3.21 DELAY REDUCTION AT NEWARK INTERNATIONAL AIRPORT USING TERMINAL WEATHER INFORMATION SYSTEMS *

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1. INTRODUCTION

Aircraft delays at Newark International Airport (EWR) are consistently ranked among the highest of all airports in the United States. This is partly the result of complex East coast weather systems, traffic congestion in the Northeast corridor, and the difficult geometry introduced by having four major airports within close proximity (EWR, JFK, LGA, TEB).

A key element in reducing delays at EWR is the New York Integrated Terminal Weather System (ITWS) demonstration system, introduced in the fall of 1998 as an important aviation weather support system used by air traffic, airline, and airport operations personnel to help them operate more effectively during adverse terminal weather conditions (Evans and Ducot, 1994). One of its key benefits is shared situational awareness: air traffic control supervisors and traffic managers from Washington to Boston have access to the same weather information and can use it to make informed decisions about what actions to take during adverse weather.

In the summer of 1999, the Terminal Convective Weather Forecast (TCWF) tool was added at the TRACON to supplement ITWS (it has since been installed at the NY ARTCC and the ATCSCC). It has been shown to provide accurate forecasts of up to one hour, of level 3 precipitation or greater, on many occasions since its installation (Hallowell, et al., 1999).

This paper presents a study of delay patterns and mitigation at Newark over a one-year period following the introduction of ITWS to New York. In Section 2, a profile of the impact and frequency of various weather-related delays is presented. A detailed study of one case when significant delay was mitigated is presented in Section 3, as are brief results from other cases. Finally, conclusions are presented in Section 4.

2. LEADING MODES OF WEATHER-RELATED DELAYS AT NEWARK

2.1 Definition of Weather Modes

The New York ITWS is the first to operate in the Northeast environment—an environment where many diverse types of weather lead to delays. ITWS had previously been tested in environments dominated by convective weather, with most of the research devoted towards convection-oriented algorithms. The goal of this study was to identify major delay-inducing weather types in New York and the effect this weather had on aviation traffic at EWR. The ability of traffic management in matching demand to the available capacity during these different weather types was also examined to determine how much delay could have been avoided through proper utilization of available capacity.

Other studies have examined weather contributions to delay at individual airports. Robinson (1989) examined delays at Atlanta's Hartsfield International Airport and found that the maximum delay per operation came from heavy fog, with thunderstorms ranking second and reduced visibility third. Weber, et al., (1991) examined delays at Chicago's O'Hare International Airport and found that the greatest delay per operation came from thunderstorms, with heavy fog ranking second and reduced visibility third. Although there were differences in the methods of these two studies, it is evident that different airports are subject to different weather phenomena and thus have different needs from weather information tools. An example is San Francisco International Airport, which has a high percentage of days with limited visibility due to marine stratus, while having climatologically few days with thunderstorms (Clark and Wilson, 1997).

This study examined delays at EWR over the first year of ITWS operations in New York City—September 1998 through August 1999. Using the Airline Service Quality Performance (ASQP) data set, all days with two consecutive hours of average delays exceeding 15 minutes were identified.[1] These days were further broken into four subcategories: thunderstorms, low ceilings and/or visibility (hereafter C&V), high surface winds, and none of the above. The C&V category implicitly includes all significant precipitation events at the airport, as they always result in low ceilings and visibility. Also, contrary to some studies, we do not consider low ceilings and low visibility as two separate categories. Low visibility and low ceilings both have similar effects on arriving aircraft—they directly limit airport arrival capacity due to horizontal or vertical visibility. Strong winds can also directly limit airport capacity by precluding the use of certain runways; however, winds can also reduce the ability to streamline arrival flows and control aircraft spacing, making this weather category more complex.

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[1] A limitation is that ASQP the data set only contains data for approximately 10 of the largest domestic air carriers. At EWR, this accounts for approximately 60% of all air traffic.

Weather data were taken from two sources: METAR data and ITWS site reports. First, days with any thunderstorm report were moved into one group. From the remaining, C&V days were defined as those that had either ceilings less than 3500 ft or visibility less than five miles. We further required that there be at least two hours of average arrival delay greater than or equal to 15 minutes which coincided with the low ceiling and visibility conditions defined above.

If a METAR report contained the mention of a thunderstorm, that day was listed as a thunderstorm day. However, we augmented thunderstorm days by reviewing the ITWS site reports issued daily. These reports generally report any thunderstorms occurring within the New York TRACON and sometimes just beyond its borders. This was a critical source of information, since thunderstorms 100 nm or more from EWR can significantly disrupt operations, even though a METAR would not mention the storm unless it tracked directly over the airport.

High wind day identification was more subjective. Ground delay programs (hereafter GDP) are frequently implemented at New York airports when strong, gusty west/northwest winds make it difficult to control aircraft spacing and limit capacity by forcing the airport into sub-optimal runway configurations. The primary parallel runways at EWR—runways 4 and 22—allow for maximum winds (including gusts) of 20-28 kts for wind directions between 260-340 deg (Figure 1). As a first estimate at finding days where high winds caused delays at EWR, all days were identified with at least two hours of average arrival delay greater than or equal to 15 minutes and where the only limiting weather type was sustained winds of at least 15 kts during any two of those delay hours. These were called wind days, with the primary assumption being that the high sustained winds of 15 kts or more were gusting to at least 20 kts and making it difficult to sequence aircraft properly.

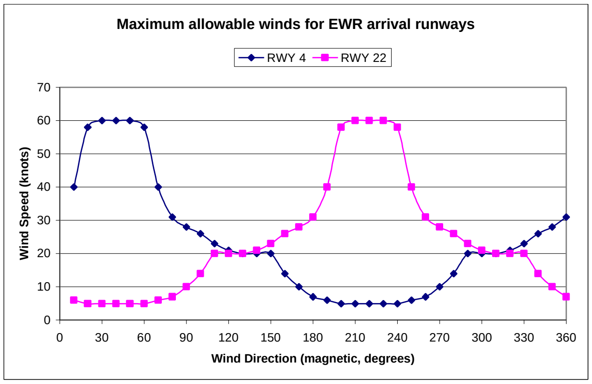

Figure 1. An illustration of reduced capacity created by strong northwest winds at EWR. Winds near or above the shown thresholds significantly reduce capacity and force use of the low capacity cross runway, 29. The problem occurs both with strong northwest and southeast winds; however, the former is by far the dominant problem at EWR. Information obtained from the ATCSCC web site (http://atcscc.faa.gov).

2.2 Weather Impacts for September 1998 through August 1999

Our findings on weather impacts during the first year of ITWS operations are listed in Table 1. Not surprisingly, thunderstorms had the greatest impact per event, although they were ranked second in total annual delay impact. A review of traffic management logs for several of these days showed that Severe Weather Avoidance Procedures (SWAP) were implemented in nearly every case. When the airports are operating at full capacity, thunderstorms can block major traffic arteries, making it necessary to plan every plane's route according to what airspace is usable at the time. ITWS has played a large role in mitigating delays during SWAPs by giving up-to-the-minute information on the evolution, characteristic, and motion of thunderstorms. Traffic management can then use this information to minimize delay.

Table 1. Summary of weather delay impacts at EWR from September 1998 through August 1999.
All delay statistics are from the ASQP data set.

Primary Weather Type	Number of Events	Delay (min * 1000)		% of total delay
		Event Average	Total	
T-storms	36	12.4	447	31.8
C&V	51	9.7	496	35.3
High Wind	27	6.9	186	13.2
None	66	4.2	278	19.7

High wind days ranked third on the list in terms of average delay per event and constituted over 13% of all delay during the year of the study. Although they were last in total annual delay, this is nevertheless a category that is often overlooked when considering what weather leads to delays. Traffic management typically institutes a GDP to manage traffic when winds are strong and gusty from the northwest, especially during the winter when pressure gradients tend to be stronger. In NYC, LGA and EWR both suffer when winds are strong during peak demand periods because of the limitations of their runway configurations.

First in total annual impact (35.3% of all delay) and a close second in average delay per event was ceiling and visibility. Like high wind days, much of this delay results from GDPs that are implemented to manage reduced capacity during IMC conditions and peak demand periods. However, there are several influencing factors besides the low ceiling and low visibility. Many of these cases occurred during east coast storms, which often featured heavy rain, freezing rain, and snow, all of which contribute their own unique difficulties to aviation. In addition, vertical wind shear is often a problem with east coast storms, although measuring its direct contribution to delay is much more problematic. A review of the site logs for the 51 C&V cases revealed that at least nine featured vertical wind shear that resulted in lower arrival rates than days with similar C&V conditions, but benign winds.

It was found that nearly 20% of all delay could not be attributed to any weather conditions. In some instances it appeared that traffic supervisors were expecting either IMC conditions or high winds to continue and instituted a ground delay program, when in fact the decreased capacity due to weather never materialized or ended abruptly. These were cases where the delay was avoidable and will be discussed further in later sections. On several days the average delay was high during very low volume hours. Thus, just a few late aircraft skew the average delay. We did not attempt to identify when delay was due to weather en route or at the point of origin of the flight, so we must state that this would have to represent some part of the "non-weather" delay category. Conversely, there was undoubtedly some delay included in the weather categories that may not have been directly related to the weather. Overall, however, we feel it is safe to say that the estimate of 20% of delay having no obvious relation to weather is a reasonable estimate.

3. AVOIDABLE DELAY AT NEWARK—BENEFIT ANALYSIS

3.1 Introduction

When addressing delay issues, it is critical to understand what amount of delay is actually avoidable and what can be done to eliminate that avoidable delay.

Perhaps the most difficult avoidable delay to address is the high wind problem. High winds tend to be a problem most often in winter when large-scale baroclinicity is greatest in the atmosphere owing to the increased latitudinal temperature gradients. Although little can be done about delays due to inability to use certain runways during high winds, controller problems in merging and sequencing aircraft to the usable runways could be mitigated by providing automation aids such as the Center-TRACON Automation System (CTAS) and high quality estimates of the 3-D winds. Model data, Doppler radar data, aircraft (MDCRS) reports, profilers, and surface sensors (ASOS) can all contribute valuable information to a wind forecast. Like the C&V problem, traffic managers usually address capacity-limiting winds by instituting GDPs. Short-term (1-3 h) predictions of high wind conditions would help reduce delay by aiding in the correct timing and duration of a GDP.

Understanding avoidable delay during thunderstorm events is very complex due to the widespread, en route nature of the problem. Since ITWS, TCWF, and other research efforts have addressed convective weather delay extensively (Evans and Ducot, 1994; Forman, et al., 1999), it will not be taken up here.

Evans (1995) suggested that a wake vortex advisory system may be a fruitful way of increasing capacity by permitting decreased spacing on landing or take-off under atmospheric conditions conducive to rapid dissipation of wake vortices. He also discussed how short-term (1-2 h) forecasts of low C&V conditions would be helpful to optimize traffic flow in cases where the flight duration of planes delayed on the ground was relatively low. The extremely busy and congested Northeast Corridor surrounding EWR is especially characterized by low-duration flights and the potential benefit of short-term C&V forecasts is significant.

Unlike SFO, EWR C&V conditions are largely driven by synoptic scale weather systems. Out of the 51 cases identified in this study, 33 were accompanied by stratiform rain of three hours duration or more. The remaining 18 cases were either rain free or featured scattered showers. Of the 33 rain events, the onset/commencement of IMC conditions coincided with the onset/commencement of precipitation in 21 instances. This suggests that the onset/commencement of precipitation may often be used as a proxy for IMC conditions. One possibility for reduction of delay under these circumstances would be to use the one-hour precipitation forecast of TCWF (Wolfson, et al., 1999) in conjunction with rapid-update satellite data to determine the onset/commencement of low C&V conditions.

3.2 12 February 1999—One Million Dollars in Avoidable Delay

3.2.1 Discussion

It has often been observed that convection rapidly decays as it moves eastward through the New York TRACON's airspace. One frequent cause of this is the influence of cool ocean water on the marine environment near the coast, which often acts to increase stability. If traffic managers know that convection to the west is dying as it moves into their airspace, they can take advantage of this to increase arrival rates accordingly. The following example is a classic case where managers were able to use ITWS effectively to great economic benefit. However, opportunities existed for substantial additional economic savings through the accurate knowledge of the onset of low C&V and the fact that a squall line had dissipated to only level 1 rain.

3.2.2 Queuing Model and Input Variables

This study utilized a queuing model (Evans et al, 1999) to estimate the amount of delay incurred by aircraft during periods when expected demand exceeded capacity. The model is run as a simple computer spreadsheet, with a multitude of derived fields. Part of the elegance of the model is that it requires only two input fields—demand and capacity. Despite this, it was able to model the actual delay very well.

To get accurate, realistic results from the model, we had to carefully construct our capacity and demand profiles to resemble reality. To produce a demand that was realistic, we took the demand profile from the five nearest, non-weather, non-delay weekdays (all cases in this study are weekday cases), added any cancellations on those days, and then averaged the five days. This profile, minus cancellations on the study day, was assumed to be the actual demand profile for a given day.

An accurate determination of capacity was more problematic. The base capacity used for this study was derived from an engineered capacity table for EWR that takes into account runway configuration, C&V conditions, and arrival/departure mix. All C&V conditions were taken from METAR reports. Runway configurations were taken from CATER—a data set that includes every flight strip from NYC metropolitan airports (EWR,JFK,LGA,TEB) and integrates all the flight strip information into a database. Arrival/Departure mix was assumed always to be near 50/50 (generally a reasonable assumption, since the other mixes applied only if arrivals or departures were over 75% of the total traffic). Actual 60-minute arrival rates, computed continuously and reported in CATER, were also culled.

On several instances, we noted that the actual arrival rate was significantly below derived capacities. It was necessary to consider instances where capacity was reduced for reasons not related to low C&V, such as a nearby thunderstorm or non-weather related issues. As a crude method to account for this, we identified where the actual arrival rate was less than or equal to 70% of expected demand and where demand was greater than 20 arrivals. If this condition was met, then the actual arrival rate was taken as the capacity (if demand was less than 15-20 arrivals, this assumption could produce VERY unrealistic capacities). If this condition was not met, then capacity was defined as the maximum of the engineered capacity or the arrival rate. This was done to take into account that EWR frequently is able to land and depart at rates that exceed engineered capacities.

Using this data, expected delay can be computed by the model. In this situation, the delay in minutes can be thought of as the minimum delay expected when demand exceeds capacity. A GDP is an attempt to incur this delay on the ground, at the originating airport, instead of in the air, holding. If the GDP is cancelled too soon, or the AAR is too high, then holding will still be the result. On the other hand, if the GDP is continued beyond the necessary time (often the case when CV events end), or the AAR is too low, then unnecessary (avoidable) delay will result. The model can be used to estimate the avoidable delay by comparing its (assumedly optimal) results with those obtained by lowering the model capacity to the actual arrival rate during the time period after the weather cleared but before the GDP was cancelled.

3.2.3 Results of Modeling 12 February 1999

Figure 2 represents the unavoidable delay (using derived capacities based on C&V conditions). The adjustment period was from 1545-2245 LT, with the start time chosen as the time the C&V conditions improved. The end time represents the time that actual arrival rates finally increased to ideal capacity. In addition, the period from 1830-1915 LT was adjusted for both runs, to represent reduced capacity during the turbulent passage of the dissipating squall line.

On 12 February 1999, a cold front tracked from west to east during the day. At EWR, the day had started out with low ceilings and visibility but improved to VFR conditions with the cold front just entering the western TRACON boundary.

During the morning, with C&V conditions still low and a strong low-level jet of nearly 50 kts, the decision was made to implement an afternoon GDP with a 34 AAR rate starting at 1300 LT at EWR. As it became increasingly apparent that the cold front featured relatively strong convection and turbulence, the decision was made to go into a SWAP at 1600 LT.

The SWAP was suspended at 2100 LT with the cold front well to the east of JFK. However, as the line entered the TRACON, it unexpectedly began to dissipate and had weakened to only a level 1-2 line when still over an hour away from impacting EWR. Frontal passage over New York was quiet, although the strong attendant wind shift led to 25 kt gains on EWR runways.

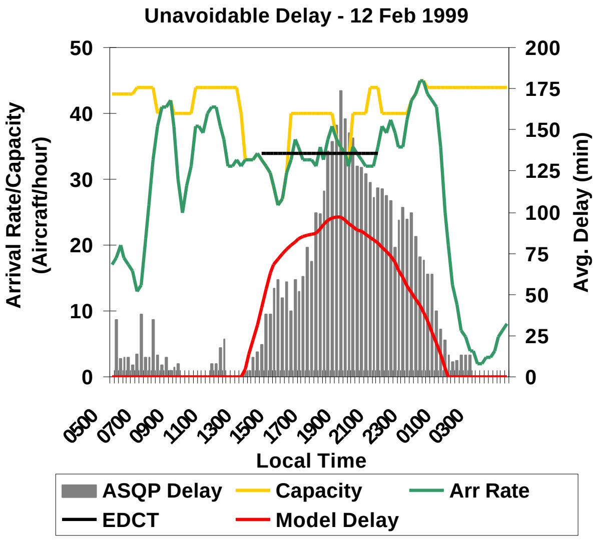

Figure 2. Delay information from the queuing model, assuming ideal engineered capacity. The period from 1830-1915 LT was adjusted to the actual arrival rate, due to a squall-line passage. ASQP delay is shown for comparison. The AAR for the EDCT program is also shown (EDCT/SWAP) for reference. Times shown are local (LT).

With the unexpected VFR conditions prior to frontal passage and the rapid dissipation of the line, there was a lengthy period between 1530 and 2245 LT where the capacity was not being met because of the SWAP and GDP. However, we assumed that traffic managers were able to match the arrival rate with capacity between 1830 and 1915 LT as the front crossed EWR. It was recognized that with the strong wind shift, gain alerts, and localized turbulence, the assumed engineered capacities would be too high.

To determine the cost of the avoidable delay, it was assumed that each hour of commercial airline delay resulted in $1000.00 of direct operating cost and $2000.00 in passenger delay cost. It was also assumed that for each hour of passenger delay there was an additional 0.8 hours of downstream delay. Using these numbers on the 12 February 2000 case, it was found that the total avoidable delay was 415.6 hours, at a cost of $1,062 063 (Table 2).

Air traffic managers were able, however, to utilize the Terminal Winds product to their advantage by landing at least three extra planes per hour after the frontal passage when there was a strong upper level jet creating significant vertical wind shear. We estimate, using the model above, that this saved them a total of 46.6 hours in delay, for a total benefit of $119,000. Although accurate statistics do not exist for use of Terminal Winds by ATC, we may assume that similar benefits were attained through ITWS for the other nine days featuring strong vertical wind shear. This yields a total of 419.4 hours of delay saved, with a realized benefit of over $1,000,000 through the use of Terminal Winds alone. We stress that this is an extremely conservative estimate since Terminal Winds is used nearly every day of the winter season by the NY TRACON and since the benefits numbers quoted by the TRACON for this event were conservative and for a very short length of time.

Table 2. Derived benefits from various ITWS case studies presented in this section.
Realized benefit occurred in cases where ITWS users cited specific examples of extra landings/takeoffs due to ITWS. Potential benefit represents cases where information from ITWS could have been used for savings, but was not.

BENEFITS OF MITIGATABLE DELAY								
PRIMARY DELAY (HOURS)		**DELAY SAVED (HOURS)**			**SAVINGS (THOUSANDS OF DOLLARS)**			
Total	Unavoid-able	Primary	Down-stream	Total	Direct Ops	Passenger		Total
						Primary	Down-stream	
Cases where benefit WAS NOT realized								
19 May 1999								
270.3	233.6	36.8	29.4	66.2	36.8	73.5	58.8	169.1
12 Feb 1999 (Precipitation event)								
757.2	526.3	230.9	184.7	415.6	230.9	461.8	369.4	1062.1
Cases where benefit WAS realized								
12 Feb 1999 (Terminal Winds benefit)								
552.2	526.3	25.9	20.7	46.6	25.9	51.7	41.4	119.0
24 May 1999 (Departure benefit)								
-	-	259.4	207.5	466.9	259.4	518.8	415.0	1193.2

3.3 Other Potential Avoidable Delay Benefits

Using the model and capacity method described above, we obtained avoidable delay statistics for a more typical day of low C&V conditions at EWR. On 19 May 1999, conditions improved to VMC earlier than forecast, and the implemented GDP lasted for 90 minutes beyond the end of IFR conditions. It was estimated that by ending the GDP at the time conditions improved to VFR, nearly $170,000 would have been saved. If this result were extrapolated to just 20 of the 51 low C&V days over the year of study, then approximately 3.5 million dollars in delay cost could have been avoided. This does not take into account how accurately GDP rates were set in relation to true airport capacity during the IFR event; just timing the end of the event.

Finally, we present an event where substantial savings from ITWS were realized. On 24 May 1999, the TRACON stated they used ITWS to depart an extra five planes per hour, per airport, for 10 straight hours. To compute savings from this, it was assumed that there was ALWAYS a departure queue. This is confirmed in CATER data, which reports the queue to slowly rise from 15 to 25 planes throughout the event, and dissipate only around midnight. If there were always a queue, then the consequence of NOT departing the extra five planes per hour would have to be an addition to the queue.

In order to compute delay saved, we assumed a baseline of no avoidable delay, then set the model up with a constant capacity of zero and a constant demand of five planes per hour. This resulted in the additional delay that would have been incurred if not for ITWS. We also assumed that after the 10-hour event, capacity rose as high as possible to flush the remaining planes out. The result was a savings of 467 hours of delay and an estimated savings of nearly 1.2 million dollars. Since the TRACON stated they were able to do this at all three airports, the presumed saving is greater than 3.5 million dollars.

4. CONCLUSIONS

The NYC ITWS commenced operations on 1 September 1998. This study examined delays at EWR during its first full year of operations to determine what benefits had been realized through use of the prototype throughout the northeast corridor. It was found that the system was a tremendous benefit during periods of active convection and through judicious use of the Terminal Winds product on days with strong vertical wind shear. It was found on one case alone that Terminal Winds resulted in nearly $120,000 of benefit, and that total benefit realized from this product in one year was likely at least one million dollars.

To determine the impact of avoidable delay at EWR, we then broke down all delay days by weather type. It was found that although convective weather yielded the most severe delays on a case-by-case basis, the overall impact of low C&V on an annual basis was greater. It was also found that strong surface winds also had a very significant negative impact on airport operations.

A case study was performed on the 12 February 1999 low C&V case to determine how much delay was avoidable and to better understand what could have been done to mitigate this delay. It was found that Air Traffic was able to use ITWS to a benefit of at least $120,000, but that the total overall avoidable delay cost was in excess of one million dollars for this one case alone. A more typical low C&V case was found to have approximately $170,000 in avoidable delay.

Finally, a specific benefit cited by the TRACON on a convective weather day was used to show a savings of over $3,500,000.

These results suggest that ITWS has already brought about substantial economic and passenger benefit. It also suggests that there is abundant room for additional benefits to be realized through the use of ITWS' initial capability. However, much more needs to be done to address research and development needs for systems that help reduce the avoidable delay of low C&V and high wind days along the east coast.

5. ACKNOWLEDGMENTS

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