Airborne Incidents

An Econometric Analysis of Severity

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Technical Summary

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16. Abstract

This is a technical summary of the 'Airborne Incidents: An Econometric Analysis of Severity' main report.

Airborne loss of separation incidents occur when an aircraft breaches the defined separation limit (vertical and/or horizontal) with another aircraft or terrain imposed by Air Traffic Control. Identifying conditions that lead to more severe loss of separation incidents can lead to policy implications and future areas of research. Previous research focused on qualitative approaches to analyzing such events, and tended to examine only the frequency of events. This report puts the severity of a loss of separation incident front and center and uses econometric techniques to examine the relationship between severity and conditional factors during the incident.

The report utilizes report data from the Air Traffic Safety Action Program (ATSAP), with a concentration on terminal airspace incidents. A number of other FAA data sources were merged to provide a robust set of information at the time of event in terms of facility, weather, and other operational characteristics. The primary focus of this research was on the use of discrete choice, multinomial logit models to better understand the relationship between these different set of factors at the time of the event and the severity outcome.

17. Key Words **Airborne loss of separation, air traffic control, incident severity, safety analysis, discrete choice, multinomial logit, ordinal logit, terminal airspace safety**		18. Distribution Statement **No restrictions**	
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TABLE OF ACRONYMS

Acronym	Definition
ATC	Air Traffic Control
ATO	Air Traffic Organization
ATSAP	Air Traffic Safety Action Program
ARTCC	Air Route Traffic Control Centers
CNAC	The Center for Naval Analyses Corporation
DTRB	The Digital Terminal Resource Book
GA	General Aviation
IFR	Instrument Flight Rules
METAR	From the French Mètéorologique Aviation Régulière. Hourly weather reports automatically generated
MNL	Multinomial Logit
NACTA	National Air Traffic Controllers Association
NFDC	The National Flight Data Center
OE	Operator Error
OED	Operational Error/Deviation
OLS	Ordinary Least Squares
OPSNET	Operations Network Database
PPO	Partial Proportional Odds
RNAV	Area Navigation
RO	Routine Operation
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules

TABLE OF CONTENTS

TABLE OF FIGURES

1. INTRODUCTION

This study analyzed airborne loss of separation incidents to determine which factors are associated with severe and Catastrophic incidents. This technical summary is a condensed version of the full report and is meant to highlights the methods used and the key results. More detailed information can be found in the full report, which this document references frequently.[1]

The Volpe team utilized robust quantitative statistical models that provide an unbiased look at what types of factors are most often associated with severe, and in particular, Catastrophic events. The resulting findings have potential implications for future policies aimed at reducing the odds of an airborne incident becoming severe.

An airborne loss of separation incident is a situation where two (or more) aircraft breach the defined separation limit (vertical and/or horizontal) imposed by Air Traffic Control (ATC). Breaching this can lead to aircraft getting dangerously close to another, with the most severe outcome resulting in either mid-air or terrain collisions. In order to reduce the likelihood of severe loss of separation incidents, understanding what the main factors and components that drive these incidents is vital.

This is the only time known to Volpe that the Air Traffic Safety Action Program (ATSAP) database, controlled by the National Air Traffic Controllers Union (NACTA), has been opened up to researchers for an econometric analysis. It provides a wealth of information on the specific factors that were present when an airborne incident occurred, as well as the severity of the resulting incident. This was combined with data on facility information (NFDC and DTRB), daily operations (OPSENT) and weather in order to provide a more complete view of the circumstances surrounding each incident.

2. LITERATURE REVIEW

The current field of research on airborne loss of separation occurrence and severity can be broken-down into two broad sets. The first set includes qualitative studies that attempt to identify specific factors that contribute to the occurrence and severity of the incidents. The second set uses predictive models to estimate the relationships between potentially relevant factors and occurrence or severity of incidents. The first set was used to provide some guidance on potential explanatory variables, while the second set provided background into the methodology that has been previously utilized and lessons learned from previous quantitative studies.

[1] Biernbaum et al. (2014)

Previous research on severity tended to focus on human and causal factor components as means to explaining incidents. Schroeder and Nye examined various measures of controller workload at the time of incidents for air route traffic control centers (ARTCC) during 1985-88 and found strong correlation between the five types of causal factors investigated but little correlation between these causal factors and other variables such as traffic complexity and number of operations in a sector.[2] In a related paper, Rodgers and Nye used data from the FAA's Operational Error Data Base, sampled from 1988-1991 and grouped operational errors into three levels of severity. They then examined how a variety of variables, including causal factors, varied across these different severity levels, and through the use of Chi-squared tests of significance found no statistical relationships between these variables and major or moderate severity.[3]

The relationship between age and/or experience is also a common area of research when investigating the frequency of incidents. The Center for Naval Analyses Corporation (CNAC) combined agency personnel records and controller experience at the time of an incident to estimate the "likelihood" of an incident occurring for several sets of experience groups.[4] The study found that experience and the likelihood of an operational errors (OE) were significantly related, with the likelihood of an OE declining rapidly in the first few years of experience. In a similar study, Broach re-analyzed the CNAC dataset to look at both controller age and experience.[5] The likelihood of operational errors was regressed on both age and experience, with the estimated coefficient on age being positive and the estimated coefficient on experience being negative. This suggests that age could increase the likelihood of an OE, while experience has the counter-effect of reducing the likelihood of an OE.

Two papers published by the FAA attempt to predict OE events through logistic regression analysis. Pfleiderer and Manning examined prediction and classification of OE and routine operations with a two stepwise logistic regression analysis.[6] The central goal of the paper was to determine how well the logistic regression model could accurately distinguish between the OE and RO events. The high-altitude model accurately predicted 80% of the cases between in-sample OE and RO events, while the low-altitude model accurately predicted 79% of the cases between in-sample OE and RO events. The second study was conducted by Pfleiderer et al. and was very similar in nature, where the authors used logistic regression analyses to determine whether a set of sector characteristics could distinguish between OE and RO events.[7] Again, a backward stepwise elimination was used to reduce the sectors variables down to the "best" statistical fit of the model. These "best" fit models were then used to predict between RO and OE events, with the low- and high-altitude models accurately classifying 75% and 79% of events, respectively.

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[2] Schroeder and Nye (1993)

[3] Rodgers and Nye (1993)

[4] Center for Naval Analyses Corporation (1995)

[5] Broach (1999)

[6] Pfleiderer and Manning (2007)

[7] Pfleiderer et al. (2009)

3. METHODS

The Volpe team used Multinomial Logit (MNL) techniques in order to tease out associations between severity levels and factors present in the ATSAP database. MNLs were pioneered by Dr. Daniel McFadden (Nobel Prize winner in 2000) in the 1980s and are now ubiquitous in discrete choice modelling. Since other ATSAP variables are held constant, the individual impact of each variable becomes apparent in this type of modelling environment.[8]

Due to the nature of the data (i.e., severity ratings from Catastrophic to Minimal), it was initially desired to focus on the analysis on the ordered family of models. However, ordered models failed to pass the parallel lines assumption necessary to warrant their use. Partial proportional odds models, a newer method to address this issue, were estimated and appear in the report's Appendix. Future research should focus on using PPO models as a way to pass the necessary assumption associated with ordered models. Therefore, the primary model of choice for this report is the multinomial logit model.

The ATSAP database breaks down incidents into Minimal, Minor, Major, Hazardous and Catastrophic severity categories. For this analysis, Major, Hazardous and Catastrophic incidents were considered "severe". The Volpe team placed a particular focus on Catastrophic events, because although rare, these are the incidents most likely to be involved in a crash, and thus have the most direct relationship to safety outcomes. The model output is the form of relative risk ratios, which indicate how much more likely a variable's inclusion makes the outcome more likely to be severe as opposed to not-severe, or at a given severity level as compared to a minimal severity level.

ATSAP consists entirely of situations in which incidents occurred, thus all comparisons are in reference to a "typical incident". Since Volpe does not have data on normal operations (flights that do not result in incidents), the results cannot be interpreted as identifying factors that leads to a flight being more (or less) likely to be involved in an incident in the first place.

It is important to note that many of the ATSAP variable are "causal factors;" these are variables of a subjective nature that were entered into ATSAP if the analyst determined not only that the given variable was present at the time of the incident, but also that it directly contributed to the relevant incident. [9] There is the potential that these variables suffer from reporting bias and measurement error. Causal factor variables were included in the modeling effort – they are interesting variables and it is important to analyze them – but the reader should keep these caveats in mind.

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[8] Section 3 provides additional information on the modeling methods chosen.

[9] Section 5.9 elaborates on the data issues inherent with causal factor variables.

4. INPUT DATA

The following presents the source and content information of each data set used in this report. A more detailed discussion on the data sources used in this report can be found in section 4 of the main document.

4.1. Air Traffic Safety Action Program Data (ATSAP)

The ATSAP database is maintained by the FAA Air Traffic Organization (ATO) in conjunction with the National Air Traffic Controllers Association (NACTA) and is a voluntary self-reporting system for air traffic controllers for safety and operational concerns. It contains 22,381[10] terminal-area airborne events from May 18, 2007 to January 25, 2013. The self-reported events are processed by a committee of experts and are assigned a severity rating based on event specific information.

The ATSAP database contains basic information on each airborne event (date, time, facility location), aircraft, parties involved (controllers and pilots), and possible causal factors. This dataset serves as our "base" dataset, where all other datasets will be integrated and merged to.

4.2. Weather Information

Hourly METAR weather readings at airports are archived by Plymouth State University in New Hampshire.[11] These METAR readings represent a standardized set of information automatically collected by weather stations. Plymouth State University was able to provide weather readings for nearly all of the location-hour pairs in the ATSAP dataset.

The hourly readings contain information about temperature, humidity, wind conditions, visibility conditions, and information about active weather such as storms. In addition, some readings contain summary amounts of precipitation for the past 6 or 24 hours.

4.3. Facility Characteristics

Facility characteristics are derived from two main sources. The National Flight Data Center (NFDC)[12] provided information on the number of runways at various facilities. The Digital Terminal Resource Book (DTRB)[13] provided information on facility level (a measure of complexity used to adjust controller pay) and the mapping between airports and the TRACONs that serve them.

[10] There were originally 22,704 events reported to the Volpe Center, with 323 non-terminal events that were later dropped by the Volpe Center from the dataset.

[11] Website: http://vortex.plymouth.edu/

[12] Website: https://nfdc.faa.gov

[13] Website: http://terminaltools.faa.gov/DTRB/

Both the NFDC and DTRB contain many variables beyond those used for this analysis. For the purposes of this analysis, only the number of runways, facility level, and the TRACON serving a given airport were collected. For airports, number of runways is a meaningful and easy calculation. For TRACONs, the total number of runways at towered airports served by that TRACON will be used.[14]

4.4. Operations Data

Daily operations data are available from the FAA through the Operations Network (OPSNET) website.[15]

Daily operations are available for both Tower and TRACON facilities, spanning the entire sample period (May 18, 2007 to January 25, 2013). Operation counts per facility are given for both itinerant and overflight IFR and VFR flights for commercial air carriers, air taxis, general aviation (GA), and military traffic.

5. RESULTS

5.1. Aircraft Information Variables

Variables in the aircraft category contain descriptors of the type of aircraft involved in an incident. Volpe determined that a number of these variables are correlated with incident severity. Most strikingly, incidents involving experimental aircraft are associated with increased likelihood of Catastrophic severity. In tower facilities, planes flying under visual flight rules also see increased severity.

Aircraft variables are grouped into sub-categories, which include aircraft type, control status, flight plan, the number of aircraft involved, phase of flight, and special events. Each sub-category was analyzed separately then brought together in the full aircraft model.[16]

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[14] See the Concerns section for more information.

[15] Website: https://aspm.faa.gov/opsnet/sys/main.asp

[16] The full aircraft model is described in section 6.1.7.

Key statistically significant results are highlighted below. Additional results, as well as regression output, can be found in section 6.1 of the report.

- Single engine props are 1.7 times more likely to be associated with severe incidents than are single-aisle jets. They are 3.6 times more likely to be Catastrophic in Tower facilities.
- In Tower facilities, incidents with experimental aircraft are 6.2 times more likely to be severe, and 21 times more likely to be Catastrophic. In TRACON facilities, they are 22 times more likely to be Catastrophic
- VFR (Visual Flight Rules) incidents are likely to be more severe than IFR (Instrument Flight Rules) incidents.
- The more planes involved, the higher the typical severity of an incident.
- Incidents that occurred during emergency situations had substantially higher severity, especially Hazardous and Catastrophic occurrences. Since this category by definition consists of unplanned, sudden events where there may be a loss of control such as in an emergency landing, this correlation is not surprising. Figure 1 shows the frequency distribution of emergency situations as compared to other special events, as well as a breakdown of special event types and severity levels. The relationship between emergency situations and hazardous/Catastrophic events is visually striking, in both Tower and TRACON facilities.

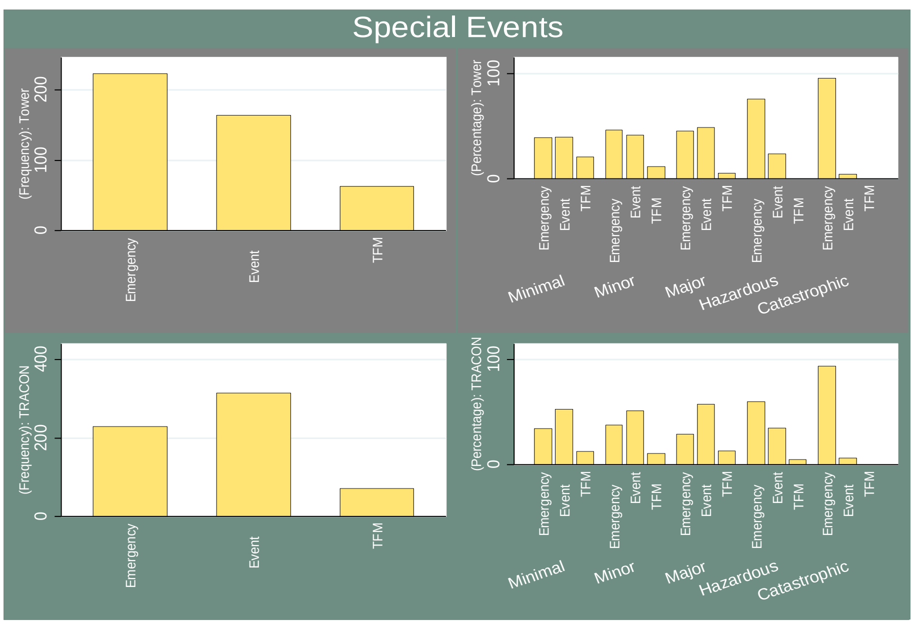

Figure 1 - Special Events

5.2. Facility Characteristics Variables

These variables describe characteristics of the facilities where incidents occurred. Data for this section is a combination of ATSAP and facility specific data detailed in Section 4 of the main report. All variables examined in this section are split between tower and TRACON facilities, due to the significant differences between the two facility types. In other words, studying facility characteristics combined across tower and TRACON will obfuscate nuanced difference between the two, and could lead to incorrect conclusions about certain variables.[17]

A detailed discussion on each individual variable examined in this section can be found in section 6.2 of the main document. The multinomial logit results for tower and TRACON facilities can be found in sections 6.2.3.1 and 6.2.3.2, respectively.

The following are the key statistical findings from the modeling exercise:

- Aircraft/Pilot Complexity Factor: When aircraft/pilot complexity is a factor in a Tower incident, there is a 120% percentage point increase in the probability for a Hazardous outcome and 100% percentage point increase in the probability for a Catastrophic outcome.
- Communication Complexity Factor: When communication complexity is a factor in a Tower incident, there is a 70% percentage point decrease in probability for Catastrophic outcomes.
- Coordination Complexity Factor: When coordination complexity is a factor in a Tower incident, the percentage change in probability decreases by close to 100% for Catastrophic outcomes.
- Traffic Complexity Rating: As facility level increases for Tower facilities, the probability of a Catastrophic outcome decreases from 0.01 to close to zero.
- Facility Influences: When facility influences are a factor for TRACON facilities, the percentage change in probability decreases by 150% for Catastrophic outcomes.
- Operations: An increase in operations had no effect on severity for Tower facilities, and a decreasing effect on the likelihood of a more severe incident for TRACON facilities.

[17] An example of this is runway count. TRACON facilities control many more runways, on average, than tower facilities. Therefore, it would be misleading to combine the two facilities types and attempt to interpret results involving runway count and severity because of this inherent difference in traffic control.

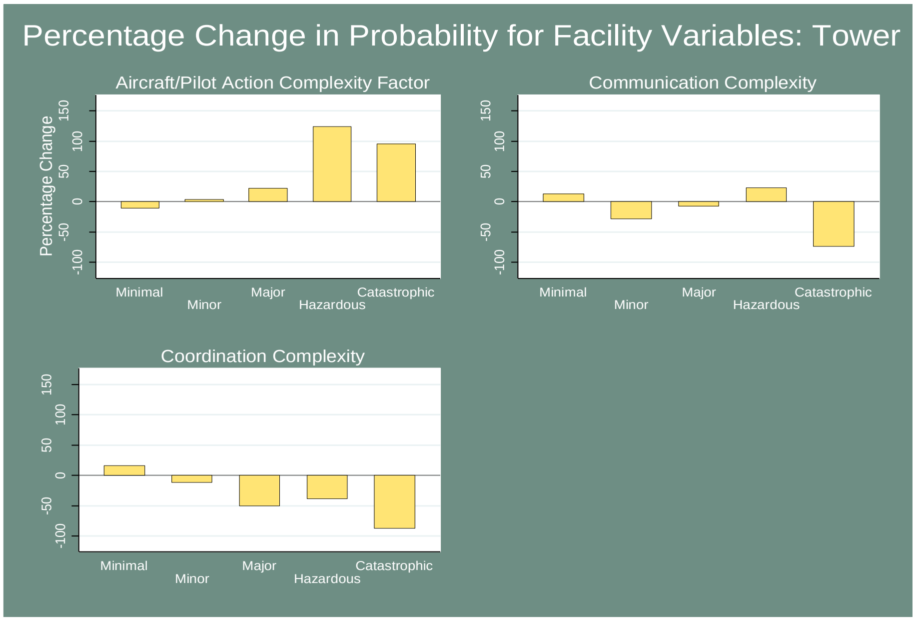

Figure 2 - Percentage Change in Probability for Facility Categorical Variables: Tower

5.3. Controller Variables

Variables in the controller category primarily contain descriptors of the type of environment a controller is working in as well as controller actions that may be related to an airborne incident. Volpe was particularly interested to see if controller experience and/or position are tied to incident severity. Some modeling approaches found a small relationship between controller experience and lower severity, while others found no relationship. Regardless, the effect is too small to have any policy implications.[18]

Controller variables are grouped into sub-categories, including approach type, controller experience, capacity, controller actions, controller influences, equipment influences, information exchange, training issues, unsafe acts, and work area influences. Data in each sub-category was analyzed separately; this information is then brought together in the full controller model. When variables such as years of controller experience and years at a facility measure similar concepts and are highly correlated; only one was used in the final model to avoid multicollinearity.

Key results are highlighted below. Additional results, as well as regression output, can be found in section 6.3 of the report.

- In the binary model, there is a small but statistically significant reduction in Severe incidents with more experienced controllers in TRACON facilities, but this result do not hold in other model specifications. Thus, it must be viewed with caution. The negligible relationship between controller experience and severity parallels the finding in the runway incursions report that any relationship between severity and experience is minor. Figure 2 (below) shows that the mean age of controllers involved in incidents does not change significantly between incident severity levels.

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[18] Section 6.3.1 provides additional detail on the relationship between controller experience and incident severity.

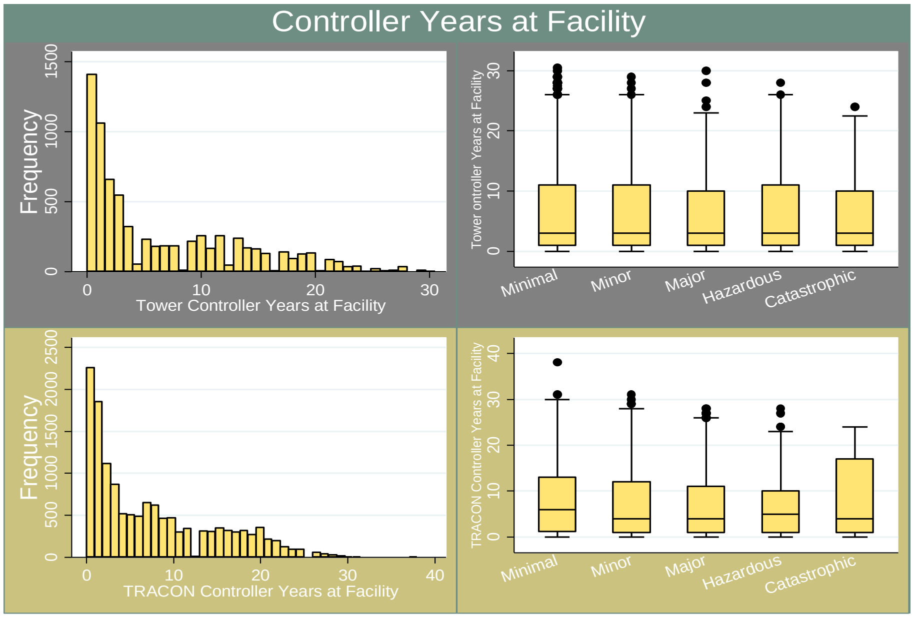

Figure 3 - Controller Experience and Severity

- Incidents that occur when controller training is in progress are 1.4 times more likely to be severe than incidents without training in progress in Tower facilities.
- Binary logit models show that incidents associated with a controller in ground position were unlikely to be severe. The data regarding ground controllers is likely skewed, however, because the ATSAP database only involves airborne incidents, with which ground controllers are unlikely to be involved.
- In TRACON facilities, incidents under Satellite Control had higher than expected severity levels, and incidents under FLM Control had lower than expected severity levels.
- Controller Influences, such as complacency, lack of experience, and personality conflict are tied to decreased severity, but the subjectivity involved in determining if one of these factors. This is highly sensitive to reporting bias, thus model results are difficult to interpret. Statistical issues associated with causal factors are discussed in section 5.9.
- Information Exchanges, which indicate a miscommunication between a pilot and controller, were tied to lower than expected severity. It may be that these miscommunications are typically quickly corrected.

5.4. ATC/Pilot Communications Variables

Variables in the ATC/Pilot Communications/Clearance category describe communication issues between ATC and pilots. Many of the communications variables in ATSAP had a small number of observations; thus similar variables were aggregated together in order to generate a large enough sample size to achieve robust statistical results. Additional information on the communications modeling can be found in section 6.4 of the report. Figure 3, below, shows some of the relationships between communication variables and severity.

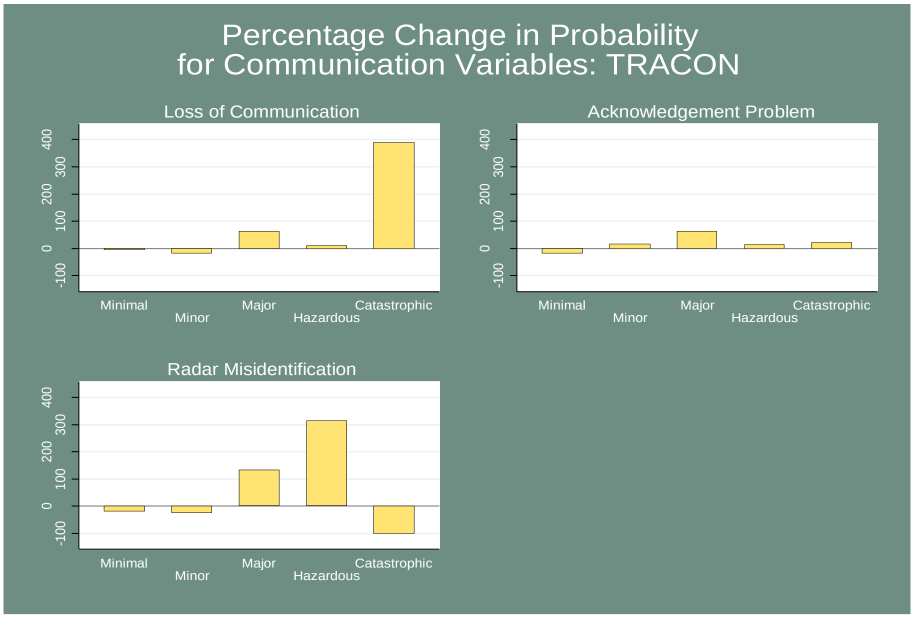

Figure 4 - Percentage Change in Probability for Communication Variables: TRACON

Key results are highlighted below. Additional results, as well as regression output, can be found in section 6.4 of the report.

- Incidents with a loss of communication are 1.4 times more likely to be severe in Tower facilities; in TRACON facilities they are 2 times more likely to be severe, and are 5 times more likely to be Catastrophic. Interestingly, our analysis showed that mere miscommunications are associated with low severity incidents. It may be that the loss of communication – which is not easily fixed – is the key differentiation.
- In both Tower and TRACON facilities, computer entry problems were associated with low severity incidents; it may be that these mistakes are typically resolved quickly before they become severe.
- In Tower facilities, flight plan/PDC processing problems are overwhelmingly low in severity. The odds of such an incident being severe are 0.000000104.
- Incidents with radar misidentification are 3 times more likely to be severe than incidents without Radar Misidentification in TRACON facilities.
- When an acknowledgement problem is cited as a causal factor, incidents are 1.7 times more likely to be severe in both Tower and TRACON facilities.

5.5. Airspace and Pilot Actions Variables

These variables describe the airspace the plane was operating in and pilot characteristics at the time that an incident occurred. These variables are exclusively causal factor and categorical in nature. The main caveat surrounding the bulk of these variables is the subjectively of the pilot causal factors, since controllers initially fill out the reports. The in-depth variable examination is found in section 6.5, while the multinomial logit modeling results are in section 6.5.9. The following are the key statistical findings from this section:

- Aircraft/Pilot action complexity factor: In Tower facilities, these are 1.6 times more likely to be associated with severe incidents, and 2.2 times more likely to be Catastrophic.
- Airspace Type D: Type D airspace is 2.3 times more likely to be associated with severe incidents for all facility types, and is 3.4 times more likely to be Catastrophic.
- Pilot Evasive Actions: There is a 300% percentage point decrease in the probability of a severe incident for all facility types if the pilot takes action to avoid a potentially dangerous situation.

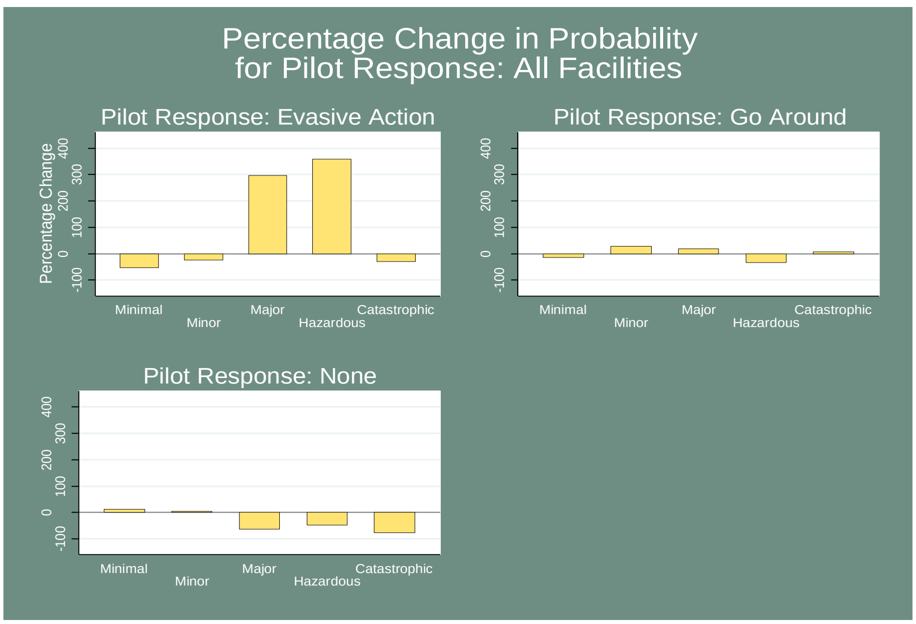

Figure 5 - Percentage Change in Probability for Pilot Response

5.6. Weather Characteristics Variables

The weather variables characterize the weather conditions during the incident. As described in Section 4.2 of the main report, the weather data originates from the METAR data archived by Plymouth University. When interpreting the data presented in this section, it is important to note that weather conditions are based on the location of the event. For Tower incidents, weather data is always local METAR data. For TRACON events, weather data is either at the positively identified location of the event (identified through the use of ATSAP event location information), or when this is not possible, the weather data the TRACON's primary airport. Due to this discrepancy in how the weather data was assembled based on facility, weather data is presented only by facility type.

Section 6.6 of the main report details the individual weather variables and section 6.6.12 presents the multinomial logit model results. There were essentially no statistically significant results for the Tower model, and relatively few statistically significant results for the TRACON model. Given the possible issues with how the weather data was merged for TRACON incidents, any conclusion drawn from these MNL results should be taken with caution.

5.7. Bouillabaisse Model

The "Bouillabaisse" Models pull the significant variables from the preceding models into comprehensive models, for Tower and TRACON facilities. It is intended to provide a quick overview of many different variables in one place, but is not intended to be a definitive index of the relationship between each individual variable and severity. It is recommended that readers who are interested in exploring any given variable in more depth reference the more focused models in Section 6 of the report. At present, there are several statistical problems that may be present in these models; these issues include but are not limited to: limited sample period, overfit, multicollinearity, and inconsistent regression results.

The Bouillabaisse models use a multinomial logit structure, following the structure of the preceding models in this report. Key results are highlighted below. Reassuringly, for the most part these results reinforce the findings from the focused models in earlier sections. Additional results, as well as regression output, can be found in section 7 of the report.

- Experimental Planes are associated with Catastrophic Incidents. Emergency Situations are associated with increased severity, while Traffic Management Initiatives are associated with low severity incidents in Tower facilities.
- Higher ATC levels are associated with a lower likelihood of Catastrophic incidents for Tower facilities.
- Controller Experience has no significant relationship with severity.
- Untimely Rolls are associated with Catastrophic Incidents in Tower Facilities.
- Higher air pressure is associated with reduced incident severity in Tower and TRACON facilities. The magnitude of this effect is small, but statistically significant.

6. CONCLUSION

The in-depth analysis of airborne loss of separation incidents found several wide-ranging and interesting findings. As expected, the factors affecting the severity of a loss of separation incident are complex and extensive. This does not mean that all the results were conclusive; further research is needed to fully understand the relationships between factors that contribute to incident severity.

One important result is that **'Catastrophic' severity incidents seem substantially different from the other four severity levels**. In other words, the interaction between the severity outcomes and variables studied in this report sometimes have the opposite effects going from the first four levels and then to Catastrophic. For example, increasing the traffic complexity rating for both Tower and TRACON facilities increases the likelihood of a more severe incident, but decreases the likelihood of the most severe (Catastrophic). Results like these have immediate policy ramifications: attempting to decrease the likelihood of an incident becoming Catastrophic by focusing on factors that would reduce the overall severity of an incident may have no end effect. This is because the factors that contribute to the first four severity outcomes do not always hold for Catastrophic incidents.

Another major finding is that **causal factor variables tend to only have a marginal statistical relationship with severity outcomes when included in fully specified models**. There were several explanations for this small impact on severity, with the most common cause being an overall lack of variation due to infrequently filled out causal factor data fields. Even after aggregating similar causal factors, small sample sizes were persistent problems. Other common issues were subjectivity and possible reporting bias of the causal factor variable. For example, several causal factors were associated with decreased severity levels; however, it was unclear whether this was a true effect, or just statistical noise due to the subjective reporting process for these variables. Better data collection and data entry for causal factor variables would help mitigate these types of potential issues.

Aside from particular areas of interests noted above, a more general area for future research should be considered. This type of statistical analysis is likely best conducted as part of a feedback loop with more traditional human factors research. That is, econometric analysis is quite powerful in differentiating which factors have the most influence on incident severity. What these models do *not* provide, however, is a specific intervention to mitigate the factor. Econometric analysis can then be seen as a first step in priority-setting for human factors research that can follow up with specific mitigations to the most pressing variables identified. Ideally, cooperating econometricians and human factors researchers can also help FAA achieve the biggest "bang for the buck" by combining information on both the size of the change to risk that can be reduced with a mitigation and the cost and likelihood of a successful mitigation.

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