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Safety assessment of implemented NextGen operational improvements

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Abstract

Since most NextGen Operational Improvements (OIs) have been implemented recently, there is no traditional safety statistics, such as the number of accidents and/or incidents available to perform their formal safety evaluations. In this paper we present a process of safety assessment using precursors that may lead to unsafe outcomes. We use the radar track data to estimate traffic separations before and after NextGen OI implementation at Memphis International Airport (MEM). The FAA implemented Phase 1of wake re-categorization (RECAT) separation standards at MEM in November 2012. We examine the counts of wake, proximity, and anomalous trajectory events for two 30-day samples of pre- and post-RECAT periods. While the paper focuses on the methodology and is not intended to provide a detailed safety evaluation of RECAT, the findings suggest that RECAT implementation did not adversely affect the air traffic safety.

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1. Introduction

The Federal Aviation Administration (FAA) is working towards the Next Generation Air Transportation System (NextGen) that will transform how the National Air Transportation System (NAS) operates to meet future traffic demand and enable efficiencies for users and service providers. Advances in navigation, communications, and traffic management provide emerging concepts that will solve existing and anticipated operational problems in the NAS.

In managing the development of NextGen, the FAA is assessing initiatives and potential components of the future system. For proposed Operational Improvements (OIs) the assessments typically are conducted through modeling, simulation, and/or Subject Matter Expert (SME) surveys. For the OIs that have already been implemented there is also an opportunity to carry out assessments which are done by estimating safety metrics before and after the implementations. While operational benefit assessment is somewhat straightforward since the throughput, delays, fuel consumption, and other operational data are readily available, measuring the safety impact is more complicated. Measuring the number of accidents as an outcome variable does not adequately capture the true safety state of the system since it measures something that does not happen frequently over time. Since most of NextGen OIs, have been implemented fairly recently, adequate accident statistics may not exist. Also, reliance on SME opinion and voluntary reporting introduces subjectivity and self-selection bias.

Proactive safety management approach is based on the early identification and mitigation of hazards before negative events occur. In other words, proactive approach identifies precursors that may lead to unsafe outcomes. For example, reductions in air traffic separations below required minimums can be considered as precursors to midair collisions, therefore, the analysis of proximity events before and after NextGen OI implementations can be used in safety assessment.

In this paper we use the radar track data from the Offload Extractor of the Sector Design and Analysis Tool (SDAT) to estimate traffic separations and anomalous trajectory events, such as missed approaches, S-turns/360 degree turns close to outer marker, and holding patterns before and after NextGen OI implementation at Memphis International Airport (MEM).

The FAA implemented Phase 1 of wake re-categorization (RECAT) separation standards at MEM in November 2012. The new standard establishes six new wake categories based on an analysis of the sixty-one most common International Civil Aviation Organization (ICAO) aircraft types operating in the busiest airports of the EU and US. Several studies have documented operational benefits of RECAT implementation at MEM, however, the safety impact was not yet addressed with the exceptions of voluntary reports by FedEx pilots.

In this study we examine traffic separations and counts of anomalous events before and after the OI implementation. Our findings suggest that RECAT implementation at MEM did not adversely affect safety. However, this paper's focus is more on the process of NextGen OI safety assessment than on the RECAT analysis results. The paper is organized as follows: Section 2 provides an overview of the System Safety Management Transformation Program (SSMT); Section 3 describes the FAA RECAT initiative; The process of risk assessment using safety precursors is presented in Section 4; Section 5 provides the results of the analysis; and Section 6 concludes the paper.

2. System Safety Management Transformation Program

In the evolving Air Transportation System (ATS), safety management transitions from a forensic approach that provides an indication that the system is not safe when accidents happen, to a proactive approach that is based on the early identification, assessment, and mitigation of any credible hazards before undesirable events occur (Pasquini and Pozzi, 2005). As the ATS is becoming more technologically and operationally complex, emerging risks are more difficult to understand. Also, quantitative assessment of risk is especially challenging when undesired events are extremely rare and the causal factors are numerous and difficult to quantify (Hadjimichael, 2009).

To be able to meet future safety goals, the safety management process has to evolve with the ATS. Civil aviation authorities in the United States and Europe have launched several initiatives that attempt to address NextGen and SESAR safety needs and focus on the proactive approach to safety management. One of such initiatives within the FAA is the System Safety Management Transformation (SSMT) program that provides an integrated safety management approach and supports a proactive strategy for building increased safety into the ATS. SSMT is developing innovative safety monitoring and risk assessment methods, which can apply to both current and future

ATM operations including emerging OIs during the transformation to NextGen. SSMT covers the entire spectrum of the ATM processes from ground management at the airport, to traffic management while the aircraft is in flight, to the network/system level processes relating to the entire set of flight operations.

The SSMT team has developed an Integrated Safety Assessment Model (ISAM) for analyzing the impact of NextGen OIs and emerging technologies on NAS safety. ISAM combines existing air transport safety models in a unified and scalable framework enabling the collection and analysis of precursor event data to improve the quality of safety modeling available to the aviation community. To compute and understand risk, ISAM models accident and incident scenarios through Fault Tree Analysis (FTA) and Event Sequence Diagrams (ESDs) (NASA, 2002). FTA is a top-down deductive failure analysis of an undesirable top-event (for example, an initiating event for Midair Collision is that aircraft are positioned on collision course). FTA represents the failure of the chosen top-event using Boolean logic to combine the various causes and faults that lead to the event. The lowest-level causes are Base Events (e.g., loss of communication) which may not be resolved further. The FTA Boolean logic describes the flow of precursor events (e.g., loss of separation) and their corresponding controls or barriers (e.g., ATC warning) from Base Events to the top initiating event. ESDs track the propagation of one or more undesirable states (initiating/pivotal events, or top-events from the fault trees) to either successful or unsuccessful End Events (e.g., aircraft continues flight or midair collision).

ISAM can be used to assess how system risk is affected by implemented or proposed OIs. However, the corresponding Fault Tree probabilities should be quantified in order to measure the changes in the system safety. For proposed OIs, that are not yet implemented, modeling and simulation or SME opinion is typically used to quantify these probabilities. For already implemented OIs, the most obvious method is to compare safety metrics before and after the implementation. However, since most of the NextGen OIs have only been introduced recently, there is often insufficient accident or incident statistics to support this. Alternatively, instead of accidents and incidents, their precursors can be used to assess the changes in system safety. These precursors that have not yet become safety incidents or statistics can be derived from available operational data, such as radar tracks or ATC-pilot communication. In this paper we use traffic separations and anomalous trajectories estimated from the radar track data for MEM traffic before and after RECAT implementation as safety precursors.

3. Wake Re-categorization

As part of the NextGen Multiple Runway Operations focus area, it has been identified that for the efficiency of parallel runway operations, and in particular for cases where those runways are 'closely spaced', one of the potentially constraining issues is related to the potential impact of aircraft wake vortex on other aircraft which are operating nearby.

Aircraft operating in the terminal area are subject to specific wake separation standards which are often larger than the Minimum Radar Separation (MRS) standards of 3 or 2.5 nm and are defined by the FAA and ICAO on a pair-wise basis[1]. The objective of these additional separation standards is to provide safe separations to aircraft that are approaching or departing the airport so that they do not risk encountering the wake of a preceding aircraft, which is potentially hazardous. Table 1 presents FAA wake separation standards, for different aircraft weight classes: Super (A380 and AN225 aircraft); Heavy (maximum certificated takeoff weight of 300,000 pounds or greater); Large (41,000 – 299,999 pounds maximum certificated takeoff weight); B757 (classified as a large, but with a special wake turbulence category); and Small (41,000 or less maximum certificated takeoff weight).

[1] The MRS is 3 NM when radar capabilities at a given location permit. A reduced separation of 2.5 NM may be applied when the average runway occupancy time of landing aircraft is statistically proven, by means such as data collection and statistical analysis, not to exceed 50 seconds, braking action is reported as good, and the runway turnoff points are visible from the control tower.

Table 1. FAA Wake Separation Standards (nautical miles at the threshold).

Leader/Follower	Super	Heavy	B757	Large	Small
Super	MRS	6	7	7	8
Heavy	MRS	4	5	5	6
B757	MRS	4	4	4	5
Large	MRS	MRS	MRS	MRS	4
Small	MRS	MRS	MRS	MRS	MRS

As the understanding of wake vortices has improved over the last decade, many organizations have concluded that the weight-based wake separation minima remain somewhat conservative and that revised separation standards could be defined based more on the wake characteristics of the aircraft, rather than simply being aggregated by weight categories. FAA experts in wake turbulence and safety/risk analysis working in collaboration with partners DOT/Volpe National Transportation System Center, EUROCONTROL and the aviation industry determined that reduced separations between similar type aircraft is as safe, or safer than current standards and if applied can also lead to considerable increases efficiency and capacity though optimized runway usage. The wake re-categorization program, Phase 1 was approved by the FAA in 2012 and Memphis became the first US airport to utilize the new RECAT Phase 1 separation standards in Nov 2012. RECAT Phase 1 replaces the previous FAA/ICAO wake--separation categories, which were based on aircraft weight, with an enhanced set of separations based on the wake turbulence characteristics of different groups of aircraft to provide more optimal separations during approach and departure operations. Table 2 presents RECAT Phase 1 separation standards.

Table 2. RECAT Phase 1 Separation Standards (nautical miles at the threshold).

Leader/Follower	A	B	C	D	E	F
A	MRS	5	6	7	7	8
B	MRS	3	4	5	5	7
C	MRS	MRS	MRS	3.5	3.5	6
D	MRS	MRS	MRS	MRS	MRS	5
E	MRS	MRS	MRS	MRS	MRS	4
F	MRS	MRS	MRS	MRS	MRS	MRS

The new RECAT Phase 1 categories are labeled A to F, with Category A including very large aircraft such as the Airbus A380 and Category F including smaller planes such as the Embraer 120. Under RECAT Phase 1 several aircraft category pairings have been allocated reduced separations, but there are also some aircraft pairs with unchanged or increased separation minima.

Since the introduction of RECAT phase 1 in Memphis, FAA has subsequently issued a new order allowing 6 additional airports to adopt RECAT and NextGen plan to adopt RECAT across all of the main NAS airports by 2017. RECAT Phase 2 will be an extension of RECAT Phase 1 with a static "pair-wise" regime, where each aircraft pair has its appropriate wake turbulence separation minima. In the longer term, NextGen are also considering RECAT Phase 3, which may support dynamic pair-wise wake separation minima taking into consideration actual aircraft weight and atmospheric/meteorological conditions.

MEM was considered a suitable candidate for the initial implementation of RECAT as it is the hub for FedEx, which is the largest carrier at the airport. FedEx were keen to improve the capacity at the airport and identified RECAT as an opportunity to achieve that goal. FedEx has around 500 operations a day at Memphis and the majority of its fleet fall into category C which with RECAT is able to operate at reduced separations (from 4 nm previously to 2.5 nm MRS). As a result of RECAT, the FAA reports that many FedEx aircraft can now proceed directly from the gate to the runway, reducing taxi time on average by around three minutes per departure. The FAA also estimates that due to the new separation standards MEM's capacity has increased by over 15% resulting in nine additional flights per hour. Also, lower fuel consumption and fewer emissions are added benefits of this newly gained efficiency.

With all of the benefits of RECAT, since implementation in 2012 no wake-related accidents were reported. However, to our knowledge, there were no formal safety studies conducted to assess the RECAT safety implications.

4. The process of risk assessment

To study the safety impact of the RECAT implementation at MEM we use the SSMT Safety Investigation Toolkit for Analysis and Reporting (SITAR) which processes the radar track data, analyzes flight trajectories and estimates traffic separations. Figure 1 presents SITAR processing diagram.

Since RECAT operations were introduced at MEM in November 2012, we use 30 days of radar-track data from pre-RECAT period (April 2012) and 30 days of data from the post-RECAT period (April 2013). The source of the radar-track data is the National Offload Program (NOP) obtained from the Offload Extractor of the Sector Design and Analysis Tool (SDAT). The selection of time periods ensured that the weather patterns are similar in pre- and post--RECAT samples. Also, the post-RECAT analysis period is 5 months after RECAT implementation, which suggests that FedEx pilots and MEM ATC had enough time to get used to the new wake separation standards.

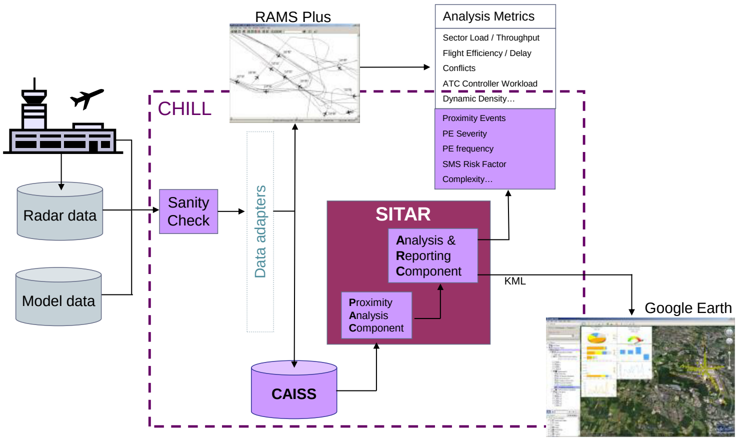

Fig. 1. SITAR Processing Diagram.

To support this analysis SITAR was enhanced to include Wake Proximity Event Indicators that recognize if the aircraft are in a leader-follower configuration and the separations are below the specified wake-separation minima. FAA/ICAO wake separation standards were used for April 2012 sample and RECAT wake separation standards were used for April 2013 sample. In addition, following metrics collected before and after RECAT implementation were analyzed:

- Counts of Category A, B, C, and PE Loss of Separation (LoS) Events
- Counts of missed approaches
- Counts of S-turns and 360 degree turns
- Counts of holdings
- Counts of departures and arrivals

Our definitions of Category A, B, C, and PE LoS events are consistent with the FAA Order 7210.56C that is presented in Table 3. Category A events are the most dangerous among four categories with 34% or less retained vertical or horizontal separation. Category PE events are the least dangerous among four categories.

Table 3. Separation Conformance Categorization.

	Category A	Category B	Category C	Category PE
Vertical Separation Retained	≤ 34%	>34% ≤75%	>75% ≤90%	>90% <100%
Horizontal Separation Retained	≤34%	>34% ≤75%	>75% ≤90%	>90% <100%

Fig. 2 illustrates how the horizontal and vertical trajectory data were used to identify the anomalous events. Thus, the SITAR Anomaly Assessment Component consumes 4D flight trajectory data and analyzes the profile in order to automatically identify anomalies:

- Aircraft holding – an aircraft is instructed to hold at a fixed altitude and performs a circuit in order to absorb a required amount of delay for arrival sequence.
- S-turn or 360-turn – an aircraft performs an unexpected S-turn or 360 degree turn close to outer marker in order to maintain required separation.
- Missed approach – an aircraft is on final approach descending for landing and then climbs again to execute another approach.

All these events have distinctive flight profiles and can be identified by analyzing the combination of lateral and vertical trajectory data.

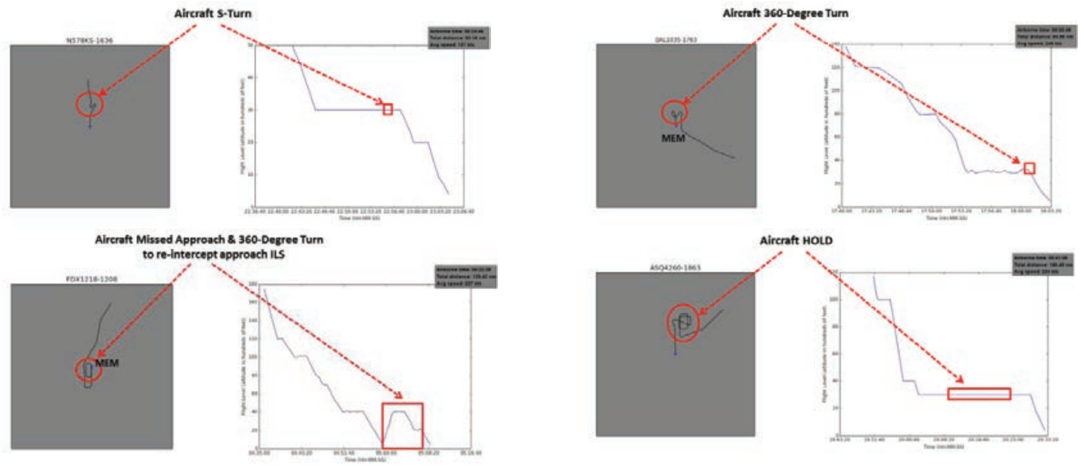

Fig. 2. Anomaly identifications from Trajectory Data.

In addition to the radar-track data we use the FAA Aviation System Performance Metrics (ASPM) data to examine operational demand and capacity, actual takeoff and landing times, and weather conditions for each 15-minute period. Since traffic load and weather conditions may have contributed to metrics of interest, we partitioned the pre- and post-RECAT sample periods into four subsamples: Light traffic load – VFR; Heavy traffic load – VFR; Light traffic load – IFR; and Heavy traffic load – IFR.

5. Analysis results

Fig. 3 presents the average hourly intraday traffic counts across the 30 sample days for MEM for April 2012 (pre--RECAT) and April 2013 (post-RECAT). The traffic counts are very similar for both periods suggesting that the results should not be influenced by different levels of traffic between periods.

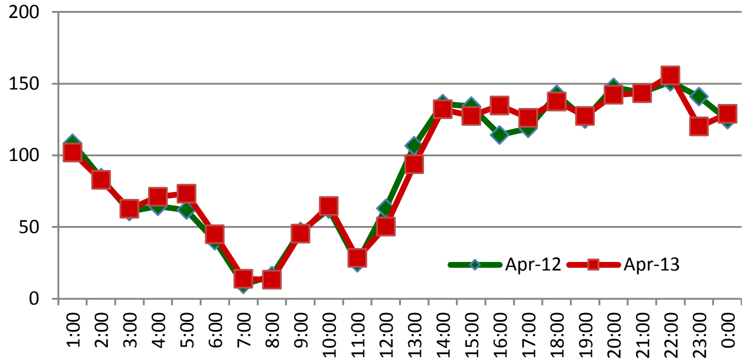

Fig. 3. Memphis Daily Traffic Loads for pre- and post-RECAT periods.

5.1. Aggregate analysis of proximity and wake events

As presented in Fig. 4, the total number of LoS events in the post-RECAT period is marginally lower than in the pre-RECAT period for all category. Also, daily counts of proximity events presented in Fig. 5 suggest that RECAT implementation did not lead to reduced traffic separations. The counts of LoS events in the post-RECAT period do not exceed the counts of the pre-RECAT period for all categories and time periods.

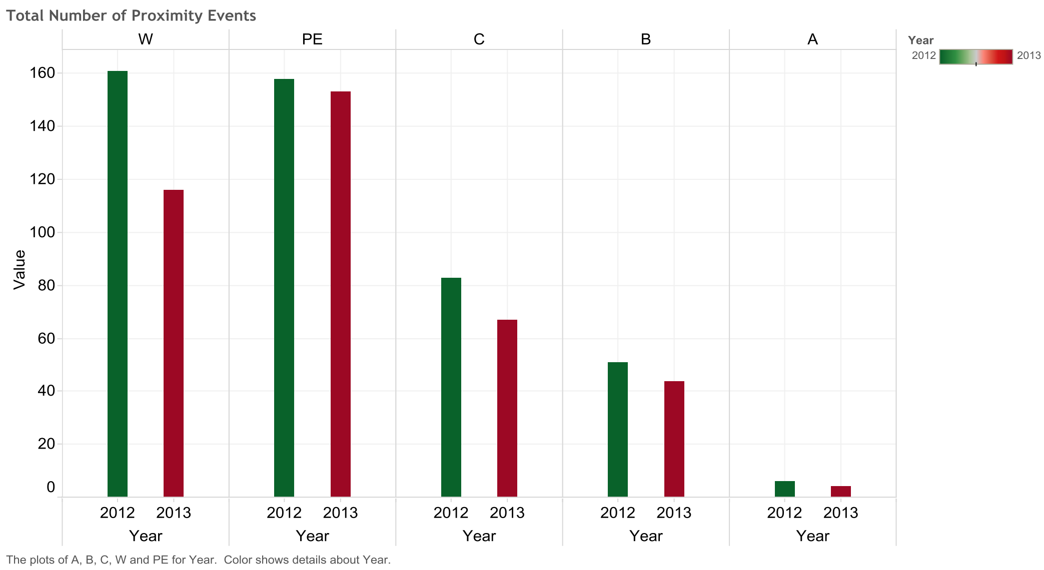

Fig. 4. Total number of proximity events by category for pre- and post-RECAT periods.

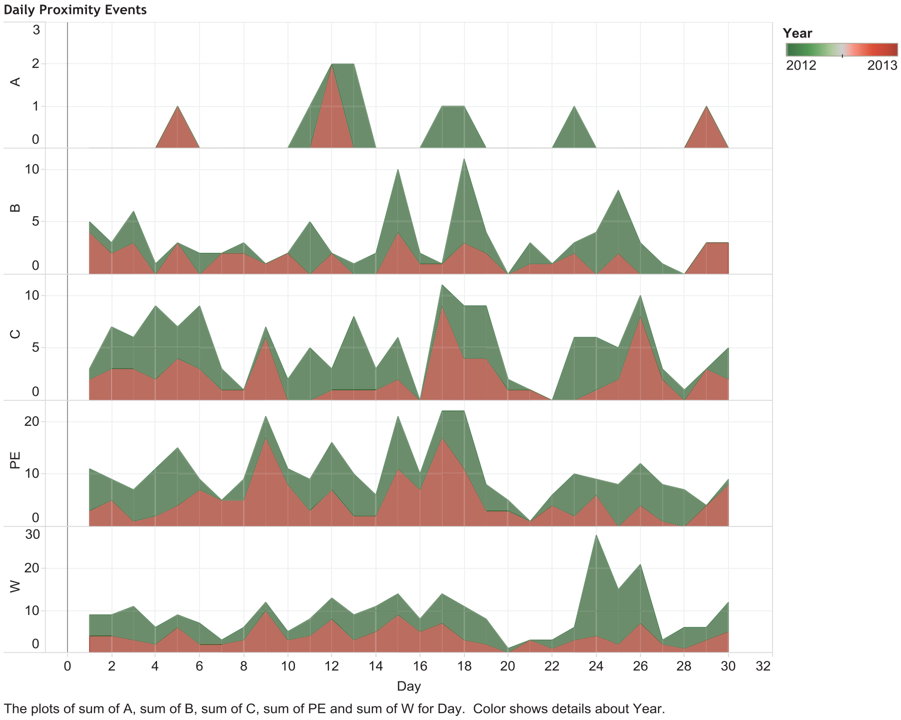

Fig. 5. Daily proximity events by category for pre- and post-RECAT periods.

5.2. Proximity and wake events by traffic load and weather conditions

As discussed in Section 4, to examine if the traffic load and weather conditions affect number of wake and proximity events, we partitioned the samples into four subsamples based on the level of traffic and VFR/IFR meteorological conditions. Table 4 summarizes the results: With the exception of Light traffic load – IFR, the number of LoS events is lower in the post-RECAT sample. In Light traffic – IFR subsample Category C, B, and PE event counts are marginally higher in the post-RECAT period. Similarly, wake event counts are lower for all subsamples except Heavy traffic load – IFR, where it seems that there were 5 more potential wake events in the post-RECAT period.

Table 4. Proximity events by traffic load and weather conditions.

Events	W		PE		C		B		A	
Traffic Load/Weather	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Light Traffic Load VFR	80	60	118	73	59	32	38	24	5	4
Heavy Traffic Load VFR	10	3	5	1	6	2	0	1	0	0
Light Traffic Load IFR	67	44	32	76	17	27	12	18	1	0
Heavy Traffic Load IFR	4	9	3	3	1	6	1	1	0	0

5.3. Statistical analysis

While the aggregate analysis of wake and proximity events suggests that RECAT implementation did not produce safety concerns, aggregation may obscure the results. To avoid potential bias we conduct the Negative Binomial (NB) regression analysis with wake and proximity event, as well as anomaly counts as dependent variables. NB regression models are widely used in safety research for accident count analyses when the data suggest the presence of over--dispersion (i.e., when the variance exceeds the mean) (Hall, 2000; Miauo, 1994). The NB regression model used in this study can be presented as follows:

Assume Y is a discrete random variable describing the count of separation events. X is a vector of covariates that potentially affect the occurrence of such an event and β is a vector of regression parameters.

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

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

and the variance is $$Var(Y_i) = \mu_i + \alpha\mu_i^2 \quad (3)$$

and α≥0 (dispersion parameter).

Specifically, the NB regression employed in this study contains the following variables:

$$SE_i = a + b_1 Log(TrafficCount)_i + b_2 RECAT_i + e_i \quad (4)$$

where:

- *SE* is a separation event (W, Cat A, B, C, or PE),
- *Log(TrafficCount)* is a Log of the count of daily of operations at MEM (arrival and departures),

RECAT is a dummy variable that indicates that an observation belongs to a period after RECAT implementation ("1" for after RECAT period and "0" for before RECAT period), and b2 is the coefficient of interest; b1 is the coefficient of variable that controls for traffic density.

The NB regression model parameter estimates are presented in Table 5.

Table 5. Negative Binomial regression parameter estimates.

	W	PE	Cat C	Cat B	Cat A	Holds	Missed Approaches	S-turns/360 turns
Constant	-4.39**	-3.73**	-7.59**	-1.83	-13.42	-10.67**	-7.49	-9.99**
Traffic Count	0.92**	0.82**	1.30**	0.36	1.79	1.46	1.04	1.55**
RECAT	-0.12	0.15	0.12	0.04	0.01	0.42	0.22	0.74**
*RR**	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*2.09*

(*) Relative Risk (RR) – change in the dependent variable in response to unit change in an independent variable; $RR = e^b$, where b is a acorresponding coefficient.
(**) Indicates statistical significance (5% or better).

The coefficient of RECAT provides the difference of event count Logs. For example, for S-turns/360 turns (S/360), Log(S/360 with RECAT) – Log(S/360 without RECAT) = 0.74. Hence, Log(S/360 with RECAT/S/360 without RECAT) = 2.09, which means that in the post RECAT implementation environment S-turns and 360 turns close to outer marker are about twice more likely than in the pre RECAT implementation period. However, as indicated by the non-significant coefficients of RECAT for Wake, Category A, B, C and PE events, the implementation of RECAT at MEM did not affect the likelihood of wake or proximity events. Also, the counts of anomalies with the exception of S-turns and 360 degree turns are not significantly different in the post RECAT implementation environment.

6. Conclusions and recommendations

The analysis presented in this paper focuses on the methodology of the safety assessment using safety precursors in a 'before and after' approach. This methodology allows the evaluation of implemented operational changes in the NAS from an air traffic safety perspective. While the presented analysis was not intended to provide a detailed safety evaluation of RECAT, the findings are encouraging: there were no significant changes in the number of wake and proximity events and anomalies between the pre and post RECAT periods. The only anomaly that seems to be more likely in the post RECAT environment is S and 360 degree turns. Future analyses for other US airports where RECAT will be introduced and which have different traffic mixes and operating conditions may provide more insights on this result and clarify if this result is airport and/or period-specific.

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