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WEATHER IMPACTED ROUTES FOR THE FINAL APPROACH SPACING TOOL (FAST)*

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ABSTRACT

This paper addresses the issue of developing weather-impacted routes for the Final Approach Spacing Tool (FAST). FAST relies on adaptation data that includes nominal terminal area routes and degrees of freedom to generate optimum landing sequences and runway assignments. However, during adverse weather some adapted routes may become unavailable due to the presence of hazardous weather. If FAST continues to generate trajectories using these routes, its schedule will not be accurate during the adverse weather. The objective of the study was to determine methods for incorporating severe weather products and weather-impacted route data into FAST.

INTRODUCTION

Increasing air traffic demand in the face of limited runways and airspace has made improving the efficiency of the nation's air traffic system one of the Federal Aviation Administration's (FAA) top priorities [1]. New decision support tools are being developed to assist Air Traffic Controllers and Traffic Managers in achieving these efficiency gains while maintaining safety.

One such tool is the Final Approach Spacing Tool (FAST), which is an element of the Center/TRACON Automation System (CTAS) being developed by NASA Ames Research Center. There are two versions of FAST: Passive FAST (pFAST) and Active FAST (aFAST). Passive FAST provides controllers with runway assignments for delay balancing and landing sequence numbers to optimize the landing order. Active FAST additionally provides controllers with heading, speed and altitude advisories to achieve these optimal sequences [2]. Passive FAST has been operationally tested at the Dallas/Ft. Worth International Airport (DFW) and has demonstrated up to a 13% airport throughput increase [3].

Active FAST, which is currently under development, is expected to offer additional increases in airport capacity. For the remainder of this paper, "FAST" will be used generically to refer to both systems.

FAST relies on adaptation data that includes nominal TRACON routes and degrees of freedom to generate optimum landing sequences and runway assignments. However, during adverse weather, some adapted routes may become unavailable due to the presence of hazardous weather. If FAST continues to generate trajectories using these routes, its schedule will not be accurate during the bad weather. The objective of the study was to determine methods for incorporating severe weather products and weather-impacted route data into FAST.

Air Traffic Control (ATC) decision support tools have many sources of weather data. Table 1 outlines some of these data sources and the information supplied.

Since FAST operates in the terminal area, the key source for weather information for this study was the Integrated Terminal Weather System (ITWS). ITWS was developed under FAA support by MIT Lincoln Laboratory (MIT/LL) and is currently being implemented for deployment at 35 locations across the continental United States. ITWS integrates weather data from a variety of sources, including Terminal Doppler Weather Radar (TDWR), Next Generation Weather Radar (NEXRAD), Airport Surveillance Radar (ASR-9), Rapid Update Cycle (RUC) model and surface sensor information. It generates a variety of weather display products for Traffic Management Coordinators (TMCs), controllers, airlines and other users. These products have been operationally tested at several sites including Dallas/Ft. Worth, Atlanta, Denver, Los Angeles and Miami, and have demonstrated significant operational benefits by allowing FAA personnel to improve their ability to manage traffic during bad weather [4].

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This study focuses on the integration and use of various ITWS weather products in FAST. It also addresses the display of an integrated system to the end-user. In this case, identified users of the system would be the Traffic Managers at either the TRACON or the Air Route Traffic Control Center (ARTCC). The italicized ITWS products from Table 1 will be emphasized in this paper.

APPROACH

A study by Rhoda and Pawlak [5] revealed pilot behavior in choosing to penetrate or deviate around hazardous weather depends on several factors. Conventional wisdom is that pilots deviate around Video Integrator and Processor (VIP) level 3 or higher weather. However, in evaluating 1,952 encounters with weather at DFW, it was found that a significant proportion of the encounters (>10%) resulted in penetration of VIP level 3, 4 or 5 weather. It was also found that the closer an aircraft was to the airport, the more likely it would penetrate VIP level 3 or higher weather. A neural net classifier was developed to create Probability of Deviation (PODEV) maps giving the probability of a typical aircraft penetrating a given region of airspace.

With the development of the Terminal Convective Weather Forecast (TCWF), Wolfson, et al. [6] showed a significant increase in skill could be achieved in forecasting the location of VIP level 3 and higher weather for line storms up to one hour in the future. TCWF has been running experimentally at DFW since the summer of 1999. This product is generated in conjunction with the ITWS testbed operated by MIT/LL at DFW. The TCWF has been proposed as a Pre-Planned Product Improvement (P3I) to ITWS.

By applying the TCWF algorithm to the forecasted weather products in ITWS, up to one hour of predicted VIP level 3 or higher weather probability maps at can be generated at 10-minute intervals. The neural net classifier used to create the PODEV maps can then be applied to the TCWF forecasts to generate Forecasted PODEV (FPODEV) maps. The PODEV and FPODEV maps are overlayed with the FAST adapted aircraft routes to generate the probability of weather impact for each route segment from the present to one hour in the future in 10-minute intervals.

An experimental weather and traffic Graphical User Interface (GUI), referred to as the Offline Traffic and Weather Display (OTWD), was developed to facilitate use of the weather-impacted route information. The aircraft, weather products and FAST adaptation routing information are displayed on OTWD. The route segments are color-coded to reflect the probability of weather impact at a particular time. A time slider was created to allow the display of the weather forecast and show the weather impact on aircraft route segments. The user can also select any route segment to determine the onset and duration of hazardous weather.

Table 1. Weather Input Data Types

Data Source	Weather Types	Coverage
ITWS	Winds *Reflectivity* *Probability of Deviation* *Convective Forecasts* Gust Fronts Microbursts	Terminal
NOAA	RUC Winds	CONUS
WSI	Reflectivity Lightning Jet Stream	CONUS
ETMS	Reflectivity Lightning Jet Stream	CONUS

An experimental version of the Airport Configuration Manager (ACM) was developed to facilitate TMC use of the weather-impacted routes information. ACM shows the impact upon the schedule of weather-impacted routes by predicting future airport configuration changes for each adapted airport. This capability alerts the TMC to weather changes in the terminal area that could affect the operation of the airport up to one hour in advance. It also suggests an appropriate future airport configuration based on predicted weather data.

Figure 1 demonstrates possible uses of ITWS weather products in FAST, from acquisition and parsing of the data to predicting impact on aircraft and terminal area operations. ITWS created precipitation maps can be converted into PODEV maps, which then can be used to identify routes and aircraft that are impacted. Delays caused by the hazardous weather can then be considered for ATC decisions such as airspace closures and re-routes. In addition, severe weather forecasts can be used to predict impacted aircraft and routes up to an hour in the future, as well as help determine appropriate future airport configurations. Schedule changes based on the weather forecasts can be utilized by TMCs to facilitate further ATC decisions.

RESULTS

OFF-LINE TRAFFIC AND WEATHER DISPLAY

The identification and display of weather-impacted routes has been developed and demonstrated both on OTWD and on the FAST Planview Display GUI (PGUI), see Figure 2 [3]. Initial evaluation was completed using feedback from MIT/LL in-house controllers resulting in the current GUI design. The development of OTWD promotes the operational concept evaluation by allowing for the rapid prototyping of display modifications. However, the current functionality has only been implemented as a playback system. Additional work is needed to implement these functions into a real-time tool and to evaluate the initial operational concept.

OTWD displays aircraft and FAST terminal area routing, as well as the various weather products. The tool reads FAST generated playback files and synchronizes its internal clock to the data file time. As the weather products are read into the system at the appropriate time, OTWD analyzes the routing structure and weather data to determine the time, duration and severity of impaction on each route segment. These route segments make up the nominal paths aircraft use to fly from the meter fix to each runway threshold.

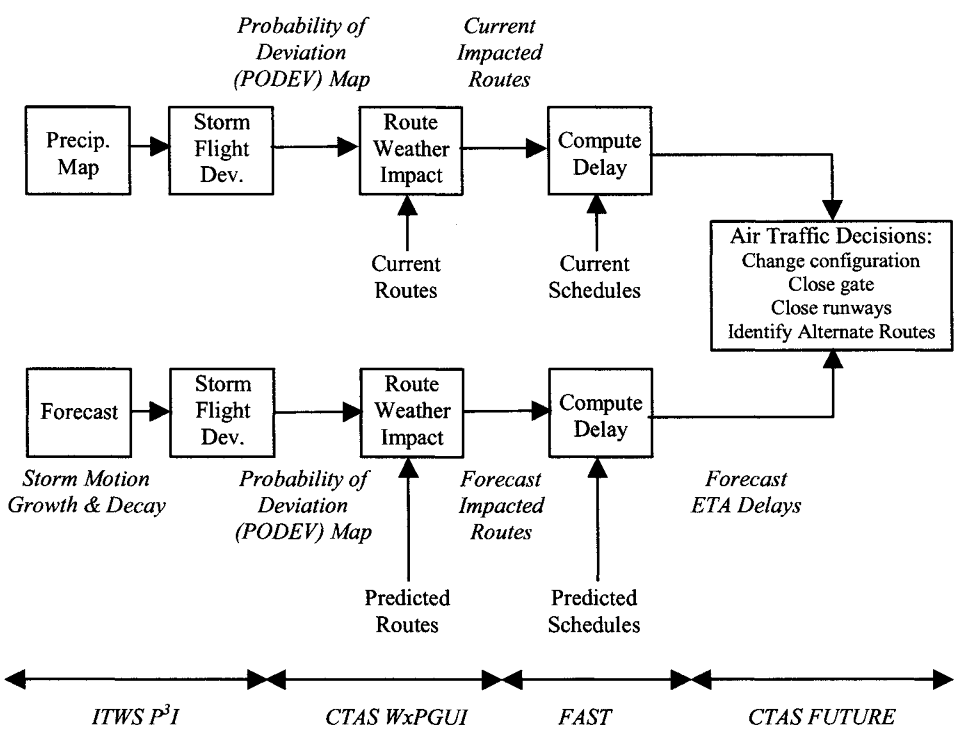

Figure 1. Weather Impacted Routes Processing

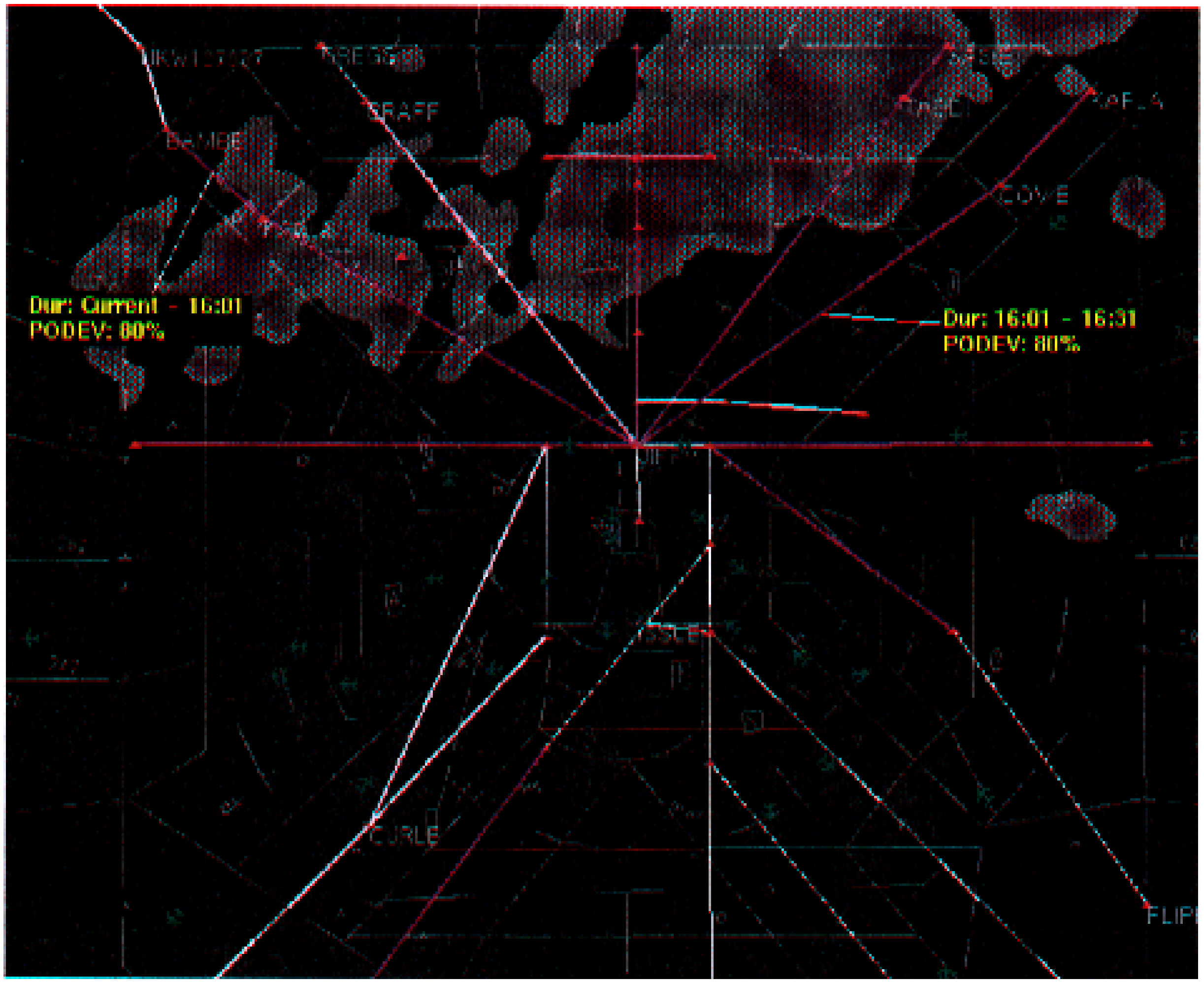

Figure 2. Offline Weather and Traffic Display, 0 Minute PODEV Forecast

Figure 2 shows an example of a PODEV map for the DFW TRACON at 15:53 GMT. The contours range in intensity level from 20% - 100% shown by increasing intensity of shaded areas. Notice the selected route segment starting at the fix "BAMBE". It has a predicted duration of impact from "Current" to 16:01, with a Probability of Deviation of 80%. This means that from 15:53 GMT until 16:01 GMT, a typical flight could be expected to deviate from this route segment 80% of the time. The information displayed for the route segment beginning at "COVIE" shows that starting at 16:01 GMT through 16:31 GMT it will have a PODEV of 80%, though this route segment is not currently impacted by severe weather.

The future weather forecast used to predict the airspace PODEVs can also be displayed on OTWD using the slider bar, as seen in Figure 3. This figure shows the FPODEV at 16:14 GMT, with the traffic data from 15:54 GMT allowing the user to visualize how airspace problems might develop over time. Though not currently part of OTWD, the display of the predicted aircraft positions at the "look ahead" time has been demonstrated and could be beneficial.

Since PODEV maps are derived from 6 VIP level and TCWF data, OTWD is also capable of displaying these data. Figure 4 shows the TCWF for the DFW TRACON. The shaded areas correspond to predicted areas of VIP level 3 or higher weather activity twenty minutes from the current time.

One area of research is to extend TCWF to other areas of the country. TCWF has been tested and works well with Convective storms. However, some areas of the country tend to have more localized thunderstorm cells. Forecasting these types of weather cells is still being researched. Hence, the PODEV and terminal area forecasts for some areas of the country may not be mature enough to predict impacted routes accurately.

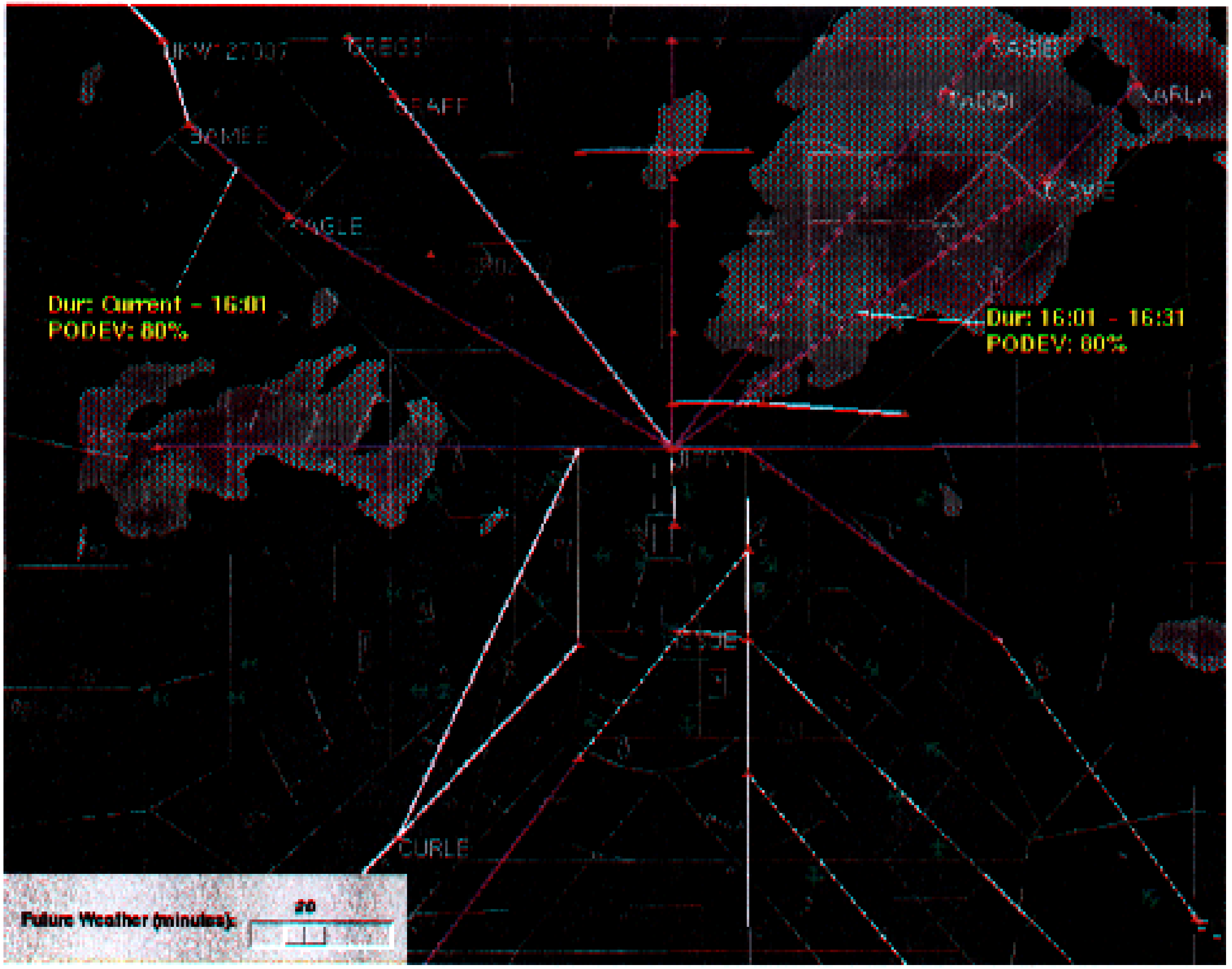

Figure 3. Offline Weather and Traffic Display, 20 Minute PODEV Forecast

AIRPORT CONFIGURATION MANAGER (ACM)

Using the identified impacted routes, an algorithm to help identify the most appropriate airport configuration for the current and predicted weather scenarios was developed. FAST uses the concept of airport configuration not only to identify the actual runways being used for landing, but also to define the different procedures used to control aircraft through the TRACON. Taking the current and forecasted weather information into account, ACM is designed to identify appropriate future configuration changes and determine their time and duration.

The most important aspect for determining the appropriate airport configuration is the condition at the runway threshold. This includes the strength and direction of the wind. However, the ITWS weather data does not currently include terminal area wind predictions. Therefore, the search for future airport configurations is limited to the configurations adapted for FAST with runways landing in the same direction as the current configuration. The algorithm necessarily assumes that the wind direction will remain relatively constant.

First, the current airport configuration is identified. The adapted configurations are searched for others that contain any of the runways used in the current configuration. This forms our basic list of choices for future configuration changes. All runways used by any configuration in this list comprise our selection of possible future runways.

Next, the time when the current runways in use will change needs to be determined. To do so, the adapted final approach segment for each runway from our possible future runways list is examined. For each 10-minute forecast interval over the next hour, it is determined whether each runway is impacted or not. Once the list of forecasted non-impacted runways differs from the runways utilized in the current airport configuration, a future configuration change is identified.

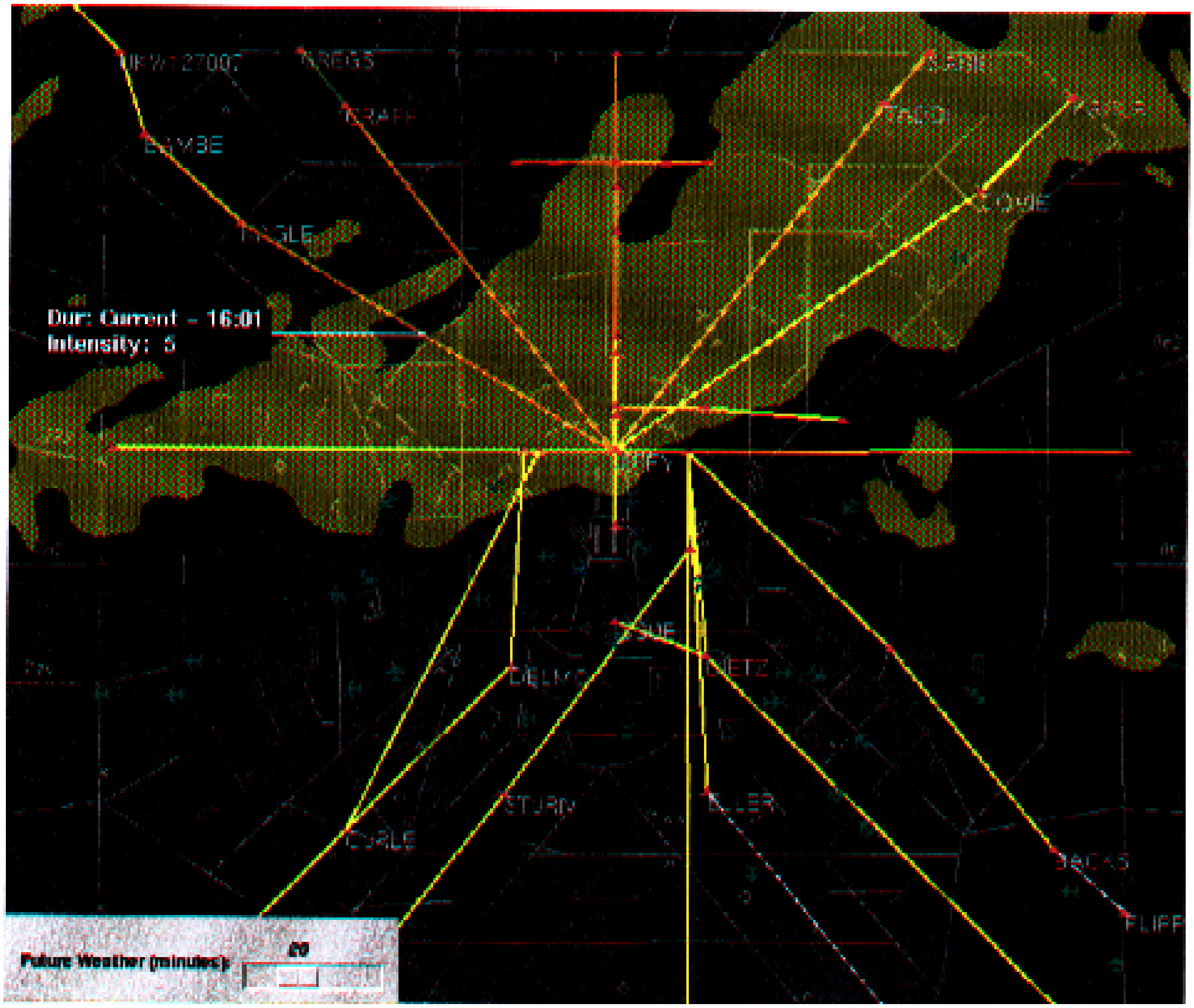

Figure 4. TCWF Display

In practice the changing of airport configurations can be difficult to perform. An arrival aircraft is assigned to a runway upon entering the TRACON. An aircraft can take up to 20 minutes to fly through the TRACON under normal conditions, so changing the airport configuration too often would not be practical. Therefore, future configuration changes are not automated in the system. Instead, a possible change is indicated, and the Traffic Managers can use the information to determine the best course of action.

NEXT STEPS

Immediate next steps include implementing a real-time version of the OTWD at DFW. One component of the implementation would be to create the infrastructure and interface to the real-time ITWS data at DFW. Integration work has already begun for the ingestion of ITWS wind data to augment the RUC forecast data. The inclusion of additional weather products would be straightforward to implement. PODEV maps are currently not included in the operational ITWS system and either another source of these maps would need to be created, or the software to create the PODEV maps would need to be integrated into FAST. Once the impacted route software is in place, the value of AMC could be evaluated using operational TMCs at the DFW TRACON.

The use of ITWS wind forecasts to help manage the airport configuration could also be investigated. As stated above, ACM uses the runways available for aircraft landing in the current direction to determine future runway usage. However, it would be more useful to include predictions of changes in the wind direction that could impact the direction aircraft can land.

As an extension to ACM, the identification and notification of impacted meter fixes to FAST could be added. This would allow the Traffic Managers to close meter fixes up to an hour in advance, giving aircraft in the En Route airspace the opportunity to re-route.

OTWD could also be expanded from the terminal area to the en route area. With the incorporation of other weather data sources such as turbulence maps and en route weather forecasts, the same tools could be applied to help predict airspace closure and aircraft intent outside the terminal airspace. This could improve predictions necessary for conflict detection and airspace overloading.

Once the prediction of weather-impacted airspace and aircraft routes is complete, a logical next step would be to identify specific aircraft with impacted trajectories. This activity would tie together the predicted configurations and weather-impacted routes development as it pertains to the runway assignment of aircraft in the terminal area. Aircraft could be color coded by weather-impact to alert the controllers to the need to utilize alternate routes.

An initial implementation could allow TMCs to graphically modify weather-impacted routes to create alternate nominal route segments for FAST to use for determining the path of flight in the terminal area. This would side step the procedural complexity of managing arrival and departure airspace.

Based on route-building algorithms and heuristics investigated by Krozel et. al.[7], the indirect effects of severe weather on the closure of airspace due to thunderstorm downstream turbulence and severe weather in missed approach areas could be researched [8]. From these analyses, FAST could ultimately develop the alternate routes automatically.

CONCLUSIONS

A method for connecting current and forecasted hazardous weather with FAST has been developed. The method utilizes previous work for creating probabilistic maps of pilot behavior in penetrating or deviating around hazardous weather. This work has been extended by applying a new method for forecasting up to one hour in advance the probability of significant weather in a given region. These two methods are combined to produce forecast maps of probability of deviation for up to one hour in advance. These probability maps are applied to FAST adaptation data to determine current and forecasted weather-impacted routes. These weather-impacted routes are used in an interactive display that could be used to provide guidance to Traffic Managers in choosing airport configurations in the presence of hazardous weather.

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LIST OF ACRONYMS

ACM	Airport Configuration Manager
ARTCC	Air Route Traffic Control Center
ASR-9	Airport Surveillance Radar
ATC	Air Traffic Control
CONUS	Continental United States
CTAS	Center/TRACON Automation System
DFW	Dallas/Ft. Worth International Airport
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FAST	Final Approach Spacing Tool
FPODEV	Forecasted Probability of Deviation
GUI	Graphical User Interface
ITWS	Integrated Terminal Weather System
MIT/LL	Massachusetts Institute of Technology Lincoln Laboratory
NEXRAD	Next Generation Weather Radar
OTWD	Offline Traffic and Weather Display
P3I	Pre-Planned Product Improvement
PGUI	Planview Display Graphical User Interface
PODEV	Probability of Deviation
RUC	Rapid Update Cycle
TCWF	Terminal Convective Weather Forecast
TDWR	Terminal Doppler Weather Radar
TMC	Traffic Management Coordinator
TRACON	Terminal Radar Approach Control
VIP	Video Integrator and Processor