

EVALUATING THE IMPACTS OF HAZE ON AIR TRAFFIC OPERATIONS

Robert S. Lee*, Chad Craun, Michael Robinson, Mark Phaneuf
AvMet Applications, Inc.

1. INTRODUCTION

Haze, a relatively complex and frequently observed weather element, can have a significant impact on the efficiency of air traffic operations at major airports throughout the National Airspace System (NAS). Visibility through a haze layer – especially at shallow angles, often reduces a normal visibility day (7-10 statute miles [SM]) to less than 3SM. Aircraft penetrating through this layer during descent or final approach may have difficulty seeing the runway or the aircraft immediately ahead resulting in the airport switching to an Instrument Landing System (ILS) approach or increasing the distance between aircraft during final descent, effectively reducing airport capacity [1]. For safety reasons, airports experiencing ILS conditions, must increase separation distances on approach from about 3SM to 4-6SM [2].

The operational impact of haze increases significantly when an airport is experiencing high demand which may result in increased delays and costs for airlines. When an airport is impacted by a haze event during a high arrival demand period, additional traffic management initiatives (TMI) such as Ground Delay Programs (GDP) or Ground Stops (GS) may be implemented to manage the needed increased spacing of aircrafts and reduced airport arrival capacity – resulting in air traffic delays. Additional impacts from haze include increased ground and airborne holding, excess fuel burn, and increased air traffic controller (ATC) workload. The typical period when haze impacts an airport is during the early morning hours through midday. Most major airports have periods of elevated arrival demand (arrival “pushes”) during the morning; this, in combination with the increased spacing needed during haze periods only magnifies the operational problems due to haze.

This study investigates haze conditions, and resultant air traffic impacts, at several major airports, including: Hartsfield-Jackson Atlanta Int. (ATL), Newark Liberty Int. (EWR), Chicago O'Hare Int. (ORD), Denver Int. (DEN), and Los

Angeles Int. (LAX). Results from this study show that haze conditions contribute to reduced airport acceptance rates (AAR) and often require TMIs to mitigate the effects of this weather constraint. Additionally, this study investigates the frequency and accuracy of haze predictions from the Terminal Aerodrome Forecast (TAF) product, as well as the correlation of these forecasts to the use of haze-related traffic management programs. Results from this study will also demonstrate the difficulties associated with forecasting haze due to limited upper air observations and lack of reliability and correlation with the surface observations. Additional implications from weather forecast requirements and weather-translation perspectives are explored in this study.

2. METEOROLOGY ANALYSIS: HAZE CLIMATOLOGY

Haze is defined by the National Oceanic and Atmospheric Administration (NOAA) as:

An aggregation in the atmosphere of very fine, widely dispersed, solid or liquid particles, or both, giving the air an opalescent appearance that subdues colors [3].

Placing NOAA's haze definition into a visual representation, Figure 2-1 gives an illustration of a non-haze day and a haze day for the same landscape. As evident in the image on the right, haze greatly reduces visibility which translates in to an impact on slant range visibility for aircrafts in final approach. Slant range visibility is the line-of-sight distance between two points that are not at the same altitude (in the case of airport operations, the end point would be the ground, runway, or a leading aircraft). The example in Figure 2-1 is a good example showing a haze induced reduction in visibility; however, from an aircraft operational perspective, the issue is primarily focused on the reduction of slant range

*Corresponding author address:

Robert S. Lee, AvMet Applications Inc.,
Reston, VA 20194
email: lee@avmet.com.

visibility and its associated impact on the airport's efficiency.



Figure 2-1: Example of non-haze (top) and haze (bottom) conditions - viewing the same landscape

With the increase in airborne particulates combined with specific (low) sun angles, the slant range visibility is often reduced even further, requiring ILS approach procedures (increased spacing between aircraft) for airport arrival traffic. ILS approaches during non-peak arrival periods may not result in an impact to operational efficiency; however, haze typically impacts an airport during the morning which coincides with many airport's heavy arrival periods. Increased spacing in-turn decreases the arrivals, increases airborne delay, and may result in TMI's.

Haze conditions are most prevalent when the atmosphere is relatively stable (e.g., no thunderstorms in the area and low wind speeds). Specifically, weather conditions supporting a haze event typically include:

- High pressure aloft (stable environment)
- Inversion near the surface (warm air trapped by cooler air aloft)

- Light winds (lack of atmospheric mixing)
- A source of pollution and/or fine particulates

Figure 2-2 illustrates some of the ideal weather conditions which supports the development and sustainment of haze. Under the conditions described above, the air surrounding the airport or city does not have the opportunity to mix with surrounding locations as it is essentially trapped by the stable air aloft and the lack of winds. The vertical profile of the atmosphere on the left side of the graph (red line) shows an illustration of the inversion – or where the temperature stops decreasing with height and starts to increase with height. When conditions improve at the surface (due to increasing surface winds or atmospheric mixing), often times the upper air inversion continues to trap the air at lower altitudes. The result of this increased mixing at the surface and trapped air near the inversion are reports of increased visibility near the surface, but continued reduced visibility aloft (haze aloft).

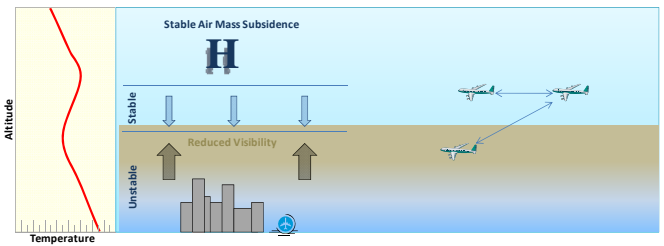


Figure 2-2: Graphic illustration of the ideal meteorological conditions which support haze events

2.1 DATA UTILIZED

For this analysis, a combination of weather, air quality, traffic, and TMI data were utilized to examine the historical occurrence of haze conditions and its impact on air traffic operations.

In this analysis AvMet utilized the following datasets for various airports throughout the NAS:

- METAR (1979-2009)
- Sounding Data (1998-2009)
- Air Quality Data (2001-2009)

- Runway Configuration Data (1998-2009)
- Airport Acceptance Rates (1998-2009)
- Aircraft Situation Display (ASDI) Data
- Aviation System Performance Metrics (ASPM)
- TMI Data
- FAA National Traffic Management Logs (NTML)

- Absence of thunderstorms or thunderstorms in the vicinity
- Absence of rain, drizzle, and snow/ice
- Absence of winds greater than 15kts

METARs were used throughout the analysis to identify surface weather observations of haze at various airports and also to aid in identifying periods when there was a reduction in arrival rates unrelated to haze. Sounding data were used to identify whether the air mass was conducive for the formation of haze (stable, with an inversion, and light winds at higher altitudes). Air quality data were also analyzed to determine if there were any correlations between the frequency of haze events, the density of particulate matter in the air, and the arrival rates for various airports. Other operationally significant data were also used to determine the extent of haze impacts on airport operations.

2.2 DEFINING A DATA DRIVEN HAZE EVENT

A key component of identifying the impacts of haze on operations is to isolate periods when haze was the primary factor which lead to a decrease in airport arrival efficiency. Often times, when a weather event occurs, there are multiple weather phenomena simultaneously impacting a location. Identifying the primary weather phenomenon responsible for the reduction in airport operational efficiency (in this case haze) is a critical factor in this study. In order to accomplish this task, a number of filters and qualifiers were used to categorize these periods to isolate surface haze events. During hours when haze was recorded as an observation in the METAR report, the following filters were applied in order to isolate periods when haze was the dominant weather phenomenon:

- Absence of low ceilings (overcast/broken clouds greater than 12,000ft)
- Absence of fog

If the definition of a haze event were strictly confined to surface weather observations, then a large pool of observations would be missing since haze (and its air traffic impact) is not restricted to the surface. While METARs frequently record haze as a present weather phenomenon, there were many periods when haze was not recorded by the METAR, but either a supplemental observation of haze by a certified weather observer through the National Weather Service (NWS) or other data sources led to the determination that haze was the primary reason for a decrease in airport operational efficiency (e.g., Pilot reports, NTML entry, etc.).

The evaluation of haze vs. no haze observations at the surface (but haze still present aloft) is an important area of focus in this study. As stated above, weather observation data at the surface for haze are readily available; however, there are no sources of data for identifying when haze is observed above the surface. To confront this data limitation, periods were identified when there is an observed haze recording at the surface AND an inversion observed in sounding data from the upper air station located closest to airport/city under investigation. While this is not an exact measurement for upper air haze events, this study will present operational data which supports that while the surface haze event ended, the haze aloft phenomena likely continued and thus, forced or prolonged an operational impact. When evaluating haze events for ATL, specific criteria were defined to support investigations of both surface haze and potential haze aloft. The upper air haze observations used in this evaluation was the sounding data from the Peachtree, Georgia station (the closest sounding data location to ATL). Specifically, when there was a surface haze event recorded in the ATL METAR report and the 1200Z upper-air sounding data from Peachtree, GA (closest sounding location to

ATL) indicated a surface inversion equal to or greater than 2°C, then the event was flagged as a potential surface and upper air haze event. The 2°C temperature threshold is considered to be indicative of a strong inversion; however, for completeness, other temperature thresholds around 2°C were also evaluated. Additionally, a relative humidity (RH) criterion (RH > 75%) was also used in conjunction with the 1200Z surface inversion criterion to extend our search for haze aloft events not coincident with surface haze reports. The RH > 75% parameter was selected as a first guess significant threshold used to identify an additional standalone criteria for surface and upper air haze events, however, this could be altered in future studies.

Additional data sources, such as the NTML, also supported this methodology. Therefore, when evaluating the data for this analysis, observations from the surface as well as sounding data were coupled with various airport operational data and used to aid in identifying cases when:

- Haze is observed at the surface, with or without an atmospheric inversion
- Haze was previously recorded at the surface, haze is no longer reported at the surface, but an inversion is present
- There were no observations of haze or significant weather at the surface and an inversion is present

The purpose this categorization serves is to identify the times when haze may be impacting the operations, yet the surface observations no longer observe the presence of haze (i.e., the haze has transitioned from a surface event to an upper air event, or is only a “haze aloft” event).

3. ATLANTA ARRIVAL RATE ANALYSIS

3.1 ATL HAZE EVENTS

In this study, ATL airport is the primary airport for identifying haze related airport operational impacts. This is primarily due to past reports of haze-related air traffic constraints and previously identified operational impacts [1]. ATL airport is

well suited to study the operational impacts related to haze because:

- ATL experiences many hazy days throughout the year
- ATL is a high demand airport, operating near capacity, and thus, can be sensitive to even minimal capacity constraints
- ATL has a high demand period for airport arrivals around sunrise during the summer months – a time of day where haze-reduced visibility may be exacerbated by the low sun angle

Another potential factor that may contribute to impacted airport operations due to haze is the runway configuration of ATL. The east/west runway configuration at ATL may also be significant, given the direction in which the aircraft lands and the decreased slant range visibility from the sun refraction off of the haze during the final approach in to ATL. Further decreased slant-range visibility resulting from the combination of haze, low sun-angle, and landing direction (i.e., “into the sun”) may necessitate a prolonged or early onset ILS approach procedure. It should be noted, however, that an east/west runway configuration is not necessarily needed for haze to impact the slant range visibility; aircraft turning into the sun during final approach on haze impact days may experience similar issues.* In addition to the focused analysis of ATL haze impacts, this study also investigates the impacts, traffic management responses, and haze forecast capabilities at other airports in the NAS (see Section 4).

Preliminary analysis of haze observations in ATL by time of year and time of day indicates the clear predominance of haze during the early hours of the summer months (Figure 3-1). Climatologically, this seasonal trend is expected, as there is typically a well-established high

*An example would be Charlotte airport (CLT), which has a predominant north-south runway configuration, but haze-reduced visibility can still impact landing operations as aircraft turn into the sun – and experience significant haze-related visibility degradation – during final approach (ZTL CWSU Meteorologist-In-Charge, personal communication).

pressure system in the southeast U.S. during the summer months. Haze is more prominent in the morning hours for most locations due to the prevalence of stronger inversions that are typically established in the morning hours. The strong inversion coupled with the high pressure, lighter winds, and trapped airborne pollutants/particles as a result of the inversion, make this an ideal set-up for surface and upper air haze events. It should be noted that the morning peak for observed haze at ATL is significant because it coincides with a peak demand period for ATL arrival traffic, when the arrival “push” most closely approaches available capacity (Figure 3-2 – see 8AM local time [LT] arrival traffic peak).

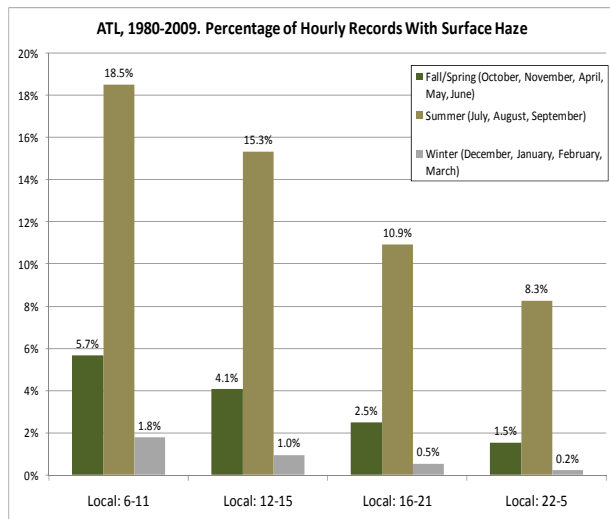


Figure 3-1: Frequency of ATL haze observations by time of day and by season

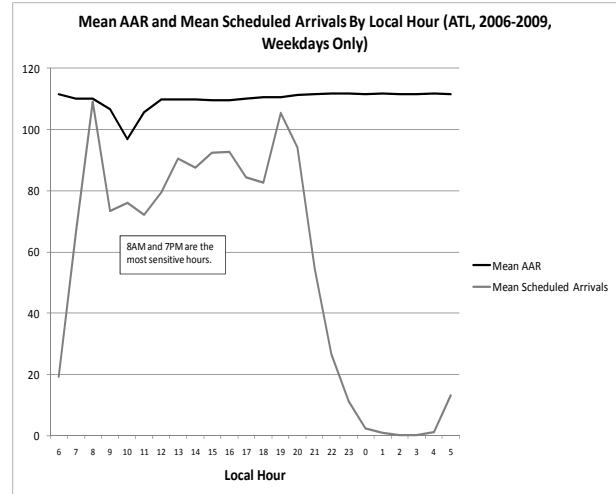


Figure 3-2: Mean ATL airport arrival acceptance rate (AAR) and scheduled arrival demand, by hour, during weekdays

3.2 ATL AIRPORT ACCEPTANCE RATE ANALYSIS DURING HAZE EVENTS

As depicted in Figure 3-3, when the haze event criteria were met, the median airport acceptance rate at ATL decreased by 11 and 10 arrivals per hour during the morning and evening hours, respectively. In this analysis, all periods when other potential weather constraints were present (see Section 2.3) were excluded, in an attempt to isolate “haze only” impacts on ATL acceptance rates. The results in Figure 3-3 demonstrate how haze can reduce an airport’s operational efficiency; however, additional analysis into the exact timing, strength, and extent of the NAS operational response to haze-related capacity reductions (e.g., TMIs) was also completed (see Section 4).

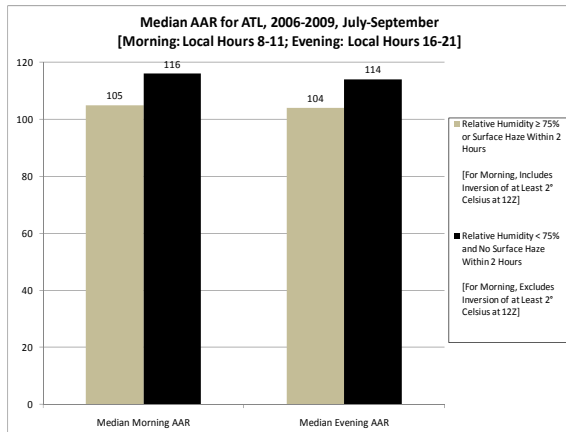


Figure 3-3: ATL airport acceptance rate (AAR) during morning and evening haze and non-haze events. Subset of morning/evening hours included in analysis coincide with periods of peak arrival demand.

3.3 ATL AIRPORT ACCEPTANCE RATE ANALYSIS DURING POOR AIR QUALITY PERIODS

As noted in the introduction, haze is primarily caused by particles in the atmosphere which scatter the sunlight. Therefore, it was suspected that a correlation may exist between decreased airport arrival efficiency due to reduced visibility and increased spacing on final approach and increased airborne particulate matter or ozone on days with poor air quality (pollutants). The Ambient Monitoring Program (AMP) managed by the Georgia Department of Natural Resources, Environmental Protection Division, Air Protection Branch measures levels of air pollutants throughout Georgia to determine compliance with air quality standards [5]. An analysis of ATL AAR during peak morning and evening arrival demand periods on poor air quality days (when the particulate matter was greater than $20\mu\text{g}/\text{m}^3$ or the ozone was greater than 0.06 ppmv) is presented in Figure 3-4. Results show that the arrival rate differences are minimal for the 34 days with high particulate matter days and the 57 high ozone days that were analyzed – compared with days with good air quality and lower measurements of airborne

particulate matter.* The primary focus for this analysis was on the arrival rate deficits; however it should be noted that additional analysis outside of arrival rate deficits is needed to better identify whether there is or is no correlation to particulate matter or poor air quality days and the impacts on aviation operations.

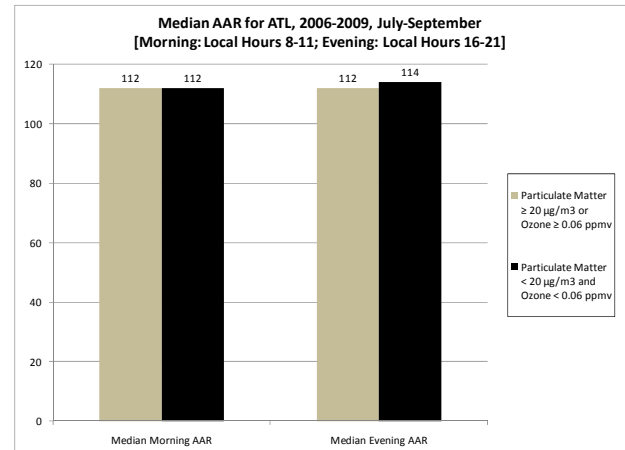


Figure 3-4: Atlanta poor air quality day AAR analysis due to particulate matter or ozone

4. HAZE EVENTS AND TRAFFIC MANAGEMENT INITIATIVES

The results of the ATL AAR analysis with and without haze conditions in the previous Section suggest that operational impacts, though not trivial, may be manageable and perhaps are not “extreme” (resulting, for example, in mass cancellations, lengthy delays, diversions, etc.). However, additional insight into the TMIs and traffic management actions completed during haze and non-haze events showed that the operational impact of haze conditions can indeed be significant. Moreover, the haze-TMI analysis effectively highlights the complexities associated with analyzing haze events. This Section discusses the TMIs used to mitigate haze impacts and explores complications associated with “mis-categorized” reasons for TMI implementation.

*As with previous analyses, this investigation included no periods with other weather constraints present at the airport (e.g., storms, low ceilings, etc.)

4.1 HISTORICAL ANALYSIS OF TMIS RESULTS

The simplest method for analyzing the frequency of haze-related TMIs is to complete a strict search for “haze” or “hz” in the TMI’s reasoning, remarks, or comments that included with the advisory. In this analysis, we conducted this search for all Ground Delay Programs (GDP) and Ground Stops (GS) issued for candidate airports throughout the NAS from 2001-2010. Results in Figure 4-1 show that the frequency airport GS programs identified in the advisory to be attributed to haze is very infrequent - less than 10 times per year for all airports included in this study. Even with the significant number of haze observations in ATL, the number of ATL GSs with “haze” or “hz” specifically cited in the advisory as the reason for the initiative is less than 5 per year on average. Other locations such as LAX, which is well known for poor air quality and hazy (smog) conditions, has a low number of GS programs initiated due to haze (further analysis of both LAX and EWR haze impacts is presented in Section 6).

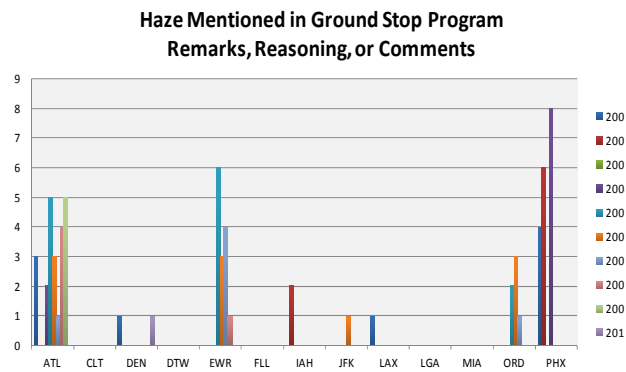


Figure 4-1: Frequency of Ground Stops, where the reason for the initiative is noted in the advisory to be related specifically to haze (2001-2010)

When evaluating the reasons for implementing airport GDPs, searching for specific mention of haze in the advisory, the results proved to be

* Airports included in Figure 4-1 but not defined include: Charlotte Douglas (CLT); Detroit Metro (DTW); Fort Lauderdale-Hollywood Int. (FLL); Houston Intercontinental (IAH); John F. Kennedy Int. (JFK); LaGuardia (LGA); Miami Int. (MIA); and Phoenix Sky Harbor Int. (PHX)

similar to the GS analysis (Figure 4-2). ATL has a relatively low number of GDP initiated due to haze; however, additional analysis is needed rather than a word search for haze or “hz” in the GDP sections. For example, a thorough read of NTML logs for periods when haze may be suspected is one such approach, although this would prove to be extremely time consuming. It should also be noted that while the frequency of the programs explicitly mentioning haze in the remarks, reasoning, or comments section was infrequent, the impact of the GDP or GS was itself significant. For example, the average delay due to the haze induced GDP was on average 60 minutes for EWR and 45 minutes for ATL.

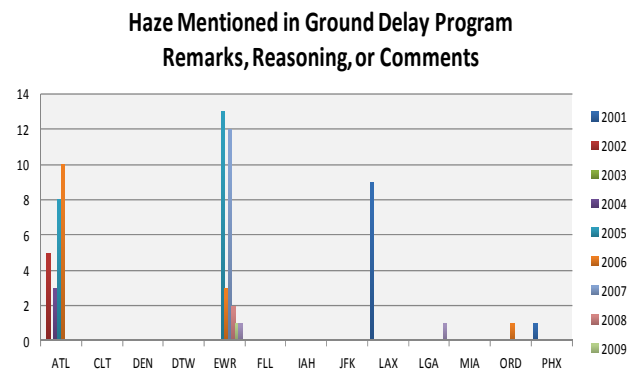


Figure 4-2: Frequency of “haze” or “hz” mentioned in GDPs (2001-2009)

4.2 “MIS-CATEGORIZED” TMIS

With the infrequency of haze being explicitly mentioned in the TMI advisories, additional analysis into the meteorological phenomena associated with haze and its relationship to air traffic management was required. Haze is a relatively difficult phenomenon to document without human intervention, for example, visibility inside the reporting range of a METAR may be good; however, an aircraft heading into final approach may be encountering haze aloft and thus need to change their operations to IFR due to the reduced visibility. Therefore, since the METAR does not state that haze as a surface observation; yet airplanes are being forced into an IFR approach, the reasoning stated in the TMI advisory may be “low visibility” or “weather” rather than “haze.” It was theorized that the

limitations of the METAR or the lack of human supplemented surface observations which may in-turn result in haze being mis-categorized as "low visibility" or "low ceiling" in the TMI. Categorizing haze as "low visibility" is logical because haze does reduce the visibility, but the reason for the low visibility is the haze. Oftentimes, haze occurs above the surface report making ASOS observation difficult to rely upon for haze aloft occurrences and categorization. Additionally, there were frequent cases where haze is mentioned in the NTML, but not mentioned in the remarks, reasoning, or comments sections of the TMI advisory. Other cases included haze being reported in the METAR, with visibility greater than 6SM, but the reason for increasing Miles-In-Trail (MIT) restrictions is cited as "low visibility." For example, on July 10, 2009, visibility at ATL was 6SM or greater the entire day, with haze being recorded in the METAR report at 1250 UTC; however, the reasoning for the 20 MIT issued at 1000 UTC (when visibility was 8SM) - for the 1130-1330Z UTC period - was "Low Visibility."

Due to the complexity surrounding the isolation of haze occurrences and the infrequency of haze being explicitly mentioned in the TMIs, a categorical system was established to identify candidate haze TMIs that were potentially mis-categorized as being related to other weather phenomena such as low visibility, low ceilings, or the general "weather" category. The assumption for this evaluation was that the provided reason for the TMI was incorrect, insufficient, or misleading when investigated against the actual airport weather conditions or when compared to more detailed impact descriptions included in NTML entries. For these reasons, we evaluated and categorized all TMIs and METAR observations by isolating potential haze-related TMIs when a TMI may have been mis-categorized as related to "low visibility" or "low ceiling" using the following categories/criteria:

- **Not haze:** Low ceiling or low visibility observed at the airport for two consecutive records AND no two consecutive records of surface haze. In this case, the reasoning for

the TMI was likely categorized correctly because the METAR report supports the low ceiling and/or low visibility categorization.

- **Possibly haze:** Surface haze observed at the airport for two consecutive records AND either low ceiling or low visibility for two consecutive records. In this case, haze is observed at the surface which was the result of the low ceiling or low visibility at the airport or haze (surface or aloft) was the motivation for the TMI but the reasoning in the TMI advisory was listed as low ceiling or low visibility.
- **Possibly haze:** No two consecutive records of surface haze, low ceiling, or low visibility reported at the airport. In this case, there were no recordings of haze, low ceiling, or low visibility yet the TMI was recorded as low ceiling or low visibility. The possible reason for the TMI could be due to haze aloft, but it was not recorded as such in the TMI.
- **Likely haze:** Surface haze observed at the airport for two consecutive records AND no two consecutive records of low ceiling or low visibility. In these cases, surface haze was recorded in the METAR report and there were no consecutive recordings of low ceiling or low visibility yet the TMI was again categorized as low ceiling or low visibility. It is likely in these cases that the reason for the TMI was haze.

Once the ten year analysis (2001-2010) of mis-categorized TMIs was completed, the results were then pooled for a select number of airports which had significant findings. For this analysis, the thresholds for low ceiling and low visibility varied per airport and were generally around 2,000ft for low ceiling and 3SM for low visibility. The thresholds for determining "low" visibility and ceiling were selected based on the impact to slant range visibility and threshold parameters for IFR conditions. It should be noted that these parameters need additional study and can be adjusted to identify additional potentially mis-categorized TMIs.

Altogether, the haze mis-categorization analysis suggests that the total annual average of likely or certain haze-related GDPs and GSS at five key airports during 2001-2009 was 50 per year.

Moreover, when considering additional GDPs or GSs issued when the issue was “possibly haze”, the annual usage of these programs to manage haze impacts may be as high as 263 per year for the five key airports included in this analysis. The methodologies leading to Figure 4-3 are conservative because many of the “possible” or “not” haze TMI’s may convert to likely haze events if additional investigation and analysis on the ceiling/visibility thresholds used in this analysis is completed or if NTML/other logs are more closely scrutinized for comments related to haze impacts. In addition to the threshold analysis or log reviewing, the analysis completed earlier focused on the surface instances of haze due to algorithms which could be applied to the data available; however, additional analysis on surface inversions could also be completed which would aid in better determining the number of traffic management programs issued due to surface haze and haze aloft. This analysis also focused on consecutive records of haze; however, our case study analyses showed that there is no correlation between the number of surface haze instances and TMI’s required to manage haze impacts (see Section 5).

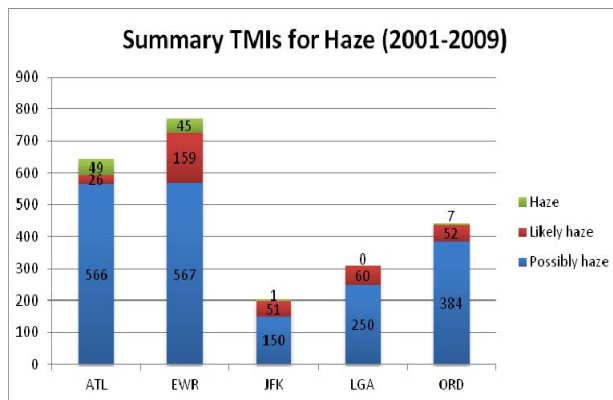


Figure 4-3: Comprehensive candidate pool of haze-related GDPs and GSs, at five airports, from 2001-2009

5. ATL HAZE IMPACT CASE STUDY ANALYSIS

It is evident from results presented in earlier Sections that multiple factors are present and

must be considered when investigating haze impacts on air traffic operations. To better understand these factors, and to expand our analysis of the impacts and operational responses to haze, a detailed weather, traffic, and ATM case study analysis was conducted for ATL arrival operations with and without haze conditions.

Figure 5-1 shows the arrival rate deficit for ATL during an extended period of METAR-reported haze on June 27, 2009. Similar to the previous analysis, the AAR deficits as a result of haze give the impression that haze has a minimal impact on Atlanta arrivals. An arrival deficit of -1, -2, and -2 during the 6-8am hours suggests a minimal operational impact related to haze-reduced visibility.

Airport	Local Hour	GMT Hour	Scheduled Arrivals	Actual Arrivals	Actual Minus Sched
ATL	0	4	2	3	1
ATL	1	5	1	1	0
ATL	2	6	0	0	0
ATL	3	7	0	0	0
ATL	4	8	2	1	-1
ATL	5	9	11	13	2
ATL	6	10	20	19	-1
ATL	7	11	78	76	-2
ATL	8	12	121	119	-2
ATL	9	13	50	51	1
ATL	10	14	66	66	0
ATL	11	15	72	75	3
ATL	12	16	81	83	2
ATL	13	17	92	90	-2
ATL	14	18	80	82	2
ATL	15	19	87	87	0
ATL	16	20	85	88	3
ATL	17	21	89	87	-2
ATL	18	22	79	78	-1
ATL	19	23	87	84	-3
ATL	20	0	72	73	1
ATL	21	1	42	42	0
ATL	22	2	25	25	0
ATL	23	3	8	10	2

Figure 5-1 : ATL hourly arrival rate deficit during haze event (yellow indicates haze recorded at the airport – METAR observation), June 27, 2009

Further analysis into this event reveals that significant MIT restrictions were required for ATL arrival traffic, and these restrictions extended to waypoints well beyond final approach paths into the airport. Several NTML entries indicated that

haze was the primary reason for these ATL restrictions (and subsequent arrival delays). For example, an NTML entry during this event stated:

ATL WAS WEST OPS--ILS APCHS--
104 AAR DUE TO HAZE. VOLUME
MANAGED WITH MIT, HOLDING AND
A ZJX GROUND STOP 1130-1220Z.

ATL MIT restrictions on 27 June ranged from 20-25 MIT for different arrival fixes – and this type of TMI response to haze and the subsequent arrival capacity reduction was evident in many days investigated for ATL. Findings from this haze event show that analyzing solely airport AAR deficits or GDP/GS program execution does not completely capture the extent of operational issues that may be experienced due to the haze.

Inspection of ATL arrival flight tracks on 27 June 2009 reveals the true extent of the operational impact of increased spacing (decreased capacity) required because of haze (Figure 5-2). At 1200 UTC, approach visibility in haze conditions decreases sharply as the sun rises, requiring increased spacing between flights in the ATL arrival flows. To manage this, pilots and ATC began flying “S-curves” (“boxed” flights in Figure 5-2) to meet the increased spacing requirements while still continuing en route to the airport. Within 10 min however, demand exceeds capacity and S-curve trajectories no longer suffice, forcing ATL arrival traffic to hold in three separate holding stacks. By 1215 UTC, 18 arrival aircraft are holding in the three holding stacks within the northeast arrival flow to ATL. Finally, at 1225 GMT, ATL arrival aircraft remain in holding (four holding stacks now containing 20 flights) and ATL arrival delays are being reported.

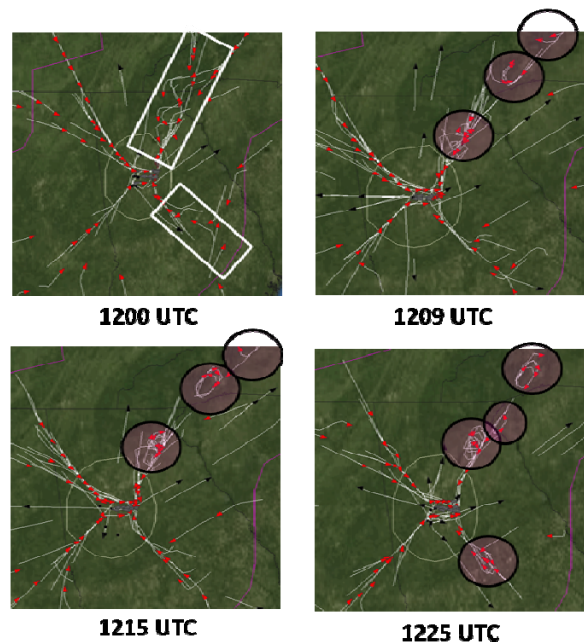


Figure 5-2: ATL arrival (red) and departure (black) traffic on June 27, 2009 when reduced visibility related to haze requires increased arrival spacing, resulting in airborne holding and delays. “S-curve” maneuvers performed to manage the increased aircraft spacing are boxed in white while aircraft holding in the air (as demand exceeds capacity given haze constraints) are circled.

The AAR deficits (see Figure 5-1) indicated minimal arrival deficits on this day because a “reservoir” of arrival aircraft was present to feed available landing slots as excess demand held in the air. In other words, analyzing the solely airport acceptance rates without the knowledge of the NTML or without a flight track analysis would otherwise indicate that haze a minimal impact on operations. However, the amount of fuel expended by the airlines due to airborne holding in response to haze constraints is significant, as evident in Figure 5-2. Moreover, this event was not an isolated incident at ATL. There were multiple cases such as June 27, 2009 for ATL where multiple aircraft were placed in airborne holding, GSs were issued, and other restrictions and delays were incurred (described below).

5.1 2009 ATL MORNING HAZE VS. NO-HAZE CASE STUDY ANALYSIS

In an expanded case study analysis of haze impacts, the operational impact of ten ATL haze days and ten ATL non-haze days in 2009 during summer months were evaluated. Figure 5-3 lists the cases days, including whether a GS was issued during the morning arrival push and whether there were observed airborne holding stacks (and if so, the total number of holding aircraft during the haze impact period was reported).

Comparing GS and holding frequency on the days with and without morning haze impacts illustrates the extent of the haze impact in 2009. Morning GSs were used on 80% of the days in which haze was observed at the surface while there were NO GSs used during the morning arrival push when haze was not observed at the airport. Morning airborne arrival holding was observed during 9 of 10 haze days, while holding was experienced on only 2 of 10 non-haze days. Figure 5-4 shows the arrival flows and holding stacks at 1230 UTC on all 10 ATL haze days.

Together, the fact that airborne holding occurred on most days when GSs was also implemented to manage haze-related capacity reductions suggests that this weather impact may have been unanticipated by air traffic managers and ATC. The “cost” of these operational impacts of haze included increased delay, increased fuel burn and airline operating costs, and increased ATC workload.

ATL Arrival Event 2009 (11-13 UTC)	Morning GS?	Holding Stack(s)?	Number of Arrival Aircraft Holding
15 Jun – Haze	YES	YES	14
17 Jun – Haze	YES	YES	12
27 Jun – Haze	YES	YES	20
07 Jul – Haze	YES	YES	10
08 Jul – Haze	YES	No	-
10 Jul – Haze	YES	YES	10
14 Jul – Haze	No	YES	10
17 Jul – Haze	YES	YES	5
30 Aug – Haze	YES	YES	4
09 Sep – Haze	No	YES	7
19 Jun	No	No	-
23 Jun	No	No	-
24 Jun	No	No	-
29 Jun	No	No	-
20 Jul	No	YES	10
21 Jul	No	No	-
24 Jul	No	No	-
06 Aug	No	No	-
10 Aug	No	No	-
13 Sep	No	YES	7

Figure 5-3: 2009 ATL haze and non-haze case study analysis days

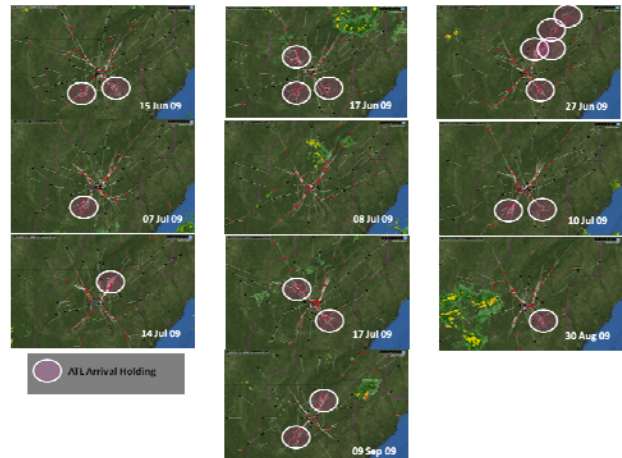


Figure 5-4: 2009 ATL arrival (red) and departure (black) traffic at 1230 UTC on haze case days in 2009 (holding stacks circled in white)

An additional area to investigate when evaluating the operational impact of haze on operations involves the use of MIT restrictions for constraint management. MIT restrictions are one of the most commonly used traffic management initiatives [6]. MITs are typically placed on the boundaries between facilities, and they specify a minimum spacing for flights in a stream that must be imposed by ATC [7]. It is apparent when investigating ATL 2009 haze

case studies, that MIT restrictions and GS programs were the primary methods for managing haze constraints (and subsequent capacity losses) at ATL. Figure 5-5 compares the frequency and mean “size” of ATL MIT restrictions (at key arrival fixes) used during the morning hours of 2009 haze and non-haze case days. As the figure indicates, the actual magnitude of the restrictions for haze and non-haze periods is negligible and often quite similar; however, the frequency in which MIT restrictions were used is higher for all but one arrival fix (ERLIN) when haze is present. The frequency of MIT restrictions increases significantly on haze days for fixes located outside of Atlanta Center (ZTL) airspace.

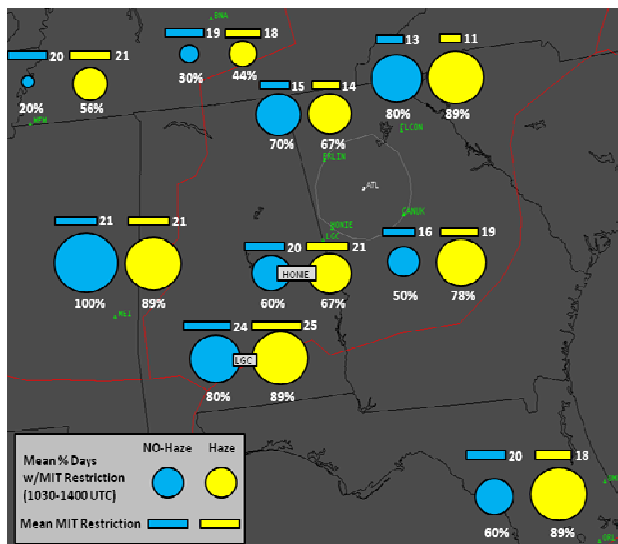


Figure 5-5: Frequency (circles) and size, in miles (bars) of MIT restrictions for key arrival fixes during morning hours on 2009 ATL haze and no-haze case days.

Further evaluation of operational impact data adds additional support that the impact of haze extends beyond the MIT restrictions and GDPs and GSs. These ASPM –derived statistics [10] demonstrate that haze impacts can indeed be substantial, impacting most key aspects of airport arrival operations. The ASPM analysis indicates the impact of haze includes:

- Although the initial analysis on AAR showed fairly moderate results (see section 3), the case study analysis indicated the hourly

capacity AAR was reduced by 10 aircraft per hour (30 arrivals per day) during haze periods,

- Terminal Arrival Efficiency Rate (TAER) reflects small decrease in overall efficiency for the terminal; however, the FAA-recognized TAER efficiency threshold of 90 is breached 20% of the haze impact days as opposed to 0% during non-haze days,
- 14% more traffic “over-delivered” on haze days (coincident with observed increased airborne holding),
- Delayed arrivals greater than 15 min increases (76% more arrivals delayed 1100-1400 UTC on haze days),
- Delay is actually higher on non-haze days (ATL aggressive operations), but fewer flights are delayed,
- Arrival delay increases by an average of 9 more hours of arrival delay per day when haze is present in the morning, and
- Gate arrival delay increases to almost twice as many delayed gate arrivals between 1100-1400 UTC when haze is present.

5.2 2009 VS. 2010 ATL HAZE CASE STUDY COMPARISON

Section 5.1 contained significant operational impacts due to haze impacting the airport during key arrival times for cases in 2009; however, research into 2010 periods presented different results. Before evaluating the data for 2010, there were some noteworthy operational changes from a traffic management point of view as well as the number of aircraft arriving at ATL during their morning arrival peak demand period. One of the main operational changes in 2010 for ATL was the increased usage of the Traffic Management Advisor (TMA) from 2009 to 2010. In 2009, ATL arrivals were first metered starting with 1500 UTC departures. In 2010, active TMA metering of ATL arrivals began at 1030 UTC (i.e., just prior to the start of the primary haze impact period for ATL). An important feature of TMA is its ability to sequence and schedule aircraft to the outer fix, meter fix, final approach fix, and runway threshold in such a way as to maximize airport and TRACON capacity without compromising safety [8]. TMA updates the

aircraft sequences, schedules, and runway assignments constantly to adapt to changes in the traffic situation, changes in the environment, or in response to inputs by the traffic management controllers. With the addition of using TMA during the primary arrival push for ATL, the traffic managers managed demand-capacity imbalances caused by haze through time-based metering and modified scheduling of departures to ATL that likely transferred more delay (impact) to arrival aircraft while still on the ground at their origin airports

Another significant operational difference between 2009 and 2010 for ATL was the dramatic decrease in air traffic during the morning haze impact period. Table 5-1 shows the decrease in traffic for ATL during the primary haze impact periods as well as the overall decrease for the day as a whole. As the table shows, there was a sharp decrease in traffic during 1100-1300 UTC. This decrease in traffic means that increase arrival spacing due to haze could be more effectively absorbed given demand would not be as excessive during periods of constrained capacity. In turn, this likely means that traffic management programs, TMIs, and airborne holding may not have been needed as frequently to manage ATL haze constraints.

Table 5-1 : ATL Scheduled arrivals, 3 month daily average

01 Jun – 31 Aug	2009	2010	% Change
1100-1200 UTC	78	66	-15%
1200-1300 UTC	121	100	-17%
0000-2359 UTC	1388	1337	-4%

Figure 5-6, Figure 5-7, and **Error! Reference source not found.** complete the analysis for the comparison between 2009 and 2010 haze operational analysis. Due to the significant decrease in arrivals and the use of TMA metering during the early ATL arrival push, the traffic management initiatives, delays, and excess demand all decreased as expected. As Figure 5-6 shows, there were no GS implemented on any days in 2010 when haze

was present at the surface. There were also no observed airborne during any of the days in 2010 which haze was present. While haze was likely causing a reduction in efficiency, the lack of demand on the airport – coupled with procedural changes (TMA) that may have transferred impacts/delays to other areas of the operation - allowed for the increase in spacing (reduced capacity) without significant implications on airborne arrival flows or at the ATL airport itself.

ATL Arrival Group (11-13 UTC)	Morning GS?	Holding Stocked?	Number of Arrival Aircraft Holding
2009			
20Jun - Haze	YES	YES	26
27Jun - Haze	YES	YES	28
28Jun - Haze	YES	YES	28
07Jul - Haze	YES	YES	20
08Jul - Haze	YES	No	-
28Jul - Haze	YES	YES	28
29Jul - Haze	No	YES	28
27Aug - Haze	YES	YES	8
28Aug - Haze	YES	YES	6
09Sep - Haze	No	YES	7
2010			
07Jul - Haze	No	No	-
28Jul - Haze	No	No	-
29Jul - Haze	No	No	-
08Aug - Haze	No	No	-
09Aug - Haze	No	No	-
08Aug - Haze	No	No	-
09Aug - Haze	No	No	-
20Aug - Haze	No	No	-

Figure 5-6: 2009 and 2010 ATL haze case study analysis days

Figure 5-7 also shows the 2010 operational impact from an MIT point of view. Though MIT restrictions were still present on ATL arrivals during the morning, when haze was present, the frequency of MIT restrictions decreased significantly (compared to similar periods in 2009). The “size” of MIT restrictions decreased as well for all fixes except those northeast of ZTL.*

*The continued use of larger MIT restrictions on northeast ATL arrival fixes in 2010 likely had more to do with TMA procedures and Inter-facility Letters Of Agreement (LOA) than with anything pertaining to haze impact mitigation.

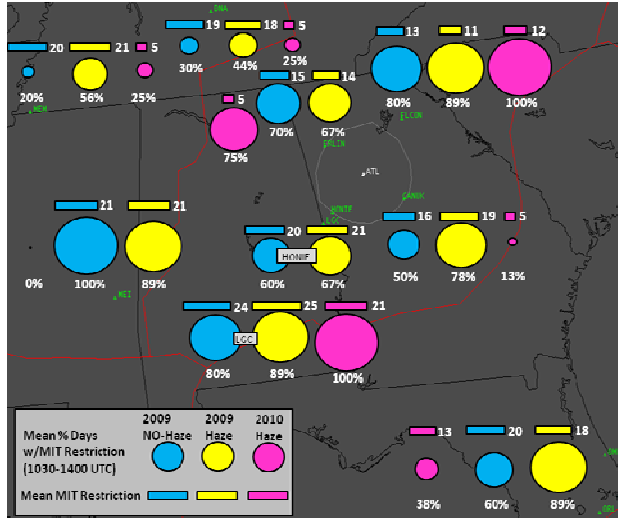


Figure 5-7: Frequency (circles) and size, in miles (bars) of MIT restrictions for key arrival fixes during morning hours on 2009 and 2010 ATL haze and no-haze case days.

ASPM statistics in Table 5-2 further illustrate that the decrease in arrival demand and modified ATM operations (TMA metering practices) practically eliminated the haze-related delays (compared to non-haze days). Moreover, the efficiency was slightly reduced (although not significant) and mean excess arrival demand during 2010 haze days was reduced to levels similar to NON-haze days in 2009. Focusing solely on the 2010 case studies, a conclusion could be drawn that haze does not have a significant impact on operations; however, the 2009 case studies drew a vastly different conclusion. One concern is that as ATL arrival demand increases again to near capacity (as in 2009, during morning hours), haze impacts may again quickly mount. In addition, more analysis is required into TMA scheduling delays (on the ground) which may have absorbed some of the ATL airborne arrival delay after TMA metering was moved up to 1030 UTC.

Table 5-2: 2009 and 2010 ASPM statistics compiled for 10 ATL haze and 10 non-haze case days

1100-1400 UTC	2009		2010		Comments
	Daily Mean HAZE DAYS	Daily Mean NON-HAZE DAYS	Daily Mean HAZE DAYS	Daily Mean NON-HAZE DAYS	
Hourly Capacity/ARR	105	115	107	117	
INER	94.5	96.9	95.3	97.3	
Excess Arr'l Demand	21%	7%	8%	3%	Indicoid excess demand in 2009 compared with diminished holding on 2010 haze days
#Delay Arrivals (≥25 min)	44	25	23	25	In 2010, low restrictions = number of delayed arrivals, rather than no holding base
Agg Gate Arr'l Delay per Flight (min)	40	48	44	43	
Total Avg Arr'l Delay	29 Hours	20 Hours	17 Hours	18 Hours	Significant reduction from 2009; in 2010, low or difference in arrival delay with 100% of morning haze
% Delayed Gate Arrivals	17%	9%	9%	9%	In 2010, low restrictions = high percentage of delayed gate arrivals on haze days eliminated

6. NEWARK (EWR) CASE STUDIES

Newark (EWR) was a prominent airports selected as part of an additional case study analysis due to EWR recording a modest number of haze observations and a relatively high number of TMIs. Figure 6-1 displays the number of days with multiple surface haze observations at major airports thought to be the most susceptible to haze impact. LAX clearly has the largest number of days with surface haze while EWR has a moderate number of days with surface haze compared to the other airports. The frequency of haze occurrence at LAX and EWR, however, cannot fully explain the need for TMIs resulting from haze at these airports. For any airport, the need for haze-induced TMIs can be described as a function of traffic demand, traffic capacity, and capacity reductions caused by haze. If a large gap exists between arrival capacity and arrival demand at an airport then the airport can sustain a capacity reduction without the need for a TMI. If, however, the airport has a limited amount of excess capacity-over-demand, then the level of capacity reductions caused by haze could result in traffic management issues significant enough to be addressed by TMIs.

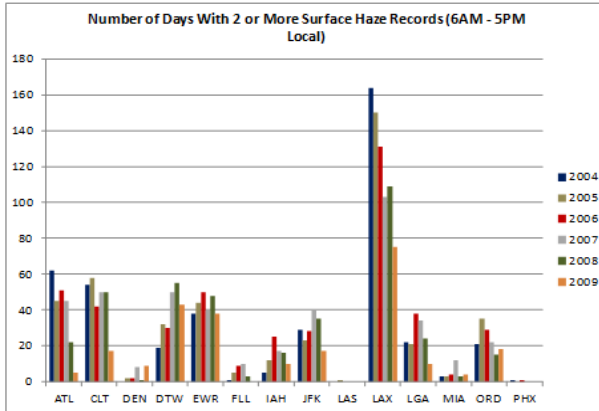


Figure 6-1: Select airports with two or more surface haze recordings from 6am-5pm

EWR has a high number of GDPs issued on days with haze relative to other major airports [Figure 6-2]. This results largely from the sensitivity of EWR's demand-to-capacity ratio as Figure 6-1 shows that EWR does not have an excessive number of days with multiple surface haze observances relative to the other airports studied.

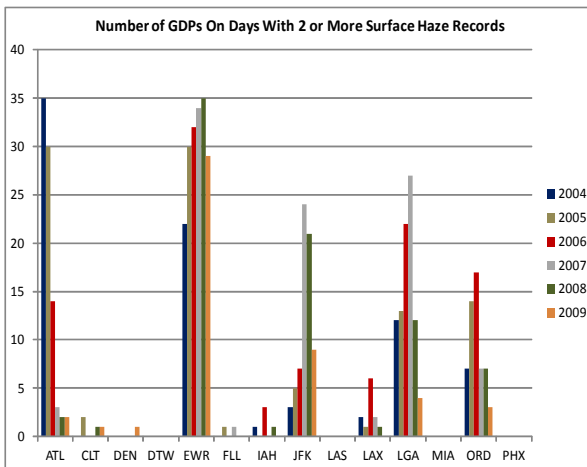


Figure 6-2: Select airports with GDPs and two or more surface haze recordings from 6am-5pm

Figure 6-3 shows that EWR has its arrival capacity strained during peak traffic hours. In the afternoon and evening hours, when arrival traffic volume is highest for EWR, there is a small margin between the airport's capacity and demand. As with LAX, the comparison for EWR

is between the airport's 90th percentile of AAR hour-by-hour (which takes into account reductions in arrival capacity due to departure pushes) and the average hourly weekday scheduled arrivals. Because of the narrow margin between these amounts in afternoon and evening hours, moderate reductions in capacity can lead to arrival deficits and increased delay at EWR.

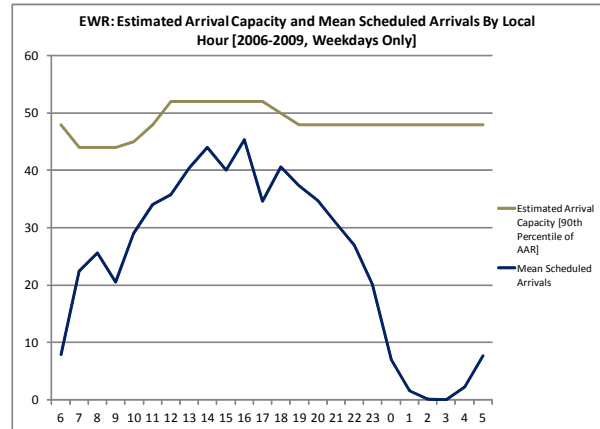


Figure 6-3: EWR mean scheduled arrivals (blue) and 90th percentile estimated AAR (tan)

6.1 HAZE IMPACT ON EWR OPERATIONS

Haze actually has a significant impact on EWR's operations. The impact to EWR's operations ranges from an AAR deficit to runway closure. For example, on June 8, 2011, EWR experienced a haze event. The GDP for this day (reason for the GDP listed as "Weather/Wind") was implemented from 1600Z-0300Z for the entire NAS including Canada. A comment in the GDP was the following: UNABLE USE OF RWY 11 DUE TO HAZE. It should also be noted that haze was not mentioned as part of the ASOS on 11 of 13 observations; however, a weather observer supplemented the missing haze observations of the automated sensor with a remark stating: HAZE ALOFT. This example not only highlights the impacts of haze on operations, but also reinforces the issues with surface and haze aloft observations. Had the weather observer not supplemented the METAR

observation, then we would not have known about the existing haze conditions aloft.

Figure 6-4 further illustrates another impact of haze on EWR's operations from an AAR perspective. On this day (April 25, 2011), EWR was impacted by multiple weather phenomena ranging from haze (red) to low ceilings (gray). As evident in the figure, both low ceilings and low visibility were simultaneously established at the airport in the morning to early midday hours. Haze was late in setting in (1-4pm local); however, the impact was significant. The combination of the low visibility and haze seemed too great for the airport and thus they were unable to land all of the aircraft. Per the northeast traffic management logs, EWR was forced to close runway 11 due to the restrictions in visibility:

2002(Z) CALLED THE TOWER ABOUT USE OF RWY 11, EWR WIND 070/7KT WITH VIS 6SM HZ. TOWER BRIEFED THAT THE RESTRICTION TO VIS PREVENTED THE USE OF RWY 11.

Due to the runway not being in use due to haze, EWR experienced a deficit in their AAR during the 15-17 local hours. The dashed line in Figure 6-4 is shown as a reference to show that on a typical day when there are no significant restrictions due to weather, EWR meets the demand during that high demand period.

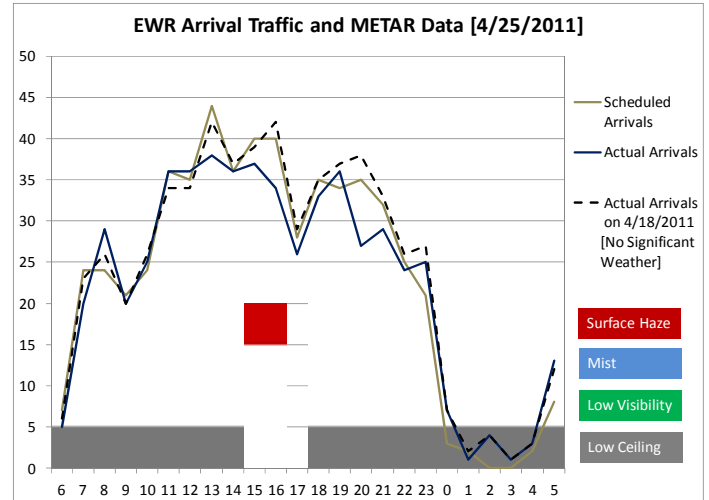


Figure 6-4: EWR haze impact example. Significant METAR weather observations highlighted by time of observance (local hrs)

Figure 6-5 shows the total airborne delay throughout the day for EWR on April 25, 2011. The onset of haze and loss of runway 11 coincides with the increase in airborne delay for the 14-17 hours (local). En-route thunderstorms are likely attributable to the drastic increase in delay; however the total delay attributable to haze, en-route thunderstorms, low ceilings, and other weather elements is a topic of future research.

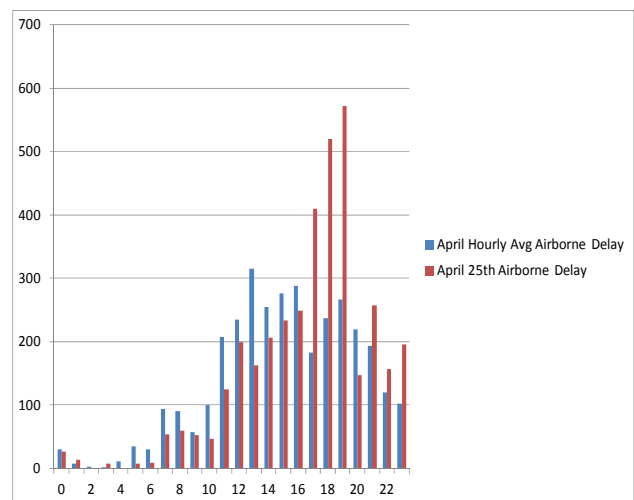


Figure 6-5: EWR airborne delay for 4/25/2011

6.2 ANTICIPATING HAZE AT EWR

Runway 11 at EWR was again impacted by haze resulting in a decrease in operations / efficiency on June 22, 2011. On this day, the surface METAR did not have any recordings of haze at the surface, yet the NY Tower informed the Traffic Management Unit of the following (source is from the Northeast NTML):

1759(Z) N90 ADVISED THAT EWR WOULD NOT BE ABLE TO LAND ON 11 DUE TO HAZE, CURRENTLY EWR HAS 43 FOR THE 17Z HOUR AND ARE AT THE 36 RATE FOR THE NEXT 3 HOURS SO THERE IS NO RECOVERY ROOM TIL 21Z HOUR, N90 AND DCC WILL BOTH KEEP AN EYE ON THE ROLLING SPIKE AND TAKE ACTION IF NEEDED. - LNK: EWR

This again highlights the difficulties associated with observing haze; however in this case the forecast for haze was included in various scheduled and amended forecasts as part of the body of the TAF and as part of many TEMPO categories. Since this event was forecast well by the CWSU, the planners had enough time to anticipate and plan ahead for the reduced rate and loss of runway 11 per the forecast. Northeast NTML states the following:

1535 (Z) Telcon Event: 1535: PLANNING TELCON conducted for GDP EWR ATCSCC...EWR LANDING 22L WITH NO USE OF 11 EXPECTED AND CONVECTIVE WX EXPECTED THIS AFT AND EVENING. N90 EXPECTING WX TO DECLINE BY 18Z, WITH SHRA, LOW CIGS, AND HZ. WOULD LIKE A GDP AT 36 RATE TO START AT 18Z....

Figure 6-6 shows the total airborne delay throughout the day for EWR on June 22, 2011. The onset of haze and loss of runway 11 coincides with the increase in airborne delay for the 13-16 hours (local). So, even though the onset of haze was well broadcast and planned, the airport still experienced a greater than average amount of airborne delay. Again, thunderstorms traversing just north of the airport

are likely attributable to the increase in delay; however there was a clear over delivery of aircraft into the area as evident by the accumulation of airborne holding.

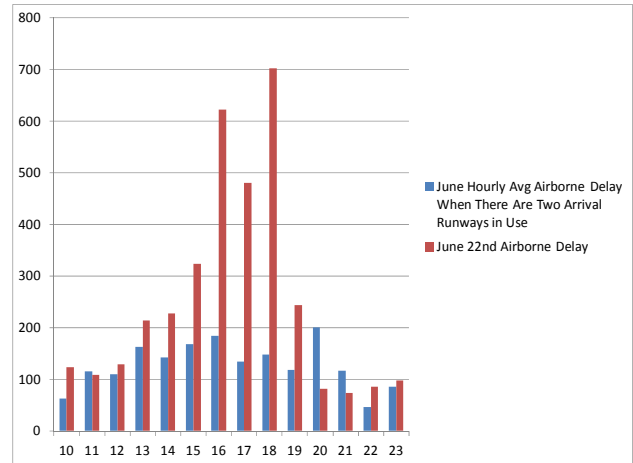


Figure 6-6: Anticipated EWR haze event (local time) with minutes of delay on y-axis

7. FORECASTING HAZE EVENTS

Forecasting haze at the surface and aloft is a primary focus for the Center Weather Service Unit (CWSU). However, forecasting haze at an airport (both surface and aloft) is not trivial. Forecasts for haze must take into account the surface winds, winds aloft, surface pollutant transportation, dew point forecasts, and stability of the atmosphere. Forecasting these components alone are difficult for most forecasters while forecasting the interactions of all of these components to determine the need to include haze as part of an operational impacting forecast (i.e., the TAF) is even more daunting. As expected, oftentimes haze is either forecast by the meteorologist and it does not materialize, or haze is not in the forecast and haze materializes at the airport. Furthermore, the verification for haze at the surface is fairly measurable since the METAR has a present weather condition programmed; however, verifying haze aloft is difficult unless a human weather observer supplements the METAR with a haze aloft observation. Overall, the forecast for haze aloft is difficult to forecast accurately and verifying these events present a myriad of issues due to the lack of observational data.

The Performance Branch resides in the Office of Climate, Water, and Weather Services (OCWWS) at National Weather Service Headquarters, and is responsible for the NWS Verification and Evaluation Programs. The primary function of the Verification Program is to track the accuracy of NWS forecasts and warnings. This includes developing software, collecting data, producing verification scores, and maintaining the integrity of the verification database [9]. Stats on Demand is the primary tool in which TAFs are verified for the NWS. The difficulty of forecasting haze can be summed up in Figure 7-1, which shows data from the NWS's Stats on Demand tool.

Figure 7-1 shows TAF accuracy in forecasting haze for the 9 hour forecast period for the airports listed in the graph. It should be noted that the data extracted from Stats on Demand is based on the regular TAFs and does not include the amended TAF forecasts. The only equivalent evaluation category for "haze" in Stats on Demand is "smoke/haze," which is displayed in the figure. A cursory analysis on the frequency of smoke indicated the vast majority of the numbers below may be considered "haze" observations or forecasts.

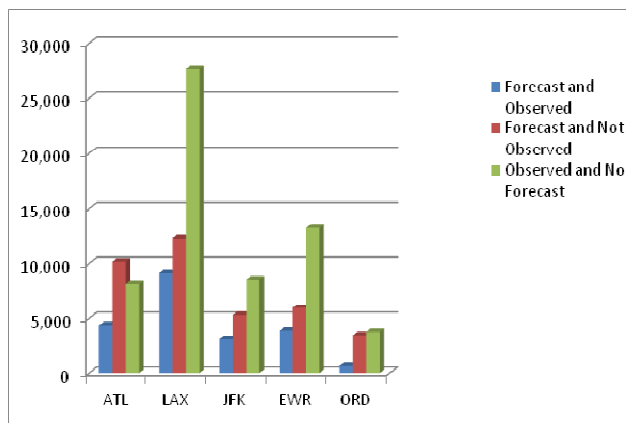


Figure 7-1: NWS Stats On Demand TAF Analysis Data; 2006-2009; April – September; Smoke/Haze (9hr max forecast horizon)

Results from Stats on Demand as depicted in Figure 7-1 show a large number of "missed" haze events that were either forecast and not observed, or observed and not forecast. For instance, LAX and EWR have a large number of

times in which haze was observed, but is not present in the forecast; which, can have a significant impact on the planning for those airports. For example, a planner may see the forecast is calling for haze and may preemptively implement a TMI in order to accommodate for the increase in anticipated demand at the airport. Additional insight into the frequency of haze at LAX and EWR is available in section 6. To better quantify the frequent missed forecasts in a different context, the number of times in which haze was observed at EWR but not forecast translates into roughly 1,000 hours of unanticipated haze at the airport.

Reverting to the 2009 and 2010 case studies mentioned earlier in the paper, the number of times haze was mentioned in the TAF is infrequent as well as inconsistent. Out of the 18 case studies in which haze was observed at the surface, only six of those case studies had a mention of haze in the TAF (including amendments). Of those six TAFs which mentioned haze, there was only two forecasts in 2009 in which haze was mentioned in two consecutive TAFs (including amendments); meaning, that haze is oftentimes inconsistently mentioned or not mentioned at all.

As mentioned earlier, there are a few difficulties with forecasting haze, however, there are also many difficulties associated with verifying haze. For example, the primary verification for haze is the METAR; however, oftentimes haze can be cleared from the surface (i.e., not recorded in the METAR) and isolated to a haze aloft event. The only observation which would capture the haze aloft events is human supplemented observations for the METAR– which does not occur nearly as frequently as the haze aloft events. Additionally, NTML log research indicated that when haze observations ended at the surface, haze aloft events continued or haze was not recorded at the surface but was observed aloft and there were operational impacts throughout the rest of the morning push period. For example: ATL WAS IMPACTED WITH HAZE EARLY IN THE MORNING WHICH RESULTED IN A ONE HOUR GROUND STOP

FOR ZJX/ZTL.* On this day, there was only a single recording of haze at the surface, but a GS was implemented this day and a large number of aircraft were left in airborne holding long after the single recording of haze. It should be noted that additional understanding, verification, and exploration is needed to further confirm the infrequency of haze aloft forecasts in the TAF as well as confirming the procedures for observation and forecasting for haze aloft events.

8. CONCLUSION

As evident in this study, the operational aviation impacts of haze are as complex as the phenomena itself is to forecast and observe. Haze, a relatively frequent observed weather element, can have a significant impact on the efficiency of air traffic operations at major airports throughout the NAS. This study showed that the horizontal and slant range visibility reduction caused by the haze layer, often results in aircraft ILS approach at least increasing the distance between aircraft during final decent (or earlier in flight via MIT), effectively reducing airport capacity. Multiple metrics were used throughout this study to measure and quantify the impacts of haze on operations including: AAR deficits, TMs, MIT restrictions, NTML, and others. This study demonstrated that various operational air traffic impacts (and resultant capacity constraints and impaired efficiency) are experienced in association with haze in terminal airspace.

The true extent of haze impacts is unclear given that haze is a misunderstood meteorological phenomenon. It is uncertain whether ASOS-recorded observations at the airport is truly capturing all of the surface observations of haze or whether some of the observations are actually being recorded as mist (for example) or perhaps some of the recordings of haze are actually haze aloft observations. There were also times in which there were no recordings of haze at the METAR yet a human weather observer supplemented the observation with "haze aloft." Further study into the ASOS algorithm which determines haze at the ASOS is needed.

Additional research into the ASOS classifying or extending the observation from surface haze to haze aloft should also be considered. At this time it is believed the ASOS is primarily measuring the haze at the surface. Since it is clear that haze can have a significant impact on operations, users such as the air traffic managers, air traffic planners, CWSU meteorologists, and pilots need better information to better determine the location and vertical extent of the haze layer.

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* Extract taken from NTML SCC Shift Summary, June 27, 2009