Development and Implementation of an Expert System for Forecasting Fog on US Highway 30 in Cedar Rapids, Iowa

Final Report

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IDOT Research Project HR-357

Iowa Department of Transportation

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Abstract:

Several accidents, some involving fatalities, have occurred on U. S. Highway 30 near the Archer Daniels Midland Company (ASM) Corn Sweeteners plant in Cedar Rapids, Iowa. A contributing factor to many of these accidents has been the large amounts of water (vapor and liquid) emitted from multiple sources at ADM's facility located along the south side of the highway. Weather and road-closure data acquired from IDOT have been used to develop a database of meteorological conditions preceding and accompanying closure of Highway 30 in Cedar Rapids. An expert system and a FORTRAN program were developed as aids in decision-making with regard to closure of Highway 30 near the plant. The computer programs were delivered to Freese-Notis Associates in Des Moines, Mr. James Phinney, Residence Maintenance Engineer in Cedar Rapids, and Surface Systems, Inc. in St. Louis for testing, evaluation, and final deployment. Reports from IDOT personnel and IDOT contract meteorologists indicate the decision tools have been successfully implemented and were judged to be helpful in forecasting road closures and in reducing costs and personnel time in monitoring the roadway.

ADM Plant Setting and Emissions

The ADM corn sweeteners plant is on the southern edge of Cedar Rapid and is located along the south side of US Highway 30, an elevated, divided, 4-lane roadway of width 35 m and elevation 9 m above the plant. The plant consists of several sets of cooling towers, grain-dryer stacks, and water-treatment ponds. More details on the plant and its operation can be found in Thomson (1995). The cooling-tower complex closest to the roadway (about 150 m south) is a 7-cell linear mechanical-draft crossflow-type alcohol cooling tower #4 that had been observed by IDOT personnel to contribute most to the reduced visibility on the roadway. When this study began in December 1992, this cooling tower complex was operated frequently, if not continuously, during the fall, winter, and spring when cool temperatures and high ambient humidities could potentially combine with tower effluent to produce copious amounts of fog. By December 1993, however, the 7-cell unit #4 was being used only sporadically during the cold season, reducing (but not eliminating) the need to close the road at this time of year. ADM personnel advised us that use of unit #4 would depend on demand and could be put back in full operation. Also, even though occurrences of fog on the roadway were reduced, IDOT personnel were obligated to continue a high volume of roadway monitoring during the winter season.

Fog Formation

Fog originates when the ambient temperature and dewpoint temperature become identical (or nearly so), provided that sufficient condensation nuclei are available. Cooling tower fogs occur when a moisture plume from a cooling tower is advected to ground level. While natural fogs generally require small dewpoint depressions (temperature minus dewpoint temperature), cooling-tower fogs can occur with relatively large dewpoint depressions of more than 15° F. However, roadway visibility does not become a problem if ambient conditions allow the copious amounts of cooling tower fog to rise and dissipate. Although some cooling-tower plumes can be large at these larger dewpoint depressions, observations indicated that a very small dewpoint depression is required to cause the ground fogging along US Highway 30 near the ADM plant.

Data Collection

IDOT began recording conditions of potential low visibility on Highway 30 in Cedar Rapids during the winter of 1989-90. A Surface Systems, Inc. (SSI) weather station at the site provided temperature, relative humidity, wind speed, and wind direction data. Visual estimates were made of the position of the vapor plumes relative to the roadway and its impact on driving visibility. Roadway closure/re-opening times and current weather conditions also were recorded with the plume observations.

Hourly surface weather observations from Cedar Rapids, Waterloo, Des Moines, Fort Dodge, Omaha, Sioux City, Ottumwa, and Mason City were archived at ISU to provide supplementary data for determining general weather conditions throughout the state. The Cedar Rapids airport is located south of the ADM plant about 4.8 km (3 mi). Comparison of portions (300 h) of the two primary data sets (Cedar Rapids airport and SSI/IDOT) revealed no significant difference in the observed temperature, dewpoint, or winds except that the SSI temperature and dewpoint sensors tended to give values about 1 degree F warmer than the airport. Additional airport data such as values and trends of cloud ceiling and measured visibility eventually were determined to be good indicators of potential fog formation.

IDOT data from October 1989 through March 1994 contain 2153 hours of observations including 27 road-closure events. Of the 27 closure events only 25 events were used due to questionable and missing IDOT data surrounding two events. A summary of the closure and monitoring information is shown in Table 1. Due to missing data, roughly 30% of the monitoring periods after November 1991 are without surface weather observations. All the available data that corresponded to periods of monitoring or road closure by IDOT personnel were used to further define the atmospheric conditions at the ADM site.

Table 1. Closure and monitoring events recorded by IDOT.

	1989-1990	1990-1991	1991-1992	1992-1993	1993-1994	Totals
Road Closure Events	3 Closures 31 h	7 Closures 77 h	12 Closures 126 h	4 Closures 46 h	1 Closure 4 h	27 Closures 284 h
Monitoring Events	25 Times 216 h	39 Times 616 h	48 Times 740 h	26 Times 459 h	17 Times 122 h	155 Times 2153 h

More details on the analysis and interpretation of these data are given in the masters thesis of Paul Thompson (Thomson, 1995)

Revised criteria for fog formation

An initial study of the cooling-tower fogs reducing visibility along U.S. Highway 30 was prepared by Radian Corporation in August of 1989. However, forecasts of cooling-tower fog based on criteria from the Radian report are too conservative and can lead to an over-prediction of fogging and a large number of 'false alarms'. This required excessive monitoring of the roadway by IDOT personnel. Analysis of data from 1989 through 1994 allowed us to revise the criteria for weather conditions accompanying and preceding the need for closure. According to on-site IDOT personnel, the revised criteria, which were forwarded to IDOT's contract meteorologists for their operational forecasts, contributed to improved forecasts from the meteorological consultants.

The revised criteria for closure are as follows:
* Air temperature: > 20° F and < 50° F
* Dewpoint depression: <2° F
* Wind direction: 120° to 270°
* Wind speed: >3 knots
* General visibility: < 2 mi
* Cloud ceiling: < 1000 ft

Software Development

Expert System

Expert systems are computer programs developed to solve real-world problems using knowledge gained from human experts. The system seeks to capture enough of the human specialist's knowledge so it too will solve problems expertly. Specifically, an expert system solves problems traditionally requiring a human expert and does so using a model of human reasoning to reach the same conclusion as a human expert.

The final version of the expert system developed for the project separates the four meteorological inputs (temperature, dewpoint, wind speed, and wind direction) to produce a probability of each variable to cause fog along U.S. Highway 30 (see Appendix C for complete program listing). These are then multiplied together, along with a correction for dewpoint depression, to give an overall probability that the cooling tower plume will trigger a road closure. The system decides (yes/no), based on this overall probability, if the roadway may need to be closed. The actual rules and probabilities were developed using discriminate analysis techniques and trial-and-error methods to develop the best combination of accuracy (false alarm rate vs. missed closure events).

For the evaluation dataset, the system predicted 90% of the road closures while giving a false alarm rate of 15% during the same period. This evaluation assumes a perfect forecast, since the actual observed conditions were used to test the system. In daily operations, it is likely the system would provide more false alarms and a slightly lower success rate at predicting road closures. Because the actual conditions for a closure are very specific and must be forecast very precisely, any errors in the forecast could have significant impact on the accuracy of the expert system to forecast road closures.

The Expert System was delivered to personnel at Freese-Notis and IDOT in Cedar Rapids in December 1993. However, starting about this same time, ADM discontinued use of the alcohol #4 cooling tower that was the main source of water vapor along U.S. Highway 30. This caused the expert system to over-predict closure events and lowered the confidence of the forecasters using it. For this reason, we developed a supplemental procedure for fog prediction.

Fortran Model

The development of a FORTRAN model to forecast plume behavior was started during the fall of 1994. The purpose of the program was to forecast plume behavior at least 24 hours in advance with little or no human intervention. In addition, the reduction of false alarms and improved accuracy over the Expert System in predicting closure events was a high priority since the reduction of roadway monitoring is a priority cost-reduction goal of IDOT.

The logic in the FORTRAN program (see Appendix D for a listing of the source code) is similar to the expert system in that individual probabilities for each factor are determined and then combined to achieve an overall probability of fog potential ($P_{fog} = P_{temp} * P_{dir} * P_{dep}$). However, the FORTRAN version does not require human input for any of the atmospheric variables. Instead, the Model Output Statistics data set from a National Weather Service computer model is used to provide a forecast of surface conditions every 3 hours out to 60 hours after the initialization data are reported. Four categories were developed to provide guidelines for using the probability forecast. The categories used are a high, medium, low, and zero probability of reduced visibility along U.S. Highway 30. The categories are very conservative in nature, so during a forecast period with a category zero there is basically no chance of fog causing problems on U.S. Highway 30.

Observations from past road closures were used to determine the threshold for the high probability category. Using a probability of 80% as the threshold between medium and high probability, the model predicted a high category for the majority of the observed closures. When high probabilities are forecast, there is a very significant probability of low visibility along U.S. Highway 30 near the ADM plant that will require the roadway to be closed. The medium category is included to account for small errors in the forecast surface conditions and variations in the actual conditions at closure. If a medium category is forecast, users should be alert to possible reductions in visibility on the roadway. The low category indicates a small chance for visibility being reduced below ambient levels along U.S. Highway 30, so monitoring of the roadway would generally not be required.

During the winter 1994-1995, forecasts were generated every 12 hours (at approximately 1100 and 2300 LST) and sent electronically to IDOT personnel in Cedar Rapids and forecasters at Freese-Notis in Des Moines. The model produces plume forecasts out to 36 hours and lists the expected weather conditions as well as the fog category for each 3-hour forecast period (0000, 0300, 0600, and 0900 for forecasts made at 2300 LST, or 1200, 1500, 1800, and 2100 for forecasts generated at 1100 LST). Beginning 1 January 1995 the forecasts were sent via e-mail to IDOT in Cedar Rapids every 12 hours, except for sporadic events when the National Weather Service data were not received at ISU. An example of the forecast sent to IDOT is shown in Appendix A. In addition to forecast plume behavior, the forecast form contains space for IDOT personnel to record observations of the plume's behavior. These are then returned to ISU to assist in verification of the model.

Evaluation of the FORTRAN model shows that during the first four forecast periods (out to 15 hours) the mean error is about 1°F for the temperature and about 0.5°F for the dewpoint. Wind direction and speed are also generally good during the short-term forecast periods. The trend is similar in the standard deviation of the errors for the early forecast periods, but longer forecast periods show a steady increase in standard deviation. A file containing the average bias for each variable at each period was produced to improve the accuracy of the forecast. This file is then used to remove some of the error occurring in each forecast. Initial results show this procedure works very well for correcting small errors in wind direction and wind speeds, temperature and dewpoint.

Results

The forecasts for the period from 1 January though 28 February 1995 were used to test the procedure. These forecasts were returned to ISU from IDOT personnel with plume and monitoring records for the period. The data include 85 separate forecasts sent to IDOT similar to the one shown in Appendix A. There were no road closures along U.S. Highway 30 during this period, but the road was monitored a total of 114 hours. Of these 114 hours, only 24 hours correspond to periods where the model was forecasting a high or medium fog probability, leaving 90 hours of monitoring when the model indicated there should be no problems with cooling-tower plumes affecting visibility along the road. During these 90 hours, only 6 hours corresponded to events missed by the Fortran program, periods where a low or zero category was forecast which also had an observed plume above the roadway at any elevation.

The model did tend to over predict fog problems during some forecast periods. However, when the plume forecasts are separated into 2 sections using the first four periods as a forecast of plume behavior and the remaining seven as an outlook, the model shows promise to significantly reduce the amount of monitoring required along U.S. Highway 30. This procedure could have cut the amount of monitoring from 114 hours to 60 hours, nearly a 50% reduction in the hours during only a single month. This assumes monitoring is required when a high or medium category is forecast which may not be the case. The decision to monitor the roadway is solely the responsibility of IDOT personnel in Cedar Rapids and the forecasts of plume behavior are only guidance to help in making those decisions. Different levels of probability could be used in determining when and if monitoring of the roadway should be started.

The forecasts produced by the FORTRAN program for the period from 1 January at 00 UTC through 28 February at 00 UTC were verified by IDOT and returned to ISU. During this period there were 21 hours when a plume was observed over the roadway, while 60 hours were predicted to have fog potential by the FORTRAN model, and over 100 hours were suggested by human forecasters to be problematic. Statistical analysis of data for all periods showed the model does have useful skill in forecasting plume behavior at the ADM facility. It should be noted that this only covers a very short period and overall results may be different if a larger data set were available. The threshold of 70% can be adjusted to fit the requirements of IDOT for the number of false alarms and missed forecasts they can tolerate.

The FORTRAN model has a very low false alarm rate while hit rates during the period approach 70%. Achieving the low false alarm rate was a goal of the project; with continued refinement during a full operational season, the hit rate should improve. The 70% hit rate is approximately equal to human forecasters, but the large reduction in false alarms means the model has better accuracy than the forecasters.

The FORTRAN code was delivered to IDOT contract meteorologists at SSI In October 1995 and was used on a daily basis for preparing their forecasts of plume behavior at the Cedar Rapids site.

During the winter 1995-96 a test was conducted to see if the FORTRAN forecast system could be ported to another city. This test was stimulated by comments by the Highway Research Board that it might be useful to have a procedure that was portable and could be used at other sites. In response to a suggestion from Mr. Royce Fichtner of Marshalltown, we redeployed the system for application to Main Street in Marshalltown due to the IES plant to the south. The transformation of FORTRAN code for application to Marshalltown required interpolation of meteorological data, since Marshalltown has no local observation site comparable to that in Cedar Rapids. However, the Marshalltown site had no road-closure database comparable with the data from Cedar Rapids, so the system could only provide an advisory based on conditions leading to road closure in Cedar Rapids. The system issued forecasts for Marshalltown on 107 days during the 1995-96 winter period (November 1995 -April 1996). During this time, the system forecast high probability of fog on 2 days, medium probability on 8 days, low probability on 23 days and zero probability on 76 days. There were no reports of road closures during the winter period. From these results, we conclude that the system can easily be ported to another location, but that without local observations to correlate meteorological conditions to roadway closures, the system only can be expected to provide a fog advisory that conditions are conducive to fog.

Summary and Conclusions

All of the road-closure events on U.S. Highway 30 near the ADM plant are the result of pre-existing fog being enhanced by moisture sources at the ADM facility. The cooling towers and grain-dryer stacks do not, by themselves, produce plumes with enough horizontal extent or optical density to warrant closure of U.S. Highway 30. However, when the ambient air is moisture laden and visibility in the area is less than 1 mile, the added moisture from the plant can form ground fogs that reduce visibility to nearly zero.

The previous addition of new 'plume abatement' cooling towers and changes in winter operating procedures have improved conditions near the plant. The addition of more 'plume abatement' towers (combined with the removal of the existing crossflow towers) and the increase of the exit height of the grain-dryer stacks would further reduce the potential for hazardous visibility along U.S. Highway 30. Similarly, relocation of the existing cooling towers to locations well south from the roadway would also reduce the probability of those towers causing ground fog along the highway.

The fog problem is worse during the winter months since cold air can only hold relatively small amounts of water vapor, forcing the rest of form visible clouds. Most of the closure events occur during only the two coldest months and then typically during periods that are unseasonably warm. However, events may occur whenever the required large-scale weather conditions are met. Therefore, an unseasonably cold event in the fall or spring may require the roadway to be closed.

To improve short and medium range (6 to 36 hours) forecasts of potential road closure events, an Expert System and Fortran program were developed. Both show good potential for reducing the amount of monitoring along the roadway while still maintaining a high degree of safety. The systems were developed using past closure events to produce rules and the probability of closure for each atmospheric variable. During initial testing, both systems predicted over 85% of the closure events and could have reduced roadway monitoring by over 50%.

A research paper summarizing the results and evaluation of the fog forecasting problem has been published by Takle and Thomson (1996). This paper evaluates the bias and threshold of forecast values for the fog problem and compares these with a previous study of the occurrence and forecasting of roadway and bridge frost (see Appendix B for copy of this paper).

References

Takle, E. S., and P. C. Thomson, 1996: Use of expert systems for roadway weather maintenance decisions. **1996 Semisesquicentennial Transportation Conference Proceedings**. Center for Transportation Research and Education. Ames, IA. 183-187.

Thomson, P. C., 1995: Development of software to forecast periods of cooling-tower fog along U. S. Highway 30 in Cedar Rapids, Iowa, MS Thesis, Iowa State University. 112 pp.

APPENDIX E. EXAMPLE PLUME FORECAST

This file created on Tue Feb 21 09:58:46 CST 1995
Reading input file ngm.mos.00.22
Model bias file not found.

Forecast created using NGM MOS data from 21 FEB 95 taken at 1800 CST

DAY	/FEB 22								/FEB 23		
HOUR	00	03	06	09	12	15	18	21	00	03	06
TEMP	35.	36.	36.	39.	48.	51.	45.	39.	36.	31.	29.
DWPT	29.	31.	32.	33.	36.	36.	35.	33.	29.	25.	22.
WDIR	180.	216.	241.	276.	287.	285.	291.	309.	308.	315.	317.
WSPD	8.	6.	4.	3.	5.	8.	8.	16.	24.	26.	25.

Plume Forecast for US Highway 30 near the ADM plant

PROB %	53.	66.	66.	47.	27.	48.	27.	27.	29.	29.	29.
CAT	0	L	L	0	0	0	0	0	0	0	0

Observations of plume behavior

ON ROAD	___	___	___	___	___	___	___	___	___	___	___
ABOVE ROAD	___	___	___	___	___	___	___	___	___	___	___
COOLING UNITS USED	___	___	___	___	___	___	___	___	___	___	___

The fog categories are based upon the predicted probability for a cooling tower fog effecting the visibility along Highway 30 near the Archer Daniels Midland plant.

The criteria for each category is:

High Probability greater than or equal to 80

Medium Probability between 70 and 80

Low Probability between 60 and 70

Zero Probability less than 60

These categories provide only a general outlook of the cooling tower plume behavior based on a national computer model which forecasts weather conditions for the area. This forecast is experimental and users should be alert to possible large errors in these forecasts of plume behavior and weather conditions.

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Use of Expert Systems for Roadway Weather Maintenance Decisions

EUGENE S. TAKLE AND PAUL C. THOMSON

We have developed and deployed automated systems for forecasting frost and fog on roadways and bridges at specific locations in Iowa. These systems ingest current observations and forecasted values of specific weather variables and produce forecasts of the indicated roadway condition. Forecasts made on the basis of uncertain (weather) input information will invariably lead to less-than-maximum hit rates and greater-than-zero false-alarm rates. A procedure, based on signal detection theory, has been developed to separately analyze the accuracy and bias of the systems. By using this procedure, the roadway maintenance manager can tune the system to achieve the optimum balance of hit-rate-versus-false-alarm rate for a given application. Comparison of the estimated levels of accuracy of these forecast systems with other reports in the meteorological literature reveals that our systems have skill levels sufficient to have practical value. Key words: frost, fog, expert system, roadway weather, decision making.

An expert system is a computer-based tool that stores a model of human expert reasoning with an associated knowledge base and combines these to reach the same conclusion as a human expert to a complex problem. *We have developed expert systems for two* specific tasks relating to roadway weather decision making. The first is a system for forecasting frost formation on bridges and roadways in central Iowa, and the second is a system for forecasting fog on US Highway 30 in Cedar Rapids, Iowa, due to plumes emitted by cooling towers at a corn-sweeteners production plant adjacent to the roadway. From these experiences we have concluded that expert systems can be useful in roadway weather maintenance decisions. These experiences also have allowed us to consider the more general issue of decision making with regard to the use of weather information.

FROST FORMATION ON BRIDGES AND ROADWAYS

Frost formation on bridges and roadways in Iowa poses a potential safety problem for motorists, in large measure due to its patchy nature. *Frost suppression measures, such as sanding and salting* affected areas, must be implemented in a timely manner. An accurate forecast of frost is needed so that the Iowa Department of Transportation (Iowa DOT) can have personnel, equipment, and material available at the locations needing attention. Under sponsorship of the Iowa DOT, we developed an expert system to forecast frost 18 hours in advance (*1,2*).

The expert system uses a backward-chaining system and consists of 32 parameters and variables and 33 rules. Roadway and bridge frost data from December, January, and February of four frost seasons (1985–89) were used to develop the rules for the system. The rules are used in combination to forecast separate values of temperature for the bridge and roadway, which are compared with the forecast of the dew-point temperature to determine the likelihood of frost.

Input to the system consists of the three data items and seven forecast variables listed in Table 1. The system was run at about 11:00 a.m. LST to forecast conditions at approximately 5:00 a.m. the following morning. In the operational setting, the input variables were supplied by the forecast meteorologists who also ran the expert system.

The verification matrix of Table 2 summarizes the performance of the system as measured against actual outcomes. The conditions for frost to occur are that (1) the surface temperature must be below freezing, (2) the surface temperature must be below the dew-point temperature, and (3) the dew-point temperature must be near (even above) freezing or else well above the surface temperature for a significant period of time. We first set the decision criterion to be that frost would form if the estimated surface temperature was less than or equal to the dew-point temperature. However, this criterion can be changed to examine the influence on the hit rate and false-alarm rate. If we increase the temperature threshold by 1°C we are saying that frost will form somewhere in the region even if the surface temperature at some reference location is 1°C higher than the dew-point temperature. The plot in Figure 1 shows how changing the threshold changes the hit and false-alarm rate.

The system was designed, tested, and deployed operationally. In practice, the forecasters typically would run the system several times with different combinations of the parameters in Table 1 to examine the sensitivity of the present situation to small changes in the forecast variables. The system was found to have accuracy comparable with human forecasters. Details of the comparison of forecast accuracy of the system are given in (*1*).

ROADWAY FOG PRODUCED BY AN ADJACENT PLANT

Heavy fog with accompanying low visibility form in the vicinity of US Highway 30 in Cedar Rapids, Iowa, due to copious amounts of water vapor released from linear mechanical-draft cooling towers at a corn-sweetener plant adjacent to the roadway. Ambient atmospheric conditions of wind speed, wind direction, temperature, dew-point temperature, and surface moisture are key conditions that determine whether the resulting water-vapor plume will lead to low visibility for motorists on Highway 30. Safety precautions by Iowa DOT in the event of fog include rerouting traffic to a city street during the episode.

Accurate forecasts of onset and termination of low visibility conditions are needed to assist Iowa DOT personnel in their moni-

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TABLE 1 Information to Be Entered into the Frost Expert System

a)	Data
	Minimum temperature yesterday
	Maximum temperature yesterday
	Minimum temperature this morning
b)	Forecasts
	Cloud cover from sunset tonight to midnight tonight
	Cloud cover from midnight tonight to sunrise tomorrow
	Maximum temperature today
	Minimum temperature tomorrow morning
	Dew-point temperature at 6 AM tomorrow
	Precipitation from 9 PM tonight to 6 AM tomorrow (yes/no)
	Average wind speed and wind direction from midnight to 6 AM tomorrow

TABLE 2 General Verification Matrix and Definitions

		Observed	
		No	Yes
Forecast	No	a	b
	Yes	c	d

Total number of events $= N = a + b + c + d$
Hit rate $= H = d/(b + d)$
False alarm rate $= F = c/(a + c)$
Miss rate $= M = b/(b + d)$
Correct nonoccurrence $= C = a/(a + c)$
Sample relative frequency $= S = (b + d)/N$
Decision criterion $= x_c = P^{-1}(1 - F)$
Index of accuracy $= d' = x_c - P^{-1}(1 - H)$
Criterion placement $= B = \exp\{-0.5\,[d'(d' - 2x_c)]\}$
P^{-1} = inverse of normal probability distribution function

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toring efforts and in scheduling closure events. Iowa DOT has supported a research project to evaluate the conditions under which low visibility occurs and to develop automated systems to forecast these events (3).

An expert system was developed using the same shell as was used in the frost problem previously described. This system determines the probability of fog *individually for* forecast values of temperature, dew-point temperature, wind speed, and wind direction. Each value is then multiplied by a probability factor and combined with the others to determine the aggregate probability that the cooling-tower plumes will trigger a road closure. The rules and probabilities were developed by use of discriminate analysis techniques and trial-and-error methods to achieve the best combination of accuracy (false-alarm rate vsersus missed closure events). The system was developed by use of meteorological data and Iowa DOT road-monitoring data from *October 1989 through March 1994*, which contained 2,153 hours of observations including 27 road closures. The occurrence of fog on the roadway is highly dependent on the plant operating procedure. In 1994, the plant reduced use of one of the cooling towers nearest the roadway, leading to an overprediction by the expert system. The system remains in use by *local Iowa DOT personnel, however, to provide* a worst-case scenario.

Citing the need to reduce the number of hours for monitoring the roadway for fog occurrences, the Iowa DOT requested an investigation of procedures to forecast fog occurrences regardless of whether they would lead to road closure. Improvements in data availability and communication during this period allowed development of a more advanced method for creating and delivering fog forecasts. The new system acquires forecast values of the key meteorological variables previously listed directly from the Nested Grid Model (NGM) Model Output Statistics (MOS) of the National Meteorological Center every 12 hours. These data were interpolated to the Cedar Rapids site and used as input to a Fortran algorithm having the same logic as the expert system. The output of the system generated a combined forecast fog probability category of high, medium, low, or zero twice daily at 11:00 a.m. and 11:00 p.m. for 11 three-hour hour intervals beginning, respectively, at noon and midnight. For evaluation purposes, the first four intervals were considered as the forecast and the remaining seven intervals as an outlook. The results of the calculation were immediately sent electronically to Iowa DOT personnel in Cedar Rapids and to the Iowa DOT forecasters without requiring human intervention.

A period from 1 January through 28 February 1995 was used to verify the automated procedure. During this period 85 separate forecasts were issued. By its previous criterion for roadway surveillance, the Iowa DOT monitored the roadway 114 hours during this period. Of these 114 hours, only 24 hours corresponded to periods where the model was issuing high or medium probability of fog, leaving 90 hours of monitoring when the model *forecast no fog* problem. Of these 90 hours, 6 hours corresponded to events missed by the Fortran program (e.g., periods where a low or zero category was forecast but for which a plume was observed above the roadway at any elevation). The model tended to over-predict fog during the early forecast periods (from three to 12 hours). In spite of this conservative bias, the model would have reduced the roadway monitoring time from 114 hours to 60 hours, a reduction of 47 percent.

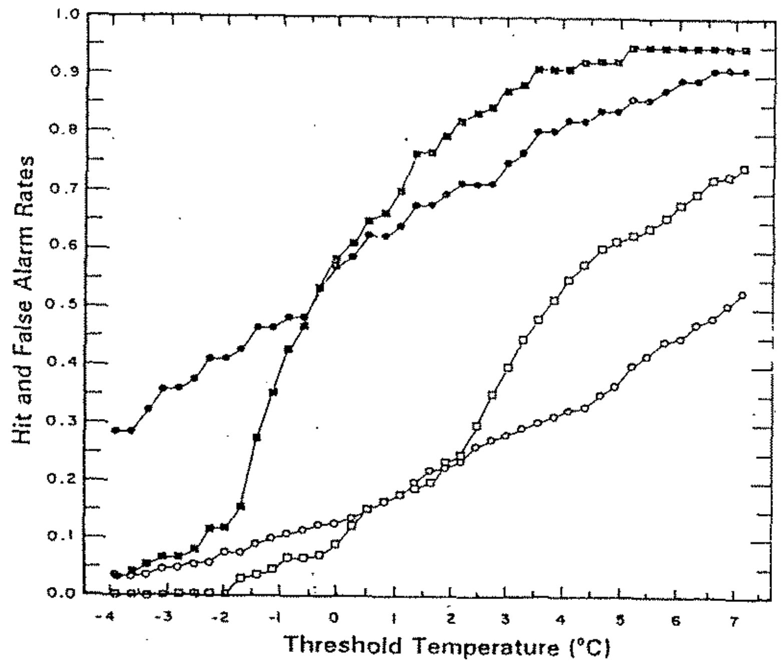

FIGURE 1 Hit and false-alarm rates for bridges and roadways for various values of the frost expert system threshold temperature. Squares represent bridges, and circles represent roadways; solid symbols represent hits, and open symbols represent false alarms. (Adapted from (1)).

The verification matrix of Table 2 was used to evaluate the model performance. The original decision criterion was that a closure would occur if the probability of fog was greater than 70 percent (forecast category medium and high). By changing this threshold we can examine the influence on hit rate and false-alarm rate, which are plotted in Figure 2 as a function of closure probability. The general trend is for both hit and false-alarm rates to increase as probability threshold decreases.

USE OF UNCERTAIN INFORMATION IN MAINTENANCE DECISIONS

The delivery of a tailored weather forecast and the development of a resulting policy decision based on this forecast raise the issue of division of responsibility. For example, a meteorologist is accustomed to issuing a forecast that there is a 30 percent chance that frost will form on a bridge. The maintenance supervisor must decide if this is sufficient justification to deploy a sanding truck.

Factors entering this decision include the actual costs of manpower, equipment, and materials but also the potential for an accident and possible litigation resulting from not taking action. Actual cost of the first (low for individual events but large in aggregate) must be weighed against the potential cost of the second (possibly very large if it occurs). The maintenance supervisor cannot ask the forecaster to give a "yes" or "no" on frost, because this would force the meteorologist to make a policy decision based on some level of risk, which is the maintenance supervisor's responsibility. Rather, the forecaster should issue a percentage chance, and the supervisor must establish a threshold, or decision criterion, beyond which frost-suppression action is taken.

The method of signal detection theory (SDT) (*4,5,6,7*) allows us to evaluate the probabilities of a "hit," "miss," "false alarm," or "correct nonoccurrence" and their relationship, separately, to forecast accuracy (the responsibility of the forecaster) and decision criterion (the responsibility of the maintenance supervisor). Increasing the hit rate also increases the false-alarm rate. By use of signal detection theory, the maintenance supervisor can balance hit rate against false-alarm rate, independently of forecast accuracy.

From SDT, an index of accuracy, d', is the number of standard deviations separating the means of the (assumed normal) distributions of decision variables preceding occurrence and preceding nonoccurrence. Thus, if d' = 0, there is no skill because the probability of hit and false alarm are equal. A second index, B, is the likelihood ratio that the given data suggest occurrence over nonoccurrence. The criterion placement is considered unbiased if B = 0, biased toward maintaining a low false-alarm rate (at the

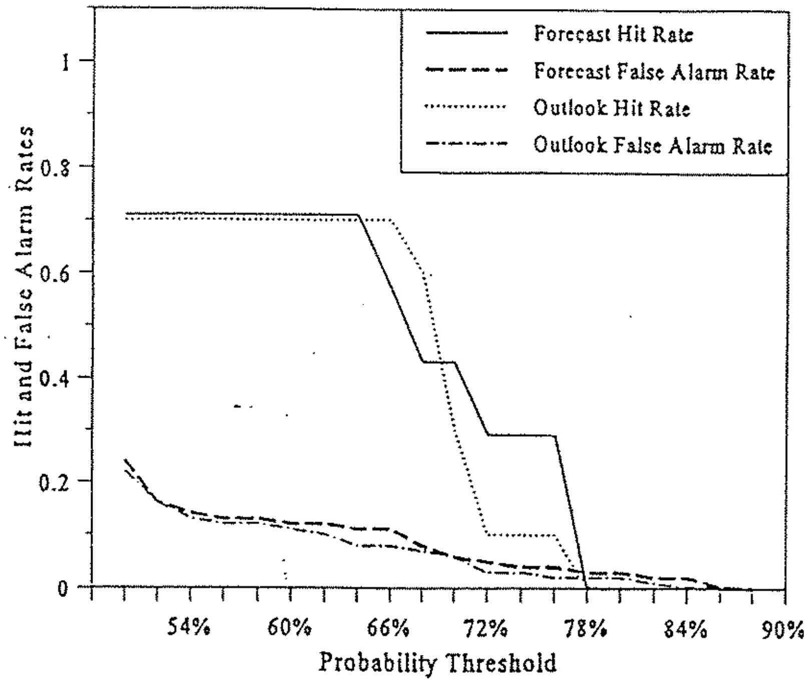

FIGURE 2 Hit and false-alarm rates for road closures for various values of threshold probability for the fog forecast model.

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expense of a lower hit rate) if B > 1, and biased toward maintaining a high hit rate (at the expense of a higher false-alarm rate) if B < 1. A third parameter, A, is the area under the curve of the SDT relative operating characteristics curve (*7*) and can be interpreted as the percentage of time that the system can distinguish between conditions leading to occurrence from conditions leading to nonoccurrence of fog or frost. Swets (*7*) considers a system with A values below 70 to have insufficient accuracy for much practical value and systems with values between 70 and 90 to be useful for some purposes.

Table 3 gives the estimated values of d', B, and A for the expert systems for bridge and roadway frost and for the Fortran program used for fog forecasting. All systems show skill at discriminating occurrences from nonoccurrences (d' > 0), and, for the decision criteria used, all systems are biased toward maintaining a low false-alarm rate at the expense of a lower hit rate. The values of A suggest that all systems exhibit skill in predicting their respective roadway conditions. For the frost project, we obtained data and computed analogous statistics for human forecasts as shown in Table 3. These results show that the human forecasters were less biased toward maintaining a low false-alarm rate, and that the skill was comparable or slightly lower than the expert system. We emphasize that this comparison is not strictly valid because the expert system is evaluated at its potential best because we have assumed "perfect forecasts" for the input variables (Table 1) to the system. For the fog problem, the human forecasters had a hit rate of 70 percent, comparable to the Fortran program, but they had approximately twice the false-alarm rate.

TABLE 3 Measures of Accuracy and Bias for Expert Systems and Human Forecasters for Forecasts of Frost and for the Fortran Model for Forecasts of Fog

	d'	B	Area
Frost, Expert System (0°C criterion)			
Bridge	1.7	2.32	85
Roadway	1.4	1.90	82
Frost, Human Forecaster			
Bridge	1.2	0.93	78
Roadway	1.4	1.60	82
Fog, Expert System (70% probability criterion)			
Forecast	1.5	3.94	83
Outlook	1.6	3.48	84

RECOMMENDATIONS FOR USE OF EXPERT SYSTEMS

Our experience in developing these systems and our observations of other expert systems that have been developed to provide more general meteorological forecasts has taught us that such expert systems are more likely to be successful if they are designed to forecast a specific event (e.g., frost on a bridge) rather than more general conditions (e.g., occurrence of severe weather). This is because the number of rules needed to discriminate occurrence from nonoccurrence is fairly limited (about 50 for our systems). Verification of simpler systems is a much more manageable task.

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APPENDIX C. EXPERT SYSTEM SOURCE CODE

The following is the source listing for the expert system delivered to IDOT and Freese-Notis personnel during December 1993.

```
DOMAIN :: COOLTWR3
ROOT FRAME :: COOLTWR

======================
   Global KB data
======================

FRAME STRUCTURE ::
   COOLTWR
Parameter groups :: (COOLTWR-PARMS)
Rule groups :: (WINDVEL-RULES DEWPOINT-RULES WINDDIR-RULES TEMP-RULES
              COOLTWR-RULES META-RULES )
Number of rules :: 46
Number of meta-rules :: 1
Variables :: (DOMAIN)
TEXTAGS :: ()
Functions :: ()

   ===============
     VARIABLES
   ===============

DOMAIN
  VALUE :: COOLTWR3

=======================
   Frame :: COOLTWR
=======================

  IDENTIFIER :: COOLTWR3
  TRANSLATION :: (a system to predict the formation of cooling tower fog on
                 Hwy 30 in Cedar Rapids, IA based on statistical data. )
  GOALS :: (FOGYES CORRECTED)
  PROMPTEVER :: (This is a PROTOTYPE Expert System to determine the
                formation of fog covering Hwy 30 in Cedar Rapids near the
                Archer Daniels Midland ((ADM)) corn sweeteners plant. The
                System was developed by E. S. Takle and P. C. Thomson. The
                developers are not responsible for accidents, damage, or
                injury resulting from the use of this System. This System
                was developed for forecasting fog around the ADM plant in
                Cedar Rapids, Iowa and may not be accurate at other
                locations. :line 2 *** This System is copyrighted and
                shall not be copied or used in any form without written
                permission from E. S. Takle *** :line 2 [if you need help
                at any prompt, press :ATTR (YELLOW BLINK) F1 :ATTR (WHITE)
                key] :line 2 Prototype Version 3.0c, 14 Oct 1993 )
  DISPLAYRESULTS :: (TEMP DEWPOINT WINDDIR WINDVEL CORRECTED FOGYES)
  PARMGROUP :: COOLTWR-PARMS
```



```
RULEGROUPS :: (COOLTWR-RULES TEMP-RULES WINDDIR-RULES DEWPOINT-RULES
              WINDVEL-RULES )
COOLTWR-PARMS  :: (CORR CORRECTED DEWPOINT FOGPROB FOGYES PB_DEWPOINT
                   PB_TEMP PB_WIND PB_WINDDIR PB_WINDVEL TEMP TEST
                   WINDDIR WINDVEL )
COOLTWR-RULES  :: (RULE026 RULE037 RULE038 RULE039 RULE040 RULE042
                   RULE043 RULE044 RULE045 RULE046 )
TEMP-RULES  :: (RULE018 RULE019 RULE020 RULE021 RULE022 RULE023 RULE024
                RULE025 )
WINDDIR-RULES  :: (RULE009 RULE010 RULE011 RULE012 RULE013 RULE014
                   RULE015 RULE016 RULE017 RULE036 )
DEWPOINT-RULES  :: (RULE001 RULE002 RULE003 RULE004 RULE005 RULE006
                    RULE007 RULE008 )
WINDVEL-RULES  :: (RULE029 RULE030 RULE031 RULE032 RULE033 RULE034
                   RULE035 )

   ==================
     COOLTWR-PARMS
   ==================

CORR
====
  TRANSLATION :: (correction factor)
  TYPE :: SINGLEVALUED
  EXPECT :: NUMBER
  UPDATED-BY :: (RULE037 RULE039 RULE040 RULE038)
  USED-BY :: (RULE045 RULE046)
  CONTAINED-IN :: (RULE046)
  RANGE :: (0 4.)

CORRECTED
=========
  TRANSLATION :: (corrected probability of fog)
  TYPE :: SINGLEVALUED
  EXPECT :: POSITIVE-NUMBER
  UPDATED-BY :: (RULE045 RULE046)
  USED-BY :: (RULE043 RULE042)
  RANGE :: (0 2.)

DEWPOINT
========
  TRANSLATION :: (the forecast dewpoint at Hwy 30)
  PROMPT :: (Enter the forecast dewpoint at Hwy 30 in Cedar Rapids)
  TYPE :: SINGLEVALUED
  EXPECT :: NUMBER
  USED-BY :: (RULE001 RULE002 RULE003 RULE004 RULE005 RULE006 RULE007
             RULE008 )
  HELP :: (Enter the dewpoint forecast in degrees (-20 to 70F) .)
  CONTAINED-IN :: (SREFMARK RULE044)
  RANGE :: (-20 70)

FOGPROB
=======
  TRANSLATION :: (Probability of fog on Hwy 30 (0. to 1.))
  TYPE :: SINGLEVALUED
```

```
  UPDATED-BY :: (SREFMARK RULE026)
  USED-BY :: (SREFMARK RULE026)
  USED-BY-THE-WAY :: (MRULE001)
  CONTAINED-IN :: (RULE037 RULE039 RULE040 RULE038)

FOGYES
======
  TRANSLATION :: (There will be a cooling tower fog on Hwy 30 near the
                  ADM plant with the forecast conditions. )
  TYPE :: YES/NO
  UPDATED-BY :: (RULE043 RULE042)
  USED-BY-THE-WAY :: (MRULE001)

PB_DEWPOINT
===========
  TRANSLATION :: (the probability for fog dew to a given dewpoint)
  TYPE :: SINGLEVALUED
  EXPECT :: NUMBER
  UPDATED-BY :: (RULE001 RULE002 RULE003 RULE004 RULE005 RULE006 RULE007
                 RULE008 )
  CONTAINED-IN :: (SREFMARK RULE026)
  RANGE :: (0 1.)

PB_TEMP
=======
  TRANSLATION :: (the probability of fog due to the temp.)
  TYPE :: SINGLEVALUED
  EXPECT :: NUMBER
  UPDATED-BY :: (RULE018 RULE019 RULE021 RULE022 RULE023 RULE024 RULE025
                 RULE020 )
  CONTAINED-IN :: (SREFMARK RULE026)
  RANGE :: (0 1.)

PB_WIND
=======

PB_WINDDIR
==========
  TRANSLATION :: (probability of fog due to the wind direction)
  TYPE :: SINGLEVALUED
  EXPECT :: NUMBER
  UPDATED-BY :: (RULE010 RULE011 RULE012 RULE013 RULE014 RULE015 RULE016
                 RULE017 RULE036 RULE009 )
  CONTAINED-IN :: (SREFMARK RULE026)
  RANGE :: (0 1.)

PB_WINDVEL
==========
  TRANSLATION :: (prob of fog due to wind velocity)
  TYPE :: SINGLEVALUED
  EXPECT :: NUMBER
  UPDATED-BY :: (RULE029 RULE030 RULE031 RULE032 RULE033 RULE034 RULE035)
  RANGE :: (0 1.)
  CONTAINED-IN :: (SREFMARK RULE026)

TEMP
====
```



```
  TRANSLATION :: (the forecast air temperature at Hwy 30)

  PROMPT :: (Enter the forecast air temperature at Hwy 30 in Cedar Rapids
  TYPE :: SINGLEVALUED
  EXPECT :: NUMBER
  USED-BY :: (RULE018 RULE019 RULE021 RULE022 RULE023 RULE024 RULE025
              RULE020 )
  HELP :: (Enter the forecast airtemp in degrees (-30 to 70F) .)
  CONTAINED-IN :: (SREFMARK RULE044)
  RANGE :: (-30 70)

TEST
====
  TRANSLATION :: (Dewpoint depression values)
  TYPE :: SINGLEVALUED
  EXPECT :: INTEGER
  UPDATED-BY :: (SREFMARK RULE044)
  USED-BY :: (RULE037 RULE039 RULE040 RULE038 SREFMARK RULE044)
  RANGE :: (0 30)

WINDDIR
=======
  TRANSLATION :: (the forecast wind direction at Hwy 30)
  PROMPT :: (Enter the forecast wind direction at Hwy 30)
  TYPE :: SINGLEVALUED
  EXPECT :: NUMBER
  USED-BY :: (RULE010 RULE011 RULE012 RULE013 RULE014 RULE015 RULE016
              RULE017 RULE036 RULE009 )
  HELP :: (Enter the expected wind direction in degrees (120 to 280) .)
  RANGE :: (120 280)

WINDVEL
=======
  TRANSLATION :: (the forecast wind velocity at Hwy 30)
  PROMPT :: (Enter the forecast wind speed (knots) Hwy 30)
  TYPE :: SINGLEVALUED
  EXPECT :: INTEGER
  USED-BY :: (RULE029 RULE030 RULE031 RULE032 RULE033 RULE034 RULE035)
  HELP :: (Enter the expected wind speed in knots (0 to 40kts) .)
  RANGE :: (0 40)


  ===================
     COOLTWR-RULES
  ===================

RULE026
=======
  SUBJECT :: COOLTWR-RULES
If Probability of fog on Hwy 30 0. to 1. is not known,
Then it is definite (100%) that Probability of fog on Hwy 30 0. to 1. is (1
minus [[[(1 minus (the probability of fog due to the temp. divided by 1.5)]
times (1 minus (the probability for fog dew to a given dewpoint divided by
1.8 )]] times (1 minus (probability of fog due to the wind direction divided
by 2. )]] times (1 minus (prob of fog due to wind velocity divided by
1.7)]]]).
```

```
RULE037
=======
   SUBJECT :: COOLTWR-RULES
   DOBEFORE :: (42 43)
If   Dewpoint depression values is less than 0.5,
Then it is definite (100%) that correction factor is [1.53 times Probability
of fog on Hwy 30 0. to 1.].

RULE038
=======
   SUBJECT :: COOLTWR-RULES
   DOBEFORE :: (42 43)
If   Dewpoint depression values is 1,
Then it is definite (100%) that correction factor is [1.325 times Probability
of fog on Hwy 30 0. to 1.].

RULE039
=======
   SUBJECT :: COOLTWR-RULES
   DOBEFORE :: (42 43)
If   Dewpoint depression values is 2,
Then it is definite (100%) that correction factor is [1.11 times Probability
of fog on Hwy 30 0. to 1.].

RULE040
=======
   SUBJECT :: COOLTWR-RULES
   DOBEFORE :: (42 43)
If   Dewpoint depression values is greater than 2,
Then it is definite (100%) that correction factor is [0.76 times Probability
of fog on Hwy 30 0. to 1.].

RULE042
=======
   SUBJECT :: COOLTWR-RULES
If   corrected probability of fog is greater than 0.8211111111111,
Then it is definite (100%) that There will be a cooling tower fog on Hwy 30
near the ADM plant with the forecast conditions..

RULE043
=======
   SUBJECT :: COOLTWR-RULES
If   corrected probability of fog is less than or equal to 0.8211111111111,
Then it is definite (100%) that There will not be a cooling tower fog on Hwy
30 near the ADM plant with the forecast conditions..
```



```
RULE044
=======
   SUBJECT :: COOLTWR-RULES
   DOBEFORE :: (37)
If   Dewpoint depression values is not known,
Then it is definite (100%) that Dewpoint depression values is [the forecast
air temperature at Hwy 30 minus the forecast dewpoint at Hwy 30].

RULE045
=======
   SUBJECT :: COOLTWR-RULES
   DOBEFORE :: (42)
If   correction factor is greater than 0.99999999,
Then it is definite (100%) that corrected probability of fog is 0.99999999.

RULE046
=======
   SUBJECT :: COOLTWR-RULES
If   correction factor is less than 0.99999999,
Then it is definite (100%) that corrected probability of fog is [correction
factor times 1.].

      ================
         TEMP-RULES
      ================

RULE018
=======
   SUBJECT :: TEMP-RULES
If   the forecast air temperature at Hwy 30 is less than 16,
Then it is definite (100%) that the probability of fog due to the temp. is
0.3.

RULE019
=======
   SUBJECT :: TEMP-RULES
If   1) the forecast air temperature at Hwy 30 is greater than or equal to
16,
     and
    2) the forecast air temperature at Hwy 30 is less than 21,
Then it is definite (100%) that the probability of fog due to the temp. is
0.45.

RULE020
=======
   SUBJECT :: TEMP-RULES
If   1) the forecast air temperature at Hwy 30 is greater than or equal to
21,
       and
    2) the forecast air temperature at Hwy 30 is less than 26,
Then it is definite (100%) that the probability of fog due to the temp. is
0.6.
```

```
    RULE021
    =======
      SUBJECT :: TEMP-RULES
If   1) the forecast air temperature at Hwy 30 is greater than or equal to
26,
        and
     2) the forecast air temperature at Hwy 30 is less than 31,
Then it is definite (100%) that the probability of fog due to the temp. is
0.66.

    RULE022
    =======
      SUBJECT :: TEMP-RULES
If   1) the forecast air temperature at Hwy 30 is greater than or equal to
31,
        and
     2) the forecast air temperature at Hwy 30 is less than 36,
Then it is definite (100%) that the probability of fog due to the temp. is
0.897.

    RULE023
    =======
      SUBJECT :: TEMP-RULES
If   1) the forecast air temperature at Hwy 30 is greater than or equal to
36,
        and
     2) the forecast air temperature at Hwy 30 is less than 41,
Then it is definite (100%) that the probability of fog due to the temp. is
0.485.

    RULE024
    =======
      SUBJECT :: TEMP-RULES
If   1) the forecast air temperature at Hwy 30 is greater than or equal to
41,
        and
     2) the forecast air temperature at Hwy 30 is less than 46,
Then it is definite (100%) that the probability of fog due to the temp. is
0.5.

    RULE025
    =======
      SUBJECT :: TEMP-RULES
If   the forecast air temperature at Hwy 30 is greater than or equal to 46,
Then it is definite (100%) that the probability of fog due to the temp. is
0.44.
```



```
      ===================
         WINDDIR-RULES
      ===================

    RULE009
    =======
      SUBJECT :: WINDDIR-RULES
      DOBEFORE :: (26)
If   the forecast wind direction at Hwy 30 is less than 131,
Then it is definite (100%) that probability of fog due to the wind direction
is 1.e-4.

    RULE010
    =======
      SUBJECT :: WINDDIR-RULES
      DOBEFORE :: (26)
If   1) the forecast wind direction at Hwy 30 is greater than or equal to
131,
        and
     2) the forecast wind direction at Hwy 30 is less than 150,
Then it is definite (100%) that probability of fog due to the wind direction
is 0.1.

    RULE011
    =======
      SUBJECT :: WINDDIR-RULES
      DOBEFORE :: (26)
If   1) the forecast wind direction at Hwy 30 is greater than or equal to
150,
        and
     2) the forecast wind direction at Hwy 30 is less than 170,
Then it is definite (100%) that probability of fog due to the wind direction
is 0.4.

    RULE012
    =======
      SUBJECT :: WINDDIR-RULES
      DOBEFORE :: (26)
If   1) the forecast wind direction at Hwy 30 is greater than or equal to
170,
        and
     2) the forecast wind direction at Hwy 30 is less than 190,
Then it is definite (100%) that probability of fog due to the wind direction
is 0.42.

    RULE013
    =======
      SUBJECT :: WINDDIR-RULES
      DOBEFORE :: (26)
If   1) the forecast wind direction at Hwy 30 is greater than or equal to
190,
```

```
    and
  2) the forecast wind direction at Hwy 30 is less than 210,
Then it is definite (100%) that probability of fog due to the wind direction
is 0.44.

   RULE014
   =======
     SUBJECT :: WINDDIR-RULES
     DOBEFORE :: (26)
If   1) the forecast wind direction at Hwy 30 is greater than or equal to
210,
    and
  2) the forecast wind direction at Hwy 30 is less than 230,
Then it is definite (100%) that probability of fog due to the wind direction
is 0.3.

   RULE015
   =======
     SUBJECT :: WINDDIR-RULES
     DOBEFORE :: (26)
If   1) the forecast wind direction at Hwy 30 is greater than or equal to
230,
    and
  2) the forecast wind direction at Hwy 30 is less than 250,
Then it is definite (100%) that probability of fog due to the wind direction
is 0.15.

   RULE016
   =======
     SUBJECT :: WINDDIR-RULES
     DOBEFORE :: (26)
If   1) the forecast wind direction at Hwy 30 is greater than or equal to
250,
    and
  2) the forecast wind direction at Hwy 30 is less than 265,
Then it is definite (100%) that probability of fog due to the wind direction
is 0.1.

   RULE017
   =======
     SUBJECT :: WINDDIR-RULES
     DOBEFORE :: (26)
If   the forecast wind direction at Hwy 30 is greater than or equal to 275,
Then it is definite (100%) that probability of fog due to the wind direction
is 0.02.

   RULE036
   =======
     SUBJECT :: WINDDIR-RULES
     DOBEFORE :: (26)
If   1) the forecast wind direction at Hwy 30 is greater than or equal to
265,
```



```
    and
  2) the forecast wind direction at Hwy 30 is less than 275,
Then it is definite (100%) that probability of fog due to the wind direction
is 0.05.

      ====================
        DEWPOINT-RULES
      ====================

   RULE001
   =======
     SUBJECT :: DEWPOINT-RULES
     DOBEFORE :: (26)
If   the forecast dewpoint at Hwy 30 is less than 5,
Then it is definite (100%) that the probability for fog dew to a given
dewpoint is 0.1.

   RULE002
   =======
     SUBJECT :: DEWPOINT-RULES
     DOBEFORE :: (26)
If   1) the forecast dewpoint at Hwy 30 is greater than or equal to 5, and
     2) the forecast dewpoint at Hwy 30 is less than 20,
Then it is definite (100%) that the probability for fog dew to a given
dewpoint is 0.2.

   RULE003
   =======
     SUBJECT :: DEWPOINT-RULES
     DOBEFORE :: (26)
If   1) the forecast dewpoint at Hwy 30 is greater than or equal to 20, and
     2) the forecast dewpoint at Hwy 30 is less than 25,
Then it is definite (100%) that the probability for fog dew to a given
dewpoint is 0.5.

   RULE004
   =======
     SUBJECT :: DEWPOINT-RULES
     DOBEFORE :: (26)
If   1) the forecast dewpoint at Hwy 30 is greater than or equal to 25, and
     2) the forecast dewpoint at Hwy 30 is less than 30,
Then it is definite (100%) that the probability for fog dew to a given
dewpoint is 0.9.

   RULE005
   =======
     SUBJECT :: DEWPOINT-RULES
     DOBEFORE :: (26)
If   1) the forecast dewpoint at Hwy 30 is greater than or equal to 30, and
```

```
     2) the forecast dewpoint at Hwy 30 is less than 35,
Then it is definite (100%) that the probability for fog dew to a given
dewpoint is 0.57.

    RULE006
    =======
      SUBJECT :: DEWPOINT-RULES
      DOBEFORE :: (26)
If   1) the forecast dewpoint at Hwy 30 is greater than or equal to 35, and
     2) the forecast dewpoint at Hwy 30 is less than 40,
Then it is definite (100%) that the probability for fog dew to a given
dewpoint is 0.235.

    RULE007
    =======
      SUBJECT :: DEWPOINT-RULES
      DOBEFORE :: (26)
If   1) the forecast dewpoint at Hwy 30 is greater than or equal to 40, and
     2) the forecast dewpoint at Hwy 30 is less than 50,
Then it is definite (100%) that the probability for fog dew to a given
dewpoint is 0.27.

    RULE008
    =======
      SUBJECT :: DEWPOINT-RULES
      DOBEFORE :: (26)
If   the forecast dewpoint at Hwy 30 is greater than or equal to 50,
Then it is definite (100%) that the probability for fog dew to a given
dewpoint is 0.1.


      ===================
        WINDVEL-RULES
      ===================

    RULE029
    =======
      SUBJECT :: WINDVEL-RULES
      DOBEFORE :: (26)
If   the forecast wind velocity at Hwy 30 is less than 5,
Then it is definite (100%) that prob of fog due to wind velocity is 0.01.

    RULE030
    =======
      SUBJECT :: WINDVEL-RULES
      DOBEFORE :: (26)
If   1) the forecast wind velocity at Hwy 30 is greater than or equal to 5,
and

     2) the forecast wind velocity at Hwy 30 is less than 7,
Then it is definite (100%) that prob of fog due to wind velocity is 0.15.
```



```
    RULE031
    =======
      SUBJECT :: WINDVEL-RULES
      DOBEFORE :: (26)
If   1) the forecast wind velocity at Hwy 30 is greater than or equal to 7,
and

     2) the forecast wind velocity at Hwy 30 is less than 9,
Then it is definite (100%) that prob of fog due to wind velocity is 0.2.

    RULE032
    =======
      SUBJECT :: WINDVEL-RULES
      DOBEFORE :: (26)
If   1) the forecast wind velocity at Hwy 30 is greater than or equal to 9,
and

     2) the forecast wind velocity at Hwy 30 is less than 13,
Then it is definite (100%) that prob of fog due to wind velocity is 0.45.

    RULE033
    =======
      SUBJECT :: WINDVEL-RULES
      DOBEFORE :: (26)
If   1) the forecast wind velocity at Hwy 30 is greater than or equal to 13,
        and
     2) the forecast wind velocity at Hwy 30 is less than 15,
Then it is definite (100%) that prob of fog due to wind velocity is 0.4.

    RULE034
    =======
      SUBJECT :: WINDVEL-RULES
      DOBEFORE :: (26)
If   1) the forecast wind velocity at Hwy 30 is greater than or equal to 15,
        and
     2) the forecast wind velocity at Hwy 30 is less than 19,
Then it is definite (100%) that prob of fog due to wind velocity is 0.3.

    RULE035
    =======
      SUBJECT :: WINDVEL-RULES
      DOBEFORE :: (26)
If   the forecast wind velocity at Hwy 30 is greater than or equal to 19,
Then it is definite (100%) that prob of fog due to wind velocity is 0.2.
```



```
      ================
        META-RULES
      ================

    MRULE001
    ========
      SUBJECT :: META-RULES
If   1) Probability of fog on Hwy 30 0. to 1. is known, and
     2) put any OBJRULES which meets the condition: Probability of fog on Hwy
        30 0. to 1. is mentioned in the rule into SET1, and
     3) put any OBJRULES which meets the condition: There will be a cooling
        tower fog on Hwy 30 near the ADM plant with the forecast conditions.
        is mentioned in the rule into SET2,
Then DOBEFORE is assigned the values: SET1.
```

APPENDIX D. FORTRAN SOURCE CODE

The following is the Fortran source code for the latest (January 1995) version of the model used to forecast cooling-tower plume behavior in Cedar Rapids. This version includes the ability to correct observed model bias when available.

```
      REAL DIV,ATEMP(19),ADWPT(19),ADIR(19),AVEL(19),PBTEMP,
     +PBDWPT,PBDIR,PBVEL,PBFOG(19),DEPP,W(3),C(4),D(4),INI(4,19),
     +X(5,19),Y(5,19),AX(19),AY(19),DIRS(5,19),BIAS(5,19)

      INTEGER I,J,TST(5),TEMP(5,19),DWPT(5,19),DIR(5,19),VEL(5,19),
     +MM,DD,YY,HH,DD1,DD2,MM2,MM3

      CHARACTER INPUTFILE*60,STATION*4,STA(4)*4,DAY*63,
     +HOUR*63,TMP(5)*6,CREAT*50,CAT(19)*1,DATE*8,TIME*4,K*1,
     +MONTH*3,MONTH2*3,MONTH3*3,CURRENT*30,VERSION*30,COMENT*50

c*******************************************
c
      VERSION='0.94    26 JANUARY 1995'
c
c  V=.90  original Beta version, 16 December 94
c         -used simple averages of NGM variables
c
c  V=.91  19 December 94
c         -added a cressman scheme on NGM variables
c         -added BRL as 4th data site
c
c  V=.92  20 December 94
c         -break wind into components
c         -corrected 122 oupout problems
c         -corrected end of month problems in output
c         -fixed problem when no data found
c
c  V=.93  30 December 94
c         -added area for DOT people to verify forecasts
c         -changed output format slightly - (PBFOG*100)
c         -fixed data read problem of large negative temp's
c           (this was also added to 0.92)
c         -fixed date output problem (added to 0.92)
c
c  V=.94 26 January 95
c         -added model bias correct output
c
c
c*******************************************
c read text file for current ngm file and time
c*******************************************
      OPEN (UNIT=99, FILE='.name.file', STATUS='OLD')
      READ (99,10) INPUTFILE
      OPEN (UNIT=98, FILE='.time.file', STATUS='OLD')
      READ (98,10) CURRENT
```



```
c********** used to select a specific ngm file **********
c      INPUTFILE='ngm.mos.00.02'
c*******************************************************

      print*,'This file created on ',CURRENT
      print*,'Reading input file ',INPUTFILE

   10 FORMAT (A60)
      CLOSE (UNIT=99)

      OPEN (UNIT=100, FILE=INPUTFILE, STATUS='OLD')

      STA(1)='.ALO '
      STA(2)='.DSM '
      STA(3)='.MLI '
      STA(4)='.BRL '
      DIV=0.0

   11 FORMAT (A4,A50)
   12 FORMAT (A63)
   13 FORMAT (A7)
c*******************************************
c
c read the temp, etc. from ngm file
c
c*******************************************

      DO 20 I=1,4


      TST(I)=0
   14 READ (100,11,END=19) STATION,CREAT
      IF (STA(I).NE.STATION) GOTO 14

c  15  PRINT*,STA(I),' data found '
      READ (100,12,END=19,ERR=18) DAY
      READ (100,12,END=19,ERR=18) HOUR
      READ (100,13,END=19,ERR=18) TMP(1)

   16 FORMAT (A6,19(I3))

      READ (100,16,END=19) TMP(1),TEMP(I,1),TEMP(I,2),TEMP(I,3),
     +TEMP(I,4),TEMP(I,5),TEMP(I,6),TEMP(I,7),TEMP(I,8),TEMP(I,9),
     +TEMP(I,10),TEMP(I,11),TEMP(I,12),TEMP(I,13),TEMP(I,14),
     +TEMP(I,15),TEMP(I,16),TEMP(I,17),TEMP(I,18),TEMP(I,19)
      IF (TMP(1).NE.'TEMP  ') GOTO 18

      READ (100,16,END=19) TMP(1),DWPT(I,1),DWPT(I,2),DWPT(I,3),
     +DWPT(I,4),DWPT(I,5),DWPT(I,6),DWPT(I,7),DWPT(I,8),DWPT(I,9),
     +DWPT(I,10),DWPT(I,11),DWPT(I,12),DWPT(I,13),DWPT(I,14),
     +DWPT(I,15),DWPT(I,16),DWPT(I,17),DWPT(I,18),DWPT(I,19)
      IF (TMP(1).NE.'DEWPT ') GOTO 18

      READ (100,13,END=19) TMP(1)
```

```
      READ (100,16,END=19) TMP(1),DIR(I,1),DIR(I,2),DIR(I,3),
     +DIR(I,4),DIR(I,5),DIR(I,6),DIR(I,7),DIR(I,8),DIR(I,9),
     +DIR(I,10),DIR(I,11),DIR(I,12),DIR(I,13),DIR(I,14),
     +DIR(I,15),DIR(I,16),DIR(I,17),DIR(I,18),DIR(I,19)
      IF (TMP(1).NE.'WDIR  ') GOTO 18

      READ (100,16,END=19) TMP(1),VEL(I,1),VEL(I,2),VEL(I,3),
     +VEL(I,4),VEL(I,5),VEL(I,6),VEL(I,7),VEL(I,8),VEL(I,9),
     +VEL(I,10),VEL(I,11),VEL(I,12),VEL(I,13),VEL(I,14),
     +VEL(I,15),VEL(I,16),VEL(I,17),VEL(I,18),VEL(I,19)
      IF (TMP(1).NE.'WSPD  ') GOTO 18

 17   FORMAT (1X,A2,2X,A2,2X,A2)
      DATE=CREAT(26:33)
      TIME=CREAT(36:39)
      OPEN (UNIT=102, FILE='TEMP.TEMP', STATUS='SCRATCH')
      WRITE (102,17) DATE(1:2),DATE(4:5),DATE(7:8)
      WRITE (102,*) TIME
      TST(I)=1
      DIV=DIV+1.0
      GOTO 19
 18   PRINT*, 'ERROR READING ',STA(I)
 19  TMP(1)=TMP(5)
     REWIND (UNIT=100)
     IF (I.GE.4.AND.TST(1).EQ.0.AND.DIV.LT.3) THEN
     PRINT*,'  '
     PRINT*,' Not enough data to make a forecast. '
     GOTO 52
     END IF
 20  CONTINUE
c*************************************************
c end of reading ngm data file
c*************************************************

c*************************************************
c    required to fix weird error with VEL(0,1)????
c*************************************************
     DO 90 I=1,19
      TEMP(0,I)=0
      DWPT(0,I)=0
      X(0,I)=0.0
      Y(0,I)=0.0
     DO 92 J=1,4
     DIRS(J,I)=REAL(DIR(J,I))*10.0
 92  CONTINUE
 90  CONTINUE

c**************************************************
c    find simple averages of the data for first guess
c**************************************************

     DO 21 J=1,4
       Y(0,J)=0.0
       X(0,J)=0.0
       IF (TST(J).GT.0) THEN
        DO 22 I=1,19
```



```
        X(J,I)=REAL(VEL(J,I))*SIN(((DIRS(J,I)*3.141592)/180.0))
        Y(J,I)=REAL(VEL(J,I))*COS(((DIRS(J,I)*3.141592)/180.0))
        TEMP(0,I)=TEMP(0,I)+TEMP(J,I)
        DWPT(0,I)=DWPT(0,I)+DWPT(J,I)
        X(0,I)=X(0,I)+X(J,I)
        Y(0,I)=Y(0,I)+Y(J,I)
 22    CONTINUE
      END IF
 21  CONTINUE

     DO 23 I=1,19
       ATEMP(I)=TEMP(0,I)/DIV
       ADWPT(I)=DWPT(0,I)/DIV
       AX(I)=X(0,I)/DIV
       AY(I)=Y(0,I)/DIV
 23  CONTINUE

c*************************************************
c     Cressman method of correction
c*************************************************
     DO 91 I=1,4
     W(I)=0.0
 91  CONTINUE

     IF (TST(1).EQ.1) W(1)=0.5923
     IF (TST(2).EQ.1) W(2)=0.1050
     IF (TST(2).EQ.1) W(3)=0.4706
     IF (TST(2).EQ.1) W(4)=0.3159

     DO 24 I=1,19
      D(1)=TEMP(1,I)-ATEMP(I)
      D(2)=DWPT(1,I)-ADWPT(I)
      D(3)=X(1,I)-AX(I)
      D(4)=Y(1,I)-AY(I)

     C(1)=(W(1)*D(1)+W(2)*D(1)+W(3)*D(1)+W(4)*D(1))/DIV
     C(2)=(W(1)*D(2)+W(2)*D(2)+W(3)*D(2)+W(4)*D(2))/DIV
     C(3)=(W(1)*D(3)+W(2)*D(3)+W(3)*D(3)+W(4)*D(3))/DIV
     C(4)=(W(1)*D(4)+W(2)*D(4)+W(3)*D(4)+W(4)*D(4))/DIV

     ATEMP(I)=ATEMP(I)+C(1)
     ADWPT(I)=ADWPT(I)+C(2)
     AX(I)=AX(I)+C(3)
     AY(I)=AY(I)+C(4)
 24  CONTINUE

     DO 25 I=1,19
     AVEL(I)=SQRT(AX(I)**2+AY(I)**2)
     IF (AVEL(I).GT.0.000001) THEN
     ADIR(I)=(180.0/3.141592)*ACOS(AY(I)/AVEL(I))
     IF (AX(I).LT.0.0) ADIR(I)=360.0-ADIR(I)
     ELSE
     ADIR(I)=999.0
     END IF
 25  CONTINUE
```

```
c*********************************************
c      apply the average bias to the forecast
c*********************************************
      DO 69 I=1,19
      DO 68 J=1,4
      BIAS (J,I)=0.0
   68 CONTINUE
   69 CONTINUE

      OPEN (UNIT=96,ERR=72,FILE="BIAS",STATUS='OLD')

       READ (96,*,END=71,ERR=71) BIAS(1,1),BIAS(1,2),BIAS(1,3),
     +BIAS(1,4),BIAS(1,5),BIAS(1,6),BIAS(1,7),BIAS(1,8),BIAS(1,9),
     +BIAS(1,10),BIAS(1,11),BIAS(1,12),BIAS(1,13),BIAS(1,14),
     +BIAS(1,15),BIAS(1,16),BIAS(1,17),BIAS(1,18),BIAS(1,19)

       READ (96,*,END=71,ERR=71) BIAS(2,1),BIAS(2,2),BIAS(2,3),
     +BIAS(2,4),BIAS(2,5),BIAS(2,6),BIAS(2,7),BIAS(2,8),BIAS(2,9),
     +BIAS(2,10),BIAS(2,11),BIAS(2,12),BIAS(2,13),BIAS(2,14),
     +BIAS(2,15),BIAS(2,16),BIAS(2,17),BIAS(2,18),BIAS(2,19)

       READ (96,*,END=71,ERR=71) BIAS(3,1),BIAS(3,2),BIAS(3,3),
     +BIAS(3,4),BIAS(3,5),BIAS(3,6),BIAS(3,7),BIAS(3,8),BIAS(3,9),
     +BIAS(3,10),BIAS(3,11),BIAS(3,12),BIAS(3,13),BIAS(3,14),
     +BIAS(3,15),BIAS(3,16),BIAS(3,17),BIAS(3,18),BIAS(3,19)

       READ (96,*,END=71,ERR=71) BIAS(4,1),BIAS(4,2),BIAS(4,3),
     +BIAS(4,4),BIAS(4,5),BIAS(4,6),BIAS(4,7),BIAS(4,8),BIAS(4,9),
     +BIAS(4,10),BIAS(4,11),BIAS(4,12),BIAS(4,13),BIAS(4,14),
     +BIAS(4,15),BIAS(4,16),BIAS(4,17),BIAS(4,18),BIAS(4,19)

      DO 70 I=1,19
      ATEMP(I)=ATEMP(I)-BIAS(1,I)
      ADWPT(I)=ADWPT(I)-BIAS(2,I)
      IF (ADWPT(I).GT.ATEMP(I)) ADWPT(I)=ATEMP(I)
      ADIR(I)=ADIR(I)-BIAS(3,I)
      IF (ADIR(I).GT.360.0) ADIR(I)=ADIR(I)-360.0
      IF (ADIR(I).LT.0.0) ADIR(I)=ADIR(I)+360.0
      AVEL(I)=AVEL(I)-BIAS(4,I)
      IF (AVEL(I).LT.0.0) AVEL(I)=0.0
   70 CONTINUE
      COMENT="Reading model bias data"
      GOTO 73
   71 COMENT="Error reading model bias file, bias data not used."
      GOTO 73
   72 COMENT="Model bias file not found."
   73 PRINT*,COMENT

c*********************************************
c       find the individual probablilities
c      ( same as adm-2.f, new as of 18 DEC 94)
c*********************************************

      DO 30 I=1,19

      PBFOG(I)=0
      IF (ATEMP(I).LT.16) PBTEMP=0.85
```



```
      IF (ATEMP(I).GE.16.AND.ATEMP(I).LT.21) PBTEMP=0.85
      IF (ATEMP(I).GE.21.AND.ATEMP(I).LT.26) PBTEMP=0.92
      IF (ATEMP(I).GE.26.AND.ATEMP(I).LT.31) PBTEMP=0.95
      IF (ATEMP(I).GE.31.AND.ATEMP(I).LT.36) PBTEMP=0.97
      IF (ATEMP(I).GE.36.AND.ATEMP(I).LT.41) PBTEMP=0.91
      IF (ATEMP(I).GE.41.AND.ATEMP(I).LT.46) PBTEMP=0.915
      IF (ATEMP(I).GE.46.AND.ATEMP(I).LT.50) PBTEMP=0.90
      IF (ATEMP(I).GE.50) PBTEMP=0.879

      IF (ADIR(I).LT.120) PBDIR=0.50
      IF (ADIR(I).GE.120.AND.ADIR(I).LT.150) PBDIR=0.90
      IF (ADIR(I).GE.150.AND.ADIR(I).LT.170) PBDIR=0.92
      IF (ADIR(I).GE.170.AND.ADIR(I).LT.185) PBDIR=0.91
      IF (ADIR(I).GE.185.AND.ADIR(I).LT.210) PBDIR=0.93
      IF (ADIR(I).GE.210.AND.ADIR(I).LT.230) PBDIR=0.90
      IF (ADIR(I).GE.230.AND.ADIR(I).LT.250) PBDIR=0.90
      IF (ADIR(I).GE.250.AND.ADIR(I).LT.265) PBDIR=0.894
      IF (ADIR(I).GE.265.AND.ADIR(I).LT.285) PBDIR=0.915
      IF (ADIR(I).GE.285) PBDIR=0.50

      DEPP=ATEMP(I)-ADWPT(I)
      IF (DEPP.LE.0.5) PBDWPT=.99
      IF (DEPP.LE.1.0.AND.DEPP.GT.0.5) PBDWPT=.98
      IF (DEPP.LE.2.0.AND.DEPP.GT.1.0) PBDWPT=.935
      IF (DEPP.LE.3.0.AND.DEPP.GT.2.0) PBDWPT=.85
      IF (DEPP.GT.3.0.AND.DEPP.LE.5.0) PBDWPT=0.80
      IF (DEPP.GT.5.0) PBDWPT=0.60

c********find overall probability and cat. of fog prob.*******

      PBFOG(I) = (PBDIR*PBTEMP*PBDWPT)
      IF (AVEL(I).LE.4.0) PBFOG(I)=PBFOG(I)*.95

      IF (PBFOG(I).GE.0.80) CAT(I)='H'
      IF (PBFOG(I).GE.0.70.AND.PBFOG(I).LT.0.80) CAT(I)='M'
      IF (PBFOG(I).GE.0.60.AND.PBFOG(I).LT.0.70) CAT(I)='L'
      IF (PBFOG(I).LT.0.60) CAT(I)='0'
      PBFOG(I)=PBFOG(I)*100.0
   30 CONTINUE
c*********************************************
c       change to CST from UTC
c*********************************************

      REWIND (102)
      READ (102,36) MM,DD,YY
      READ (102,37) HH
   36 FORMAT (1X,I2,2X,I2,2X,I2)
   37 FORMAT (1X,I2)

      HH=HH-6
      IF (HH.LT.1) THEN
         HH=HH+24
         DD=DD-1
      END IF

      IF (DD.LT.1) THEN
       MM=MM-1
```

```
 IF (MM.EQ.1.OR.MM.EQ.3.OR.MM.EQ.5.OR.MM.EQ.7.OR.
+MM.EQ.8.OR.MM.EQ.10.OR.MM.EQ.12) DD=31
 IF (MM.EQ.4.OR.MM.EQ.6.OR.MM.EQ.9.OR.MM.EQ.11) DD=30
 IF (MM.EQ.2) DD=28
 END IF

 IF (MM.LT.1) THEN
   MM=MM+12
   YY=YY-1
 END IF

 DD1=DD+1
 MM2=MM
 IF (MM2.EQ.2.AND.DD1.GT.28) THEN
 MM2=3
 DD1=1
 END IF
 IF (MM2.EQ.4.OR.MM2.EQ.6.OR.MM2.EQ.9.OR.MM2.EQ.11.
+AND.DD1.GT.30) THEN
 MM2=MM2+1
 DD1=1
 END IF
 IF (MM2.EQ.1.AND.DD1.GT.31) THEN
 MM2=MM+1
 DD1=1
 END IF
 IF (MM2.EQ.3.AND.DD1.GT.31) THEN
 MM2=MM+1
 DD1=1
 END IF
 IF (MM2.EQ.10.AND.DD1.GT.31) THEN
 MM2=MM+1
 DD1=1
 END IF
 IF (MM2.EQ.12.AND.DD1.GT.31) THEN
 MM2=MM+1
 DD1=1
 END IF

 IF (TIME.EQ.'0000'.AND.DD1.EQ.1) MM=MM+1
 IF (MM2.GT.12) MM2=1

 DD2=DD1+1
 MM3=MM

 IF (MM3.EQ.2.AND.DD2.GT.28) THEN
 MM3=3
 DD2=1
 END IF

 IF (MM3.EQ.4.OR.MM3.EQ.6.OR.MM3.EQ.9.OR.MM3.EQ.11.
+AND.DD2.GT.30) THEN
 MM3=MM3+1
 DD2=1
 END IF

 IF (MM3.EQ.1.AND.DD2.GT.31) THEN
```



```
 MM3=MM+1
 DD2=1
 END IF
 IF (MM3.EQ.3.AND.DD2.GT.31) THEN
 MM3=MM+1
 DD2=1
 END IF
 IF (MM3.EQ.10.AND.DD2.GT.31) THEN
 MM3=MM+1
 DD2=1
 END IF
 IF (MM3.EQ.12.AND.DD2.GT.31) THEN
 MM3=MM+1
 DD2=1
 END IF

 IF (MM3.GT.12) MM3=1

c*****should be in a loop  ;)

   IF (MM3.EQ.9) MONTH3='SEP'
   IF (MM3.EQ.10) MONTH3='OCT'
   IF (MM3.EQ.11) MONTH3='NOV'
   IF (MM3.EQ.12) MONTH3='DEC'
   IF (MM3.EQ.1) MONTH3='JAN'
   IF (MM3.EQ.2) MONTH3='FEB'
   IF (MM3.EQ.3) MONTH3='MAR'
   IF (MM3.EQ.4) MONTH3='APR'
   IF (MM2.EQ.9) MONTH2='SEP'
   IF (MM2.EQ.10) MONTH2='OCT'
   IF (MM2.EQ.11) MONTH2='NOV'
   IF (MM2.EQ.12) MONTH2='DEC'
   IF (MM2.EQ.1) MONTH2='JAN'
   IF (MM2.EQ.2) MONTH2='FEB'
   IF (MM2.EQ.3) MONTH2='MAR'
   IF (MM2.EQ.4) MONTH2='APR'
   IF (MM.EQ.9) MONTH='SEP'
   IF (MM.EQ.10) MONTH='OCT'
   IF (MM.EQ.11) MONTH='NOV'
   IF (MM.EQ.12) MONTH='DEC'
   IF (MM.EQ.1) MONTH='JAN'
   IF (MM.EQ.2) MONTH='FEB'
   IF (MM.EQ.3) MONTH='MAR'
   IF (MM.EQ.4) MONTH='APR'

c*************************************************
c       output sections
c*************************************************

    print*,' '
 38 FORMAT ('Forecast created using NGM MOS data from ',I2,' ',
   +A3,' ',I2,' taken at 0',I1,'00 CST')
 39 FORMAT ('Forecast created using NGM MOS data from ',I2,' ',
   +A3,' ',I2,' taken at ',I2,'00 CST')
```

```
      IF (TIME.EQ.'1200') THEN
      PRINT 38,DD,MONTH,YY,HH
      ELSE IF (TIME.EQ.'0000') THEN
      PRINT 39,DD,MONTH,YY,HH
      END IF

      print*,' '
      print*,' '

      IF (TIME.EQ.'0000') THEN
      PRINT 41,MONTH,DD1,MONTH3,DD2
      ELSE IF (TIME.EQ.'1200') THEN
      PRINT 42,MONTH,DD,MONTH2,DD1
      END IF

31    FORMAT (A5,11(F5.0,1X))
32    FORMAT ('WDIR ',11(F5.0,1X))
33    FORMAT (A5,3x,11(A1,5x))
34    FORMAT (A6,1x,11(F3.0,3X))
35    FORMAT ('HOUR  ',1X,11(A2,4X))
41    FORMAT ('DAY   /',A3,2X,I2,40X,'/',A3,2X,I2)
42    FORMAT ('DAY   /',A3,2X,I2,17X,'/',A3,2X,I2)
50    FORMAT (A5,2X,11(A3,3X))
51    FORMAT (A7)

      IF (TIME.EQ.'0000') THEN
      PRINT 35,'00','03','06','09','12','15','18','21','00',
     +'03','06'
      ELSE IF (TIME.EQ.'1200') THEN
      PRINT 35,'12','15','18','21','00','03','06','09','12',
     +'15','18'
      END IF

      PRINT*,' '
      PRINT 31,'TEMP ',ATEMP(1),ATEMP(2),ATEMP(3),ATEMP(4),ATEMP(5),
     +ATEMP(6),ATEMP(7),ATEMP(8),ATEMP(9),ATEMP(10),ATEMP(11)
      PRINT 31,'DWPT ',ADWPT(1),ADWPT(2),ADWPT(3),ADWPT(4),ADWPT(5),
     +ADWPT(6),ADWPT(7),ADWPT(8),ADWPT(9),ADWPT(10),ADWPT(11)
      PRINT 32,ADIR(1),ADIR(2),ADIR(3),ADIR(4),ADIR(5),ADIR(6),
     +ADIR(7),ADIR(8),ADIR(9),ADIR(10),ADIR(11)
      PRINT 31,'WSPD ',AVEL(1),AVEL(2),AVEL(3),AVEL(4),AVEL(5),
     +AVEL(6),AVEL(7),AVEL(8),AVEL(9),AVEL(10),AVEL(11)
c      PRINT*,' '
      PRINT*,' '
      PRINT*,'   Plume Forecast for US Highway 30 near the ADM plant'
      PRINT*,' '
      PRINT 34,'PROB %',PBFOG(1),PBFOG(2),PBFOG(3),PBFOG(4),PBFOG(5),
     +PBFOG(6),PBFOG(7),PBFOG(8),PBFOG(9),PBFOG(10),PBFOG(11)
      PRINT 33,'CAT  ',CAT(1),CAT(2),CAT(3),CAT(4),CAT(5),CAT(6),
     +CAT(7),CAT(8),CAT(9),CAT(10),CAT(11)
      PRINT*,' '
      PRINT*,' '
      PRINT*,'     Observations of plume behavior'
      PRINT*,' '
      PRINT *,' ON'
      PRINT 50,'ROAD','___','___','___','___','___','___','___','___'
     +,'___','___','___'
```



```
      PRINT*,' '
      PRINT *,'ABOVE'
      PRINT 50,'ROAD','___','___','___','___','___','___','___','___'
     +,'___','___','___'
      PRINT*,' '
      PRINT 51,'COOLING'
      PRINT *,'UNITS'
      PRINT 50,'USED','___','___','___','___','___','___',
     +'___','___','___','___','___'
      PRINT*,' '
      print*,'The fog categories are based upon the predicted
     +probability for a'
      print*,'cooling tower fog effecting the visibility along
     +Highway 30 near'
      print*,'the Archer Daniels Midland plant.'
      print*,' '
      print*,'  The criteria for each category is: '
      print*,' '
      print*,'  High    Probability greater than or equal to 80'
      print*,' '
      print*,'  Medium  Probability between 70 and 80'
      print*,' '
      print*,'  Low     Probability between 60 and 70'
      print*,' '
      print*,'  Zero    Probability less than 60 '
      print*,' '
      print*,'These categories provide only a general outlook of
     +the cooling tower '
      print*,'plume behavior based on a national computer model
     +which forecasts '
      print*,'weather conditions for the area.  This forecast is
     +experimental and '
      print*,'users should be alert to possible large errors in
     +these forecasts of '
      print*,'plume behavior and weather conditions.'
52    PRINT*,' '
      PRINT*,' '
      PRINT*,'            Version ',VERSION
      PRINT*,' '
      PRINT*,'            By:  E.S. Takle and P.C. Thomson '
      PRINT*,'email:  gstakle@iastate.edu     pthomson@iastate.edu'
      PRINT*,' '
      CLOSE (100)
      CLOSE (99)
      CLOSE (98)
      END
```