Aviation Infrastructure Risk Assessment: Effect of Communication and Surveillance Facility Service Outages on Traffic Separations

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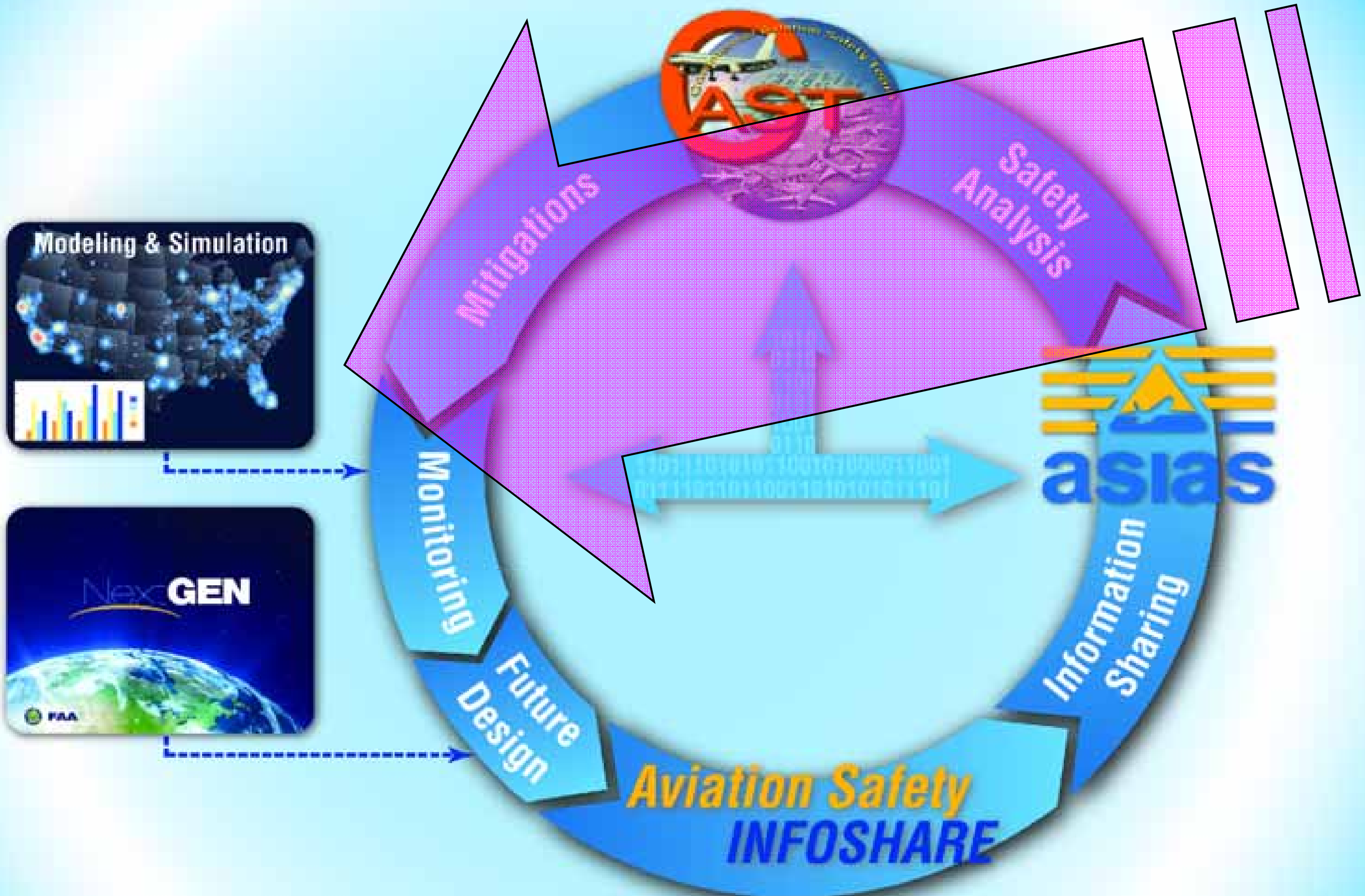
Improving Aviation Safety



Background

System Safety Management Transformation (SSMT)

Measuring safety as an outcome variable in a High Reliability Organization is difficult and does not adequately capture the true safety state of the system

Historic (forensic) approach cannot reveal emerging future hazards

Proactive approach is based on early identification, assessment, and mitigation of any credible hazards

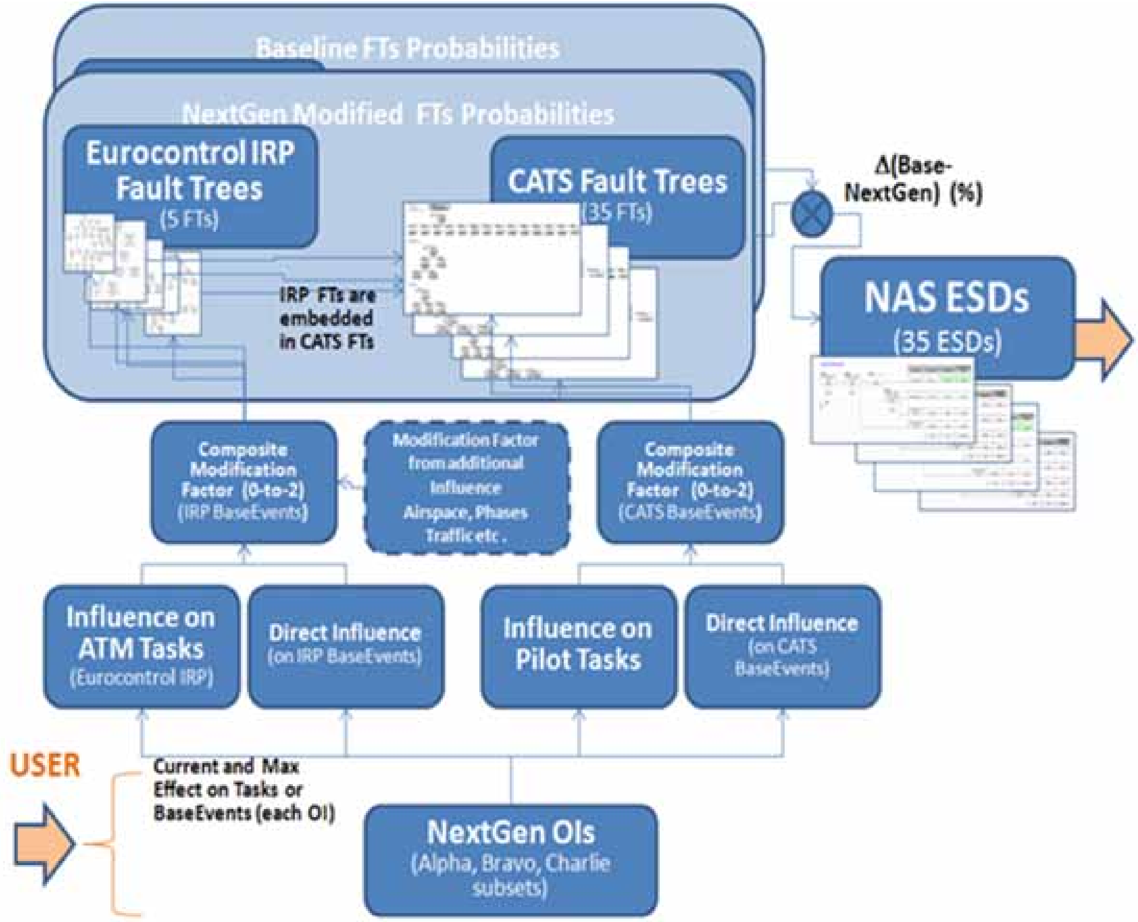
System Safety Assessment (SSA) uses risk modeling and forecasting capability to identify potential risk issues

SSA examines historical causes of events and potential future exposures to develop appropriate risk models

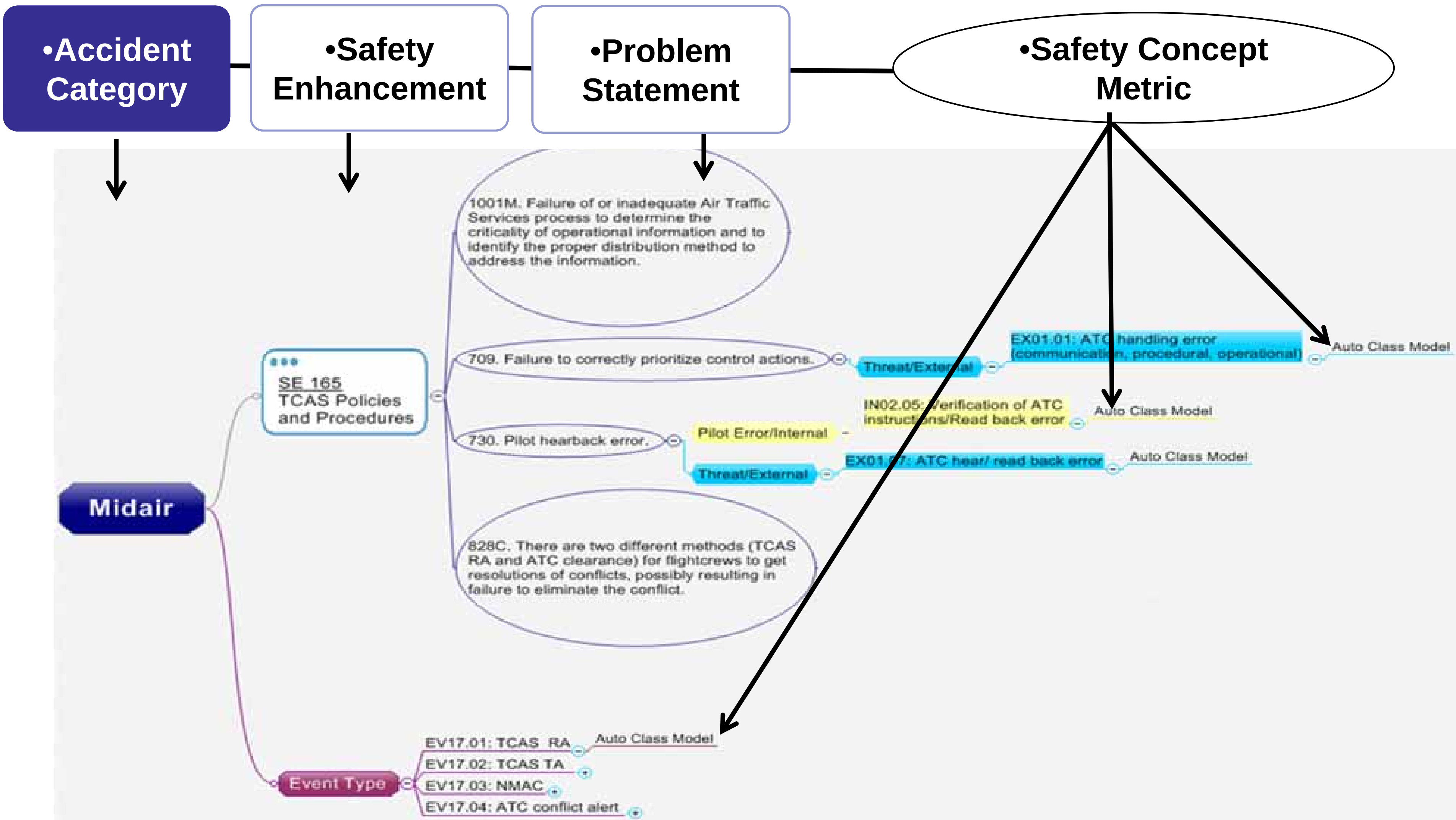
This study investigates how unscheduled service outages affect traffic separations

Unscheduled service outages are precursors that may lead to unsafe outcomes

Integrated Safety Assessment Model (ISAM)

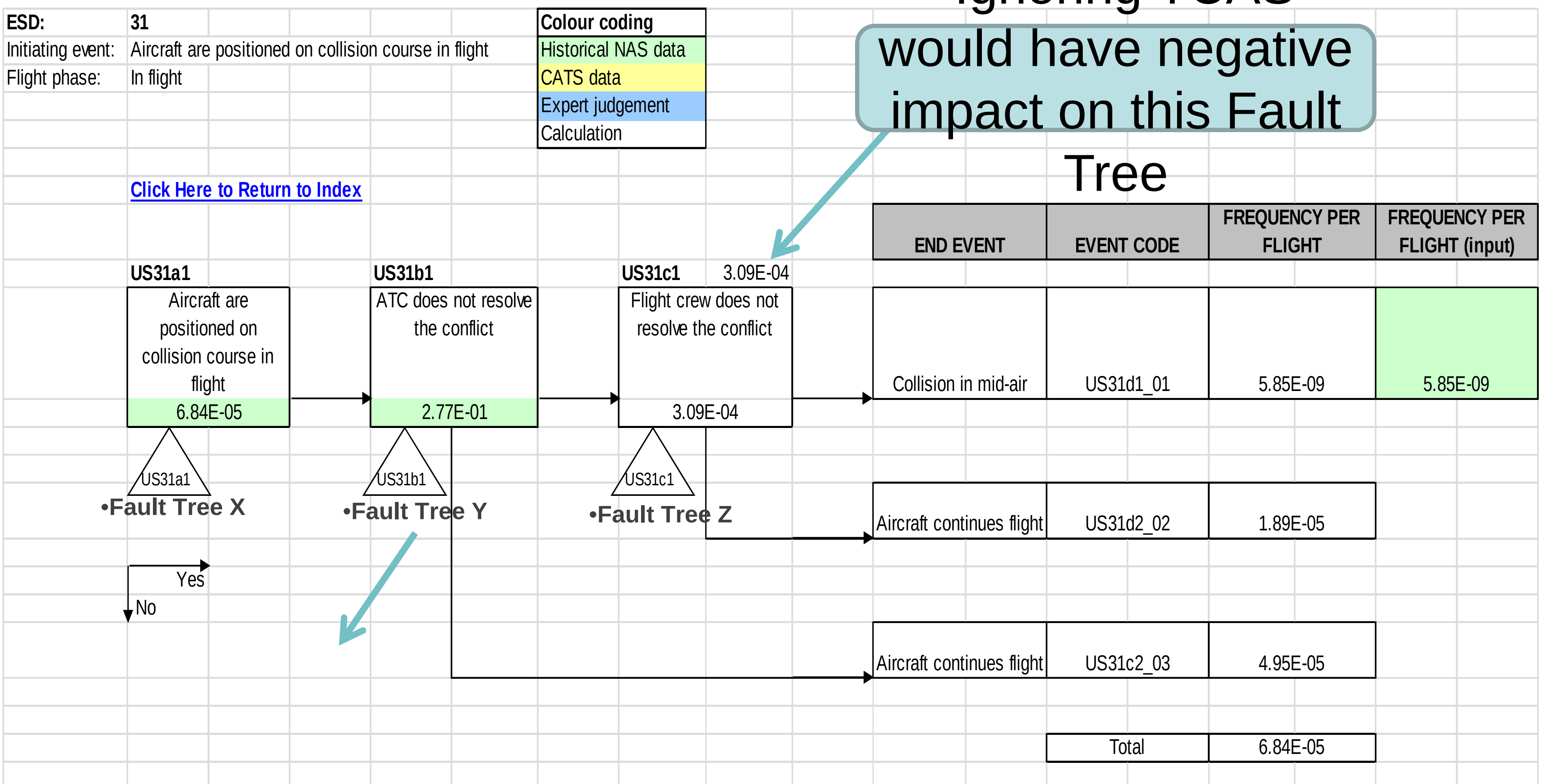


Midair Collision (MAC):
ASAP Safety Concept Mind Map - Similarity to ESD



Aircraft on Collision Course: ESD US-31

- Ignoring TCAS would have negative impact on this Fault Tree



Background

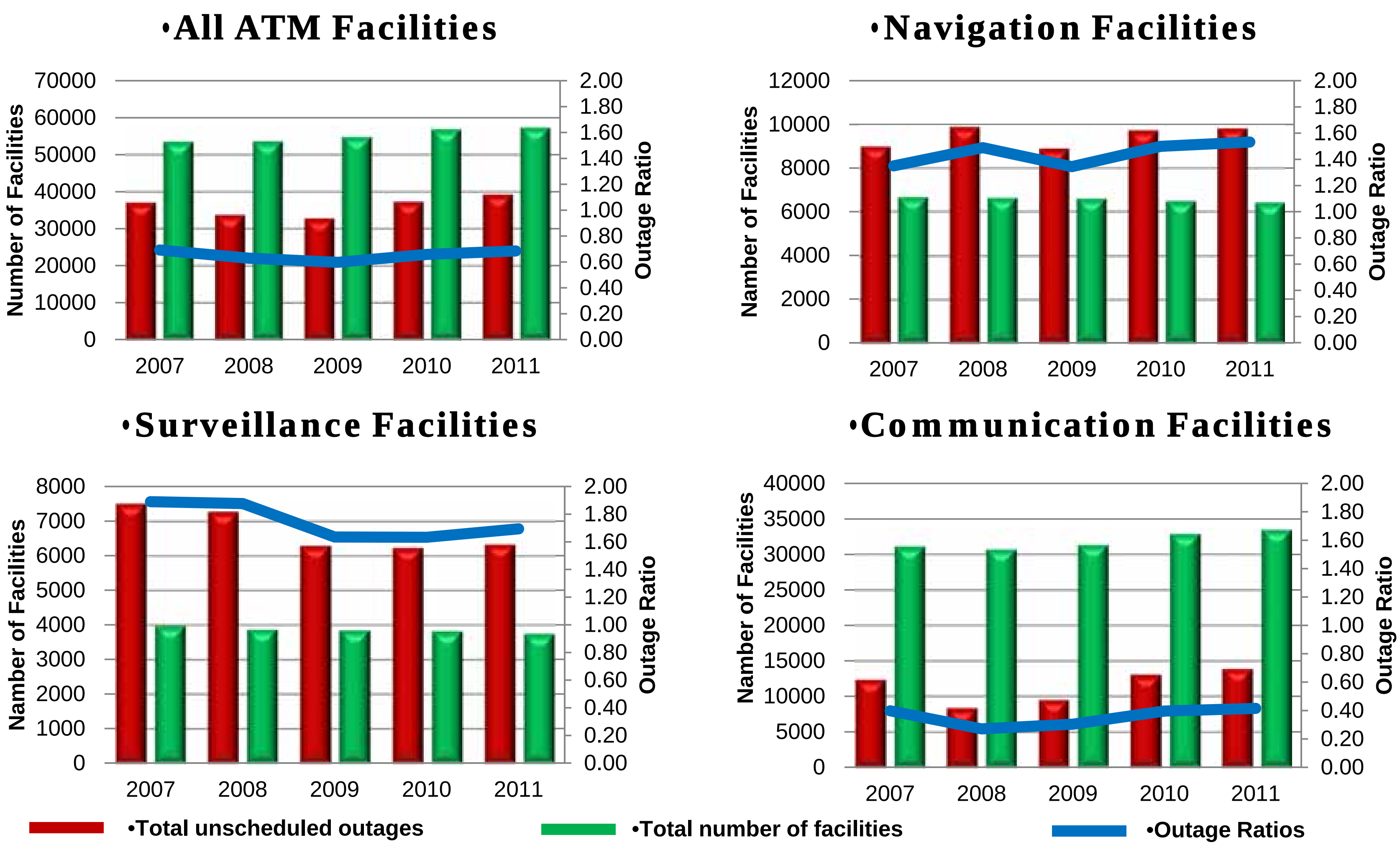
57,558 ATM facilities were functioning in the NAS in 2011

40,000 of them experienced unscheduled service outages

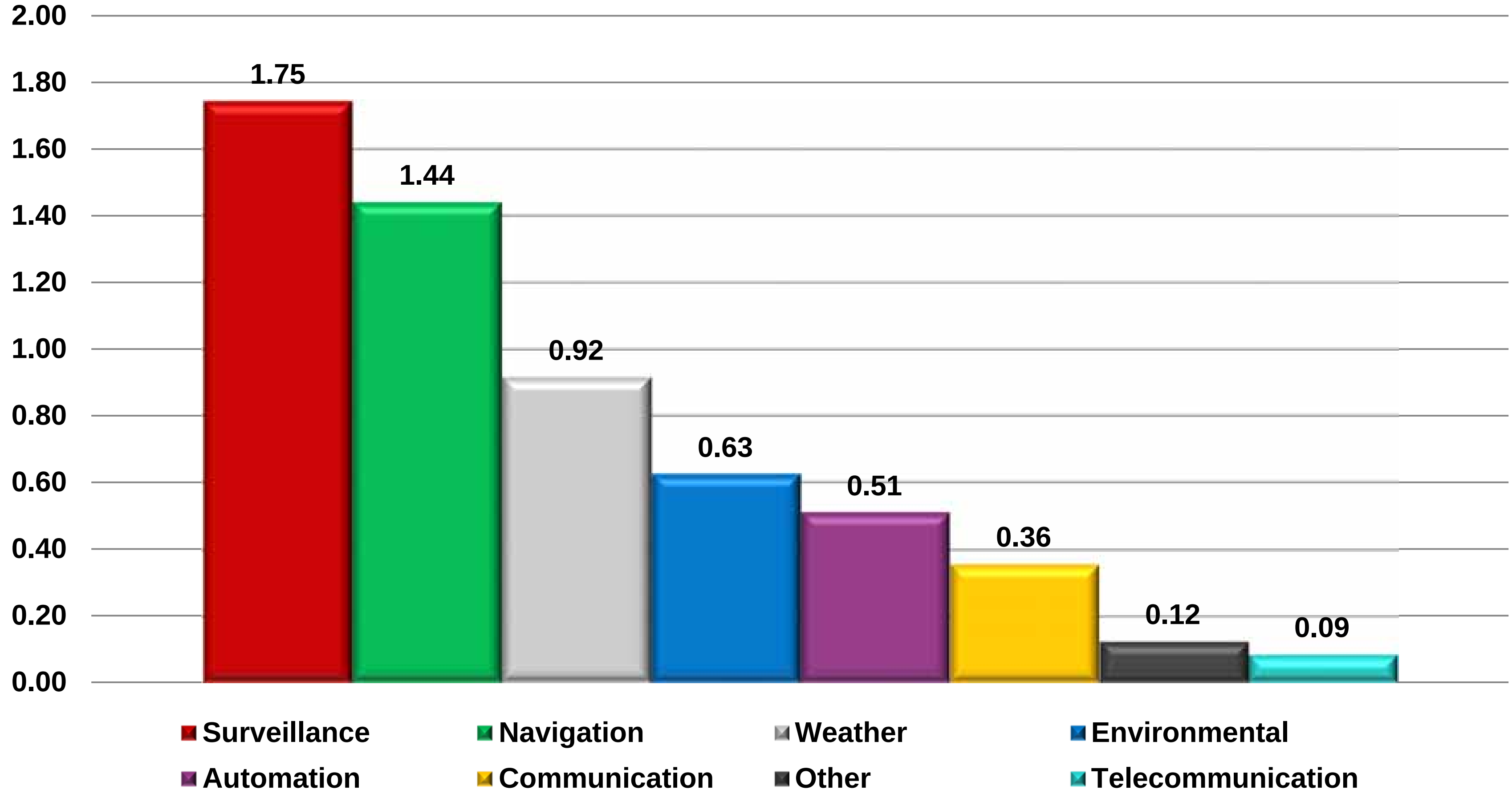
Implied average annual outage ratio of 0.69

What are the ATM safety implications?

Number of Outages vs. Number of Facilities (2007-2011)



Annual Outage Ratios
2007-2011 Average



Study Objectives

Overall

- Examine safety impact of communication and surveillance facilities service outages

Specific

- Investigate impact of outages on TCAS RA and separation events in the facility service volumes
- Investigate impact of outages on the separation index
- Estimate marginal effects of outages for different types of facilities

Sample Construction

Unscheduled Service Outage Data in the vicinity of 15 major traffic hubs (2010–2011)

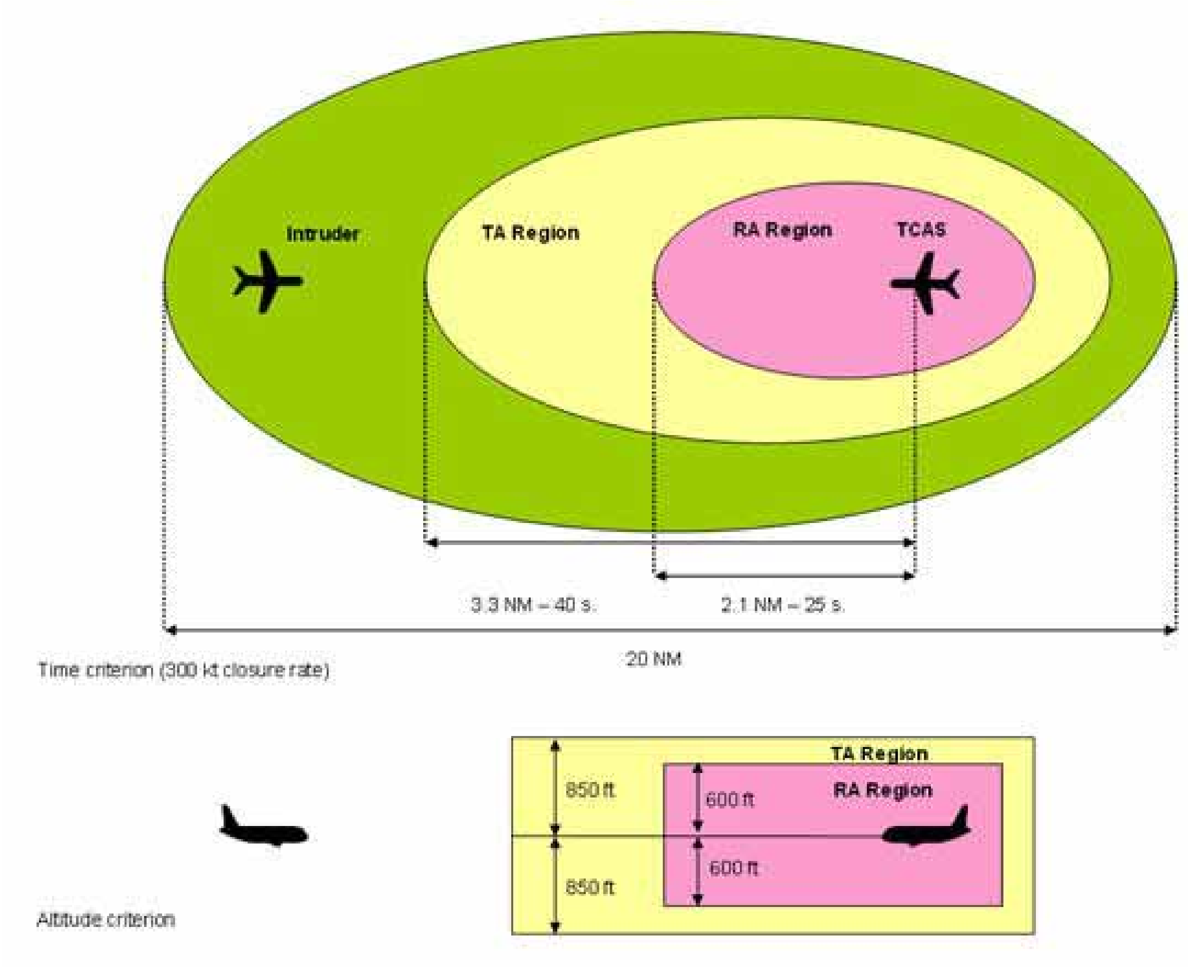
- Source: National Airspace System Performance Analysis System (NASPAS)
- 222 Communication and 116 Surveillance Facility Outages

Traffic Separation Data for Facility Service Volumes

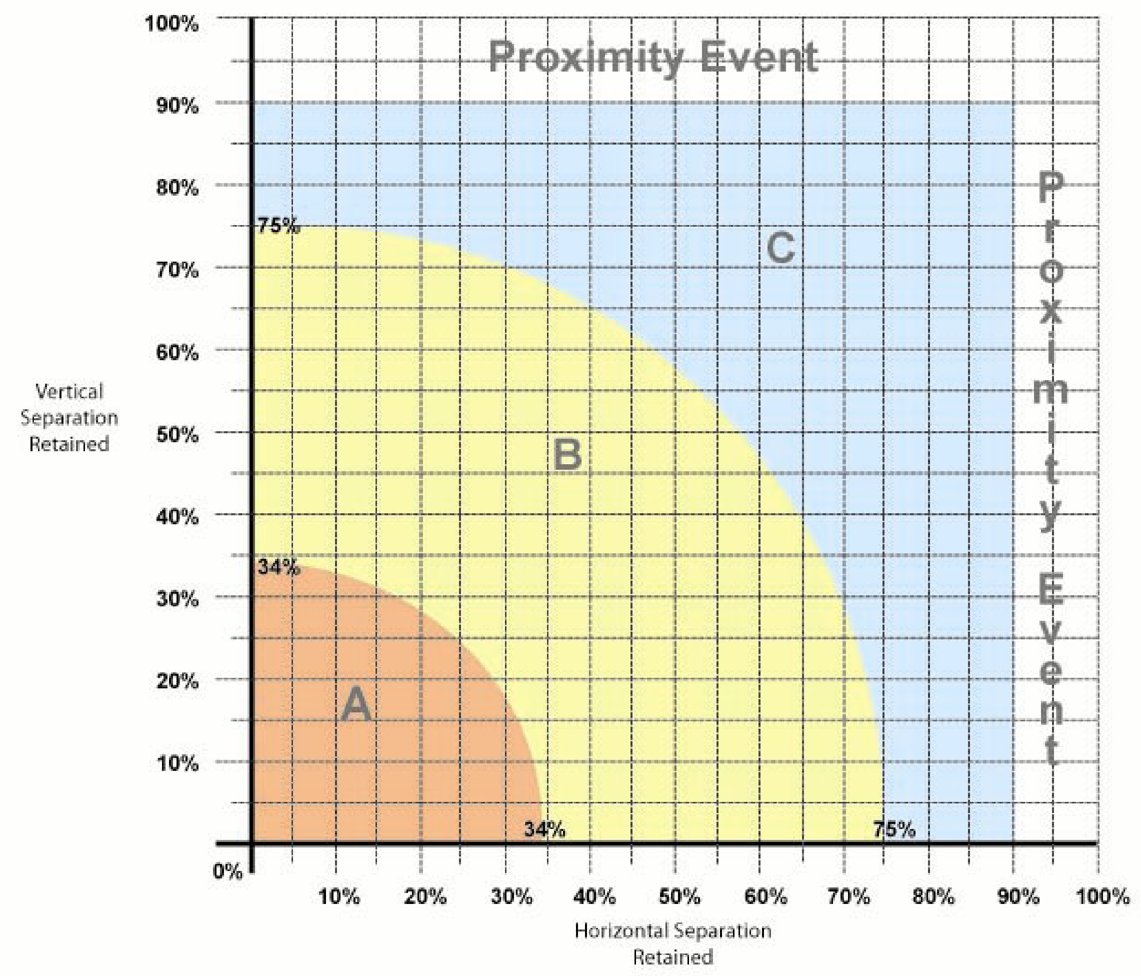
- Radar track data for +/- 30 min of an outage. Source: Offload Extract of Sector Design and Analysis Tool (SDAT)
- Traffic separations estimated by ISA

TCAS RA Modeling by ISA

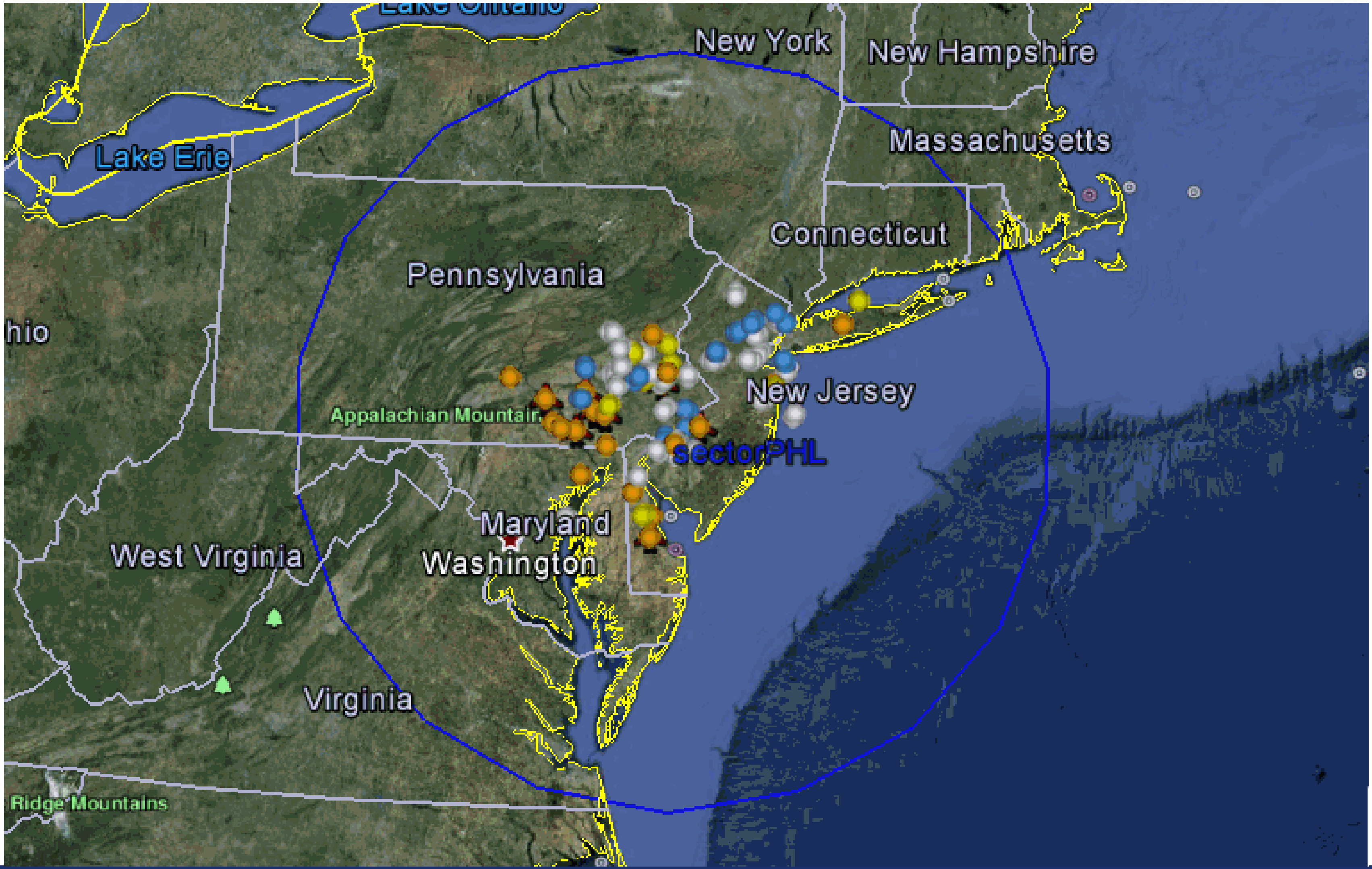
TCAS RA Modeling



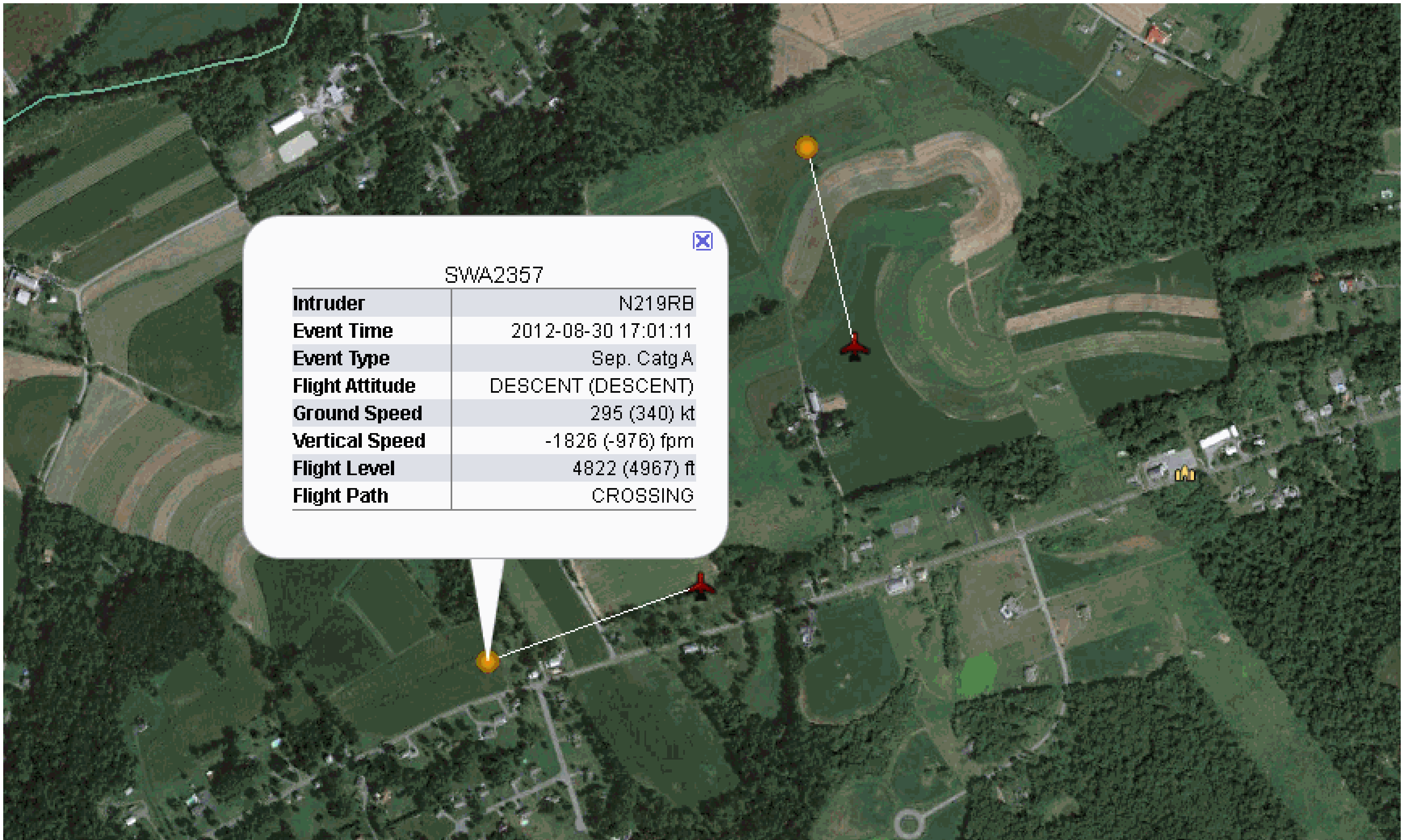
Separation Conformance Categorization



ISA Separation Modeling

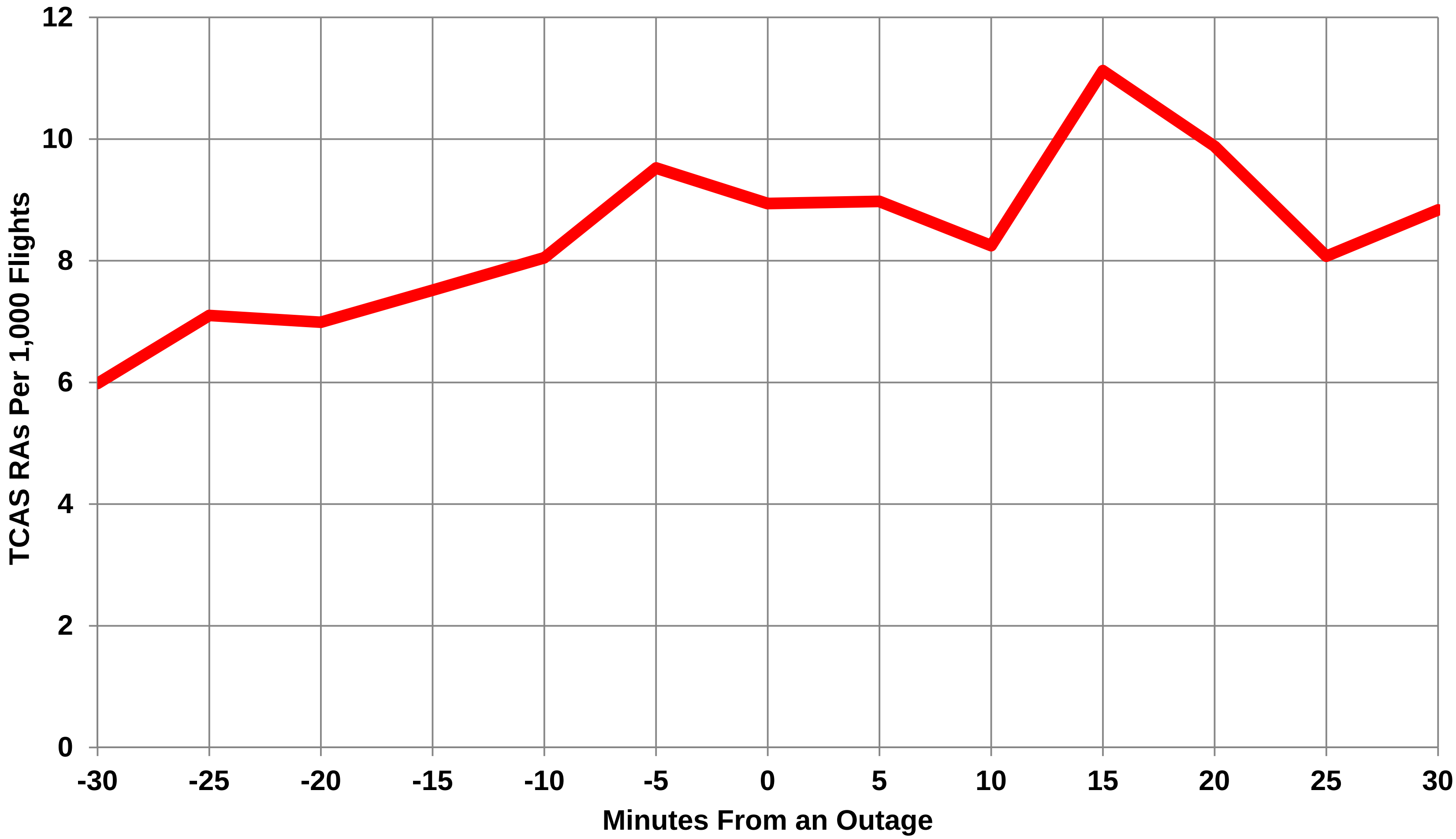


ISA Separation Modeling



ISA Separation Modeling

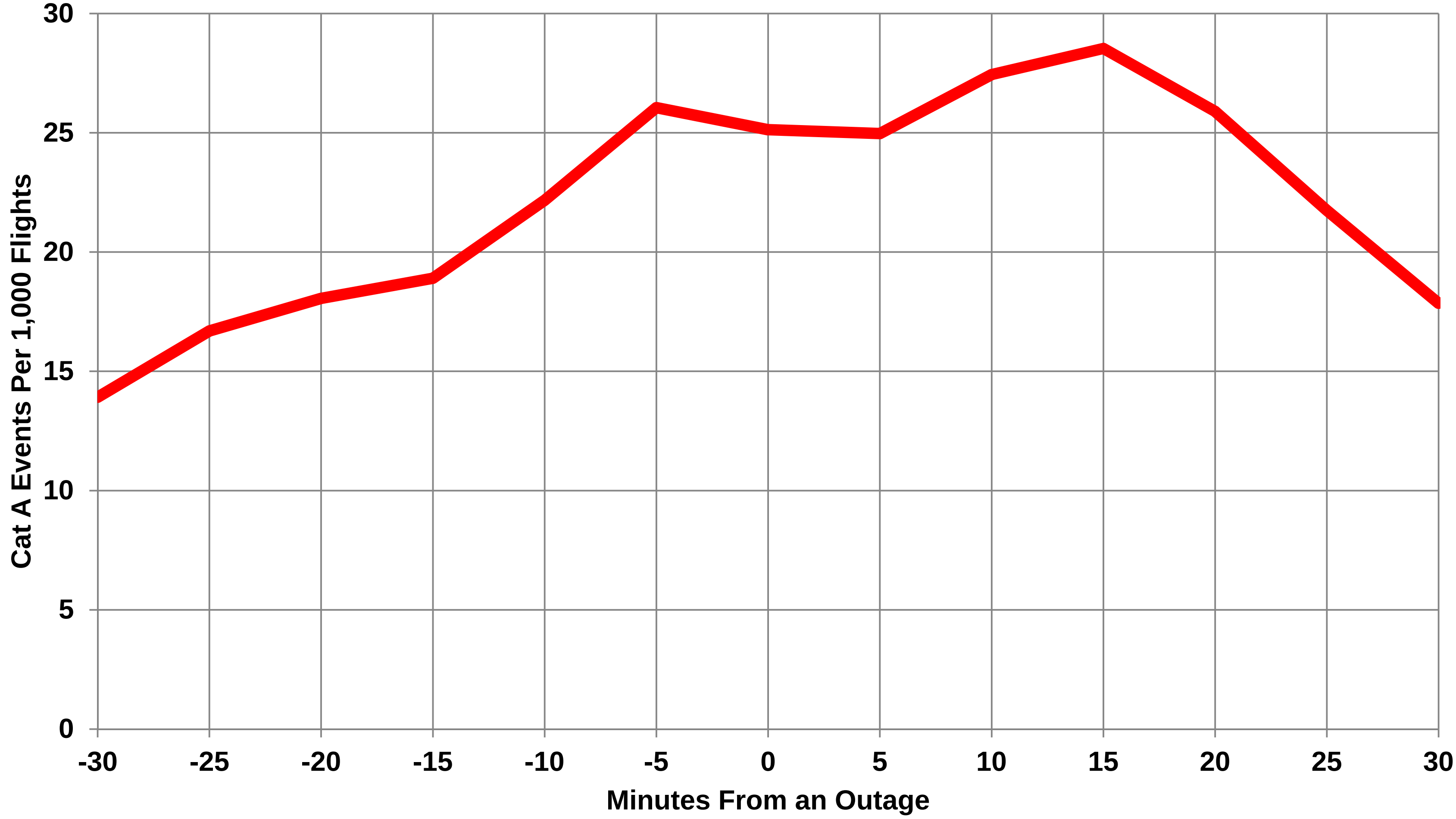
Average TCAS RA Count



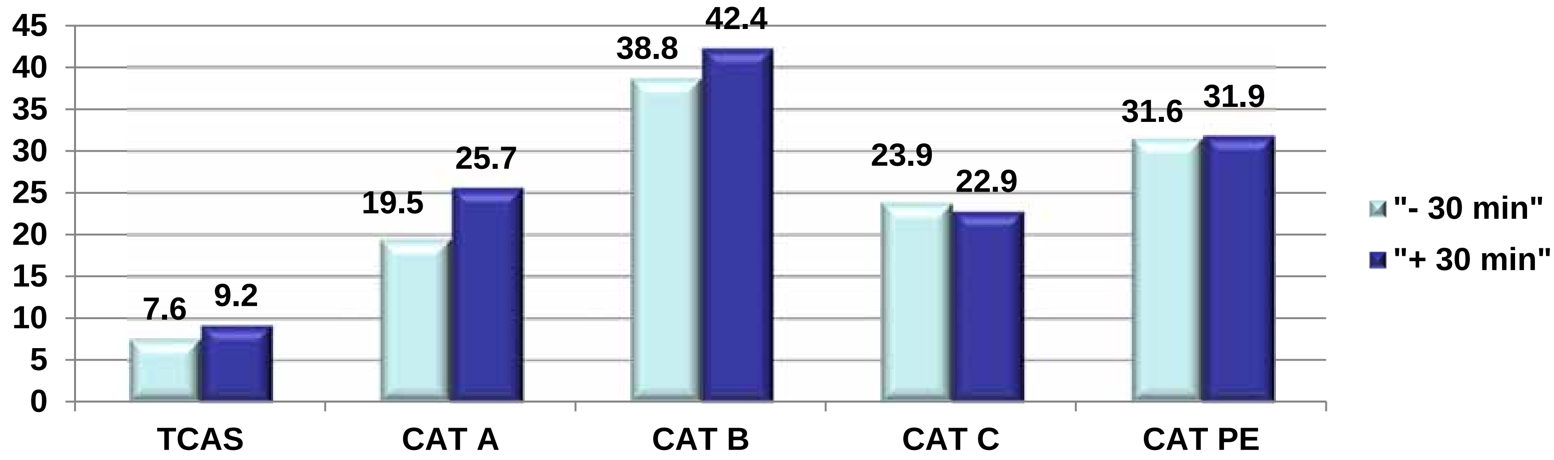
Actual TCAS RA Encounters MIT Lincoln Labs 2009 Study

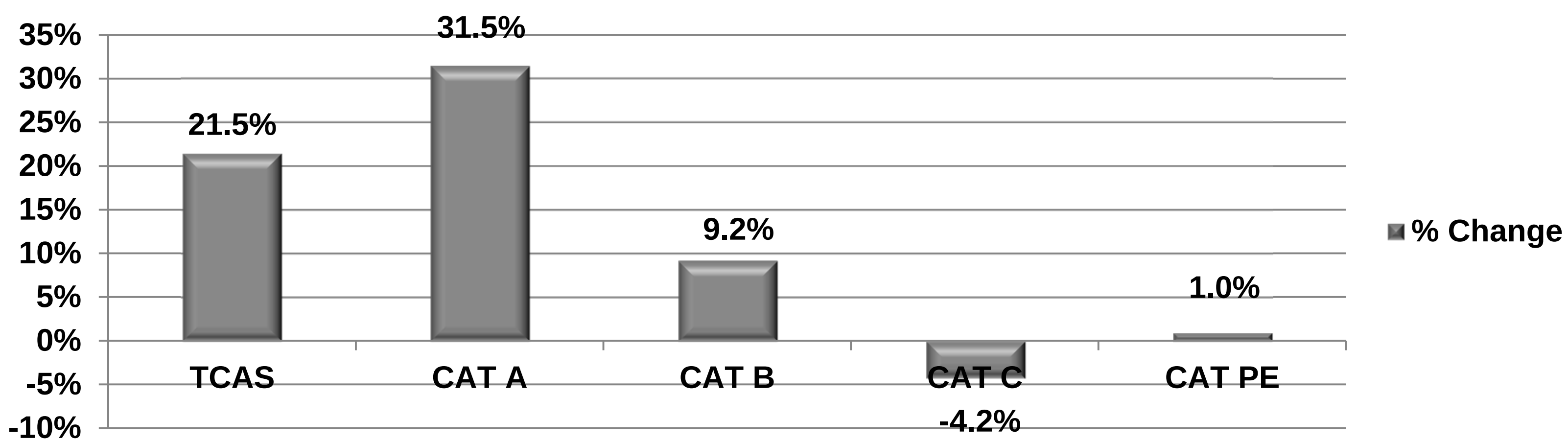
Airport	Rate per operation	Rate per 1,000 flights
EWR	1 in 90	11.1
JFK	1 in 291	3.4
LGA	1 in 93	10.8
ISP	1 in 107	9.3
CDW	1 in 934	1.1
FRG	1 in 125	8.0
HPN	1 in 34	29.4
MMU	1 in 90	11.1
TEB	1 in 28	35.7
	Average	13.3

Average CAT A Event Count



Before and After Average Counts





Analysis Methodology

Count data analysis

- RA encounters; Loss of separation events
- Negative Binomial regression model

Continuous data analysis

- Separation index values
- Lognormal regression model

Count Data Analysis

TCAS RA and Lost Separation Events Data

Count data that cannot be negative

TCAS RA and Lost Separation Events Data

Presence of over-dispersion	When variance greater than the mean

Negative Binomial Regression Model

Widely used in biomedical and highway safety research	Should be controlled for traffic density in the facility service volumes

Negative Binomial Regression Model

$$p(Y_i = y_i) = p(y_i) = \frac{\Gamma\left(y_i + \frac{1}{\alpha}\right)}{\Gamma(y_i+1)\Gamma(\frac{1}{\alpha})}\left(\frac{1}{1+\alpha\mu_i}\right)^{1/\alpha}\left(\frac{\alpha\mu_i}{1+\alpha\mu_i}\right)^{y_i}$$ •, $y_i = 0, 1, 2, 3, 4,$

•where $\mu_i = E(Y_i) = w_i[e^{x_i'\beta}] = w_i[e^{\sum_{j=1}^{k} x_{ij}'\beta_j}]$ •, $i = 1,2,3,\ldots,n.$

$Var(Y_i) = \mu_i + \alpha\mu_i^2$ •where $\alpha \geq 0$ – dispersion parameter

•Specifically:

$$SE_i = a + b_1 OUT_i + b_2 SUROUT_i + b_3 COUNTS_i + b_4 VOLDIS_i + e_i$$

- **Where:**
  - SE is a separation event (TCAS RA, Cat A, B, C, or PE)
  - OUT is a dummy variable that indicates if the service was out or not
  - SUROUT is a dummy variable that indicates that the facility that lost service was a surveillance facility
  - COUNTS is the number of traffic counts in the facility service volume
  - VOLDIS is the total distance in nm that all flights flown in the facility service volume during examined period
  - b1 and b2 are coefficients of interest; b3 and b4 are coefficients of variables that control for traffic density

Negative Binomial Regression Model Parameter Estimates

SE	*Const.*	*OUT*	*SE OUT* / *SE NOUT*	*SUROUT*	*COUNTS*	*VOLDIS*
TCAS RA	-0.30*	0.27**	**1.31**	0.00	0.000056**	0.000017**
CAT A	-0.06	0.27**	**1.31**	0.00	-0.000031	0.000064**
CAT B	2.14**	0.14**	**1.15**	0.00	-0.000014	0.000018**
CAT C	1.60**	0.01	**N/A**	0.00	0.000018**	0.000009**
PE	1.76**	0.06**	**1.06**	0.00	0.000031**	0.000009**

•* Indicates marginal (10%) statistical significance; ** Indicates statistical significance (5% or better)

•Interpretation: coefficient of *OUT* indicates the difference of event count Logs. For example, for TCAS RAs: *Log(RA with Outage) – Log(RA without Outage) = 0.27*. So, *Log(RA Out/RA No Out) = 0.27*, making (*RA Out)/(RA no Out) = 1.31*. TCAS RA encounters are 1.31 times more likely in the service volume of the facility with service outage.

Results of the Separation Events Analysis

- TCAS RA Encounters and Cat A separation events are 1.31 times more likely in 30 minutes following a service outage than in 30 minutes before an outage
- Cat B events are 1.15 and PE events are 1.06 times more likely in 30 minutes following an outage. Cat C events are not affected by service outages
- Surveillance facility outages are not marginally different from communication facility outages

Continuous Data Analysis

Separation Index Data

Ratio of actual minimum distance between aircraft at the same altitude to required separation distance. For example, if the minimum distance between aircraft was 6 nm when required separation was 5 nm, the separation index is 120%

Separation Index Data

Cannot be negative. Only data for aircraft within 10 nm of another aircraft is used

Lognormal Regression Model

- Typically used when dependent variable cannot be negative
- Should be controlled for traffic density in the facility service volumes

Lognormal Regression Model

$Y = \beta' x + e$ •where y is positive $E[Y] = \beta' x$ •and $Var[Y] = \sigma^2 [\beta' x]^2$

•In this model $E[LogY] = Log(\beta' x) - 2\sigma^2$ •and $Var[LogY] = \sigma^2$

•Specifically:

$$SI_i = a + b_1 OUT_i + b_2 COMOUT_i + b_3 COUNTS_i + b_4 VOLDIS_i + e_i$$

- Where:
  - SI is a separation index for aircraft within 10 nm of each other
  - OUT is a dummy variable that indicates if the service was out or not
  - COMOUT is a dummy variable that indicates that the facility that lost service was a communication facility
  - COUNTS is the number of traffic counts in the facility service volume
  - VOLDIS is the total distance in nm that all flights flown in the facility service volume during examined period
  - b1 and b2 are coefficients of interest; b3 and b4 are coefficients of variables that control for traffic density

Lognormal Regression Model Parameter Estimates

	Const.	OUT	COMOUT	COUNTS	VOLDIS
SI	1.71**	-0.19**	0.15**	0.00	0.000005**

•** Indicates statistical significance (5% or better)

•Interpretation: coefficient of *OUT* indicates how the separation index was affected when a surveillance facility lost service – the separation index decreases by 19%. The coefficient of *COMOUT* indicates how the separation index was affected when the facility that lost service was a communication facility – the separation index increased by 15% comparing with a surveillance facility outage. Adding 15% to -19% results in -4%. The separation index decreases by 4% when a communication facility loses service.

Results of Separation Index Analysis

- The separation index for flights within 10 nm of each other is 19 percent lower in 30 minutes following a surveillance facility outage than in 30 minutes before an outage

- The separation index is only 4 percent lower for communication facility outages

Next Steps

Surface surveillance equipment outages (ASDE, ASDE-X) and RW incursions

- More than 12,000 runway incursions in the US from 2001 to 2013
- Do ASDE (-X) outages contribute to the likelihood of runway incursions?

ISAM (Integrated Safety Assessment Model)

- ISAM depicts a complete risk picture and incorporates all of the aspects related to safety hazards collectively, **including equipment outages**
- Event Sequence Diagrams (ESDs) are quantified using US data
- Fault Trees (FTs) are used to model initial and pivotal events in ESDs
- Service outages will be integrated in FTs

Questions?

Thank you very much!