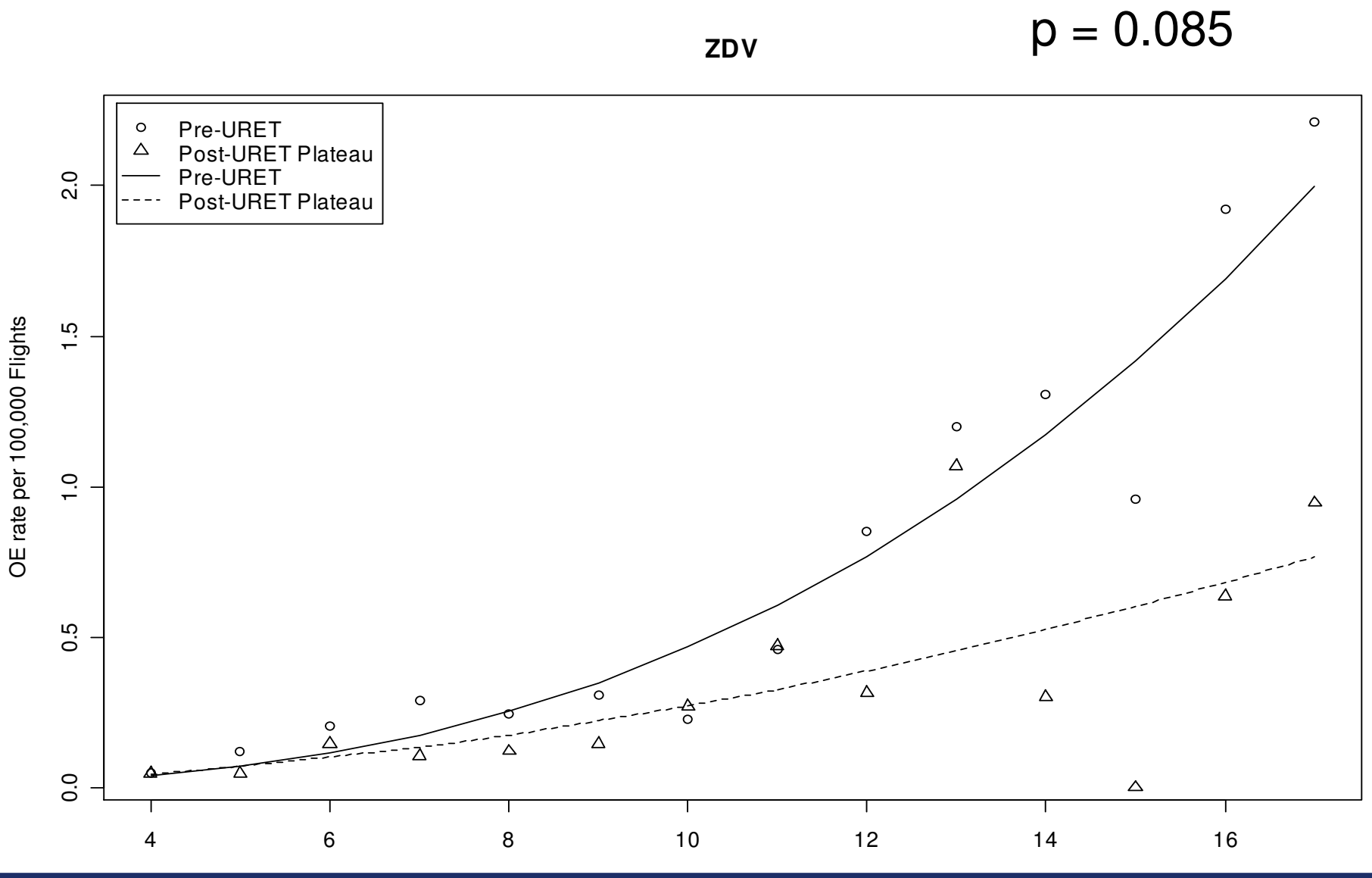
Sector time computed from HAME data

Traffic Summary

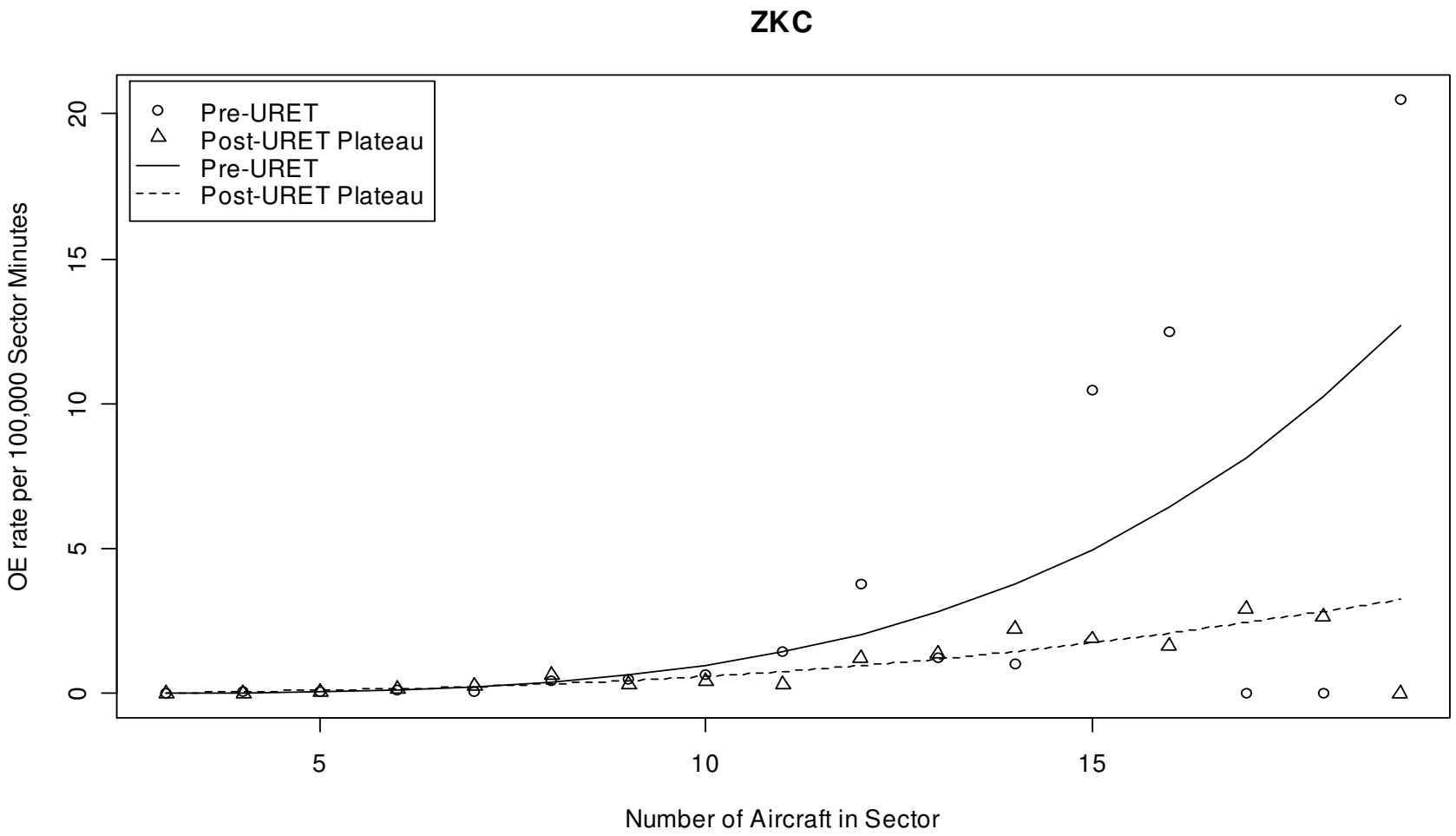
- **ZMA traffic has varied significantly over the past several years**
- **Instantaneous sector traffic distributions shift to larger counts as overall traffic increases (Little's Law with constant mean sector time)**
- **Shift in sector traffic distributions imply that as traffic grows, OE rate will increase**


ZAU
p = 0.002
Pre-URET
Post-URET Plateau
Pre-URET
Post-URET Plateau
OE rate per 100,000 Flights
0
2
4
6
4
6
8
10
12
14
Number of Aircraft in Sector

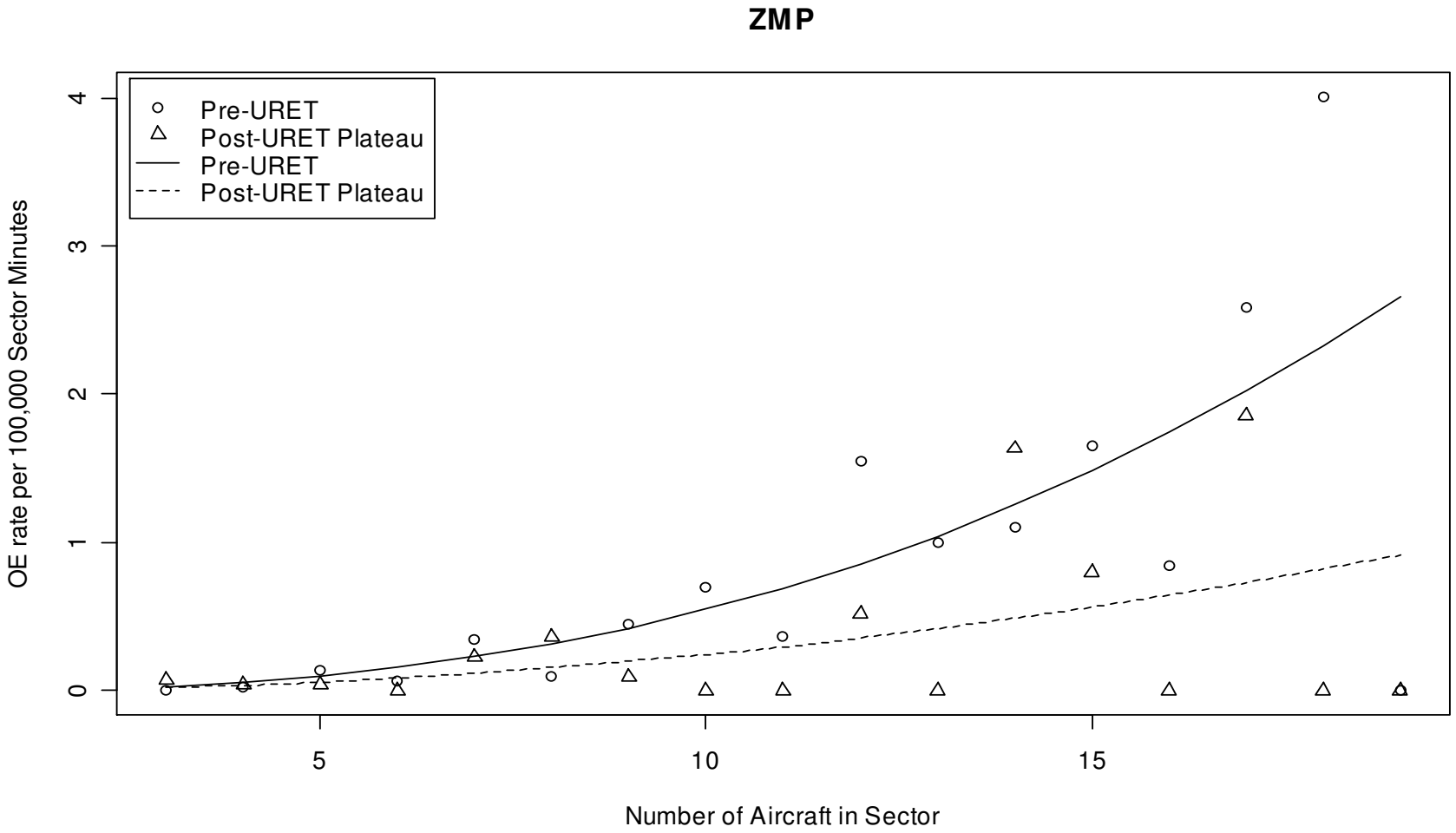

ZDC
p = 2e-05
Pre-URET
Post-URET Plateau
Pre-URET
Post-URET Plateau
OE rate per 100,000 Flights
0
10
20
30
5
10
15
Number of Aircraft in Sector

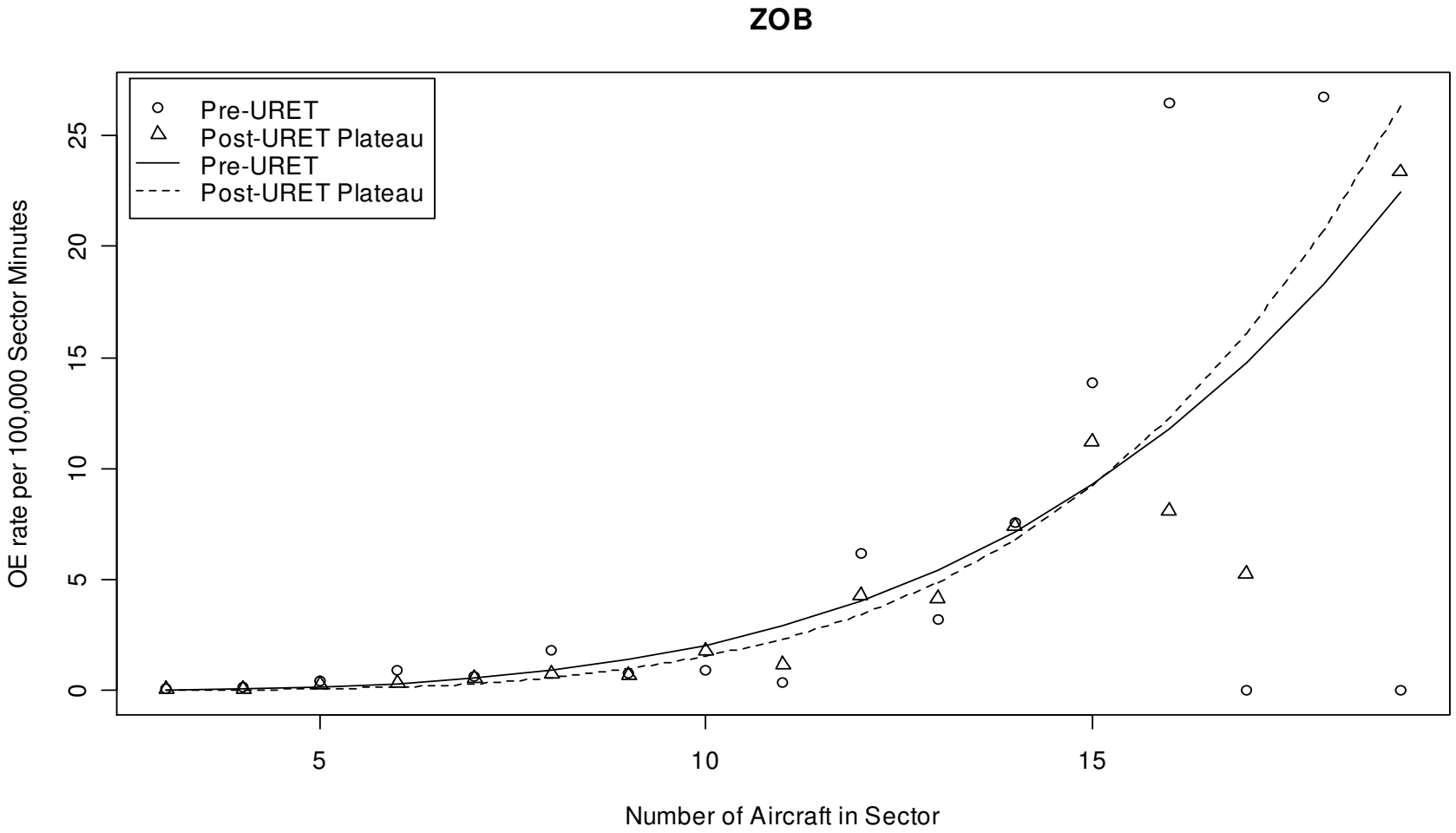

ZDV
p = 0.085
Pre-URET
Post-URET Plateau
Pre-URET
Post-URET Plateau
OE rate per 100,000 Flights
0.0
0.5
1.0
1.5
2.0
4
6
8
10
12
14
16
Number of Aircraft in Sector

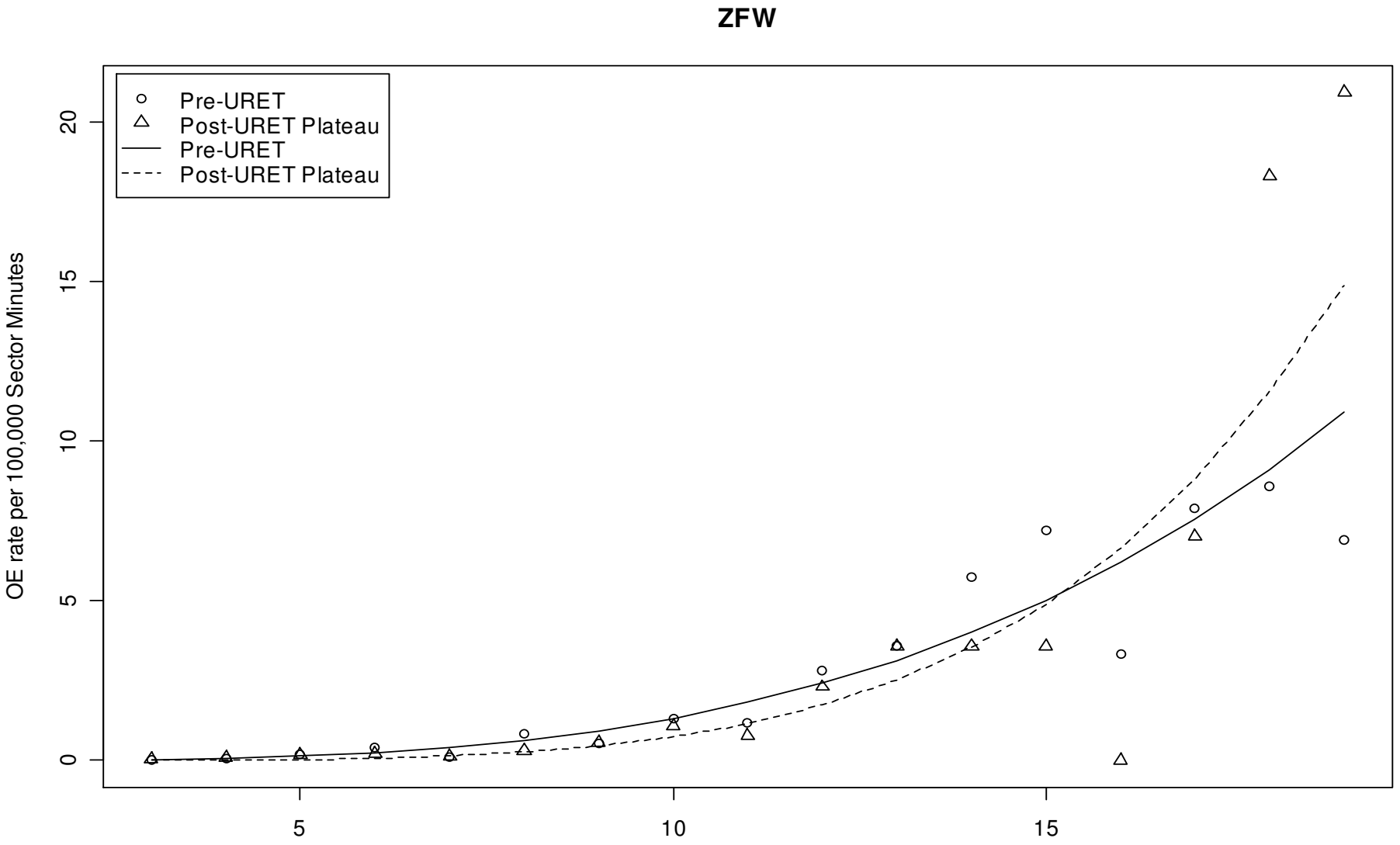
p = 0.007


ZKC
Pre-URET
Post-URET Plateau
Pre-URET
Post-URET Plateau
OE rate per 100,000 Sector Minutes
0
5
10
15
20
5
10
15
Number of Aircraft in Sector

p = 0.026


ZMP
Pre-URET
Post-URET Plateau
Pre-URET
Post-URET Plateau
OE rate per 100,000 Sector Minutes
0
1
2
3
4
5
10
15
Number of Aircraft in Sector


ZOB
Pre-URET
Post-URET Plateau
Pre-URET
Post-URET Plateau
OE rate per 100,000 Sector Minutes
0
5
10
15
20
25
5
10
15
Number of Aircraft in Sector


ZFW
Pre-URET
Post-URET Plateau
Pre-URET
Post-URET Plateau
OE rate per 100,000 Sector Minutes
0
5
10
15
20
5
10
15
Number of Aircraft in Sector