J3.9 HUB FORECAST PROTOTYPE TEST

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1. INTRODUCTION AND BACKGROUND

The National Weather Service (NWS) has recognized gaps in the services provide by the Center Weather Service Units (CWSUs) and the need for change (NWS, 2003, 2005; Johnston and Ladd, 2004). These changes are necessary in order to capture improvements in weather forecasting as well as utilize new technology (Mass, 2002) that has become available to both the private sector and the NWS.

Each Traffic Management Unit (TMU) of the Air Route Traffic Control Centers (ARTCCs) require current knowledge of adverse weather conditions and weather forecasts for en route and terminal conditions. Moreover, this information is also needed by TMUs operating in TRACONs and selected towers that are physically removed from the Centers. The traditional point-of-delivery for this information is the network of CWSUs and text messages of current weather at terminals (METARs).

The traditional weather forecast product for terminals is a TAF—a 24 hour forecast of traditional meteorological variables, updated every 6 hours. However, TAFs are not well-matched to the current needs that have evolved for Air Traffic Control (ATC) and Traffic Flow Management (TFM). Moreover, the skill of these forecasts has not improved in decades (NWS 2005). The modern airspace is crowded and flight time is short. The managers of the National Airspace System (NAS) need more accurate, precise, consistent and more frequent weather forecast products.

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Proposed improvements of CWSU operations (Rodenhuis and Sims, 2004) include a description of an Interactive Weather Briefing (Rodenhuis, 2004). The foundation for such a concept is a suite of weather forecast products that are immediately useful for traffic management. Three Prototype Tests are needed to prove the concept: terminal products, en route products and a communication system to bring both traffic managers and weather forecasters to a common understanding of weather impacts on and TFM. The first, a prototype Hub Forecast by meteorologists is designed to meet the needs of users in the FAA who manage the NAS, and of dispatchers at commercial airlines who plan flight operations.

2. CONCEPT

Managers and users of the NAS make critical decisions based on estimates of ***capacity*** of the terminal system. The current concept for traffic management at Traffic Management Units (TMUs) is to conduct TFM based on estimated aircraft arrival rates (AARs) determined from the experience of tower operators after reading current weather conditions and the terminal weather forecasts (TAFs). This concept is adequate for terminals of low traffic density or for operations in the absence of adverse weather conditions.

However, for airports with large traffic loads (Hubs) where operations exceed 1% of the national operations, this concept is inadequate. Under these conditions TMUs may utilize unrealistic arrival rates that are unnecessarily conservative in order to maintain safety. The AAR is strongly influenced by weather conditions, runway configuration, and surface conditions. The judgment of the operator also depends on local terrain, type of aircraft, the mix of arrival/departures and recent experience.

For the first time, the Hub Forecast has utilized terminal weather forecasts and known surface conditions on designated runway configurations to estimate terminal capacity (AAR) that is needed for decision-making by users. The intended users of the products are the Traffic Management Unit (decision makers) and the Center Weather Service Units (providers of forecasts) that are located at Air Route Traffic Control Centers (ARTCCs) and TRACONs.

Of course, operational users will continue to use the sanctioned forecast products at terminals (TAFs), notwithstanding the existence of an improved forecast for selected hubs

The potential of this new forecast for TFM is quite independent of an IWB or the existence of CWSUs. Nor does this product necessarily depend on the use of experienced forecasters, since it can be improved and automated (Vislocky and Fritsch, 1993; Leyton and Fritsch, 2005), as suggested recently for public weather forecasts by Baars and Mass (2006).

3. DESCRIPTION

The Hub Forecast is a terminal forecast of essential weather variables, updated every hour, and includes a Tactical Decision Aid (TDA): an estimate of the primary impact variable, the aircraft arrival rate, associated with the weather forecast and the chosen runway configuration. All this information is presented on a graphical user interface with supporting weather information **(Figure 1a,b)**

4. OBJECTIVE

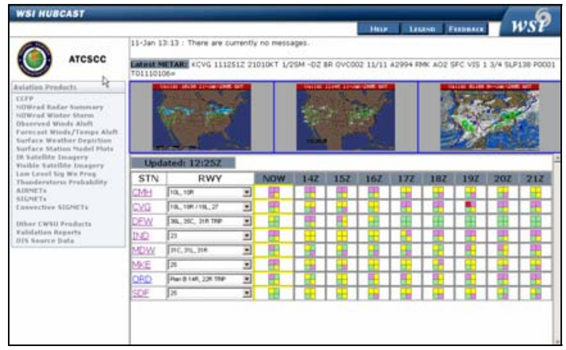
The objective is to *prove the concept* of a new, prototype product, the *Hub Forecast*, including the forecast skill, the adequacy of the GUI, and the utility of the TDA (estimates of actual arrival rate). The Hub Forecast is treated as a stand-alone, prototype product. Proving the concept is a test of the value and potential benefit of prototype terminal products as input to an Interactive Weather Briefing.

The adjacent airspace of ZAU and ZID were selected for the Prototype Test. A limited selection of terminals were identified for the test:

Hubs: ORD, MDW, CVG, DFW[1]
Terminals: IND, CMH, MKE, SDF

[1] - DFW is outside the test areas of ZAU and ZID, but ZFW/CWSU was considered to be a valuable source of feedback (reaction), and we sought their interest by producing a Hub Forecast for DFW.

a)



(b)

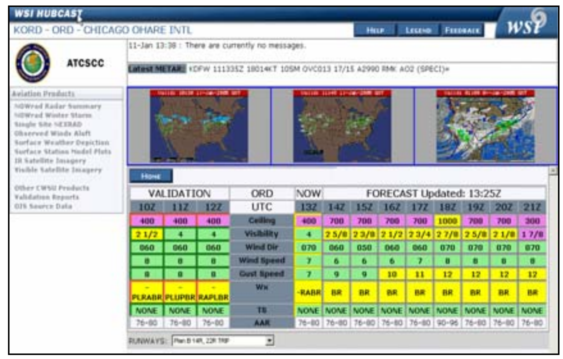


Figure 1 – Examples of the presentation (Graphical User Interface) of the Hub Forecast. (a) For all Hubs: the current observations and an overview of the forecast out to 8 hours; (b) For one Hub: the validation of the forecast for the past 3 hours, and a detailed forecast out to 8 hours. The estimate of capacity (aircraft arrival rate) is given on the last row, depending on the choice of runway configuration and condition (bottom of the display).

The Hub Forecasts were intended for the following Traffic Management Units:

ARTCCs: ZAU, ZID
TRACONs: ORD, CMH
National: ATCSCC

The configuration for a Prototype Test of the Hub Forecast is shown in **Figure 2.**

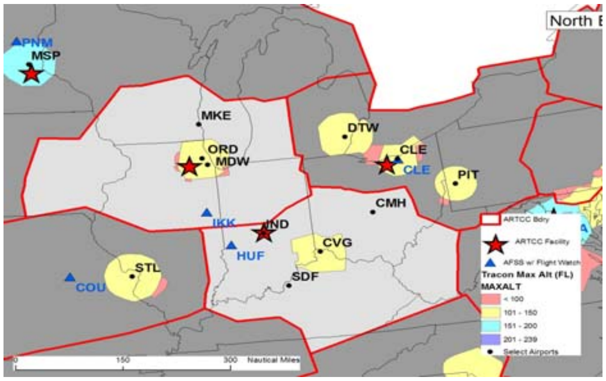


Figure 2 – The configuration for the Prototype Test

Specific questions to prove the concept of the Hub Forecast are:

1) Is the Hub Forecast equal or better to the current terminal forecast (TAF)?
2) Is the increased updating frequency of the Hub Forecast of value?
3) Is an awareness of the weather forecast impacts on estimated arrival rate (as defined by the TDA) useful to weather forecasters and traffic managers?
4) Does the graphical user interface present quick-glance value for traffic managers who must integrate weather and terminal capacity for decision-making?

Subsequently, during the period (September 2004 – April 2005) the OST[2] contractor completed the preliminary research on hub arrival rates, and the WSI[3] contractor performed planning and training. During the operational phase (1 February – 30 April, 2005), WSI produced the Hub Forecasts (15 hours/day x 5 days/week) and the users in the centers were given an opportunity to evaluate the user interface. OST collected the user responses, and WSI performed a systematic, quantitative verification.

5. AIRCRAFT ARRIVAL RATES AND OBSERVED WEATHER

The critical element of the Hub Forecast is to connect forecast weather variables with Aircraft Arrival Rates (AAR). For this purpose, historical AAR can be related to concurrent weather (METARs). Some work has already been produced in the Capacity Benchmark Report by MITRE-CAASD (2004). However, those results are not sufficiently detailed for the present purpose.

Therefore, the runway configuration for each of the 8 terminals was determined. Subsequently, the relationship between adverse weather and capacity (actual arrival rate) is estimated from FAA Operational Information System (OIS), and the results subjectively confirmed and adjusted after interviews with tower operations. The Capacity Benchmark Report was used as a gross check. The adverse weather at terminals is defined by 7 variables:

- Height of cloud ceiling
- Prevailing visibility
- Winds (speed, direction, gusts)
- Weather phenomena
- Probability of thunderstorms

The relationship between actual aircraft arrival rate and categories of adverse weather are different for each terminal and for each runway configuration; for example, the ceiling/visibility threshold for Visual Operations (for all runway configurations) at different terminals were:

ORD	1900 ft. and 3 miles
DFW	3500 ft. and 5 miles
CVG	3000 ft. and 7 miles.

An example for CVG terminal is shown in **Table 1.**

An assessment of these results and their use in practice shows that the relationship between weather and actual operating conditions (throughput) is uncertain, even when the runway selection is specified. However, there is plentiful data for analysis that could be used in a subsequent analysis to stratify the observations into (runway configuration, weather category, actual arrival rate). From this analysis the mean, max, and range of AAR could be determined. These improved empirical relationships would increase the value of the Hub Forecasts.

[2] - Optimal Solutions and Technologies, Washington, DC.
[3] - Weather Services International, Herndon, VA.

Runway	Green – Vis Approach		Yellow – VFR , Blo Vis		Purple – IFR		Red – Below Mins	
Land / Depart	Ceil	Vis	Ceil	Vis	Ceil	Vis	Ceil	Vis
18L, 18R **/** 18L, 27	≥3000	≥7	<3000	<7	<1000	<3	<200	<½1/2
AAR	**75**		**72**		**72**			
18L, 18R **/** 18L, 18R	≥3000	≥7	<3000	<7	<1000	<3	<200	<½1/2
AAR	**60 - 65**		**60 - 65**		**60**			
18L, 18R **/** 27	≥3000	≥7	<3000	<7	<1000	<3	<200	<½1/2
AAR	**60**		**60**		**60**			
36L, 36R / 36L, 27	≥3000	≥7	<3000	<7	<1000	<3	<200	<½1/2
AAR	**72**		**72**		**72**			
36L, 36R / 36L, 36R	≥3000	≥7	<3000	<7	<1000	<3	<200	<½1/2
AAR	**60-65**		**60-65**		**60**			
36L, 36R / 27	≥3000	≥7	<3000	<7	<1000	<3	<200	<½1/2
AAR	**60**		**60**		**60**			
18L, 18R Staggered	≥3000	≥7	<3000	<7	<1000	<3	<200	<½1/2
AAR	**72**		**72**		**48**			
36L, 36R Staggered	≥3000	≥7	<3000	<7	<1000	<3	<200	<½1/2
AAR	**72**		**72**		**48**			
Any Single Runway	≥3000	≥7	<800	<2	≥800	≥2	<200	<½1/2
AAR	**36**		**32**		**28**			

Below Minimum AAR rate not shown - it varies considering Cat II-III

Departure runway availability is relevant for AAR purposes at this airport

Table 1 – An example of empirical arrival rates associated with different weather conditions and runway configurations: for CVG.

6. FORECAST SKILL

During the training and test phase (1 February – 30 April 2005) of 64 days, Hub Forecasts were produced 15 hours per day for a total of forecast delivery opportunities. Each delivery time produced 12 forecasts, 1 hour apart, out to 12 hours, for a total of 11,520 forecasts of 7 weather variables at 8 sites, or a potential ***645,120*** Hub Forecasts were produced during a period of 3 months of the operational phase of the Prototype Test.

Adverse weather forecasts were made for ceiling and visibility in the following categories:

- Visual approach
- Visual Flight Rules (VFR)
- Instrument Flight Rules (IFR)
- Category 1 minimum conditions

Categories for the other meteorological parameters were selected as described in the Performance Plan (WSI, 2005).

During operations, the skill of the past 3 hours of forecasting was calculated and presented on the GUI for the user as a measure of confidence or caution when interpreting the current forecast (Section 7).

Furthermore, for the entire operational period of 3 months, Hub Forecasts variables were verified in each category as True/False, and subsequently summarized as percent correct. The results are summarized in the following figures, and presented in full detail in a Validation Report (WSI, 2005).

6.1 *Skill at Leadtime 3 Hours*

Table 2 shows the overall skill (percent correct) for the 7 adverse weather variables with a forecast Lead Time of 3 hours, for all sites. The value of skill for thunderstorms should be disregarded because of the absence of convection during the late winter months. The other variables showed accuracies of greater than 80%, except wind gusts.

WSI Hub Forecast	Overall Skill Score
Thunderstorm	99.61 %
Wind Direction	93.51 %
Wind Speed	92.88 %
Visibility	85.73 %
Ceiling	84.28 %
Weather	80.89 %
Wind Gust Speed	71.30 %

Table 2 – Skill of the HUB Forecast for each adverse weather variable for all stations (8) and all times (3 months).

6.2 *Influence of Experience*

Prior to the operational phase, training in the use of the interface was conducted. Furthermore, during the first month, an extra effort was made to include other users, listen to feedback, and perform additional training. Nevertheless, a systematic increase in skill at Lead Time of 3 hours was detected in most forecast variables throughout the entire operational phase. **Figure 3** shows this trend for all variables and all sites.

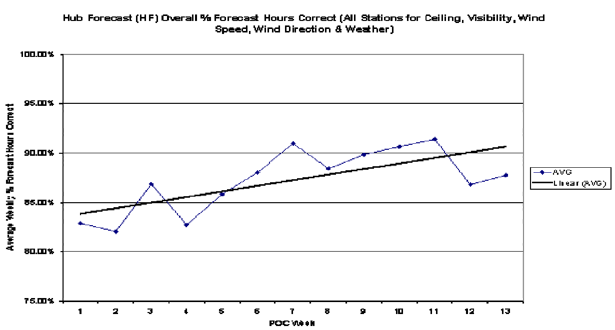


Figure 3 – The increase in skill of the Hub Forecast with Lead Time of 3 hours over the entire period of the operational phase of the Prototype Test.

The results are similar for each weather variable individually. It is assumed, but not proven, that the change of weather conditions from February into April did not change in such a way to become easier to forecast. In fact the development of convection in early spring would make forecasting more, not less difficult. In spite of that, the skill increased. It is concluded that the forecasters became more proficient at producing hourly forecasts and/or adjusting to frequent updates of current weather conditions.

6.3 *Decay of Skill*

The skill results cited above will vary somewhat with leadtime. The decrease in skill, as well as the variance in skill, is shown as a function of Leadtime in **Figure 4**. Data were taken for all terminals, but limited to IFR conditions. Likewise, the visibility parameter is more difficult to forecast and also decreases with Leadtime in **Figure 5.**

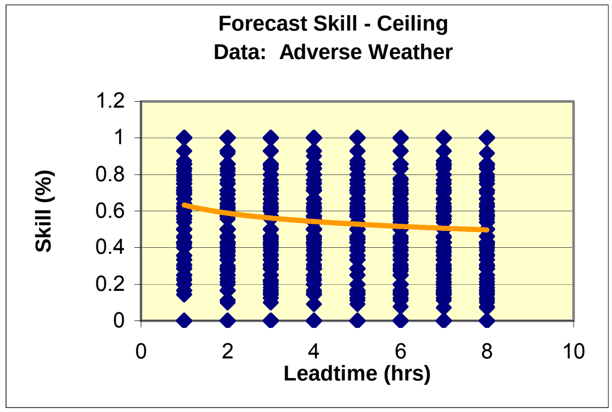


Figure 4 – Decrease in forecast skill of ceiling as a function of Leadtime for IFR conditions; all terminals.

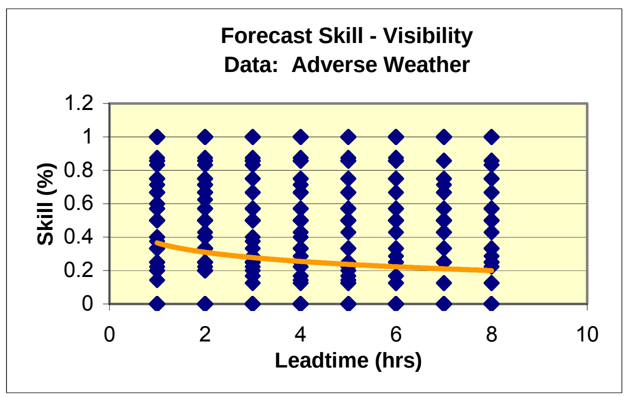


Figure 5 – Decrease in forecast skill of visibility as a function of Lead Time for IFR conditions

6.4 *Comparison of Skill*

For comparison with traditional terminal forecasts the operational TAFs delivered by the National Weather Service Weather Service Forecasts Offices were used. When making this comparison, 2 factors are involved: 1) differential skill of the products, and 2) the competitive advantage/disadvantage of update frequency (1 hour for the Hub Forecast; 6 hours for the TAF, unless amended). For this comparison only the forecasts with a Lead Time of 3 hours are used.

The TAFs at each site were interpolated to the dates/times of the Hub Forecasts following a method described in Validation Report (WSI, 2005). The results were tested for quality by performing the same interpolation of the WSI TAFs that are produced independently. There was no significant difference between the forecasting skill between these two standards, and the interpolation method was judged to be a reasonable comparison.

The skill of the Hub Forecasts compared to the interpolated TAFs is shown in **Figure 6.** Although the results are similar for wind speed and visibility variables, the Hub Forecast has a distinct advantage for the forecasts of ceiling and wind speed. This difference in forecast skill could be a significant advantage in the operation of the terminal.

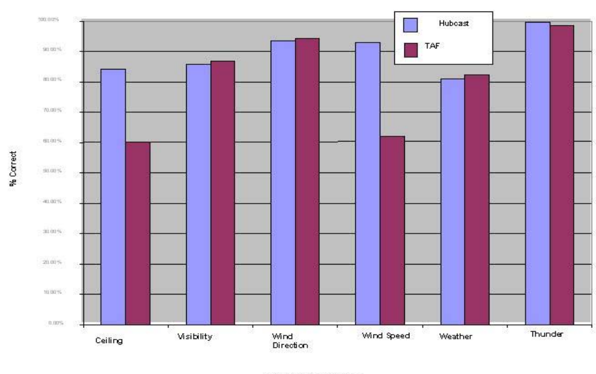


Figure 6 – The skill (percent correct) for Hub Forecasts and the operational terminal forecasts (TAFs). All weather conditions; all terminals; Lead Time is 3 hrs.

Moreover, the superior skill of the Hub Forecasts increases for ceiling forecasts when conditions of only low ceiling/visibility are considered **(Table 3).** For wind speed, the difference in skill remains the same, regardless of the ceiling or visibility.

6.5 *Influence of Location*

The differences between the Hub Forecast and the operational TAF (forecasts of ceiling and wind speed) are apparent at every site within the Prototype Test, at least for the forecasts with 3-hour Lead Time (**Figure 7, 8, 9).** This is an encouraging result that comes from increasing the forecast frequency, and further increases in skill may become apparent at different lead times.

Adverse Ceiling and Visibility (<3000/3)		
	Ceiling	Visibility
Hub Fcst	**52.4%**	60.9%
TAF (NWS)	**24.3%**	64.1%
Note: Wind direction & speed scores changed little from the overall wind scores.		

Table 3 – Skill (percent correct) of the Hub Forecasts of ceiling and visibility for adverse weather (less than 3000 ft. and 3 miles) compared to the operational terminal forecasts (TAFs) produced by the NWS for all sites for the entire operational period. Forecast Lead Time is 3 hours.

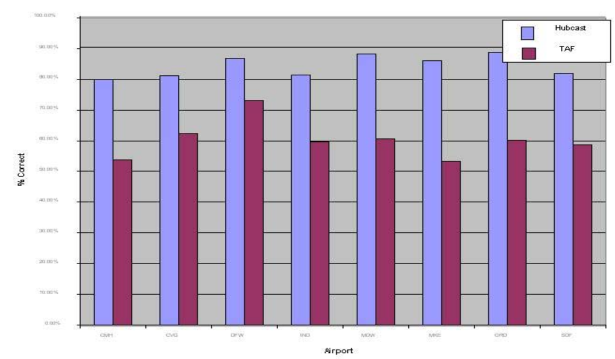


Figure 7 – The improvement in skill of Hub Forecasts of CEILING compared to TAFs for all weather conditions at 8 sites. Lead Time is 3 hours.

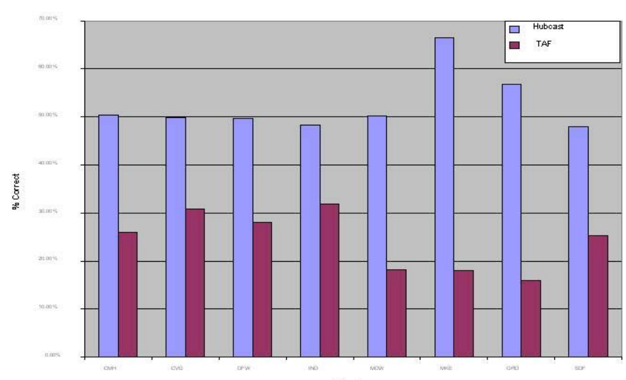


Figure 8 - Same as (a), except only for conditions of low ceiling/visibility (<3000 ft/ 3 miles). Consequently, there is an overall reduction in skill of approximately 30% in both forecast methods.

With Hub Forecasts it is possible to achieve a doubling of skill in the forecast of ceilings, and at least a 50% increase in skill in the forecast of wind speed, at least at a Lead Time of 3 hours. This is an extraordinary result and requires an explanation.

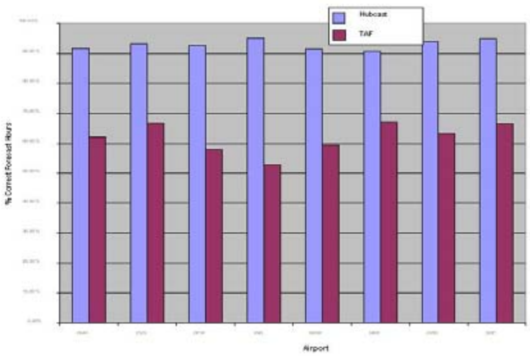


Figure 9 – Same as (a), except for WIND SPEED.

It is apparent that the meteorologists producing the Hub Forecasts showed a steady increase in skill throughout the period (Figure 3). This is consistent with the hypothesis that increases in skill (ceiling; wind speed) are caused by improved monitoring of current conditions and frequent (hourly) updating the forecast; ie, *paying attention and learning by experience and feedback*.

By comparison, the NWS forecasters are located at sites remote from aviation operations and have other responsibilities for "public weather" that competes for their attention. Frequently the responsibility for generating terminal forecasts (TAFs) falls to the least experienced forecaster in the office (personal communication). The forecast is made for large blocks of time at remote sites with no feedback from the actual users.

If this hypothesis is the root cause for improvement of the Hub Forecasts over the operational TAFS, why aren't there commensurate improvements in the forecasts of visibility, wind direction, wind gusts, and weather? The tentative explanation is that these variables contain more natural variability and are more difficult to forecast. Further study is needed to examine the skill of Hub Forecasts as a function of lead-time for all forecast variables.

7. GUI DESIGN AND FEEDBACK

The Graphical User Interface (GUI, Figure 1a,b) was designed to quick-glance value of adverse weather conditions, and to facilitate the impacts of weather on the choice of runway configurations. Thus, the Hub Forecast should be useful to both the CWSU meteorologist and the TMU specialist.

The meteorologist (who knows the weather forecast) can easily see the potential influence on arrival rate, and the traffic manager (who knows the capacity of the terminal from the tower operator) can easily see the potential limitations implied by the weather forecast.

For the evaluation of the forecast products and the presentation on the GUI, an attempt was made to collect the opinion of the users. The "users" fall into different categories, each with a different perspective:

- Traffic Management Specialists represented by NATCA at ARTCCs and TRACONs
- Traffic Management Supervisors at ARTCCs and TRACONs
- CWSU meteorologist at ARTCCs
- ATCSCC National Traffic Management Officers (NTMOs)
- ATCSCC Weather Unit Specialists

In order to attract user feedback, several actions were initiated:

- User Feedback Survey was designed by the OST contractor with input from WSI and the project lead (Attachment A2, Performance Plan).
- a web site was designed for easy submission of the Survey.
- NATCA was briefed and invited to participate.
- Briefings were given to the Managers of Traffic Operations (MTOs) with a request for participation from management and supervisors.
- A POC for the Hub Forecast was identified at every TMU in ARTCCs and TRACONs.
- Personal phone calls and email were used to solicit input from the POCs identified at each ARTCC and TRACON.
- The ATCSCC Weather Unit was informed and invited to participate.

Notwithstanding this effort, the formal response from the users was minimal. The response from the NWS meteorologists was limited because the NWS declined to participate. The response from Traffic Management Specialists was limited because NATCA did not endorse the Prototype

Test. No comments were received from the ATCSCC Weather Unit or NTMOs.

It is impossible to reduce this information to an affirmative statement. However, under the adverse environment in the NWS and NATCA, and under the time limitations of supervisors to evaluate a new product, we can speculate that the Hub Forecast did not solicit an adverse reaction. In fact, personal comments from users indicated a very positive response.

8. CONCLUSIONS

For the first time a prototype product has been designed that brings a terminal weather forecast of essential weather variables together with an estimate of capacity of the terminal (aircraft arrival rate). The Hub Forecast was developed as an element of an Interactive Weather Briefing.

A Prototype Test of the Hub Forecast was conducted, but with several important limitations:

- The short interval of the test period (3 months) prevented a robust statistical response, especially an evaluation of the product during the summer season of convection and thunderstorms.
- The full complement of elements to prove the concept of the Interactive Weather Briefing (IWB) were not present (Hub Forecast, TRACON Forecast, weather briefing, and communications and display System). The Proof of Concept was reduced to a single component: a Prototype Test of the Hub Forecast (an hourly terminal forecast, the Tactical Decision Aid (TDA) and the Graphical User Interface (GUI)).
- The lack of participation by the NWS limited the evaluation and encouraged the direct use of the Hub Forecast by Traffic Management Specialists without the interpretation of CWSU meteorologists.
- The lack of endorsement by NATCA prevented a robust response and feedback.

This imposes some limitation on the interpretation of results. However, it does not impact the primary objective of proving the concept and answering the questions posed (Section 1.2):

- Is the Hub Forecast equal or better to the current terminal forecast (TAF)?

  YES
- Is the increased updating frequency of the Hub Forecast of value?

  YES
- Is an awareness of the weather forecast impacts on estimated arrival rate (as defined by the TDA) useful to weather forecasters and traffic managers?

  QUALIFIED YES, since the relationship between adverse weather and estimated arrival rate has not been made before. Unfortunately, the lack of response from users cannot be taken as affirmation.

- Does the graphical user interface present quick-glance value for traffic managers who must integrate weather and terminal capacity for decision-making?

  PASSIVE YES, although there was insufficient feedback to evaluate the GUI. The lack of response may also be interpreted as an absence of a negative reaction, and this a passive acceptance.

Therefore the concept of a Hub Forecasts has been demonstrated and proved. Beyond the concept, the Prototype Test has demonstrated a substantial improvement in forecast skill in several critical variables for the operation of a hub terminal. This discovery needs further examination.

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