4.9 # A FUZZY LOGIC SYSTEM FOR AUTOMATED SHORT TERM AVIATION WEATHER FORECASTS

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1. INTRODUCTION

Aviation safety and operational efficiency in the National Airspace System depend heavily on accurate and timely forecasts for weather conditions in the airport terminal area. Statistics compiled by the National Transportation Safety Board show poor ceiling and/or visibility conditions to be the leading cause or contributing factor in weather-related general aviation fatalities (GAO, 1988). In addition to these safety concerns, low ceiling and/or visibility often severely limit airport operations, causing delays and sometimes diversions to alternate airports. It is therefore very important that decision makers, whether they are pilots, dispatchers or air traffic control personnel, have the best possible forecasts for these conditions.

In November of 1999, the Federal Aviation Administration (FAA) completed a comprehensive two-year study of weather needs in support of the Traffic Management Unit (TMU) of Air Route Traffic Control Centers (ARTCC) (FAA, 1999). This study concluded by identifying the need for three new forecast products, each corresponding to an area of operational emphasis: a center (ARTCC) area forecast, a terminal approach control area forecast, and an airport terminal area forecast. Each of these forecasts should be valid for the period 0-8 hours. Furthermore, and very importantly, each of these forecasts should be updated on timescales "measurable in fractions of hours rather than multiples of hours." This last requirement, particularly when coupled with the requirement for ceiling and visibility forecasts for the airport terminal area, can only be achieved through some automation of the forecast process.

2. CEILING AND VISIBILITY FORECASTS TODAY

The prediction of ceiling and visibility conditions has always been a particular challenge for meteorologists. For many years, and still today, statistically post-processed numerical model output guidance has been the main tool for making these forecasts. Model Output Statistics (MOS) derived from the Nested Grid Model (NGM) and the Aviation Model (AVN) both provide ceiling and visibility forecast guidance at three-hour intervals. The Local AWIPS MOS Program (LAMP) is another guidance tool, and it provides ceiling and visibility forecasts at one-hour intervals. Forecast products demonstrate skill over the no-change persistence forecast. Furthermore, verification also shows that National Weather Service (NWS) Terminal Aerodrome Forecasts (TAFs) consistently show additional skill over the guidance forecasts. However, the TAFs are issued at six-hour intervals, and for this reason, they do not meet the timeliness requirements identified in the FAA TMU needs document. At any given time, the TAF may be several hours old, and updates to the TAF are not always available as quickly as needed for tactical decisions regarding the airport terminal area, particularly during difficult and rapidly changing forecast situations.

3. FUZZY LOGIC CEILING AND VISIBILITY FORECASTS

Harris Corporation, provider of WARP and OASIS weather processing systems for the FAA, has a fuzzy logic forecast system for short term ceiling and visibility forecasts that has demonstrated significant accuracy over a verification period of almost two years. Harris also successfully uses fuzzy logic in other systems such as the STAT® line of security tools.

Fuzzy logic is based on the principle that *everything is a matter of degree* (Kosko, 1993), and that any given object can belong to one of more fuzzy sets to a degree ranging from 0 to 1. In practical terms, this might mean that a glass of water might belong to the fuzzy set "full" to the degree of 0.5, while also belonging to the fuzzy set "empty" to a degree of 0.5. Or a person might belong to the fuzzy set "tall" to a degree of 0.7. Three very important characteristics of fuzzy logic systems are worthy of further emphasis: (1) fuzzy systems are essentially math-free, (2) it does not matter if the variables are independent and normally distributed, as often required by traditional statistical theory, and (3) the relationship between inputs and output can take any form—it need not be linear.

Harris' fuzzy logic forecast system produces automated ceiling, visibility, wind and weather forecasts for 465 terminal locations in the continental United States. The forecasts are generated upon arrival of each new surface observation (METAR) and are therefore always current. Inputs to the forecasts include the latest METAR, NGM MOS, AVN MOS, LAMP, and additional output from the Rapid Update Cycle (RUC) model.

The fuzzy logic forecast system consists of eight fuzzy systems, including four for ceiling and four for visibility. Many texts describe the concepts of fuzzy sets and fuzzy logic as well as their applications for modeling

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techniques (Von Altrock, 1995; Yen, 1999). The fuzzy systems were developed from a sample of forecast verification data for 465 forecast locations, using forecasts issued at 00 UTC, 06 UTC, 12 UTC, and 18 UTC and subsequently verified 3, 6, 9, and 12 hours after issuance. After gathering the developmental input/output data, a systematic approach using the following steps was employed to develop the fuzzy systems:

- determine the ranges of all input and output variables
- build membership functions for all the input and output variables
- develop the fuzzy inference structure containing qualitative relationship (IF/THEN) rules among all the variables.
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Use of the fuzzy systems requires the latest METAR and guidance data as inputs, which then proceed through fuzzification, fuzzy inference and defuzzification steps to produce the forecast output. Weighted outputs from the eight fuzzy systems produce the final ceiling and visibility forecasts.

4. VERIFICATION RESULTS

Real-time verification statistics for almost a two-year period indicate that the fuzzy logic based ceiling and visibility forecasts have shown improvement not only over guidance forecasts from numerical models, but over official National Weather Service forecasts as well.

Each ceiling and visibility forecast is verified by 'category error', which is defined as the absolute value of the forecast MOS category (values 1..7) minus the observed MOS category (values 1..7). For verification purposes, the output of the fuzzy forecast system is rounded to the nearest MOS category, corresponding to similar forecasts from other guidance and NWS forecasts.

Figure 1 summarizes the verification results for over 8 million ceiling forecasts for the period September 2000 through July 2002. For all forecast periods, the fuzzy forecasts had lower root mean square errors (RMSE) than persistence, all the other guidance products, and the official NWS TAFs. Similar verification results for visibility forecasts are shown in Figure 2. Once again, the fuzzy forecasts had the lowest RMSE. Although not shown graphically, the fuzzy forecasts outperformed guidance and official NWS forecasts 22 of 22 months

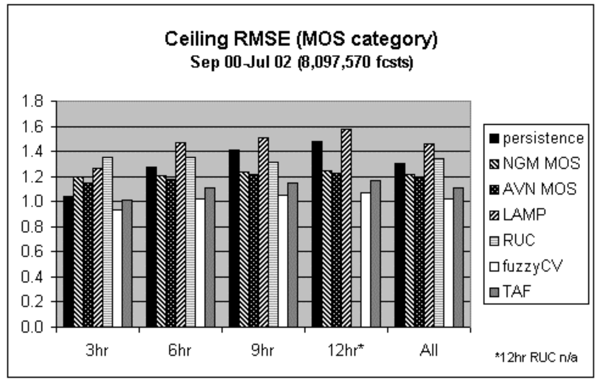

Figure 1. Ceiling root mean square error, in MOS categories

during this verification period for both ceiling and visibility.

To investigate forecast performance during the more difficult and more important forecast conditions, verification statistics were computed for forecasts made during this same period when Instrument Flight Rule (IFR) ceiling and/or visibility conditions were either forecast or observed. The results for IFR ceiling

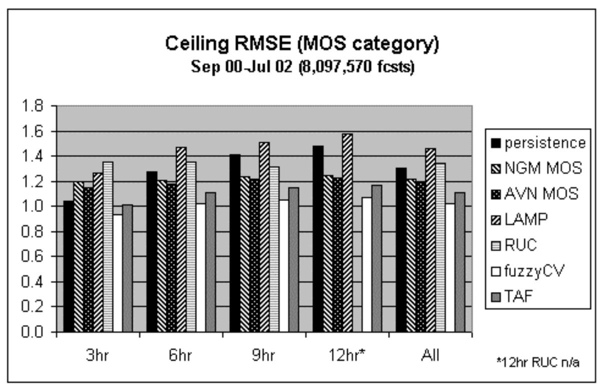

Figure 2. Visibility root mean square error, in MOS categories

conditions are shown in Table 1, and results for IFR visibility conditions are shown in Table 2. For IFR ceiling conditions, performance of the fuzzy forecasts was very similar to the TAF for probability of detection (POD), false alarm ratio (FAR), and critical success index (CSI). The fuzzy forecasts did have a slightly higher overall score with a CSI of 0.26.

(IFR ceiling conditions)	POD	FAR	CSI
persistence	0.40	0.61	0.24
NGM MOS	0.42	0.64	0.24
AVN MOS	0.36	0.61	0.23
LAMP	0.53	0.76	0.20
RUC	0.13	0.68	0.10
fuzzyCV	0.32	0.41	0.26
TAF	0.31	0.45	0.25

Table 1. Comparative verification for IFR ceiling events (3, 6, 9, 12 hrs)

(IFR visibility conditions)	POD	FAR	CSI
persistence	0.30	0.71	0.17
NGM MOS	0.40	0.71	0.20
AVN 2MOS	0.28	0.70	0.17
LAMP	0.36	0.67	0.21
RUC	0.11	0.74	0.09
fuzzyCV	0.14	0.37	0.13
TAF	0.23	0.53	0.18

Table 2. Comparative verification for IFR visibility events (3, 6, 9, 12 hrs)

For IFR visibility conditions, the critical success index of the fuzzy forecasts (0.13) was a little worse than the TAF and the guidance forecasts, except for the RUC. The lower probability of detection (0.14) was the main reason for the lower CSI. However, the false alarm ratio (0.37) of the fuzzy forecasts was the best overall, indicating when the fuzzy forecast calls for IFR visibility conditions, they will probably occur.

5. SUMMARY

Verification results for almost two years indicate that the fuzzy logic forecast system has generally outperformed all guidance and official forecasts for the 3, 6, 9, and 12-hour forecasts for both ceiling and visibility. Furthermore, and very importantly for decision makers, the forecasts are always current and are based on the latest surface conditions and the latest model output. This forecast tool is not intended to replace aviation meteorologists, but it can provide meteorologists with automated first-guess forecasts that can lead to more timely and more accurate aviation forecasts for decision makers.

6. REFERENCES

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