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Analysis of Delay Causality at Newark International Airport*

S. S. Allan, J. A. Beesley, J. E. Evans, S.G. Gaddy**

Lincoln Laboratory
Massachusetts Institute of Technology
Lexington, Massachusetts, U.S.A.

Determining causes of aviation delay is essential for formulating and evaluating approaches to reduce air traffic delays. An analysis was conducted of large weather-related delays at Newark International Airport (EWR), which, located in the heart of the congested northeast corridor of the United States, is an airport with a significant number of delays. Convective weather and reduced ceiling and visibility were found to be the leading contributors to large delays at EWR between September 1998 and August 2001. It was found that 41% of the cumulative arrival delay (delay relative to schedule) on days in this period averaging more than 15 minutes of delay per arrival occurred on days characterized by convective weather either within or at considerable distances from the New York terminal area. Of the remaining delays, 28% occurred on days characterized by low ceiling/visibility conditions, while 14% occurred on fair weather days with high surface winds, and 2% were caused by distant non-convective storms. Known causes other than weather accounted for 9% of the delays, and causes were unknown for 6%. When delay types (airborne, gate, taxi-out etc.) were categorized by the type of weather causing the delay, it was found that: (1) departure delays (gate + taxi-out) were much larger than arrival delays for thunderstorms in the NY terminal area and (2) taxi-out delays were the dominant type when delays were caused by distant convective weather. The fraction of total delay time explained by preplanned Ground Delay Programs (GDP) rose sharply during 2000, accounting for over 40% of total the arrival delay that year, and then decreased slightly in 2001. On days with thunderstorms in the NY TRACON, arrival and departure delays were significantly higher during the year (2000) that GDPs were used most frequently.

1. Introduction

The percentage of flights delayed at New York's Newark International airport (EWR) consistently ranks among the highest of all airports in the nation. Located in the heart of the busy northeast corridor of the United States and operating daily at or near capacity, any event at Newark that reduces capacity immediately creates delays. These delays have local impact, and they also affect flights downstream due to the ripple effect (Beatty et al., 1999). Weather affecting New York airports routinely creates serious disturbances in the traffic flow that are felt throughout the National Airspace System (NAS).

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** Mr. Gaddy is currently affiliated with Meridian Environmental Technology, Inc.

The FAA Office of Inspector General (OIG) was recently asked to examine the sources and causes of flight delays and cancellations. The OIG audit reported "while the Bureau of Transportation Statistics (BTS), the Federal Aviation Administration (FAA), and air carrier systems provide information on the quantity of delays, information on the causes of delays was found to be incomplete and inconsistent."[1] They noted that a detailed understanding of the causes of delays would be needed for formulating effective long-term solutions. This is a particularly significant observation since there are several air traffic management (ATM) decision support tools focusing on various aspects of the delay problem that are already being developed (e.g., Davis et al, 1997, Hoffman and Ball, 2000; Lee and Sanford, 1998; Smith, 1998).

Motivated in part by the OIG concerns, the study described in this paper tackled the development of a

[1] Source: Office of Inspector General Audit Report, "Air Carrier Flight Delays and Cancellations", *Federal Aviation Administration*, CR-2000-112, 25 July 2000.

methodology for analyzing delay causality. The methodology was applied to the determination of causes of delays at EWR, taking advantage of the availability of detailed information on weather phenomena during the three-year period covering September 1998 through August 2001[2]. In our study, we have made a concerted effort to address two airport delay factors that have often been ignored in many previous studies:

1. convective weather occurring well away from the airport's location, and
2. high winds occurring in otherwise fair weather.

We anticipate that the results will be of considerable interest to developers seeking to address the overall delay problem by enhancing and improving traffic management tools for the future.

The primary conclusion of our study was that weather is the dominant cause of overall delay. The different types of delay (gate delay, taxi-out delay, airborne delay, and arrival delay) are broken out to assess the contributions of the different types of weather events (i.e., terminal convection, high winds, low ceilings and visibility, and en route weather) to each. Gate and taxi-out delays at EWR, which account for a large fraction of that airport's delay, are particularly sensitive to the presence of convective weather – both within the TRACON and en route. In general, convective weather poses a more difficult problem for air traffic managers than low ceilings or high surface winds, because convection not only affects the departure and arrival frequency but also blocks flight routes in the region.

Given the ranking of convective weather in the list of probable causes of delay, the paper then examines the year-to-year changes in flight delays attributed to convective weather and discusses how those delays are related to changes in air traffic management initiatives such as Ground Delay Programs (GDP).

2. Data Sources

Data sources for this study can be classified into three broad categories: delay data, traffic management data, and weather data.

Delay Data

Delay data were drawn from the Consolidated Operations and Delay Analysis System (CODAS) and its successor system, the Aviation System Performance Metrics (ASPM). Both systems are operated by the FAA Office of Aviation Policy and Plans (FAA, 2001). CODAS covers the period 1997-2000 and was designed for analysis of archived data. ASPM supports near-real time analysis by operational personnel and covers 2000-present. One key difference is that ASPM uses data gathered by Aeronautical Radio Inc. (ARINC) while CODAS uses Airline Service Quality Performance (ASQP) data. Both also use Enhanced Traffic Management System (ETMS) and airline schedule data to round out their analysis.

Both systems report two main types of flight delay: airborne and arrival.[3] Both are given as averages in units of minutes per arrival. Over a given period, average arrival delay is always larger than average airborne delay because it includes departure delay and delay incurred on previous flight segments.

Although it is beyond the scope of this paper to discuss the detailed differences between CODAS and ASPM, a brief comparison of the two data sets for the summer of 2000 showed some significant differences. On average the magnitude of arrival and airborne delay in the CODAS data set were about 20% higher than ASPM. By contrast, gate delay[4] in CODAS was lower than ASPM. Of particular concern for the EWR study was the fact that taxi-out delay[5] was reported to be about 13% less in CODAS. CODAS deleted taxi-out time exceeding 99 minutes as erroneous outliers. Since taxi-out delays of over 99 minutes are not uncommon at the NYC metropolitan airports during periods of convective weather, underestimation in taxi-out delay resulted.

[2] The time period was chosen to take advantage of the availability of data collected at a prototype Integrated Terminal Weather System (ITWS) field site operated by MIT Lincoln Laboratory and located in Garden City, New York (http://www.ll.mit.edu/AviationWeather).

[3] Airborne delay is measured relative to the flight duration predicted at the time of takeoff. It is the actual flight duration minus the predicted flight duration. Arrival delay is measured relative to scheduled arrival time. It is the actual gate arrival time minus the most recent OAG scheduled gate arrival time and therefore includes departure delays accrued at the departure airport.

[4] Gate delay is the difference between the actual gate departure time and the scheduled gate departure time.

[5] Taxi-out delay is defined as the difference between actual taxi-out time and unimpeded taxi-out time by airport, carrier and season. The unimpeded taxi-out time is the estimated taxi-out time for an aircraft under optimal operating conditions when neither congestion, weather, nor other factors delay it during its movement from landing to gate.

Because of the differences in these data sets, one must take great care in comparing the magnitude of the 2001 delays to delays from 1998-2000.

Traffic management data

GDP data, used in the study, is drawn from both ASPM and CODAS. In addition, traffic management logs from the New York TRACON, EWR, John F Kennedy International Airport (JFK), LaGuardia International Airport (LGA), the New York En Route Center (ZNY), and the Washington En Route Center (ZDC) were used. In some cases FAA users and airline personal were interviewed for additional information.

Weather data

The primary sources of weather information were the Integrated Terminal Weather System (ITWS) (Evans and Ducot, 1994) daily operations reports from the New York ITWS prototype. These reports provide analyses of both weather and causes of delay at all the New York airports, as well as background weather information for much of the Eastern United States. In addition, surface observations and national radar mosaics from the National Climatic Data Center were used.

3. Delay Causality at EWR

Methodology

The first step in designing the study was to create a suitable database of days on which significant delays occurred. Using CODAS for the period from September 1998 through August 2000 and ASPM for the period from September 2000 through August 2001, we identified all days with average arrival delay exceeding 15 minutes for two consecutive hours. We refer to these as High Arrival Delay (HAD) days. Any hour with fewer than 10 arrivals was not considered, because one or two flights could bias the average. For each HAD day[6], we identified a primary cause of air traffic delay, based on ITWS operations reports and on other data. Since it was clear that weather (particularly local weather) was the dominant contributor to delay, the HAD days were then split into two main groups. One group included delays directly attributable to weather in New York airspace and the other group included delays attributable to causes unrelated to weather in New York airspace.

[6]Delays on days that did not meet these criteria, and therefore are not included in the study results, accounted for 18% of all arrival delay during the period of study.

The data were further assigned to one of three subcategories in the first group (thunderstorms, low ceilings and/or visibility, and high surface winds) or one of three in the second (delay due to weather elsewhere in the country, delay unrelated to weather, and delay where cause was unknown). For days for which multiple causes were identified, the following priorities applied: thunderstorms, low ceilings and/or visibility, high surface winds, weather elsewhere, unrelated to weather, and unknown.

Assessing the cause of a specific delay event is not always straightforward. Differences in the weather data provide one source of confusion. Traditionally, surface METAR weather observations are used to identify weather configurations that impact airport operations. This method works well for low ceiling and visibility conditions, but it has a number of inherent problems when the weather conditions are complex. For example, on 30 January 2001, rain and low ceilings restricted New York airport operations and standard Ground Delay programs were employed. However, a more serious problem occurred on this day in that strong vertical wind shear, with winds over 70 kts was reported at 3000 ft. As a result, LGA had significant holding delays and Miles-In-Trail (MIT) restrictions had to be expanded over a number of fixes. In this instance, looking at METAR surface data alone would have led one to an incorrect assessment of the source of the delay.

Similarly, EWR and LGA often experience delays on clear days when high surface winds force them into sub-optimal runway conditions. This is illustrated in Figure 1, which shows the operational wind threshold limits for Newark's parallel 4/22 runways. Serious capacity reductions occur when strong northwest or southeast crosswinds force the closing of this runway and the use of single runway 11/29. By comparison, JFK does not suffer as much from such problems because it has two pairs of parallel runways. Without this airport-specific piece of information, a METAR report might incorrectly imply that delays caused by high winds on a fair weather day were a result of high traffic volume or some other cause.

Understanding the effect of the location of thunderstorms on delay poses yet another challenge. In the northeast, where traffic volume is high and flight route options are limited, thunderstorms over 100 miles from an airport can have a significant impact on an airport's operation. To properly attribute convective weather as the cause of delays, one must consider convective weather within a large radius of the airport[7]. In contrast, an airport such as Orlando International (MCO) often operates without delay unless thunderstorms are very close to the airport.

The most common approach to explaining delays at an airport is based on associating them with reduced capacity during Instrument Meteorological Conditions (IMC) at that airport, when compared to capacity during Visual Meteorological Conditions (VMC). The simple IMC vs. VMC airport capacity model does not explain the actual delays because it fails to capture the causal relationship between the environment and delay. For example:

1. Convective delays arising from distant storms may be associated with IMC, VMC, or a mixture at the airport (Allan et al, 2001)
2. High winds can cause delays during both IMC and VMC conditions.

No single source of weather data was exclusively used to attribute causes to the delay. Where possible and when data was available, multiple sources were used to determine what weather type fit each delay category.

4. Contributions of Adverse Weather to Delay

Convective weather, occurring primarily during spring and summer, has the greatest impact on EWR operations on HAD days. Figure 2 summarizes the percentage of the cumulative arrival delay contributed by each weather category on HAD days from September 1998 through August 20001. Of the cumulative arrival delay, 41% occurred on days characterized by convective weather either within or at considerable distances from the New York terminal area. Of the remaining delay, 28% occurred on days characterized by low ceiling/visibility conditions, while 14% occurred on fair weather days with high surface winds, and 2% was caused by non-convective distant weather (most likely snowstorms). Other non-weather-related causes accounted for 9% of the delays. We were unable to determine causes for 6% of the cumulative delay on HAD days.

[7] The problem in using METAR data to assess convective weather impacts on terminal operations is also discussed by (Bieringer, et al., 1999). They concluded that the use of thunderstorm day climatology for an airport to estimate the frequency of terminal operations impact by convective delays will under represent the frequency of convective impacts by a factor of 2 to 2.5 depending on the type of convection.

Figure 3 shows the cumulative delay distribution of average hourly arrival delay on HAD days for four delay categories: thunderstorms in the TRACON (local convective weather), en route convective weather, ceiling and visibility, and high wind. The associated hourly delays during convective events are the most severe of any weather category. Thunderstorms tend to disrupt air travel severely because level-3 or greater thunderstorms generally have tops from 25,000 to 50,000 ft—too high for most aircraft to fly over. When thunderstorms are present in TRACON airspace, delays are almost 1.5 hours or greater for 20% of all hours that have average delay exceeding 15 minutes. Arrival delays sometimes exceed five hours in duration. Cancellations and diversions are also worse on these days than with any other weather category (not shown). In fact, delays associated with convective weather both inside and outside New York TRACON airspace account for approximately 41% of all arrival delay at EWR.

Low ceiling and poor visibility (C&V) are similar to thunderstorms in total annual impact and second in average delay per event. More than 50% of the total delay due to C&V was attributed to preplanned departure delays. This is likely caused by the long duration of many C&V events. There are other factors besides low ceiling and visibility involved in some of these cases. Many cases occurred during east coast storms, which can include heavy rain, freezing rain, snow, strong winds, and high vertical wind shear. Significant vertical wind shear was present on about 20% of C&V days. On these days, delays were generally 10 percent greater than the overall C&V average, while cancellations averaged 50 percent higher.

Average delays were 10 percent greater during severe winter weather events, but cancellations nearly doubled, due to because of the relatively long-lead time in the prediction of snowstorms. Snowplow and runway treatment operations also contribute to increased delays. Overall, however, low C&V was the leading, persistent factor contributing to delay on all days in this category.

High wind days ranked third on the list in terms of average delay per event, and constituted over 14% of delay during the period of the study. This is a category that is often overlooked when considering the relationship between adverse weather and delays. It can be difficult to predict and react to surface wind conditions, since they can be highly variable and localized in nature. As noted above, limitations in the runway configuration options for EWR and LGA often force traffic managers typically institute GDPs or expanded MIT restrictions when winds are strong and gusty from the northwest. This problem is more serious in winter when pressure gradients tend to be stronger. On some days winds are accompanied by strong vertical wind shear, which leads to higher average delays and cancellations, especially when occurring during peak demand.

More than 15% of all delay was caused by weather elsewhere in the country. It is likely that the true number may be even higher than this. When thunderstorms occur anywhere between EWR and Chicago O'Hare (ORD), arrival and departure delays of over an hour frequently result at EWR. To accurately identify the causes of delay in New York—especially during convective season—the weather across the eastern half of the United States must be examined. We often observed cases in which the New York skies were clear of weather, but empty of airplanes, because convective weather blocked routes into and out of the east.

There were a number of cases in which weather did not appear to be a factor in delays. The delay per event and the overall delay for the year were small for these cases. On some of these days, haze in New York reduced capacity slightly, even though the surface visibility was above the study threshold of 5 miles. On other days, the high delays were attributed to major equipment outages. The existence of these "no weather" delays, however, exemplifies how closely the New York airports operate to VFR capacity.

Normalizing Delays

Table 1 illustrates the significant differences across the three years included in the study--both in terms of the number of days with different weather types and in traffic management strategies in utilizing GDPs. When measuring and discussing year-to-year changes in delay, one must take into account the fact that delays are sensitive to many factors that vary considerably from year to year. We have shown that thunderstorms cause more disruption to air traffic than any other weather type. Thunderstorm delay is very sensitive to the location, intensity, day of week, and time of day of these events. It is also very sensitive to the traffic management strategies employed to cope with the storm disruption and to the capacity of the airports being affected.

Allan et al. (2001) used a simple queuing model to measure the benefits of increasing arrival capacity at LGA, EWR, and JFK during both convective weather events and days where high winds restricted arrival capacity. They showed that LGA had the biggest delay reduction because it operated at or near capacity for a much longer period of time than either EWR or JFK. It was also shown that delays are highly sensitive to the time of day affected by adverse weather, simply because the greatest delays occurred during the highest demand periods. This is true for the four weather categories described in this study: terminal convection, high winds, low ceilings and visibility, and enroute weather. Since delay is so sensitive to these variables, it will be difficult to directly measure success or failure of a delay-reducing tool by normalizing or constructing a baseline year.

5. Correlation Between Weather Type and Delay Category

ASPM and CODAS both break delay into several different categories including gate, taxi-out, airborne, taxi-in, and arrival. Taxi-in delay at EWR is usually fairly small regardless of weather type, with some rare exceptions such as airport gridlock. We therefore focused on the other four categories of delay to see if a correlation could be identified between the type of delay and the type of weather that was assigned as the dominant cause.

We looked at ASPM data from January 2000 through August 2001. Figure 4 shows average delay per arrival for four delay types as a fraction of six weather categories. If we define departure delay as the sum of gate plus taxi-out delay, it is evident that departure delays are much greater than arrival delays during both local and en route convective events. Arrival delays during convective enroute events average 16 minutes per aircraft, while departure delays average more than 34 minutes per aircraft. Taxi-out delays are high, and strongly correlated with convective situations (Allan et al, 2001). Traffic managers reported that departure delays were the biggest problem at the New York airports, with management options generally much more restricted than arrivals. These results suggest that new technology and tools for traffic planners in New York need to be focused on expediting departures.

Average airborne delay per arrival at Newark is relatively small compared to the other delays plotted in Fig. 4.[8] Airborne delay is mainly an indicator of

[8] The total airborne delay, measured over the year across all airports, is not insignificant, however, since airborne delay occurs on the many clear weather days which predominate (Welch, et.al., 2001).

airborne holding, and airborne holding delays are minimized by ground holds and GDPs.

In summary, the following broad statements apply:

1. On high wind days, delays are due primarily to ground delay programs. This is true on low ceiling and visibility days as well.
2. Convective weather causes the highest amount of delay in all delay categories. Departures are affected more than arrivals.
3. The major delay contribution at EWR during en route weather events appears to be taxi-out delay. Arrivals were delayed to a lesser extent, usually in association with the use of GDPs.

6. Comparing Delays during the Convective Seasons of 2000 and 2001

We then examined year-to-year changes in flight delays to see how they are related to the changes in air traffic management strategies. From FAA traffic management logs and from discussions with FAA personnel, we learned that GDPs instituted in response to weather conditions are sometimes too restrictive. The days with GDPs in effect were identified based on information from ASPM, facility logs, and ITWS daily reports. This raised the question; does the implementation of GDPs with convective weather actually produce a noticeable increase in flight delays? This question is addressed by comparing the average delay per flight for each of the delay categories listed above with the frequency of GDP implementation from year to year. The convective season, defined here as April through August, of 2000 and 2001 was the focus of the analysis.

Data Considerations

To remove issues arising from differences in the data between CODAS and ASPM, we limited ourselves to a single data source. We chose to use the ASPM data set because it covers the most recent time period and presently is growing, which would allow the analysis to be extended in the future. The days with GDPs in effect were identified based on information from the ITWS daily reports. This analysis focused on delays caused by local thunderstorms and convective weather elsewhere, which are the dominant contributors to delay during the spring-summer season.

Since we are averaging only over days with weather-related traffic delays, this removes a potential bias arising from the effect of year-to-year changes in the number of storms. In addition, the total number of arrivals and departures per day was about 550 during this period in both 2000 and 2001, so one should not expect the overall scheduled traffic volume to have been a significant contributor to differences in delays. The average delay per delay category per flight was computed as the sum of delay minutes for each category divided by the total number of flights that actually arrived or departed. This removes cancelled flights from the study, which is an important factor in developing an accurate picture of delay since cancellations are typically more numerous in bad weather and (if included) would tend to lower the average delay estimates. Of course, flights affected by weather will have much higher delays than the daily average, which includes many flights that occurred under better flying conditions during the same day. There is one additional potential issue that should be mentioned as part of this analysis. Changes in the seasonally averaged severity of the weather events could theoretically introduce a bias with respect to the results. When weather events are more severe, one would expect a higher probability that a GPD would be implemented, as well as longer delays. This bias would make correlation between GDP usage and delay times more positive. An initial comparison of the 2000 and 2001 convective events found no obvious differences in weather severity.

Differences between 2000 and 2001

Table 2 shows the average delay in minutes for airborne, arrival, gate and taxi-out delays during the convective seasons of 2000 and 2001, plus the percentage of days with GDPs for each season. These statistics are further broken down into two categories, depending on whether local thunderstorms or convection elsewhere was the primary cause of the delays.

For days with delays caused by thunderstorms, the frequency of GDP usage dropped by almost 40% from 2000 to 2001. Arrival delays also decreased significantly during this period. The decrease in arrival delays is consistent with the notion that having fewer GDPs allowed local traffic managers to land more aircraft. One possible negative side effect of instituting GDPs less frequently is that the greater influx of flights could lead to greater airborne holding delays. The results, however, indicate that the increase in airborne delay was minimal, only about a minute per flight. Delays in departure time (the sum of gate and taxi-out delays) also dropped by a significant margin, with reductions in gate delays accounting for the bulk of the overall decrease. The decrease in gate delays may be partially explained by the fact during periods of high delay, efforts are made to decrease aircraft turn around time at the gate to reduce down stream delay.

The results for the days with delays caused by convective weather elsewhere are qualitatively similar to local thunderstorm delays in that there were less of all types of delay except airborne delays when fewer GDPs were used. The most noticeable difference is that the use of GDPs for local thunderstorms dropped 40% between 2000 and 2001 whereas GDPs for en route storms dropped only 12%.

Why was there such a pronounced decrease in GDPs for local convective weather from 2000 to 2001? Although it is the ATC Command Center that ultimately decides whether to implement a GDP, this decision is strongly influenced by facility suggestions during conference calls held every other hour. Participants in the conference call represent the command center, major regional air traffic facilities and airlines. There was no official change in policy regarding the use of GDPs between the two years. Based on our discussions we believe the change in GDP usage seen in these statistics most likely reflects the influence of the NY TRACON, which found from experience that in many cases they were able to handle more traffic more expeditiously without a GDP.

7. Conclusions and Recommendations

Accurately attributing causes of delay has become increasingly important both to the aviation community and its users. This study has used a comprehensive approach to determine causes of delay at EWR during the period of 1998-2001. It has also investigated the correlation between the types of weather events and the resulting type of delay. Arguments were presented for rejecting the simple IMC vs. VMC airport capacity model since it fails to capture the causal relationship between the environment and delay and therefore does not explain the actual delays *at an airport*. Finally the usage of GDPs during adverse weather was calculated, noting that the percentage of arrival delay due to GDPs on days with convective weather rose sharply in 2000, but fell again during the convective season of 2001. This correlated very well with trends in both arrival and departure delay.

Further analysis and development is needed. Reducing the frequency and duration of significant delays due to weather involves improvements in the quality of weather prediction products, as well as improvements in the coordination and effort between the FAA System Command Center and various en route centers throughout much of the country.

In future, in order for traffic planning tools that are intended to reduce delay to be effective during adverse weather, they must be especially tailored to address the connection between the specific problem areas and the type of adverse weather. Knowledge of the relative weather impacts on both arrival and departure delays is critical to the success of this process – allowing developers of these tools to prioritize the way in which current and future weather products should be used to support the automation. A key finding of this study was that departure delay is a major problem during convective events both near and far from EWR, while airborne delay does not appear to be a significant problem in New York on HAD days. This finding, along with other key results, suggests that new technology and tools for traffic planners, particularly those managing highly congested airspace such as New York, needs to be focused not only on the arrival problems, but equally, if not more, on departures.

Both the use of GDPs, and the considerable year-to-year variability of weather events found in this study, suggest that these and many other variables beyond the weather characteristics (e.g. the quality and usage of multi-hour forecasts) must be considered when normalizing delays in a given year. Another critical need is the continued analysis of the operations during various types of delay events to determine how much of the delay that occurred is "avoidable" and what mixture of weather and ATM decision support is needed to eliminate the "avoidable delay". A case study of such an analysis by Allan et. al (2001) was done for a low ceiling/visibility event at EWR. This work needs to be extended to all weather types and broadened to a national scale.

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Table 1.

Number of events and GDP statistics for EWR arrivals from September 1998 through August 2001. GDP data was missing from late June to late August of 2000. The GDP results in the table for that period are extrapolated from those months where the data were available. This is not expected to change the results significantly.

Primary Delay Cause	Number of Events			Percent of delay due to GDP per category		
	1998-1999	1999-2000	2000-2001	1998-1999	1999-2000	2000-2001
Thunderstorms	36	48	41	31.0	60.7	52.9
Low Ceiling/Visibility	53	42	48	36.2	51.9	62.3
High Winds	25	44	24	24.6	46.3	51.7
Convective Weather Elsewhere	31	36	35	6.3	52.6	43.5

Table 2.

All statistics are taken from ASPM and cover the months of April through August. Delays are given in minutes per aircraft.

	Thunderstorms		Enroute Convective Weather	
	2000	*2001*	*2000*	*2001*
Number of Events	38	33	32	28
% of Events with GDP	79%	48%	44%	39%
Gate Delay	28.0	20.5	17.2	15.8
Taxi-out Delay	21.3	18.0	22.6	18.9
Airborne Delay	5.1	6.7	4.8	5.4
Gate+Taxi-out Delay	49.3	38.5	39.8	34.7
Arrival Delay	29.7	21.0	19.4	16.7

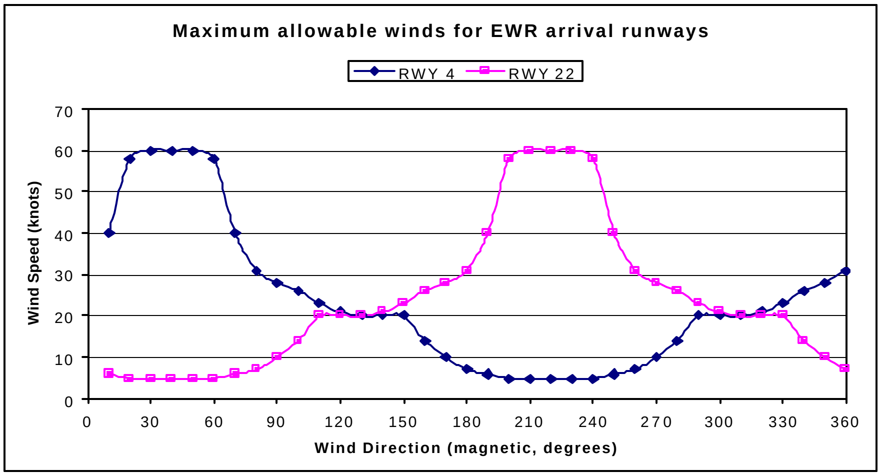

Figure 1. Operational wind thresholds for Newark runways 4/22. Winds above the shown thresholds significantly reduce capacity, and force use of the low capacity cross runway, 29. Information obtained from the ATCSCC web site (http://www.fly.faa.gov/ois).

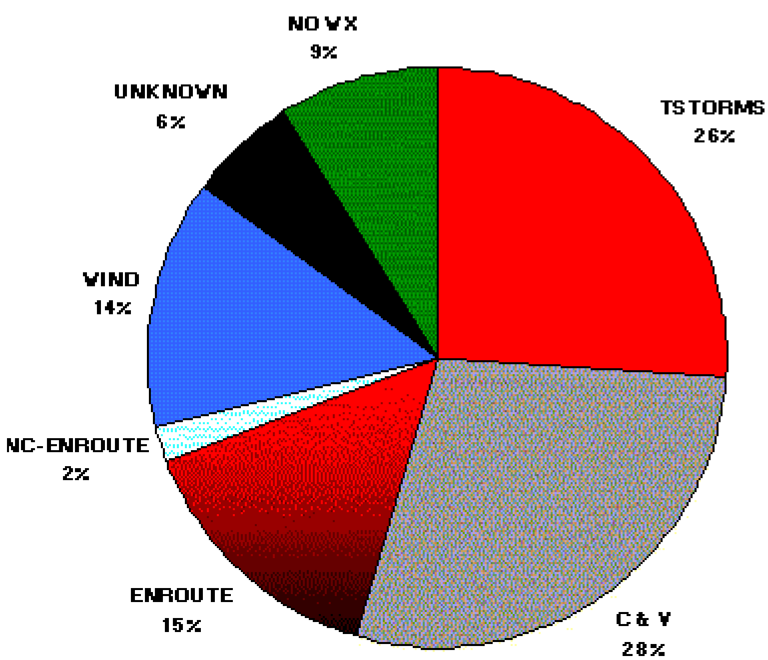

Figure 2. Percentage of arrival delay on HAD days contributed by each group defined in study. Delay from weather outside the NY TRACON is separated into convective (ENROUTE) and non-convective (NC-ENROUTE) events. Results shown are for the three-year period September 1998 through August 2001.

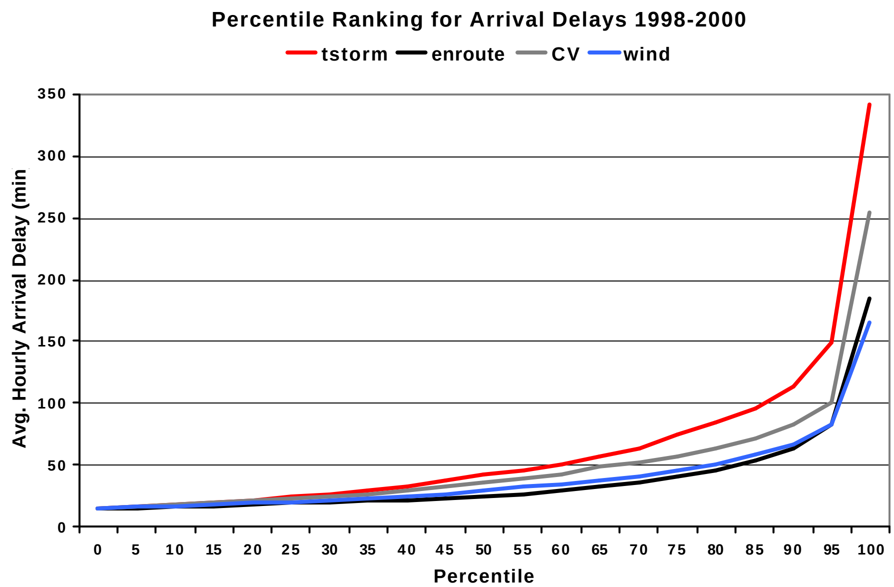

Figure 3. Percentile ranking of average hourly arrival delays (> 15 minutes) for each weather category. Arrival delays are worse during convective events than the other events defined in this study.

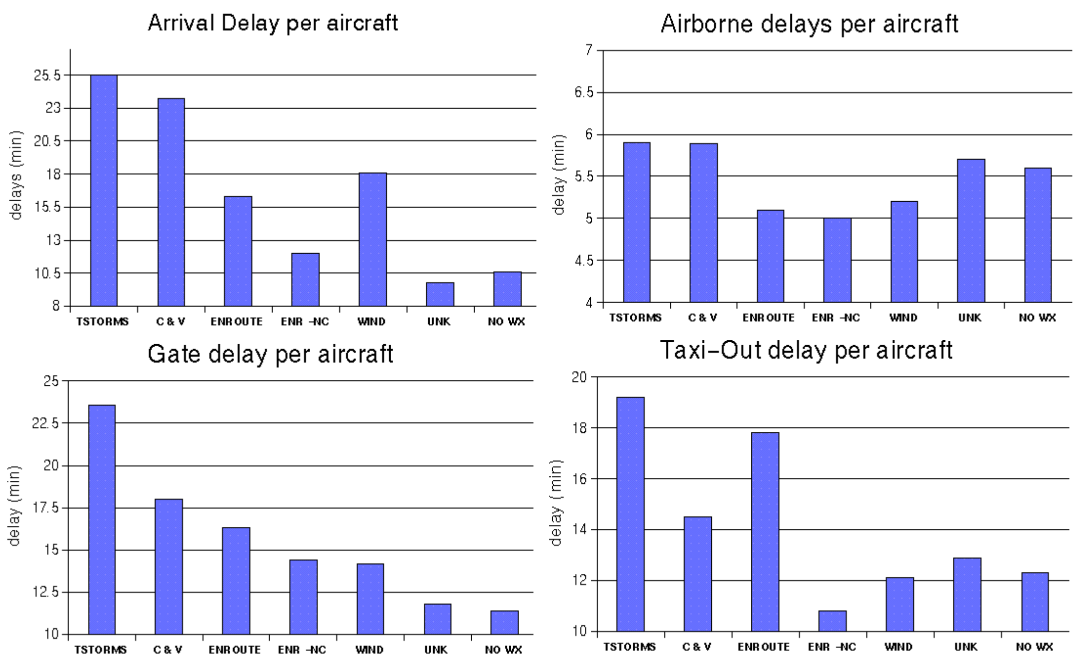

Figure 4. Delay per aircraft broken out by delay type for each weather category. The statistics are calculated for the full period of January 2000 through September 2001 and are based on the ASPM data set

Biographical Notice:

Shawn Allan received his Master's Degree in Science from the University of McGill in Montreal, Canada in 1998. He received an Honor's distinction for his thesis work on high-wind storms off the Atlantic coast of North America. Shawn currently is an Associate Staff member with MIT Lincoln Laboratory and the manager of a field site prototype Integrated Terminal Weather System (ITWS) located in Garden City, New York. He has continued working with wind fields by taking an active role in the ITWS Terminal Winds product, while also spending time researching Terminal operations in New York during adverse weather and analyzing causes of aviation delay within and around the New York TRACON.

Tony Beesley received a Ph.D. in atmospheric sciences from the University of Washington. Afterwards, he participated in field experiments on the Arctic pack ice and served as a visiting scientist at the University of Illinois and at the National Ice Center. His previous research, involving data analysis and numerical modeling, has focused on arctic meteorology and cloud physics. He has published his results in Journal of Geophysical Research, Journal of Climate, and Canadian Journal of Remote Sensing.

James Evans received all (SB, SM and PhD) his degrees in electrical engineering from the Massachusetts Institute of Technology (MIT). For the past 20 years, he has been developing new aviation weather decision support systems. This has included heading the Lincoln Laboratory programs to develop the Terminal Doppler Weather Radar (TDWR) (now at 43 major airports), the Integrated Terminal Weather System (ITWS), and the Corridor Integrated Weather System (CIWS). His current professional interests include operations research on alleviating the impacts of adverse weather on the aviation system, environmental sensing and weather prediction. He has authored over 50 publications in refereed journals, conference proceedings and book chapters.

Stephen Gaddy holds an M.S. in meteorology from the University of Oklahoma and a B.S. in meteorology from the Pennsylvania State University. He is now working in forecasting, programming, and product development for Meridian Environmental Technology, Inc., in Grand Forks, North Dakota. Meridian specializes in the development and support of weather information systems for transportation related industry.