

Investigating the Impacts of Specific Weather Phenomena on Airport Operations and Runway Configuration

Robert S. Lee and C. Craun
AvMet Applications Inc., Reston, Va.*

1 INTRODUCTION

An airport's capacity and ground management is highly dependent upon its chosen runway configuration. The National Aeronautics and Space Administration-funded System Oriented Runway Management (SORM) concept was developed to evaluate opportunities for enhanced surface, terminal, and en route operations that may increase airport capacity and improve operational efficiency. The SORM Runway Configuration Management (RCM) initiative was designed to address capacity and efficiency issues while accounting for historical weather phenomena and associated operational impacts. AvMet Applications, Inc. (AvMet) supported the SORM project through targeted weather analyses, including evaluating the affect of specific weather phenomena on RCM, analyzing current runway configuration usage at the study airports given specific aviation weather conditions and constraints, and investigating the impact of the weather phenomena on airport operations and efficiency.

AvMet's historical database of weather observation and forecast data, and airport operations data allowed for a highly focused analysis that bolstered the airport capacity degradation modeling for the SORM project. Included in this study was a detailed approach to determine and isolate the measureable impacts from simultaneous occurrences of various weather events (such as reduced visibility and strong winds). Additionally, wind data at several airports were analyzed to evaluate the range of wind direction in which specific runways would remain in use. Weather model forecast accuracy was also evaluated in order to better understand the variability in forecast performance and expectations for forecast accuracy given a range of prediction periods for both automated forecast products and current, official human-generated operational weather forecast products produced by the National Weather Service (NWS). Results from this study provided additional guidance for airport runway management options and risk mitigation needs given forecasts for operationally-significant weather.

2 TERMINAL WEATHER IMPACTS AND RUNWAY CONFIGURATION PREFERENCES

Runway configuration is a fundamental component in determining an airport's capacity. Weather may

degrade an airport's operations alone by constricting airspace, blocking key flows to/from an airport, or by placing the airport in a non-optimal runway configuration—resulting in a reduction in capacity (i.e., arrivals and/or departure rates). This terminal weather-focused analysis portion of the SORM project evaluated specific weather phenomena observations at the New York airports (i.e., JFK, EWR, and LGA) and incorporated the runway configurations selected by the airport as recoded by the Federal Aviation Administration's (FAA) Aviation System Performance Metrics (ASPM) database.

2.1 Summary of Results

Results from this study were applied to the future developments of the SORM algorithms, as they provide insight into the current operations at the New York airports and the anticipated degradations in operations associated with specific weather phenomena and associated runway configuration selections. The analysis focused on surface weather conditions including no weather (i.e., nominal/ no operationally significant weather observations with minimal wind), rain only, low ceiling only, rain and low ceiling, fog only, haze only, thunderstorms, and snow/ice.

For this study, the period 2005-2009 was used as the evaluation period. Daily observations between the local hours of 07 and 21 were evaluated. Cases with winds 10 knots (kts) or greater were excluded in order to isolate periods when winds were not the primary factor for determining the preferred runway configuration. As Figure 1 shows, LGA runway configuration of 22 | 13 (arrival configuration | departure configuration) was the most commonly used arrangement when there is no weather present at the airport (29% of the time). The use of this runway configuration was even higher for nearly all weather events analyzed (i.e., 41% for rain, 35% for low ceilings, 30% for low ceilings with rain, 44% for fog, 58% for haze, and 61% for thunderstorms). Preferences for 22 | 13 over others was also apparent during haze and thunderstorm events and there was an increased preference for 4 | 13 during snow/ice events. It was also discovered that when low ceilings were observed, 13 was the runway of choice for departures.

*Corresponding author address: Robert S. Lee, AvMet Applications Inc., 1800 Alexander Bell Dr., STE 130, Reston, VA 20191. email: lee@avmet.com

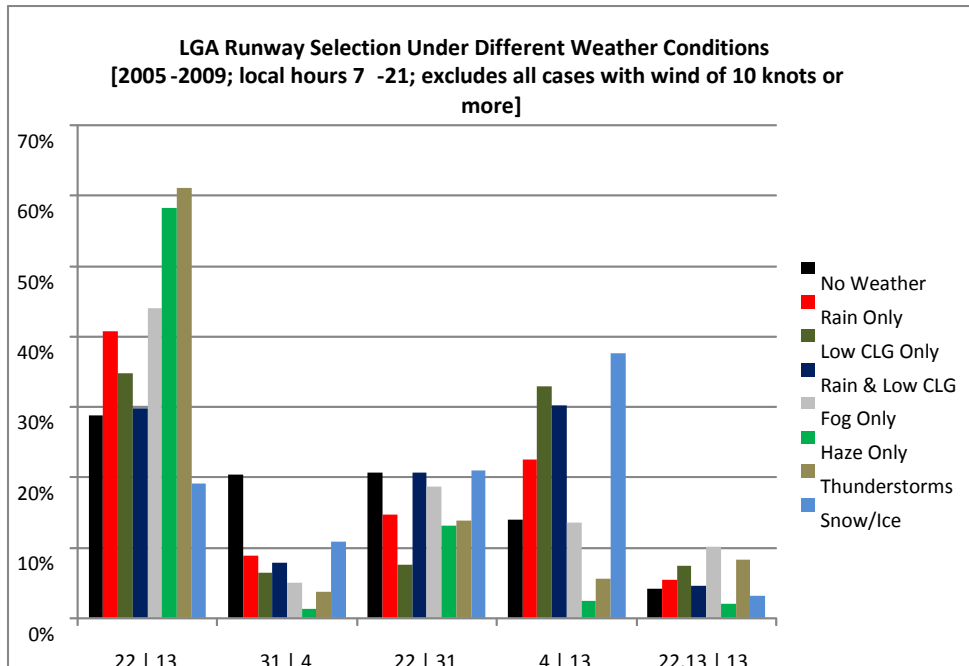


Figure 1: LGA runway Selection During Various Weather Phenomena

JFK has a much more complex set of potential runway configurations. It was found that for JFK, no one runway configuration was used the majority of the time for any weather event analyzed, as the percentages were largely under 20% (Fig. 2). However, the usage of 22L | 22R was higher during fog, haze, and thunderstorm events compared to the use of this configuration when there were no operationally significant weather observations. During rain and low

ceiling observations, 4R | 4L, 31L experienced an increase in runway configuration preference. During snow/ice events at JFK, 31L, 31R | 31L and 4R | 4L had increased usage. It should be noted that because JFK utilizes many different runway configurations the sample sizes of an individual configuration for a specific weather event tends to be very small, making capacity estimations difficult.

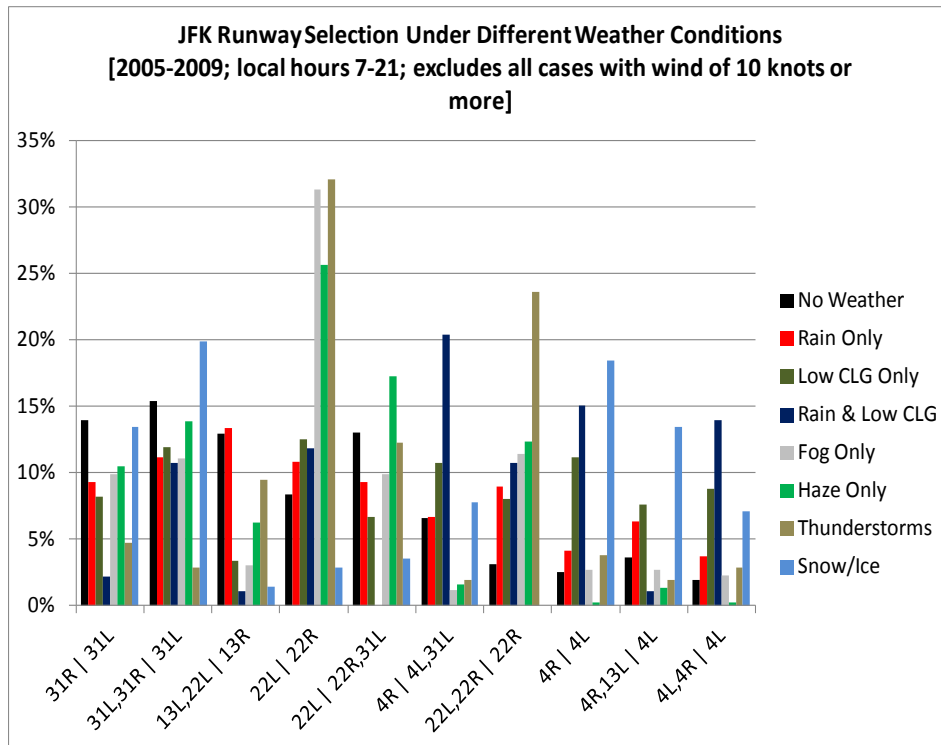


Figure 2: JFK Runway Selection During Various Weather Phenomena

The SORM study also found that specific weather phenomena and runway configuration selection typically did not show a significant improvement in the arrival and departure rates observed at the airport. In the dataset analyzed, there were some slight differences when there was no operationally significant weather at the airport for a runway configuration for JFK, but the differences were within five arrivals/departures per hour. The same differences were seen for the majority of the observed weather elements and runway configurations, with the exception of haze and snow/ice. When there was haze or snow/ice observed at the airport, it was evident that the runway configuration was critical to the operations. For example, 31R | 31L had significantly more arrivals and departures compared to the other runway configurations, while haze had two equally efficient runway configurations, with 4R | 4L being a suboptimal runway configuration for this weather phenomenon. The preference could be caused by reduced slant-range visibility; however, this aspect was not studied in-depth. It should be noted that EWR did show an increase in arrival/departure rates when runway 11 was included as part of the arrivals in operations during thunderstorm events. Moreover, snow and thunderstorms were found to have the largest impact on operations. While it was expected that snow/ice would have a significant impact on operations there was some variability in the extent to which the impact could be attributed to the selected runway configuration. For instance, when EWR was impacted by snow/ice, runway configuration 22L | 22R had

significantly better performance than the 4R | 4L runway configuration, from an arrival and departure standpoint.

3 CONVECTIVE WEATHER LOCATION, AIRPORT PERFORMANCE, AND RCM

It is well known that convective weather has a significant impact on an airport's operations. The location of those storms is one of the primary determinants of impacts to arrival rates and/or departure rates. This part of the study was done to quantify the impact of convective weather on an airport's arrival rates (captured via ASPM) when convective weather was located in specific areas, quadrants, and/or key operational areas surrounding the airport. For the convection data, the National Convective Weather Diagnostic (NCWD) was used to evaluate the convective weather observations. The diagnostic analysis combined WSR-88D national radar and echo top mosaics with cloud-to-ground lightning. The convective weather data were aggregated and analyzed in 15-minute intervals for the 2010 convective weather season (March-October).

3.1 Grid Description

This study focused on convective weather impacts on the New York metro area airports (EWR, JFK, and LGA). The goal was to analyze multiple runways in a metroplex environment and their associated runway configurations when convective weather was observed within a 50 mile radius centered on LGA in order to

capture the usage of key arrival fixes the three terminals. The radius was large enough to also include JFK, EWR, and the surrounding New York TRACON (N90) area for all three airports. The region was subdivided into a set of radial sectors (Fig. 3).

In creating the radial sectors, we were able to analyze each area, and identify the impact on the airport's arrival rate of convection within each individual radial sector, combination of radial sectors, specified

quadrant(s), or specified area(s). NCWD data was aggregated to 15-minute increments synchronized with 15-minute aggregated arrival rates from ASPM. Each of the sectors, or designated areas, was analyzed in order to determine if there was a *sensitivity* to the convective weather from an arrival rate and runway configuration perspective for the New York Metroplex.

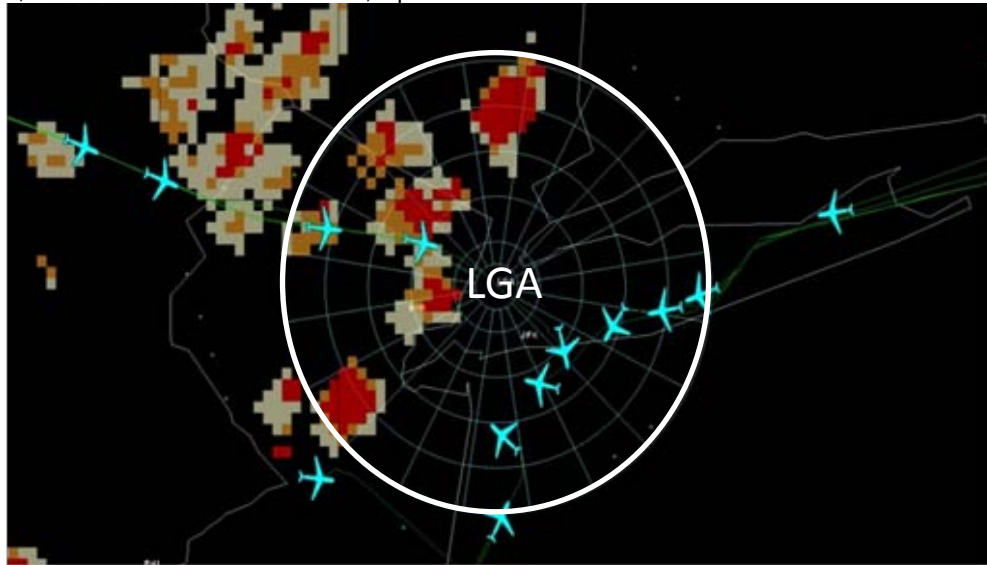


Figure 3: NCWD Data (level 3 and above) and Aircraft Locations Overlaid on Radial Sectors

3.2 Summary of Results

It is important to acknowledge that convective weather location is not the only weather factor for determining runway selection; winds also play a leading role. To validate the results from the convective weather locations study, time periods when surface winds were 7 kts or greater within an 18° envelope on either side of one of the New York airport runway directions were analyzed. This offered the ability to distinguish whether the convective weather location itself or the wind was the driving factor in runway selection when convective weather was present in the study region. The following scenarios summarize the results.

When wind was at least 7 kts from 300-330° (a headwind and preference for LGA 31, JFK 31L/R),

usage of LGA 31 (arrivals) was significantly lower when convective weather was present (Fig. 4). As this is a favorable wind direction for this runway, it was used ~80% of the time when there was no convective weather, but only 21% of the time when convective weather was present within the study area. It was also found that LGA 31 (departures) was used with somewhat greater regularity when convective weather was present. Additional runway configurations found to have an increase (of at least 10%) in preference when convective weather was present included LGA 22 | 31; JFK 22L | 22R; EWR 22L | 22R. Conversely, some runway configuration preferences decreased significantly (by more than 10%) when convective weather was present including: LGA 31 | 4; JFK 4L | 4R; EWR 4L | 4R.

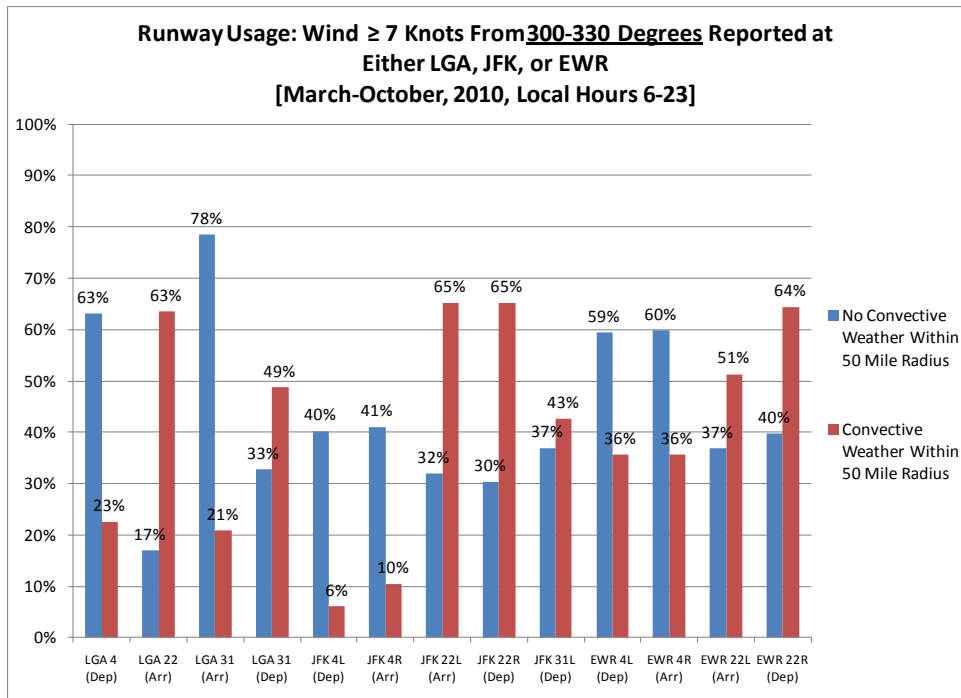


Figure 4: LGA, JFK, and EWR Runway Usage for Winds \geq 7 kts from 300°-330°, with and without Convective Weather Present within a 50 mi-Radius of the Airports

Other runway ‘envelopes’ favoring a specific New York runway were evaluated throughout this portion of the study. The following are some of the more significant findings: When wind was at least 7 kts from 120-150° (headwind for LGA 13, JFK 13L/R), usage of LGA 13 (arrivals) dramatically increased when convective weather was present. The winds were favorable for LGA 13, but it is notable that the runway was only used 44% of the time when there was no convective weather, compared to 70% of the time when convective weather was present. EWR 11 (arrivals) was used fairly often (47% of the time) when the wind direction was favorable for the runway; however, when convective weather was present, this runway was used rarely (7%) despite the favorable winds.

When wind was at least 7 kts from 30-60° (headwind for LGA 4, JFK 4L/R, EWR 4L/R), JFK 4L | 4R were found to be used less when convective weather was present. As this is a favorable wind direction for the runways, they were used quite often when there was no convective weather, but were used with somewhat less regularity when convective weather was present.

4 FREQUENCY AND IMPACTS OF VFR AND IFR ON AN AIRPORT’S OPERATIONS

Understanding how terminal area weather affects airport runway configuration selection and airport operations is a foundational component for supporting future enhancements of the SORM algorithms. An

airport’s operational efficiency is highly impacted by the weather conditions experienced within the terminal area. Reduced ceilings and visibility impact an airport by reducing the visual approach criteria, which may require pilots to fly primarily by reference to instruments, reducing an airport’s efficiency.

The SORM research evaluated the frequency and impacts of Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) on an airport’s operations based on the observed weather conditions at the time for a number of major airports throughout the United States. The airports included in this study were Atlanta (ATL), Dallas-Ft. Worth (DFW), Dulles International (IAD), Chicago O’Hare (ORD), EWR, JFK, and LGA. This study incorporated the runway configurations that were selected during the IFR and VFR periods along with various operational impact measurements. It should be noted that airports largely experience VFR with only a relatively small sample of the entire dataset qualifying for IFR.

For the airports included in the analysis, this study identified the frequency of VFR and IFR conditions and how often IFR conditions occurred during various weather events; identified significant operational impacts (arrivals and departures) from IFR conditions; and identified the runway configurations as well as the impact observed during VFR and IFR conditions. This study evaluated meteorological data and VFR/IFR thresholds for the period 2005-2009.

4.1 Summary of Results – Frequency Analysis

Airports operated in VFR conditions the majority of the time; however, there were a substantial percentage of operations occurring in IFR conditions. The airports operated under IFR flight rules 15-25% of the time. This equates to approximately 1,000-2,000 hours of conditions per year for each airport that can potentially result in a loss of operational efficiency. The IFR/VFR data presented is as reported in the FAA's ASPM database, where ASPM identifies periods when the airport was operating under VFR or IFR.

IFR conditions for the airports were found to show a strong diurnal signal (Fig. 5). Onset of the conditions typically occurred after 0Z, and peaked in the morning around 12Z before declining in the afternoon hours. While the time of day for IFR conditions at the airports included in this study was relatively consistent, the amplitude and frequency of IFR conditions varied greatly from airport to airport. ATL, for example, typically operated under IFR conditions at 1100GMT roughly 40% of the time (60% of the time ATL operated under VFR conditions), while JFK for the same hour operated in IFR conditions roughly 17% of the time.

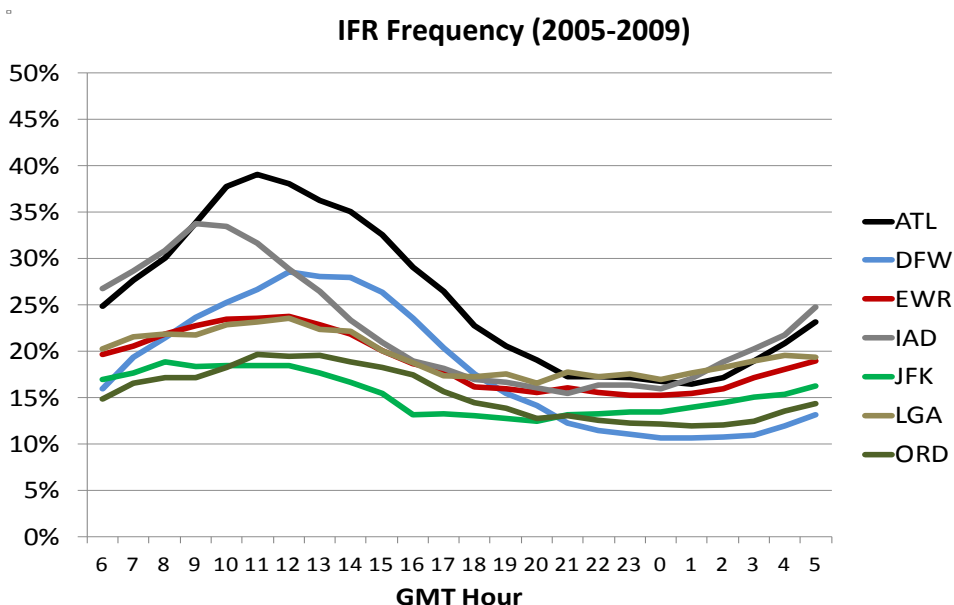


Figure 5: IFR Frequency by GMT Hour (2005-2009) for Key Airports

4.2 Summary of Results – RCM Analysis

As identified in the previous section, airports experience weather conditions that do not require IFR the majority of the time. The study also illustrates that although the frequency of IFR is not nearly as frequent as VFR, the impact to an airport's operations during IFR conditions can be significant and objectively quantifiable. As shown in Figure 6 for ATL, although 26R, 27L, 28 | 26L, 27R was the most common configuration in VFR conditions (38%), in IFR conditions it was used less frequently (21%) than 8L, 9R, 10 | 8R,

9L (30%). Interestingly, the preference for directions when landing during VFR / IFR conditions switched completely, with the preference being the opposite direction for arrivals and departures. The preference for 8L, 9R (and 10) | 8R, 9L almost doubled when ATL was operating under IFR conditions. A possible cause for this change in runway configuration may be due to reduction in slant range visibility caused by the morning sun since the majority of IFR conditions for ATL occur during the morning hours.

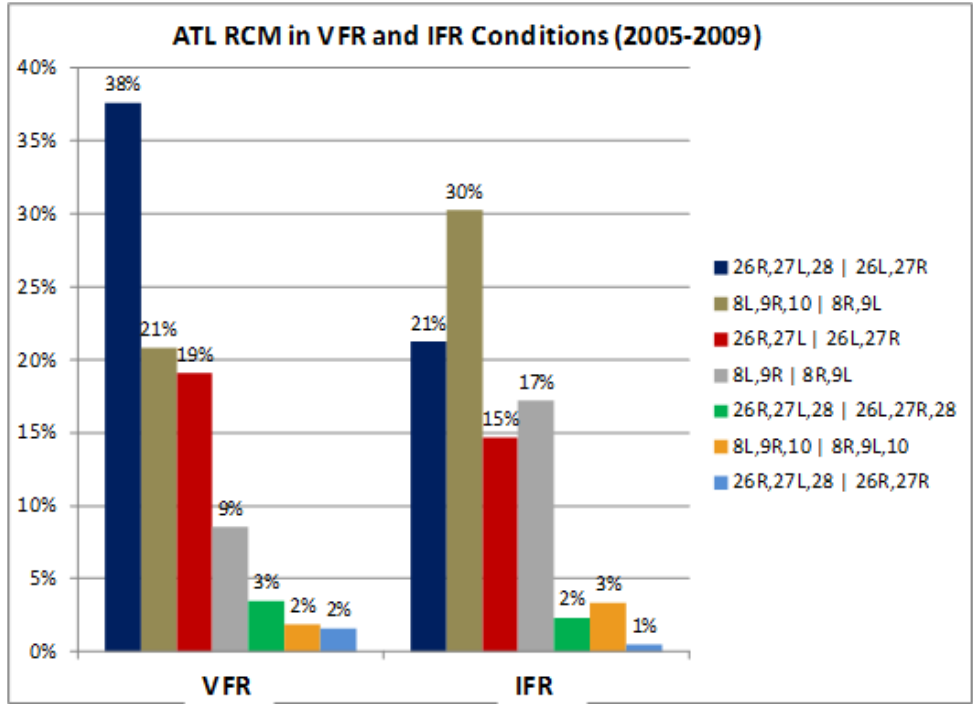


Figure 6: ATL Runway Usage in VFR and IFR Conditions (2005-2009)

In the IFR/VFR RCM analysis for JFK, it was found that 22L | 22R was used over twice as frequently (20%) in IFR conditions compared to VFR conditions (8%) while the most frequently used runways during VFR conditions are used significantly less when operating under IFR conditions. This supports earlier findings that the usage of 22L | 22R is higher during fog, haze, and thunderstorm events (potential IFR causal factors) as

compared to the usage of this configuration when there is no or relatively insignificant weather. The other less frequently used runway configurations during VFR conditions increased in prominence compared to when JFK was operating under IFR conditions. JFK tends to not utilize their longest runway (13R/31L) during IFR conditions and slightly favors the parallel runways 22L/R and 4L/R (Fig. 7).

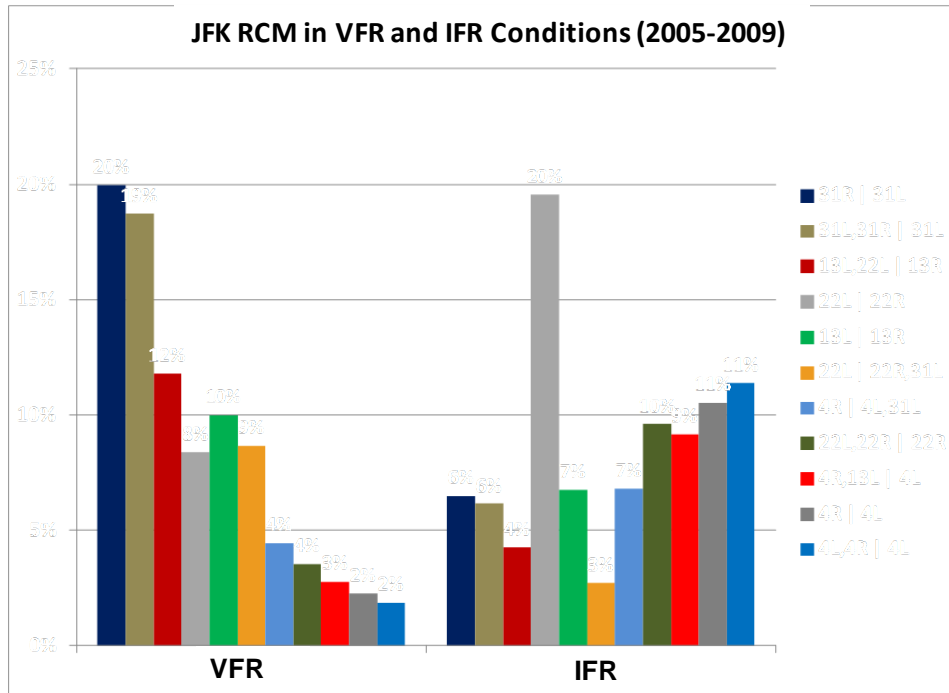


Figure 7: JFK Runway Usage in VFR and IFR Conditions (2005-2009)

A considerably more complicated airport, ORD, was also analyzed in this study. ORD has a significant number of runway configurations at its disposal; therefore, only the more frequently used runways are presented in this analysis. Although none of the runway configurations were heavily favored during VFR and IFR conditions, ORD tended to favor 22R,27L,28 | 22L,32L,32R and 4R,9R,10 | 4L,9R,32L,32R (Fig. 8). Both of these runway configurations are typically used

during VFR and IFR conditions with a moderate increase in the use of 27L,28(with or without 27R) runways for arrivals and 22L and 28 for departures. It should be noted, and it is evident from Figure 8, that the percentage distribution for most of the runway configurations do not indicate a preference towards or away from a specific runway configuration during either VFR or IFR conditions.

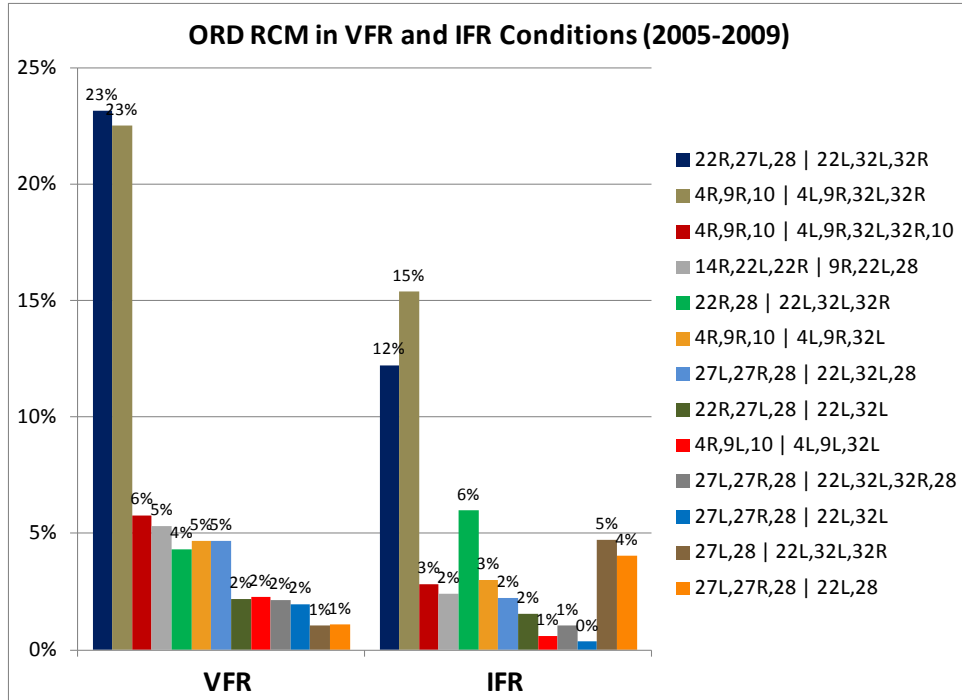


Figure 8: ORD Runway Usage in VFR and IFR Conditions (2005-2009)

4.3 Summary of Results – Impact Analysis

Operational impacts were compared for different runway configurations when the airports were operating under VFR and IFR conditions. Large differences in capacities and delays were observed for different runway configurations, particularly when comparing IFR impacts among the configurations. For example (Fig. 9) when ATL does not operate with runway 28 for arrivals in its 26R,27L | 26L,27R configuration, operational impacts were minimal under VFR conditions (average hourly arrival delay increased by about 20 minutes), but impacts were larger under IFR conditions (average hourly arrival delay increased by nearly 400 minutes when 28 was not used as an arrival runway). It should be noted that construction of the 10/28 runway was completed in May 2006, and some of the data included in this study is during a period of time when ATL did not have the option of using this auxiliary runway. The percentage of delayed gate arrivals for ATL in VFR conditions was near 20% for the 26R,27L | 26L,27R configuration whether or not the auxiliary runway, 28, was available for arrivals. However, in IFR conditions, the percentage of delayed gate arrivals for this configuration increased from 33% when runway 28 was available for arrivals compared to 39% when it was not.

When ATL did not use runway 10 for arrivals in its 8L,9R | 8R,9L configuration, operational impacts were again much larger in IFR conditions than when the runway configuration was used in VFR conditions. Percentage of delayed gate arrivals was near 19% in VFR conditions for the 8L,9R | 8R,9L configuration, whether or not 10 was used for arrivals. In IFR conditions, however, the percentage of delayed gate arrivals increased from 36% to 43% when 10 was not available for arrivals.

In VFR conditions, departure delay for ATL was seemingly unaffected by whether or not the 10/28 runway was in use for arrivals. However, the ability to use 10/28 for arrivals did have a cascading effect resulting in increased departure delay in IFR conditions. For the 26R,27L | 26L,27R configuration, average hourly departure delay increased by around 200 minutes when 28 was not available as an arrival runway in IFR conditions. For the 8L,9R | 8R,9L configuration, average hourly departure delay increased by around 300 minutes when runway 10 was not in use as an arrival runway in IFR conditions.

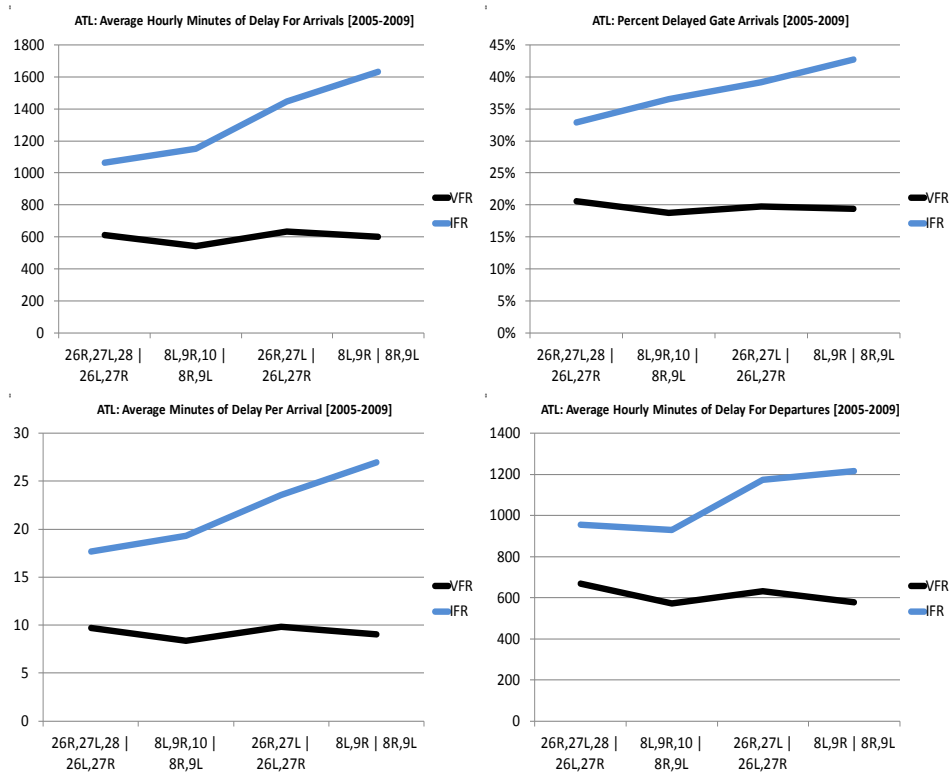


Figure 9: ATL Runway Configuration Delay Analysis During IFR Conditions

For EWR, the analysis indicates the availability of runway 11 for arrivals had a large impact on delay in IFR conditions but not in VFR conditions (Fig. 10). Average minutes of hourly arrival delay was comparable for both 22L | 22R and 22L,11 | 22R in VFR conditions. In IFR conditions, however, the average hourly arrival

delay was about 350 minutes larger when 11 was not available as an arrival runway in this configuration. Percent of delayed gate arrivals increased from 41% to 47% when 11 was not as an arrival runway in the configuration.

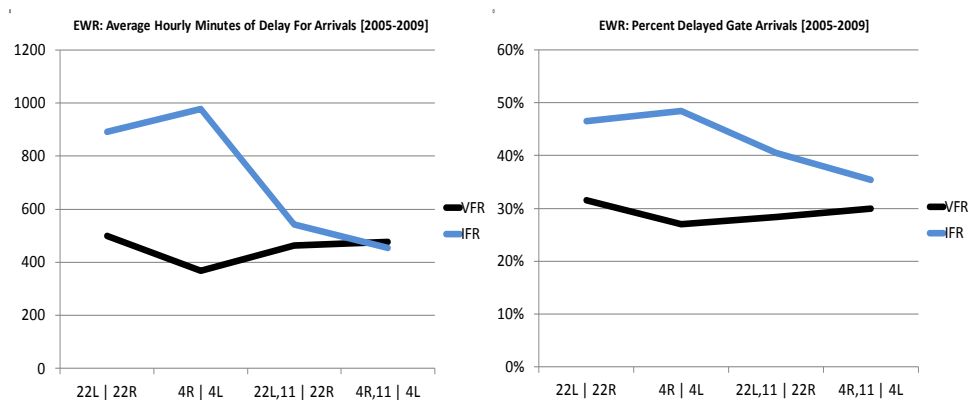


Figure 10: EWR Runway Configuration Delay Analysis during IFR Conditions

For JFK, the 31R | 31L configuration produced the least hourly average minutes of arrival and departure delay both in VFR and IFR conditions (see Fig. 11). The 13L,22L | 13R configuration had the highest hourly

average arrival and departure minutes of delay in VFR conditions, but in IFR conditions this configuration had the second lowest delay; only 31R | 31L was better.

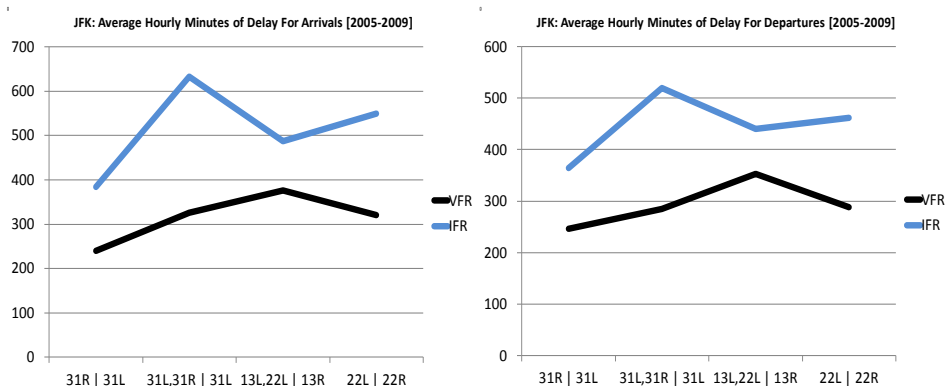


Figure 11: JFK Runway Configuration Delay Analysis During IFR Conditions

As illustrated in this section, IFR conditions can have a significant impact on operations compared to VFR conditions due to the increased spacing on final approach as dictated by the IFR flight rules. For the airports included in this study, the frequency of VFR and IFR conditions and how often IFR conditions occur during various weather events were identified; significant operational impacts (arrivals and departures) from a delay perspective were highlighted for periods when airports operate in IFR conditions; and the impact of IFR operations to the preferred runway configurations were also analyzed. Overall, each airport was found to have a noticeable impact to operations while operating under IFR conditions (with delay and runway configuration selection being the primary measurements for this study). Results from this study provided SORM the insight into the current operations at the various airports and the anticipated degradations in operations as well as runway selections associated with IFR conditions.

5 LAMP WEATHER FORECAST ANALYSIS (JFK)

The purpose of this analysis was to compare the Localized Aviation Model Output Statistics (MOS) Product (LAMP) forecasts with the surface weather observations (METAR) at JFK in order to aid in determining, and setting, expectations for weather forecast uncertainty. Weather forecast accuracy is critical for strategically selecting optimal runway configurations. In this study, the frequency with which LAMP forecasts were within reasonable accuracy for RCM and input into the SORM algorithm were evaluated. Weather phenomena used for this evaluation were the wind direction/magnitude forecasts for various production cycles and forecast horizons of the LAMP. In addition to the wind analysis, this study also analyzed the runway availability according to LAMP forecasts, compared to runway availability according to METAR (i.e., if the wind speed was within the runway-specific

threshold for the wind direction under the runway condition, then the runway was considered available; otherwise, it was deemed unavailable.) in the study period for this portion of the SORM project included January, May, and June 2009. METAR data was used for verification. The primary forecast horizons analyzed during this study were aggregated into larger time blocks and included the near-term planning horizons (1-3hr forecasts) and the longer-term strategic planning horizons (4-6hr and 7-12hr forecasts). Although the LAMP model is updated hourly, this analysis focused only on the 0Z, 6Z, 12Z, and 18Z production cycles.

5.1 Summary of Results – LAMP Weather Forecast Analysis (JFK)

The primary focus of the wind direction and magnitude analysis was to determine whether the LAMP model accurately predicted a runway as being available for operations (with the crosswind threshold as the determinant factor).. Initial results focused on the accuracy of the wind direction and magnitude, regardless of runway configuration and crosswind thresholds. Among the many results, this study found the standard deviation of the wind magnitude difference between LAMP and METAR ranged from 2.5 kts to 4.1 knots, with the best (2.5 kts) occurring during the near-term (1-3hr) forecast period issued at 0000 UTC. These magnitude ranges were quite low indicating the model was producing good forecasts for wind magnitude in the 1-3hr time period. The wind direction analysis for the 1-3hr forecasts issued at 0000 UTC showed that the LAMP model was within 3 kts of METAR in 82% of the records. In the 30 degree wind envelope analysis, LAMP wind direction was also found to be within 30 degrees of METAR wind direction in the vast majority of records in 1-3 hour forecasts and a reasonable number of records in 4-6 hour and 7-12 hour forecasts (Fig. 12).

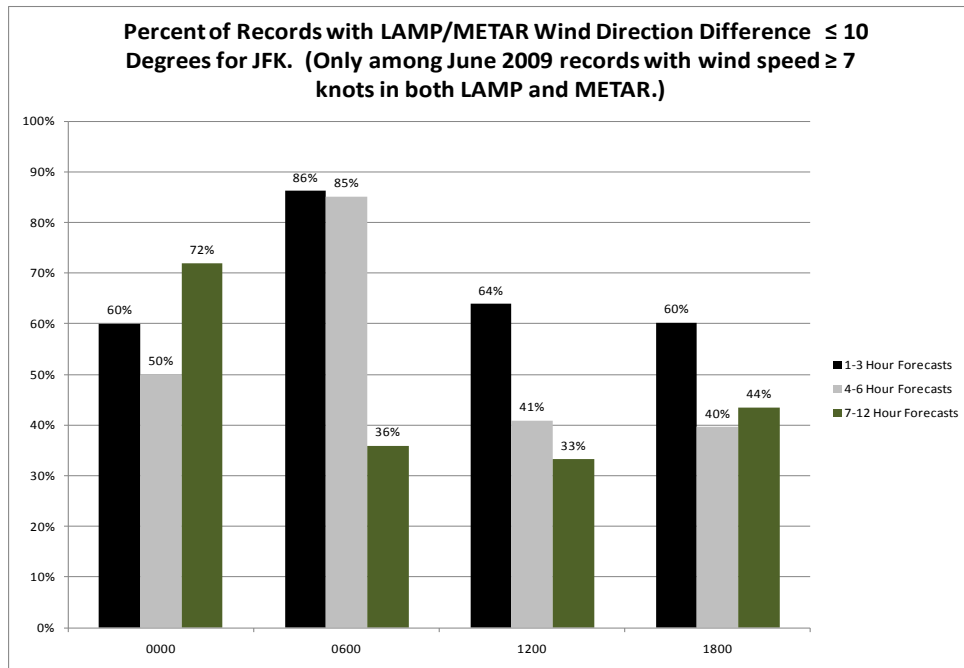


Figure 12: June 2009 LAMP/METAR Wind Direction Analysis for JFK for Various Time Periods and LAMP Issuance Times

When conducting the runway availability analysis, it was found that (depending on the runway and the forecast projection) for records with a runway available according to LAMP data, anywhere from 56%-90% of records also had the runway available according to METAR data for the month of May (Fig. 13). For records with a runway available according to LAMP data for the month of January, roughly 95% also had the runway available according to METAR data (again, depending on the runway and the forecast projection). It was noted

that during the critical NAS strategic planning periods (1500 – 1800 UTC), 1-3 hr runway availability forecast accuracy for JFK's 31L/31R was nearly 95% in January (2009) with a notable decrease to 56% accuracy for the 1800 UTC LAMP model run in May. The SORM team used these data and results to evaluate their algorithm's results when using a forecast that is reliable and accurate in forecasting runway availability (January) and when the forecast model is not nearly as accurate (May) during a higher traffic volume period for JFK.

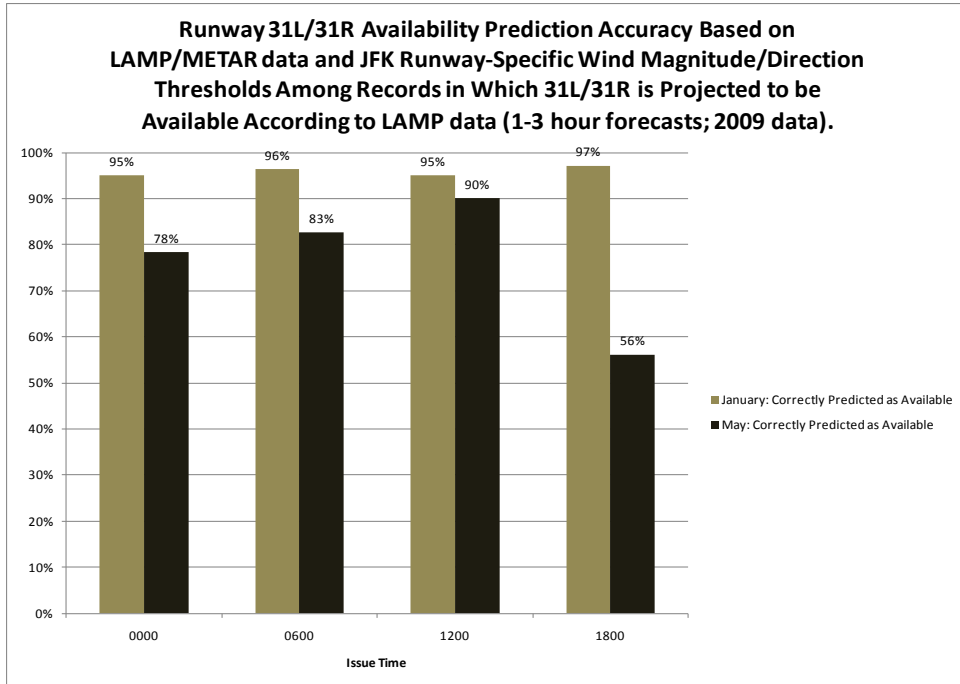


Figure 13: LAMP 1-3hr Forecast for Runway Availability Analysis for JFK (January and May 2009)

6 CONCLUSION AND FUTURE WORK

This study has evaluated the effects of specific weather phenomena on runway configuration management; provided weather data for SORM modeling; analyzed current runway configuration usage at several major airports; and investigated the impact of various weather phenomena on airport operations and efficiency. The detailed analysis of the weather's impact on operations and runway configuration management in various specific weather conditions has been leveraged by the SORM team to better model capacity degradations and runway configuration expectations as a result of specific weather element(s). Results from this analysis provided guidance for weather-related SORM RCM selection and risk mitigation needs given forecasts for operationally-significant weather

This high-level analysis, however, could be expanded and honed to provide further targeted operations research application including further investigations of forecast uncertainty and anticipated RCM; metroplex operations, RCM interactions, and operational impacts; modeling capacity estimates and arrival/departure rates for runway selection during VFR versus IFR conditions; specific weather phenomena impact and surface operations (e.g., queue/taxi management, modeling, winter operations); and aircraft type impacts given: airport, metroplex, demand, VFR/IFR conditions, weather phenomena and RCM.

7 ACKNOWLEDGEMENTS

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