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1 INTRODUCTION

The evaluation of weather forecast quality, as related to air traffic management initiatives (TMI), is of primary importance to Federal Aviation Administration's (FAA) System Operations. The National Weather Service (NWS) Terminal Aerodrome Forecast (TAF) is one of the many forecast products used amongst the aviation community in daily operations. The TAF is particularly important, compared to other forecast information, because it is International Civil Aviation Organization (ICAO) compliant and required to be used for domestic and international carriers in order to determine flight specific, crucial information such as fuel load. TAFs are also utilized by the system operations side of the aviation community in order to help determine if TMIs are needed, the length of potential TMIs and their associated arrival and departure rates.

Historically, weather forecasts such as the TAF have been assessed by the meteorological community using metrics such as Probability of Detection (POD) and False Alarm Ratio (FAR). While POD and FAR can be used to evaluate the quality and consistency of a forecast from a meteorological point of view, both verification methods provide minimal insight into forecast quality and its inherent relationship to aviation operations. Given this void, the FAA recognized the need to correlate weather forecasts and air traffic operations in order to review overall performance on a day to day basis. In late 2011, the FAA requested AvMet Applications Inc. (AvMet) to develop an automated web-based tool that assesses TAF performance integrated with air traffic information available for next-day analysis.

The intent of this paper is to describe this FAA-funded, automated web-based tool (Automation Tool), discuss its significance, examine the research capabilities, and note enhancements expected in the near future.

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2 AUTOMATION TOOL OVERVIEW

Weather accounts for nearly 70% of the delays in the National Airspace System (NAS) and results in constraints to en route traffic flow structure and terminal operations. TMIs refer to a set of tools used to balance airspace availability capacity with demand resulting in the safe and orderly movement of air traffic. Two types of TMIs that are applicable for all weather constraints in the NAS terminal environment are Ground Delay Programs (GDP) and Ground Stops (GS). GDPs are issued to control air traffic volume at an airport where the air traffic demand is expected to breach the acceptance rates for an extended period of time. When a GDP is issued, controlled departure times are issued for flights scheduled to arrive at the airport in order to control the demand and meet the airport's acceptance rate. A GS is issued under similar circumstances but for when demand is expected to breach the acceptance rates for a short period of time. During a GS flights that are destined for the airport under the GS are held at their departure airport until the GS is cancelled. GDPs and/or GSs mitigate risk and manage traffic demand that is constrained by weather phenomena.

Through balancing capacity and demand, GDPs and GSs impact aviation stakeholders. Airlines incur delay depending on the specifics of these programs, such as the prescribed arrival rate that is determined based off of forecasted weather conditions. Because of this, the evaluation of GDP and GS performance is of upmost concern to the FAA in order to satisfy stakeholder needs and learn ways to alter the system to improve performance. On a daily basis, metrics are examined from previous day operations in order to optimize terminal operations. Weather (observed and forecasted) is considered an important component in the success of these TMIs. Given that GDPs and GSs are considered a reliable source for how well the NAS operated, the initial focus of the Automation Tool has been on terminal operations and the performance of these TMIs. From a forecast perspective, the TAF, which is an official operational aviation forecast product issued by the NWS, was chosen to analyze because it is ICAO compliant, widely used by the aviation community, and includes a forecast for all of the weather phenomena that could potentially trigger a TMI.

In the initial development stages of the Automation Tool, one of the primary requirements was that it needed to offer insight into the interactions between terminal operations, observed weather, and forecasted weather. Given this vision, the tool was developed with several purposes in mind. Firstly and foremost, the Automation Tool was established to provide metrics regarding weather forecast support provided within TMI time constraints, essentially providing a high-level analysis of the TAF's ceiling, visibility, and wind (magnitude and direction) forecasts within the context of NAS operations. The Automation Tool thus allows for an objective next-day review of TAFs. Additionally, the Automation Tool's purpose was to offer insight into weather and operational impacts. This is one of the many reasons that the Automation Tool analyzes TAF and METAR observations using specific wind, ceiling, and visibility thresholds that are unique to each terminal. The thresholds are based off of a MITRE Benchmark Report developed at the request of the FAA that used interview techniques as a method to determine the weather thresholds for ceiling, visibility, and wind at the Core airports. Furthermore, the Automation Tool was intended to provide the capability to be archived on a daily basis for quick reference, review, and offer the ability to conduct an historical analysis on the data as the need arises. As a result of these requirements, the Automation Tool integrates weather and air traffic data to enable the objective analysis of forecast, observations, and terminal impacts by delivering a review of the TAF's 4-hour forecast performance during periods when TMIs, specifically GDPs and/or GSs, are implemented at the Core airports in the NAS.

2.1 Automation Tool Data Flows

The Automation Tool is used by a diverse user community including meteorologists and air traffic specialists at the Air Traffic Control System Command Center (ATCSCC) for post-analysis impact and assessment of the previous day's NAS operations. Because of this, data quality, data integrity, and timeliness of data are of upmost importance. Figure 1 highlights the process adopted by the Automation Tool to ensure that the supporting data is updated on a timely basis with the proper information. The two primary sources of ingested data are TMI information from the National Traffic Management Logs (NTML) as well as TAF and METAR observations from NOAAport. AvMet receives a live-weather data feed from NOAAport via satellite and has databased an extensive archive of various weather data. These data supply multiple analysis tools used by the AvMet analysts on a daily basis. The vast majority of the data which is collected and stored is available in various querieable and parameterized databases for use within various tools AvMet maintaines and developes including the Automation Tool. Once the data is ingested, the 4-hr TAF information is isolated, extracted, and filtered accordingly to align with the hourly METAR data in order to evaluate TAF performance on an hourly basis.

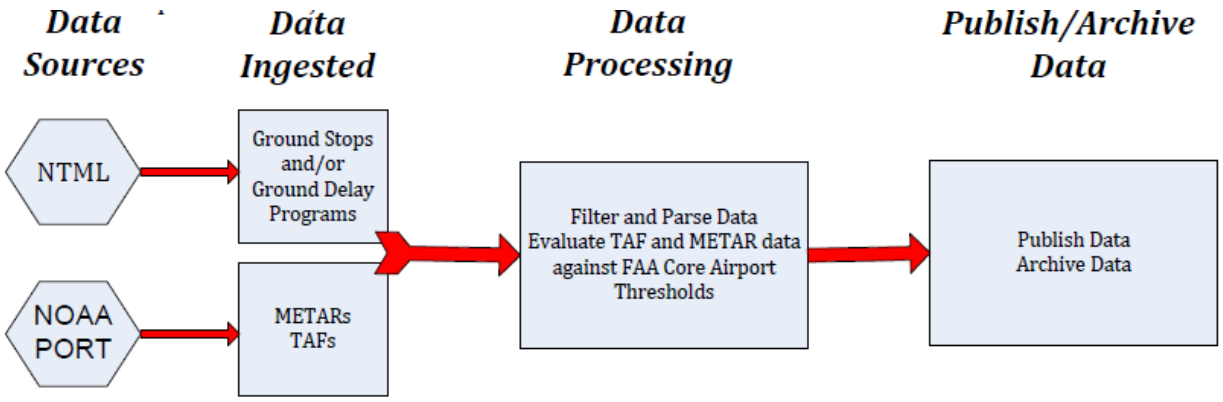


Figure 1: Automation Tool Ingest and Processing Flows

3 THE AUTOMATION TOOL VIEWS

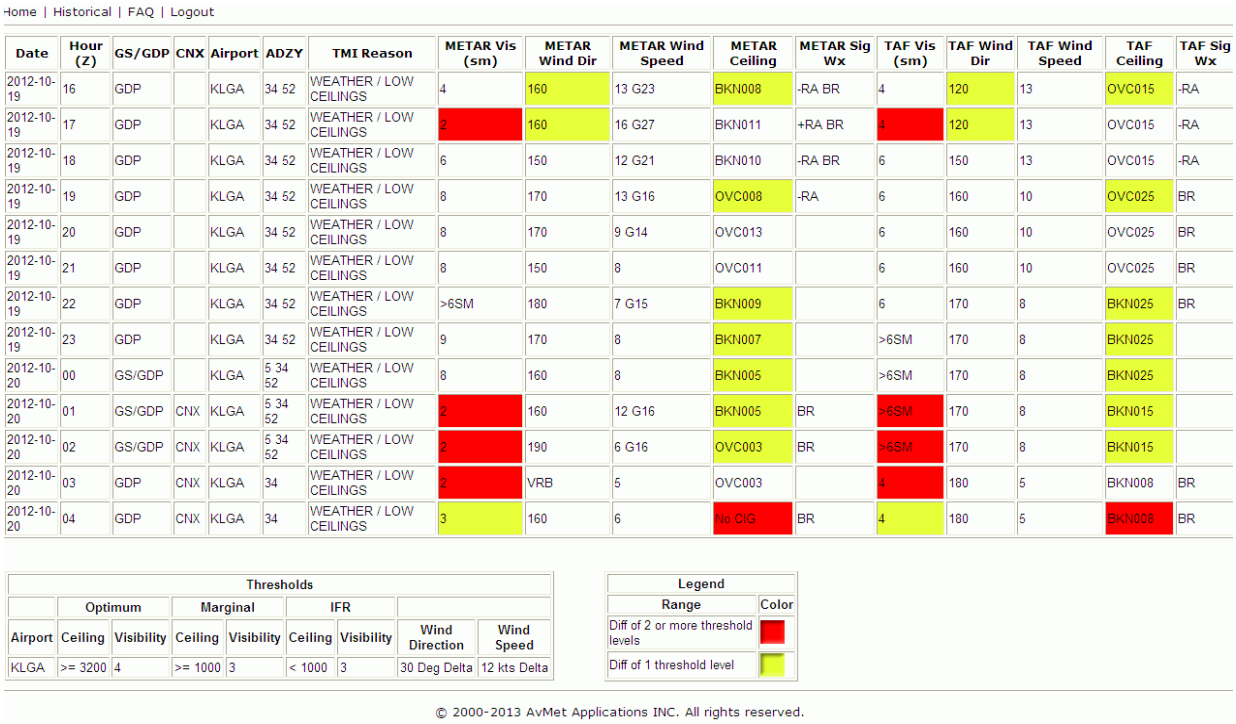
The Automation Tool and its various assessment capabilities provide benefits to aviation stakeholders in a number of ways. A primary benefit of the Automation Tool is its archival ability and the fact that operations and forecast performance can be reviewed on a next-day, month to month, or year to year basis. Another benefit is it provides the capability for stakeholders to use an integrated approach to reviewing the interactions within the NAS from the previous day. Via the Automation Tool, stakeholders have the ability to analyze the 4-hr forecast of the TAF versus airport observed weather and system reactions in a combined approach, i.e., not solely evaluating the FAA performance and forecast performance as separate entities, but as combined components to the NAS. The Automation Tool accomplishes this benefit through its unique verification scheme.

The verification scheme for the Automation Tool is unique in that it is focused around what is deemed significant to terminal operations from a weather threshold perspective. Because of this, the Automation Tool verifies 4-hr TAFs based on airport specific weather thresholds from a Mitre Benchmark Report (see Appendix A – Airport-Specific Weather Thresholds). The thresholds, for ceiling and visibility, are categorized as IFR, marginal, and optimal conditions. The Automation Tool determines the category observed in the METAR and compares this to the category which was forecast in the 4-hr TAF's predominant conditions (i.e., excluding the TEMPO category). Essentially, if the categories do not align, the Automation Tool counts the occurrences as a categorically missed forecast. Since there are three categories, the forecast is recorded as being exact, off by one threshold, or off by two thresholds. This threshold strategy was leveraged to account for weather phenomena impacting the Core NAS terminals in different ways. Winds are also verified in the Automation Tool. For the verification of winds, the Automation Tool uses the same direction and magnitude thresholds for all Core terminals. If the forecast is not within the same threshold as the observation, then it is considered off by one threshold level. The color coding and results of the threshold accuracy can be seen on the daily assessment figure in the following pages.

3.1 Daily Assessment

The daily assessment tab of the Automation Tool provides the highest resolution of detail possible. On a daily basis, assessments (see Figure 2) are developed for every Core terminal that implemented a TMI the previous day. Through this page, stakeholders have access to the TMIs for each day, their associated durations, and how the forecast versus observed weather verified for every hour of TMI issuance. This view specifically includes information such as the type(s) and duration (hours of the day) of the TMI, the airport impacted, the TMI reason, the FAA advisory number for the TMIs, and 4-hr TAF and METAR observations.

The daily assessment view is also the location where the verification scheme, as discussed in the previous section takes place. As illustrated in Figure 2, yellow highlighted boxes are where the 4-hr TAF was off by one threshold in comparison to the METAR observation while red denotes that it was off by two thresholds. Regardless of the reason for the TMI, every element (ceiling, visibility, wind direction, and wind magnitude) are assessed and evaluated in this manner. Aviation stakeholders reviewing performance data from the previous day can easily evaluate if the 4-hr TAF forecast was accurate, and if not, which elements of the TAF may have been the reasons for concern.



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Date	Hour (Z)	GS/GDP	CNX	Airport	ADZY	TMI Reason	METAR Vis (sm)	METAR Wind Dir	METAR Wind Speed	METAR Ceiling	METAR Sig Wx	TAF Vis (sm)	TAF Wind Dir	TAF Wind Speed	TAF Ceiling	TAF Sig Wx
2012-10-19	16	GDP		KLGA	34 52	WEATHER / LOW CEILINGS	4	160	13 G23	BKN008	-RA BR	4	120	13	OVC015	-RA
2012-10-19	17	GDP		KLGA	34 52	WEATHER / LOW CEILINGS	2	160	16 G27	BKN011	+RA BR	4	120	13	OVC015	-RA
2012-10-19	18	GDP		KLGA	34 52	WEATHER / LOW CEILINGS	6	150	12 G21	BKN010	-RA BR	6	150	13	OVC015	-RA
2012-10-19	19	GDP		KLGA	34 52	WEATHER / LOW CEILINGS	8	170	13 G16	OVC008	-RA	6	160	10	OVC025	BR
2012-10-19	20	GDP		KLGA	34 52	WEATHER / LOW CEILINGS	8	170	9 G14	OVC013		6	160	10	OVC025	BR
2012-10-19	21	GDP		KLGA	34 52	WEATHER / LOW CEILINGS	8	150	8	OVC011		6	160	10	OVC025	BR
2012-10-19	22	GDP		KLGA	34 52	WEATHER / LOW CEILINGS	>6SM	180	7 G15	BKN009		6	170	8	BKN025	BR
2012-10-19	23	GDP		KLGA	34 52	WEATHER / LOW CEILINGS	9	170	8	BKN007		>6SM	170	8	BKN025	
2012-10-20	00	GS/GDP		KLGA	5 34 52	WEATHER / LOW CEILINGS	8	160	8	BKN005		>6SM	170	8	BKN025	
2012-10-20	01	GS/GDP	CNX	KLGA	5 34 52	WEATHER / LOW CEILINGS	2	160	12 G16	BKN005	BR	>6SM	170	8	BKN015	
2012-10-20	02	GS/GDP	CNX	KLGA	5 34 52	WEATHER / LOW CEILINGS	2	190	6 G16	OVC003	BR	>6SM	170	8	BKN015	
2012-10-20	03	GDP	CNX	KLGA	34	WEATHER / LOW CEILINGS	2	VRB	5	OVC003		4	180	5	BKN008	BR
2012-10-20	04	GDP	CNX	KLGA	34	WEATHER / LOW CEILINGS	3	160	6	No CIG	BR	4	180	5	BKN008	BR

Thresholds								
	Optimum		Marginal		IFR			
Airport	Ceiling	Visibility	Ceiling	Visibility	Ceiling	Visibility	Wind Direction	Wind Speed
KLGA	>= 3200	4	>= 1000	3	< 1000	3	30 Deg Delta	12 kts Delta

Legend	
Range	Color
Diff of 2 or more threshold levels	
Diff of 1 threshold level	

Figure 2: Example of Daily Assessment

3.2 Daily Recap and Monthly Overview

Information from the daily assessment view is used to feed the other two views that are available in the Automation Tool, the daily recap and the monthly overview. The intent of both these views is to provide aviation stakeholders with quick-glance views of the terminals that were in TMIs on any given day and the associated 4-hr TAF performance.

The daily recap (see Figure 3) provides a daily summary of the TMIs that were issued. It specifically highlights the TMI impacted airport(s), the type/classification and timing of the TMIs, the reason for TMI issuance, and the advisory number. The advisory number is linked to the FAA advisory website for easy access to more specific information about the TMI such as the arrival rate or the number of times the TMI was amended. The other key piece of information in the daily recap is the overall weather forecast assessment, which is a metric that is driven by the color-coded boxes from the daily assessment tab. The intent of the overall weather forecast assessment is to provide a quick-glance analysis on the 4-hr TAF performance for theday of interest. The color shading of the box indicates the percentage of forecast elements that were off by one or more threshold value. In addition, the 4-hr TAF included in the assessment is based on the reason for the TMI. For example, if the reason for implementing a TMI is ceiling or visibility, both the ceiling and visibility elements of the 4-hr TAF are used to determine the color coding appropriate for the categorization. Specifically, if a TMI was implemented for ceilings from 16z-20z, the number of missed ceiling and visibility 4-hr TAF forecast periods within the 16-20Z time period would be summed up and divided by the total number of forecast opportunities, which is 10 (5 time slices for ceiling and 5 time slices for visibility). If wind is the reason for the TMI, then wind magnitude and direction are the elements driving the categorical differences assessment. Finally, if multiple reasons are given, then all elements within the 4-hr TAF are used to determine the color coded assessment (e.g., the TMI reasoning could be ceilings and wind). As exemplified through the overall weather forecast assessment metric in Figure 3 for October 19, 2012, there were more forecast misses for Boston Logan International (BOS), Charlotte Douglas International (CLT), Newark Liberty International (EWR), John F. Kennedy International (JFK), LaGuardia (LGA), and Philadelphia International (PHL) than the other airports that had TMIs issued for this particular day. This assessment metric therefore allows stakeholders a quick glance view regarding the 4-hr TAFs forecast and its accuracy during the active TMI issuance periods.

Yesterday Summary - 2012-10-19

Overall Weather Forecast Assessment	Airport	From	To	Reason	Type	ADZY
	KBOS	19 - 1923Z	20 - 0259Z	WEATHER / LOW CEILINGS	GDP	46
	KBWI	19 - 2203Z	20 - 0259Z	WEATHER / THUNDERSTORMS	GDP	55
	KBWI	19 - 2340Z	20 - 0045Z	WEATHER / THUNDERSTORMS	GS	70
	KCLT	19 - 1204Z	19 - 1330Z	WEATHER / LOW VISIBILITY	GS	16
	KCLT	19 - 1204Z	19 - 1415Z	WEATHER / LOW VISIBILITY	GS	23
	KDCA	20 - 0045Z	20 - 0145Z	WEATHER / THUNDERSTORMS	GS	6
	KDCA	20 - 0115Z	20 - 0215Z	WEATHER / THUNDERSTORMS	GS	16
	KDCA	19 - 2330Z	20 - 0045Z	WEATHER / THUNDERSTORMS	GS	68
	KEWR	19 - 1430Z	20 - 0359Z	WEATHER / LOW CEILINGS	GDP	29
	KEWR	19 - 1430Z	20 - 0359Z	WEATHER / LOW CEILINGS	GDP	42
	KEWR	19 - 1430Z	20 - 0359Z	WEATHER / LOW CEILINGS	GDP	49
	KJFK	19 - 1800Z	19 - 2059Z	WEATHER / LOW CEILINGS	GDP	39
	KJFK	19 - 2208Z	19 - 2330Z	VOLUME / VOLUME	GS	56
	KLGA	20 - 0028Z	20 - 0130Z	WEATHER / LOW CEILINGS	GS	5
	KLGA	19 - 1600Z	20 - 0359Z	WEATHER / LOW CEILINGS	GDP	34
	KLGA	19 - 1600Z	20 - 0159Z	WEATHER / LOW CEILINGS	GDP	52
	KORD	19 - 1200Z	19 - 1859Z	WEATHER / LOW CEILINGS	GDP	8
	KPHL	19 - 1146Z	19 - 1300Z	WEATHER / LOW CEILINGS	GS	14
	KPHL	19 - 1400Z	19 - 2059Z	WEATHER / LOW CEILINGS	GDP	26
	KPHL	19 - 1400Z	19 - 1959Z	WEATHER / LOW CEILINGS	GDP	38
	KPHL	19 - 1400Z	19 - 2159Z	WEATHER / LOW CEILINGS	GDP	43
	KSFO	20 - 0122Z	20 - 0759Z	WEATHER / FOG	GDP	18
	KSFO	19 - 1500Z	19 - 2259Z	WEATHER / LOW CEILINGS	GDP	28
	KSFO	19 - 1500Z	20 - 0059Z	WEATHER / LOW CEILINGS	GDP	45

Legend

Percentage Of Category Differences	Color
0-24%	
25-49%	
50% and above	

Figure 3: Example of Daily Recap View

The monthly overview view (see Figure 4) provides an archived snap shot of TMI issuances over the course of a month along with the categorical assessment described in the previous section. The data is presented in a monthly calendar view with information regarding the types and reasons for TMIs as well as how the forecast performance was for the duration of the TMI. The color coded boxes in the monthly overview is the overall weather forecast assessment from the daily recap. The monthly overview allows stakeholders to quickly look historically over the course of the year to determine days which were particularly problematic for the NAS, both from the perspective of weather forecast performance as well as overall weather impact causing issuances of TMIs. In the example below, October 2nd and 19th stand out as difficult ceiling and visibility days for the NAS which potentially highlights days to investigate further for end of season review lessons learned or other examination points to enhance system operations.

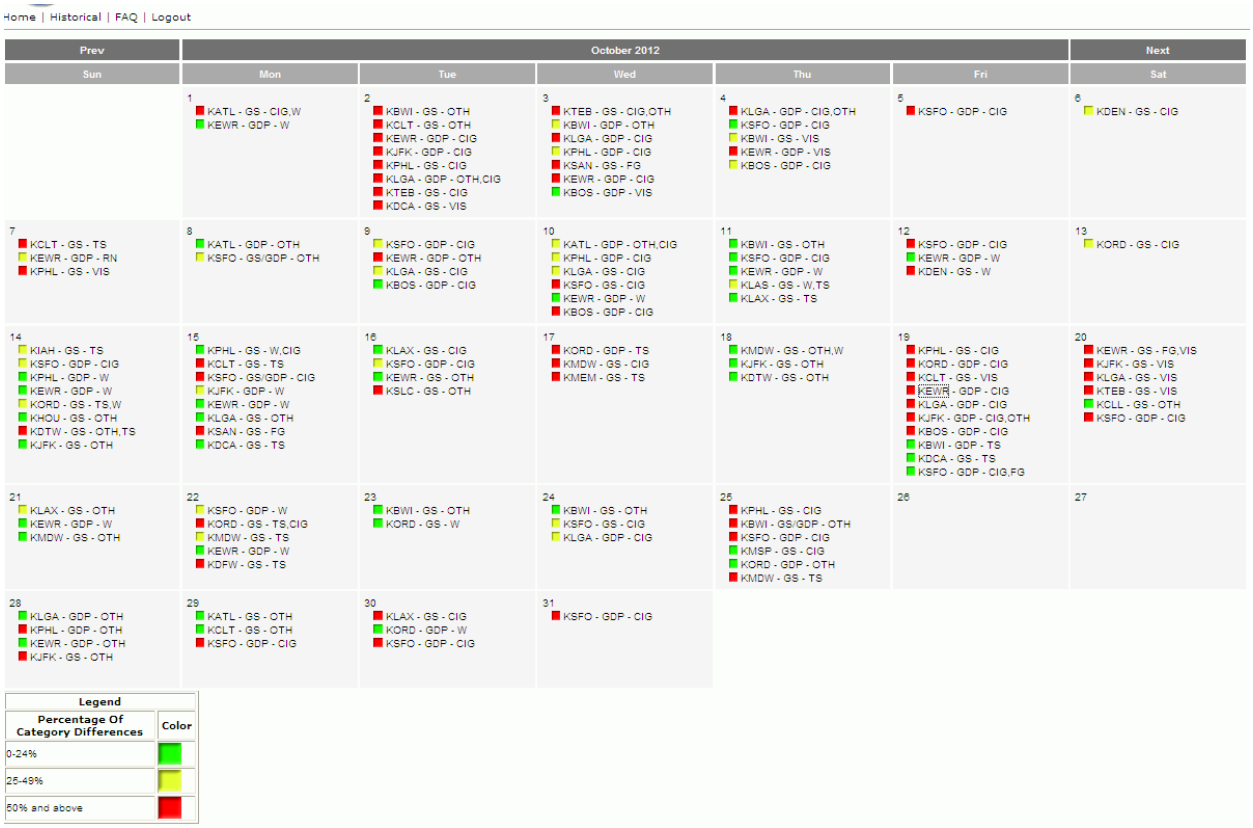

Figure 4: Example of Monthly Overview

4 RESEARCH AND ANALYSIS

The Automation Tool has immediate access to archived TMI issuance information, weather observations and weather forecasts via the TAF. Because of the availability of these datasets, an additional benefit aside from support of next day TMI and 4-hr TAF forecast analysis is the ability to use the Automation Tool to research key areas associated with the interactions between weather, weather forecasts, and TMI issuance. The types of analyses that could be conducted using this information would help to inform both the weather and aviation communities on where focused research efforts could take place to enhance and improve upon system operations. One example of the types of research that could take place is highlighted in Figure 5. Using the results from the Automation Tool, the results shown in Figure 5 highlight the occurrences of 4-hr TAF ceiling forecast errors within TMI active period for a select number of New York metro airports (i.e., EWR, LGA, and JFK). The results of this analysis highlight that while low ceilings occur on a lower frequency during the 09z-12z hours (x-axis) the forecasts are less accurate during those periods (TMI active period counts are on the y-axis). This analysis shows that over half of the time periods when low ceilings occurred, the forecasts were off by at least one threshold during the 09z-12z hours.

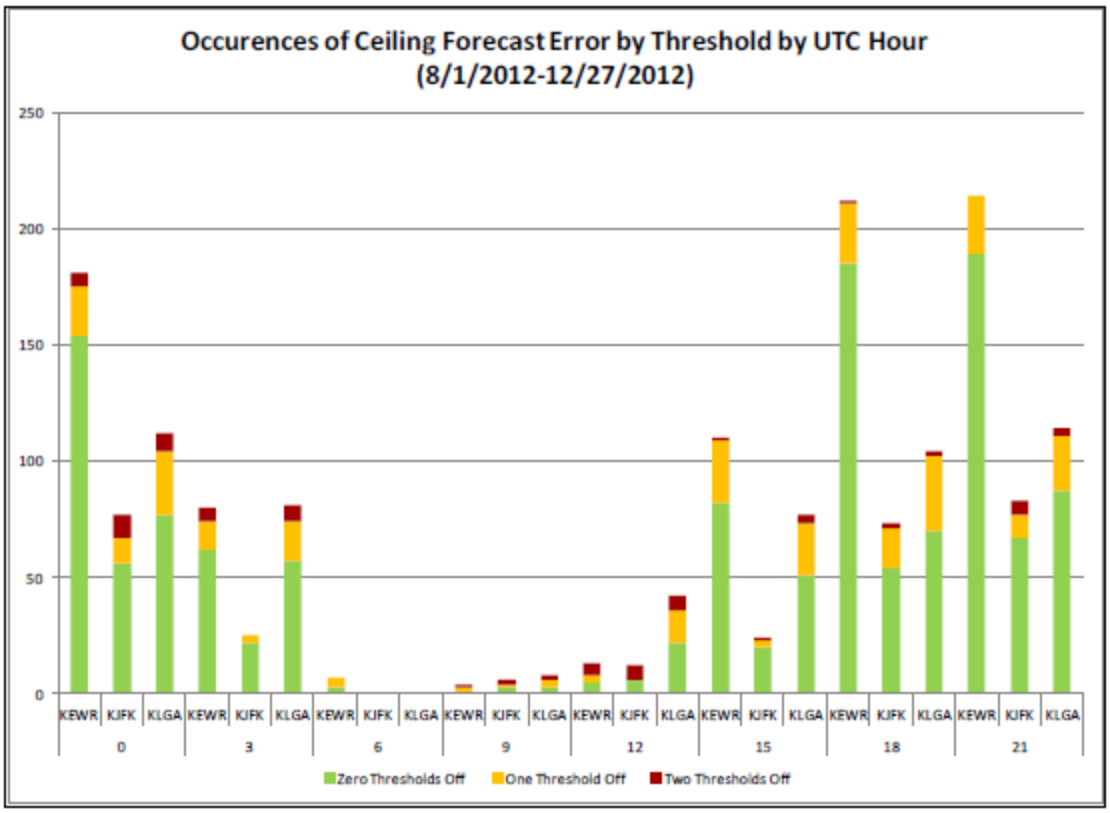

Figure 5: Occurrences of Ceilings Forecast Error by Hour

Armed with type of analysis and information, various communities (including the NAS planners, aviation stakeholders, and the forecasting entities) can recognize that early morning low ceiling events that could pose unanticipated (from a forecasting perspective) threats to New York terminal operations. Additional research using the tool could be focused in directions framed as how the weather forecast impacted the outcome, implementation/cessation times, and/or arrival rate selection of the TMI; how observed weather impacted the duration of the TMI; during what season and/or time of the day are certain weather phenomena more of a problem for Core Airports in the NAS; etc.

5 FUTURE ENHANCEMENTS

The Automation Tool fulfilled an immediate next-day verification need for the FAA by providing a fully-automated, weather forecast-evaluation tool focused around daily TMIs. There are a number of immediate enhancements that could be incorporated into the tool. Specifically in regards to the TAF, the incorporation of 2-hr and 6-hr lead time forecasts would provide significant value in evaluating the resolution of a forecast and how it may have changed leading up to the weather event. This enhancement would provide a more detailed view of the weather community interactions and allow for additional insight into weather forecast lead time requirements for TMI issuance. Additionally, temporary conditions (TEMPO groups within the TAF), because of their complex nature of verification, are not included in the forecast assessment nor flagged in the tool. Flagging and analyzing when TEMPO groups are present within the TAF and including this piece into the assessment metrics will add to the value of the tool.

Aside from these more immediate enhancements, the future intent of the Automation Tool is to continue to integrate this tool into the post-analysis framework of the aviation operations and weather forecasting in order to provide a location where stakeholders can evaluate an objective analysis of weather verification and its associated correlation to aviation impacts (specifically the TMIs). In order to accomplish this task, the vision is to incorporate hourly airport-specific impact metrics such as hourly diversions, hourly holding, arrival/departure rates, and aircraft arrivals/departures. These metrics,

and many others, could be integrated into the assessment scheme which would allow users to recognize days with various weather elements and their associated varying levels of impact. The addition of such metrics would allow for the development of additional measurements that correlate air traffic impact with weather observations and forecasts which would further increase post-analysis common situational awareness amongst aviation stakeholders. Additional research can be then conducted on the baseline airport-specific weather thresholds that are currently used. Also, the Automation Tool is currently focused around the TAF and its interactions with GDPs and GSs. The addition of other weather products that are specific to terminal operations could be incorporated. Finally, thus far the focus has been on terminal operations, but the inclusion of Airspace Flow Programs (AFP) and the associated weather products used to issue such TMIs would prove of additional value for aviation stakeholders. These enhancements will allow for the Automation Tool to continue providing objective assessments of the weather when in matters most to NAS operations.

6 ACKNOWLEDGEMENTS

This project was funded by the FAA's System Operations

APPENDIX A – CORE 29 AIRPORT-SPECIFIC WEATHER THRESHOLDS

	Optimum		Marginal		IFR			
Airport	Ceiling	Visibility	Ceiling	Visibility	Ceiling	Visibility	Wind Direction	Wind Speed
LGA	>=3200	4	>=1000	3	<1000	3	Off by more than 30 degrees	Off by more than 12 knots
JFK	>=2000	4	>=1000	3	<1000	3		
EWR	>=3000	4	>=1000	3	<1000	3		
PHL	>=2300	4	>=1000	3	<1000	3		
ATL	>=3600	7	>=1000	3	<1000	3		
BOS	>=2500	3	>=1000	3	<1000	3		
BWI	>=2500	5	>=1000	3	<1000	3		
DCA	>=3000	4	>=1000	3	<1000	3		
IAD	>=3000	7	>=1000	3	<1000	3		
ORD	>=1900	3	>=1000	3	<1000	3		
SFO	>5000	8	3500 - 5,000	5	<3500	5		
CLT	>=3600	5	>=1000	3	<1000	3		
DEN	>=2000	3	>=1000	3	<1000	3		
DFW	>=3500	5	>=1000	3	<1000	3		
DTW	>=3000	5	>=1000	3	<1000	3		
FLL	>=4000	5	>=1000	3	<1000	3		
IAH	>=4000	8	>=1000	3	<1000	3		
LAS	>=5000	5	>=1000	3	<1000	3		
LAX	>=2500	3	>=1000	3	<1000	3		
MCO	>=2500	3	>=1000	3	<1000	3		
MDW	>=1900	3	>=1000	3	<1000	3		
MEM	>=5000	5	>=1000	3	<1000	3		
MSP	>=5000 or >=3500	7 or 10	>=1000	3	<1000	3		
PHX	>=4500	10	>=1000	3	<1000	3		
SAN	>=2000	3	>=1000	3	<1000	3		
SEA	>=4000	3	>=1000	3	<1000	3		
SLC	>=5300	3	>=1000	3	<1000	3		
TPA	>=2100	3	>=1000	3	<1000	3		
OTHER	>=3200	4	>=1000	3	<1000	3		