Analysis of Runway Incursion Data

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A statistical analysis of runway incursion (RI) events was conducted to ascertain relevance to the top ten challenges of the National Aeronautics and Space Administration Aviation Safety Program (AvSP). The information contained in the RI database was found to contain data that may be relevant to several of the AvSP top ten challenges. When combined with other data from the FAA documenting air traffic volume from calendar year 2000 through 2011, the structure of a predictive model emerges that can be used to forecast the frequency of RI events at various airports for various classes of aircraft and under various environmental conditions.

Nomenclature

ANOVA = Analysis of Variance
ASIAS = FAA Safety Information Analysis and Sharing
ATADS = Air Traffic Activity Data System
AvSP = NASA Aviation Safety Program
CI = Confidence Interval
CY = Calendar Year
DX8 = Design-Exert software (Version 8) from Stat-Ease, Inc.
FAA = Federal Aviation Administration
LSD = Least Significant Difference bars
METAR = A format for reporting weather information
NASA = National Aeronautics and Space Administration
RI = Runway Incursion
RS = Response Surface

I. Introduction

ONE focus area of the National Aeronautics and Space Administration (NASA), enabled through the Aviation Safety Program (AvSP) of the NASA Aeronautics Research Mission Directorate, is to improve aviation safety. The AvSP[1] (http://www.aeronautics.nasa.gov/programs_avsafe.htm) seeks to provide increasing capabilities to:

- predict and prevent safety issues
- monitor for safety issues in-flight and lessen their impact should they occur
- analyze and design safety issues out of complex system behaviors, and
- analyze designs and operational data for potential hazards

Within this domain, the issue of runway safety is one thrust of investigation and research. One component of the runway safety thrust is that of runway incursion (RI) events. Runway incursions, as defined by the Office of Runway Safety[2] of the Federal Aviation Administration Aviation (FAA), are the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft, as reported by the respective air traffic control personnel.

Looking into the literature on this topic, a recent NASA study on non-towered airports[3] indicated that the number of RI events is increasing with time, with about half of the events being of low severity and the remainder being split among moderate, high, and severe RI events; among these events, intersecting runaways are noted as the highest contributing factor. A recent presentation by the Boeing Company[4] shows that flight hours, departures and the size of the worldwide fleet have generally increased, while accident rates have remained essentially flat (but at a very low level) over the last 20 years; the same presentation points to about 6% of all accidents being associated with final approach, landing, takeoff and initial climb. A recent U.S. Department of Transportation, Volpe Center[5] report shows that the spacing of parallel runways has just a small effect (if any) on the number of RI events across all severity categories; the same reports illustrates that crossing the hold short line, entering the runway and crossing a runway as the most likely types of RI events. A recent journal article[6] illustrates a dramatic increase in the number of RI reported in 2008 compared to previous years, with pilot deviations always being the largest source of these events. A recent FAA report[7] described the strong correlation among airport geometry, complexity and various communication tools (including signage and runway markings) with RI events. A Pilots Association report[8] illustrates the increase in RI events with air traffic, but with overall the RI event being less than 6 per million operations; this reports also points to major domestic airports (Chicago, Atlanta, Dallas/Fort Worth, Los Angeles, St. Louis and Philadelphia) as having the greatest number of RI events.

To that end of improving runway safety, a statistical analysis of the Runway Incursion (RI) Database[9] from the FAA Safety Information Analysis and Sharing (ASIAS) website was conducted to ascertain its relevance to the top ten challenges of AvSP. The information contained in the RI database was found to contain data that may be relevant to several of the AvSP top ten challenges[1] including: 1) the assurance of flight critical systems [i.e., airport operations], (2) the discovery of precursors to safety issues, and 3) improve crew decision-making and response in complex situations.

When combined with other data from the FAA, documenting air traffic volume from calendar years 2000 through 2011, the initial structure of a predictive model emerges that is used to forecast the frequency of RI events at various airports and under various environmental conditions.

II. Methodology

The scope of the work detailed in this paper employs two commercially–distributed software products: Microsoft Excel and Design-Expert (version 8, referred to herein as DX8) from Stat-Ease, Inc[10]. The general workflow that was employed in this study was to first to download the RI data set from the ASIAS web site. Then, the air traffic volume data set[11] was downloaded from the FAA Data & Research / Aviation Data & Statistics / Air Traffic Activity Data System (ATADS) / Airport Operations web site. These datasets were downloaded in Microsoft Excel format and this software was used to sort and extract the information of interest in addition to some statistical processing. The intent of this data pre-processing was to develop representative marginal and conditional probabilities of specific events, causes, combinations of contributing factors, and the participant types (aircraft classes, and if vehicles or pedestrians were involved) of RI events that occurred. In this context, it is not necessary that these searches and sorts be 100% accurate, but merely that they provide reasonable guidance about the relative percentages. Having prepared the data set into suitable formats, the data was then imported into DX8 for the development of response surface (RS) models via the analysis of variance (ANOVA) technique, and for additional statistical processing with the software[12].

The software choices noted above simply represent software currently available to the author, and software packages to which the author is quite familiar, but in no way represent an official federal government or NASA endorsement of these software packages. However, these software packages are known to include the desired capabilities for accomplishing the objectives of this study.

The RI database consists of 10459 records for RI events from October 1, 2001 through September 30, 2011. Obviously, only data from part of the calendar year (CY) is included in this set for 2001 and 2011. Hence, information for CY 2001 was extrapolated from the existing CY 2001 data by using a multiplicative factor of 4; likewise information for CY 2011 was extrapolated by using a multiplicative factor of 4/3. Each record includes the following fields: Event ID, Event Local Date, Event Local Time, Event State, RI Category, Airport ID, Event Location, Takeoff/Landing Runway, Aircraft 1 Type, Aircraft 2 Type, Aircraft 1 FAR category, Aircraft 2 FAR category, Weather Condition, and a Narrative Summary. RI Category, noted above, is a qualitative measure of the level of risk associated with each event. In order to enable numerical processing of this field, an assumed numerical risk value was associated with each qualitative category identifier. The categories employed within the RI database include:

- A / Collision – an actual collision between two objects occurred (Assumed Risk = 5)
- A – a collision was narrowly avoided (Assumed Risk = 4)
- B – significant potential for collision existed (Assumed Risk = 3)
- C – a RI event occurred with ample time and/or distance to avoid a collision (Assumed Risk = 2)
- D – A runway incursion with no immediate safety consequences (Assumed Risk = 1)
- Other (E, N/A, P, Assumed Risk =0)

The Aircraft-type fields identify the manufacturer and model of the primary (and secondary, if present) aircraft involved in the RI event, if applicable. The FAR Category fields classify the primary and secondary object(s) involved in the RI event, including aircraft, ground vehicles, and pedestrians, if applicable. The primary FAR aircraft categories are 121 (commercial), 135(air taxi) and 91(general aviation), but there are other categories such as MAINT (taxi of an airplane by a non-pilot / mechanic when the aircraft needs maintenance or when it needs to be moved from one parking position to another), MIL (military aircraft), PED / VEH (the secondary object was a pedestrian or ground vehicle, respectively), and other aircraft of less interest to this study, such as FAR categories 125 (business aircraft), and 129 (foreign aircraft).

The air traffic volume data set provided quantitative measures of how many landings and takeoff (grouped together) occurred by year at each of over 400 domestic airports in several categories of aircraft, including itinerant air carriers, air taxis, general aviation and military aircraft, and local civil and military aircraft. The total air traffic volume is for each airport is also provided. These datasets were used to investigate issues such as the percentage of the air traffic volume (total, or at a specific airport) that resulted in runway incursions over a given period of time, and the true, traffic–normalized risk level is associated with those RI events. Again, the intent of the various data analysis operations was to develop representative marginal and conditional probabilities of specific events, causes, combinations of contributing factors, and participant the types of RI events that occurred. The data operations need only provide reasonable guidance about the relative percentages.

III. Results

The number of RI events from the RI database was analyzed as function of calendar year (CY), Figure 1, and was found to be increasing over time in a statistically significant way. The term "statistically significant" takes on a specific meaning in this context. A "statistically significant" change is the smallest change is the response of statistical significance to a chosen confidence level, here 90%, as indicated by the Least Significant Difference (LSD) bars enclosing the linear RS predictive model. The number of RI events reported for each calendar year is shown (red dots) as a function of calendar year. A linear RS predictive model from DX8 is also shown in the figure, along with the 90% confidence interval (CI) LSD bars. Hence, the number of projected RI events for 2012 is predicted to be about 1289, but any number of RI events between about 1205 and 1372 would be "the same" (as in not distinguishable) from a statistical significance consideration. Furthermore, the number of projected RI events are increasing as function of calendar year in a statistically significant way, since the LSD bars for CY=2001 and CY=2011 do not overlap.

As discussed above, relative to Field 5 in the RI data base, an assumed risk level was associated with each of the RI events, based upon their severity category, as assigned by the FAA Office of Runway Safety. The assumed risk value sum for reported RI events from the RI database was analyzed as function of calendar year and found to be increasing as function of calendar year in a statistically significant way, as shown in Figure 2. Also, a significant increase in the assumed risk sum value occurred over the period 2007 and 2008, compared to the previous risk sum levels. This may be attributed to an RI definition change by the FAA between 2007 and 2008, described in a 2010 paper by Chapman[13]. The same reference also presents several key findings of importance to the runway safety domain, namely:

1. RI at non-towered airports are not reported in the data set analyzed
2. More RI events have been classified as lower risk in 2010 than similar events in 2002 and 2003
3. Pilots consistently rated RI events at higher severity than FAA

The first of these findings is troubling since more airports may utilize non-towered control in the future due to the potential of budget cuts. The second finding is also troubling in that it may suggest a trend toward downgrading of the severity of RI events over time. Lastly and especially troubling in that it also reflects the difference of perspective from a pilot involved real time in a crossing paths event, versus an outside observer (air traffic controller) looking down on the scene.

The air traffic volume (combined landings and takeoffs) data set from the FAA Data & Research / Aviation Data & Statistics / Air Traffic Activity Data System (ATADS) / Airport Operations web site was analyzed for several different classes of aircraft as a function of calendar year from 2000 through 2011. Despite many documents showing trends with increased numbers of passengers over time (e.g., Ref 4), there is a statistically significant decrease in the itinerant air carrier traffic volume (combined landings and takeoffs) as a function of calendar year, as shown in Figure 3. As many air travelers today would attest, planes are more likely to be at full capacity today than in previous years. Likewise, there is a statistically significant decrease in the itinerant air taxi, general traffic and military air traffic volume as a function of calendar year.

The RI database includes entries from 492 domestic airports; a unique tracking number was assigned to each individual airport to facilitate analysis and presentation. As shown in Figure 4, the number of reported RI events varies considerably from airport to airport. Nearly half (48%) of all the airports considered had 10 or fewer reported RI events. About two thirds of the airports considered had a number of reported RI events below (in a statistically significant way) the mean value (about 21) of all the airports considered. A few airports, such as INT (Winston / Salem, NC) and FWA (Fort Wayne, IN) had a number of RI events well above the mean value for all the airports considered (228 and 164, respectively).

As previously stated, the assumed average risk summation can be analyzed as a function of the airport number. This is shown in Figure 5. In this case, airports with large traffic volume, such as ORD (O'Hare, Chicago, IL) and ATL (Atlanta, GA) clearly stand out with statistically significant high average risk sums. Again, many airports are found to be below the mean value (about 17) of all airports considered. When the average risk summation is normalized by the air traffic volume associated with each airport, other smaller airports stand out with statistically significant high risk levels. This indicates that even though many RI events occur at ORD or ATL, because of the large traffic volume at these sites, a flyer's actual risk of being involved in a RI event at one of these high traffic volume airports may actually be significantly lower than the risk at other smaller volume airports.

The data previously considered and reported as RI event count by year is now analyzed as a function of risk severity category and year to determine which risk severity categories are increasing over time. As shown in Figure 6, the only risk severity categories that have exhibited a statistically significant growth over time are those for risk severity categories C and D, the purple and grey lines, respectively. There has been no statistically significant growth in the number of risk severity category RI events A (with collision), A (without collision) or B (near misses) over the time period examined. The large increase in lower severity events between 2007 and 2008 is consistent with the previously noted findings of Chapman[13].

The Weather Condition data were sorted and searched to collect marginal probabilities for the correlation of various environmental conditions with RI events. Note that several sub-items have been merged together within each of the main categories of environmental conditions (Figure 7) to account for the inconsistencies in reporting of similar weather phenomena. Adverse lighting conditions may have the greatest overall and the most consistent contribution to severe runway events. These types of conditions were cited in about 25% of all the RI events with weather conditions noted, and to 90% CI, they were cited in 22% to 28% of the RI events; this is a relatively small band of uncertainty due to statistical significance. A statistically significant correlation also exists between poor visibility and runway event risk, with more collision events (25%) citing these conditions than RI events with ample time to avoid a collision (8%). Overall, snow (and other freezing conditions) is statistically less of a potential contributor to runway events (only 2% to 9% of RI events cite these conditions) than wind, rain, visibility and lighting. An unexplained significant inverse correlation exists between lightning and runway risk events. Possibly, the pace of runway operations is greatly slowed under these circumstances due to enhanced vigilance of pilots and control personnel, leading to fewer RI events; however, this remains a topic for future investigation.

The prevalence of RI events as a function of FAR category and risk severity is now examined. As noted previously, the three FAR categories of greatest interest for this study are 121 (commercial), 135 (air taxi) and 91 (general aviation). First, approximately 53% of all the reported RI events do not involve one of these three types of aircraft, or do not have an assumed risk level greater than zero. Table 1 shows values for each of the three FAR categories, in each of the risk severity categories, as a percentage (marginal probability) of all RI events reported. As observed within the tabular data, for those RI events of interest, by far the biggest total contribution is from general aviation (FAR Category 91) aircraft, which account for about 27% of the RI events of interest. Commercial air carriers (FAR Category 121) account for almost 16% of the RI events of interest. Likewise, Category A risk severity events account for about 1% of all the RI events reported.

A number of primary causes, contributing factors and interventions to RI events were discerned from the data. This analysis involves reading the narrative summary of each event and parsing from the narrative summary a sequence of events in order to establish the root cause of the RI event. This is a very time consuming manual process that is somewhat subjective; each of the summaries were written by individual people at various places and times over the course of a decade. Although a common structure is usually employed, establishing the event sequence and root cause of each RI event requires interpretation and judgment. An automated parsing scheme for a select list of key words and phrases, implemented in Microsoft Excel, was developed and applied by the author to the approximately 5000 RI events with narratives provided and many fewer (hundreds) were actually read completely. Again, the goal was to provide reasonable guidance about the relative percentages of various kinds of events.

The primary causes are summarized in Table 2. Among all the reported RI events, by far the most prevalent cause of RI events is pilot error, which accounts for about 72% of all the RI events examined to date, with an unauthorized person or vehicle accounting for about 19% of the RI events. Among the pilot errors, two contributing factors were readily identified as major contributors: accidental use of the wrong runway or taxiway (about 25% of pilot errors), and confusion about the extent of authority granted to the pilot at a specific time by the air / ground / local traffic control personnel (about 20% of the pilot errors). Surprisingly, only about 16% of the RI events examined included some form of intervention, where a corrective or mitigative action taken. When an intervention or mitigation occurred, these actions were successful in reducing the RI event severity about 70% of the time. By far a “go-around” being issued to incoming planes was the most common form of intervention.

A second and third round of data analysis for RI events was undertaken while this paper was in the approval process. The second round examined 5020 RI events. These RI events were mostly overlapping with the original 10459 records and covered the period from 10/1/2007 through 12/5/2011, but with event narratives provided by the FAA. The data set revealed the following information:

- 37.5% involved a single aircraft
- 36.5% involved two aircraft
- 14.3% involved a single vehicle
- 6.9% involved a single aircraft and single vehicle
- 3.7% involved a pedestrian only
- 1.1% involved a single aircraft and a pedestrian

The third round investigated 4038 RI events (a subset of the 5020 RI events noted above) which could easily be grouped into four sub categories, as shown in Figure 8: 1) a baseline group with no contributing weather factor and no mitigating actions (2325 RI events), 2) a group with weather as a contributing factor with no mitigating actions (884 RI events), 3) a group with mitigating actions but no weather as a contributing factor (609 RI events), and 4) a group with both weather as a contributing factor and mitigating actions taken (220 RI events). The relative frequency of the various severity categories can be compared among these four groupings. As shown in Figure 9, and as expected, weather as a contributing factor increased the frequency of occurrence among category A through C severity RI events, relative to the baseline group. The probabilities of risk category A and B events each increased by more than 30% in the presence of weather as a contributing factor. Mitigating actions reduced the frequency of occurrence of Category A and B severity RI events (in this data set the mitigating actions actually eliminated all category A and B severity RI events), but doubled the frequency of occurrence for category C events, compared to the baseline group. The fourth group of RI events, with both weather as a contributing factor and mitigating actions taken also reduced the frequency of occurrence of Category A and B severity RI events and again doubled the frequency of occurrence for category C events, compared to the baseline group.

IV. Conclusions

The number of runway incursion (RI) events is increasing as a function of calendar year in a statistically significant way. Using an assumed quantitative (numerical) risk value that is associated with each of the qualitative risk severity levels defined by the FAA, the actual risk associated with runway incursions is also increasing as a function of calendar year in a statistically significant way. The air traffic volume (combined takeoffs and landings) for itinerant (air carrier, air taxi, general aviation and military) and local (civil and military) aircraft, and total airport operations, are decreasing as a function of calendar year in a statistically significant way. When considered together with the trends for risk events and assumed quantitative risk values, the normalized risk for RI is dramatically increasing.

Many airports have a number of reported RI events well below the mean value of all airports, but numerous airports also have significantly higher numbers of reported RI events. Similar trends are observed for average risk and traffic normalized analyses.

The only risk severity categories that have exhibited a statistically significant growth over time are those for risk severity categories C and D, with assumed risk values of 2 and 1, respectively. There has been no statistically significant growth in the number of risk severity category RI events A (with collision), A (without collision) and B (near misses) over the time period examined.

Among the environmental conditions examined, adverse lighting conditions appear to have the greatest overall, and the most consistent, contribution to RI events. A statistically significant correlation also exists between poor visibility and runway event risk, with more (percentage wise) collision / near miss events citing these conditions than RI events with ample time to avoid a collision. Overall, snow (and other freezing conditions) is statistically less of a potential contributor to runway events than wind, rain, visibility and lighting. An unexplained significant inverse correlation exists between lightning and runway risk events.

Among all the reported RI events, the most prevalent cause of RI events is pilot error. Among the pilot errors, two sources were readily identified as major contributors: 1) accidental use of the wrong runway or taxiway, and 2) confusion about the extent of authority granted to the pilot at a specific time by the air / ground / local traffic control personnel. Only about 16% of the RI events examined noted some form of corrective or mitigative action taken; when taken these actions were successful about 70% of the time and frequently resulted in a "go-around" being issued to incoming planes.

It was shown that weather as a contributing factor increased the frequency of occurrence among category A through C severity RI events, relative to the baseline group. Mitigating actions reduced the frequency of occurrence of Category A and B severity RI events but doubled the frequency of occurrence for category C events, compared to the baseline group. The combination of weather as a contributing factor and mitigating actions taken also reduced the frequency of occurrence of Category A and B severity RI events and doubled the frequency of occurrence for category C events, compared to the baseline group.

Acknowledgments

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Table 1. Correlation of FAR Aircraft Categories with RI Event Severity.

FAR\Risk	A	B	C	D	Total
121	0.33	0.20	7.73	7.50	15.76
135	0.12	0.15	1.51	2.33	4.12
91	0.56	0.48	8.78	17.21	27.03
Total	1.01	0.83	18.02	27.04	

Table 2. Primary Causes of RI Events.

Primary Cause	Marginal Percentage
Pilot Error	72.07
Unauthorized Person or Vehicle	19.1
Airport Ground Crew	6.67
Control Error	2.16

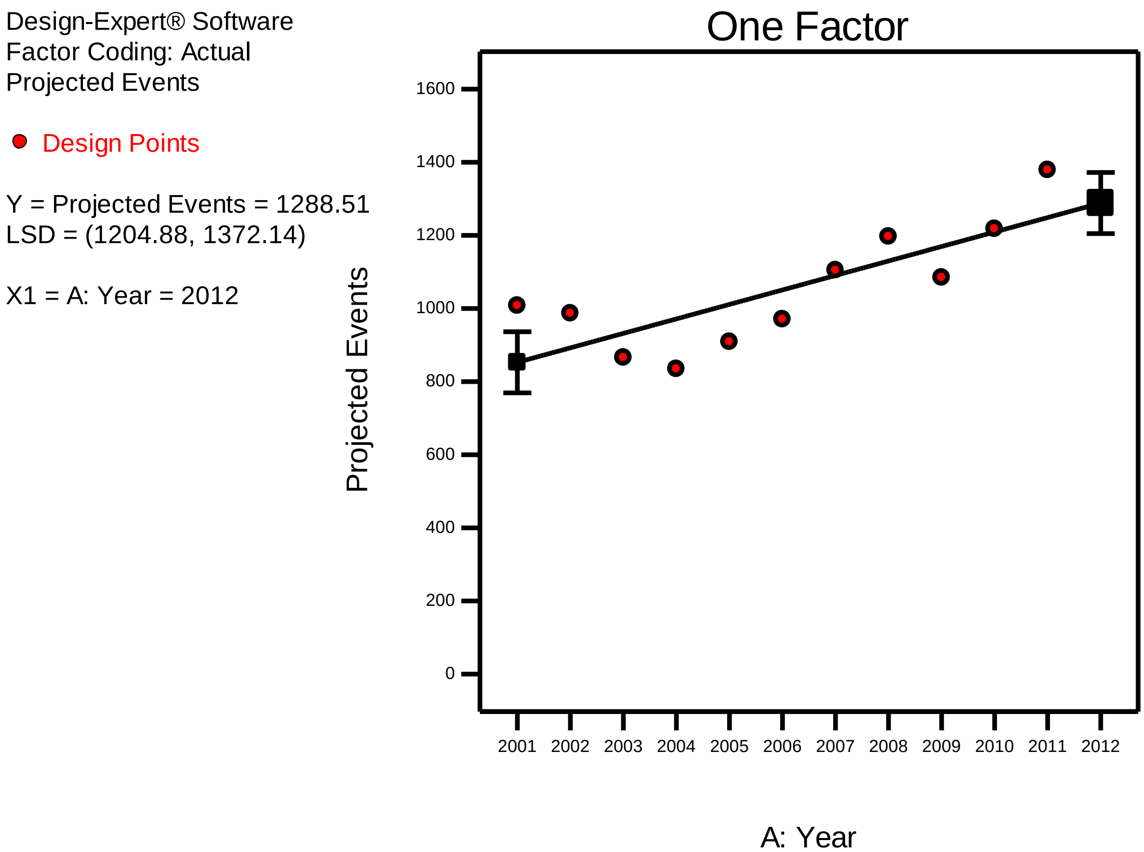

Figure 1. Projected Number of RI Events as a function of calendar year.

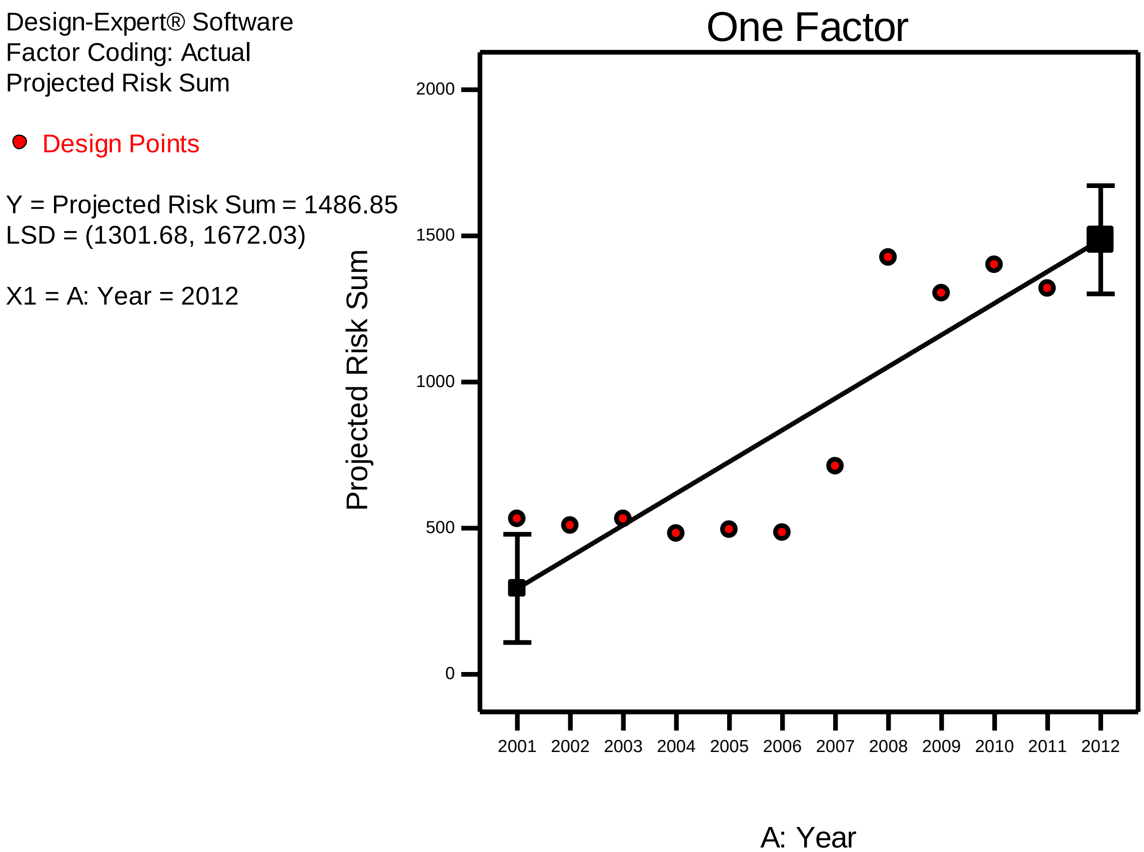

Figure 2. Projected Runway Incursion Event Assumed Risk Sum by Year

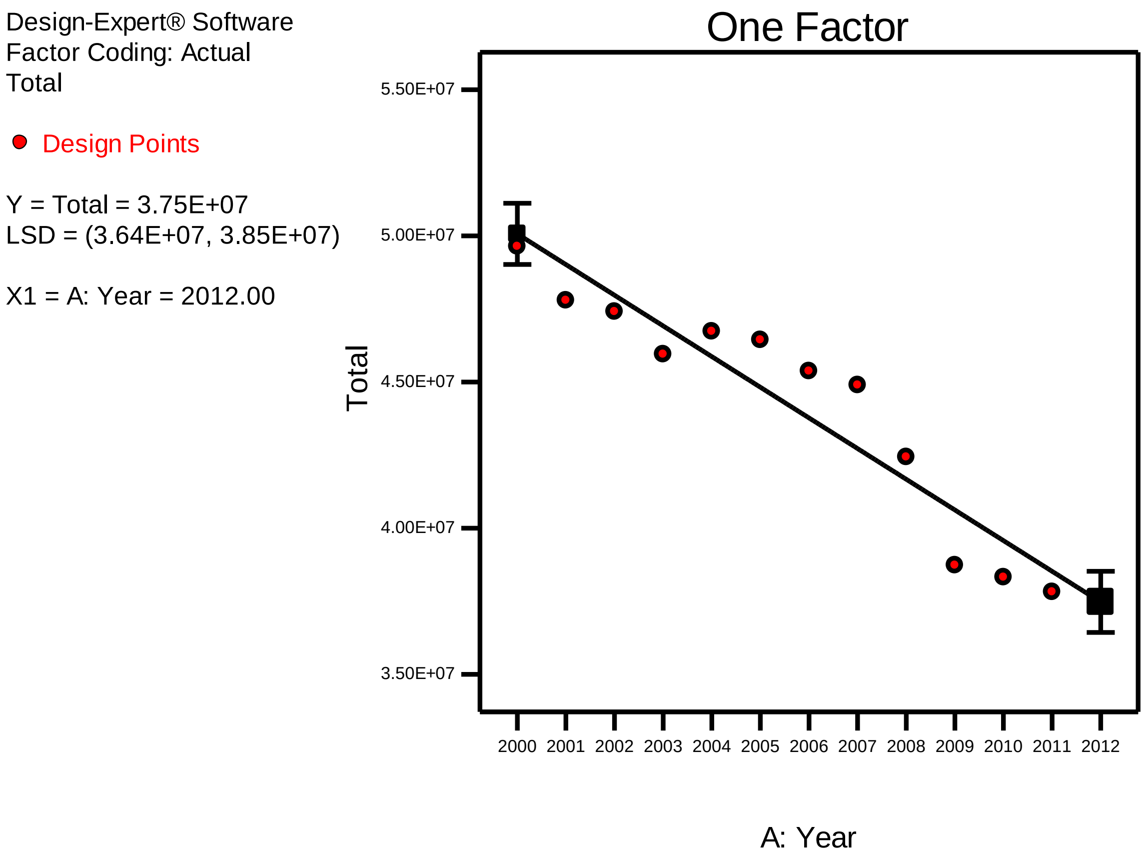

Figure 3. Total Itinerant air traffic as a function of calendar year.

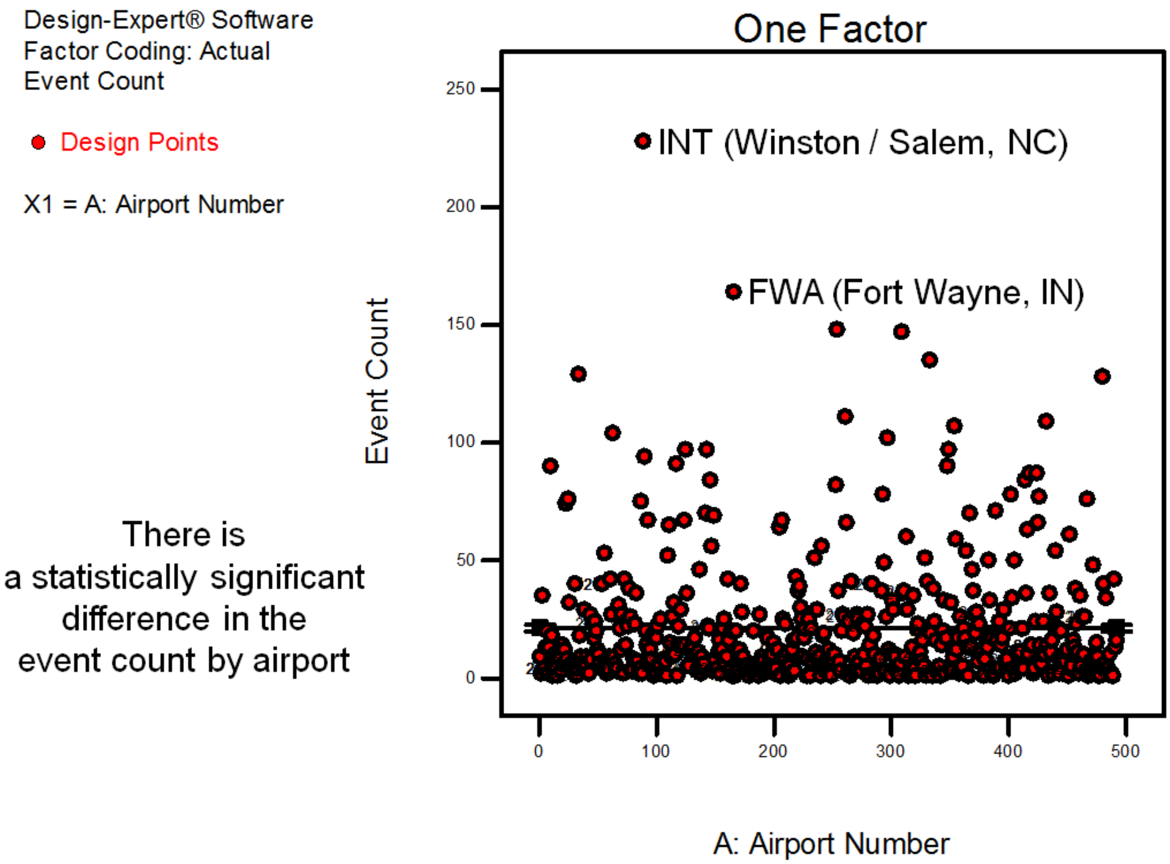

Figure 4. Reported RI Events by Airport, Mean Value RS Model.

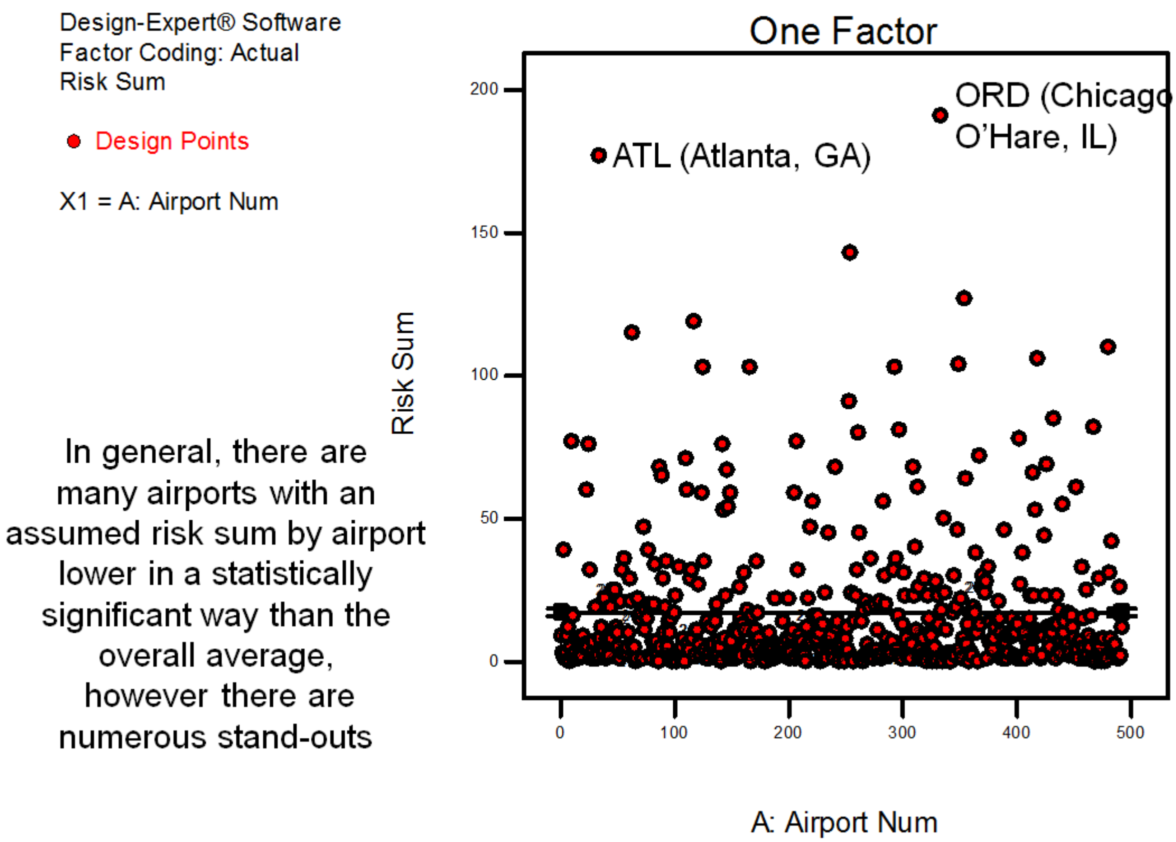

Figure 5. Average Assumed Risk by Airport, Mean Value RS Model.

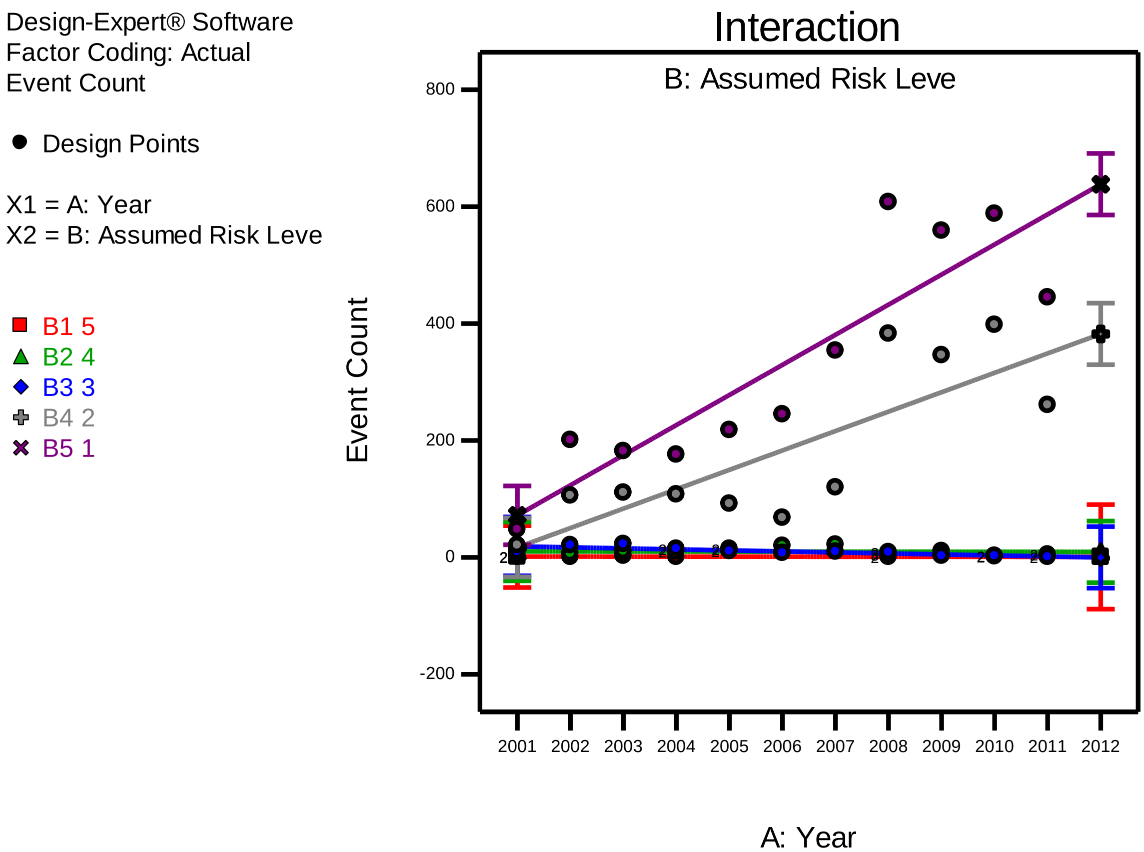

Figure 6. RI Event Count by Risk Severity Category and Year, Linear RS Models.

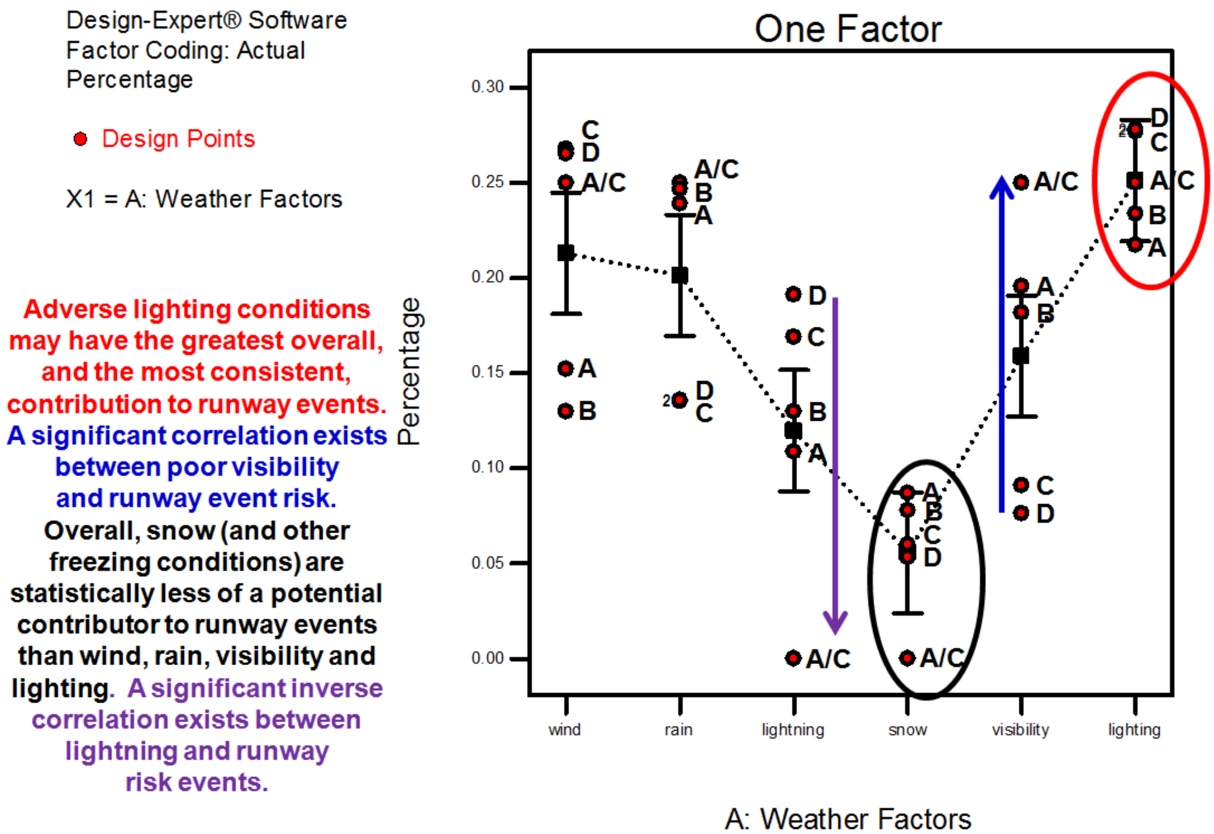

Figure 7. RI Event Correlations with Environmental Factors and Risk Severity Category.

Groups	No Cont	Yes Cont	Sum
No Mit	2325	884	3209
Yes Mit	609	220	829
Sum	2934	1104	4038

Figure 8. Data Groups for Analysis of Contributing Factors and Mitigating Actions.

FACTORS	A	A+B	A+B+C
NONE BASELINE	0.0082	0.0129	0.3247
CONT	0.0113	0.0170	0.3258
MIT	0.0000	0.0000	0.6591
CONT+MIT	0.0033	0.0099	0.6700

Figure 9. Conditional probabilities related to weather as a contributing factor and the influence of mitigating actions.