PASCON: An Expert System for Passive Snow Control on Highways

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Blowing and drifting snow is a common occurrence on roadways in cold regions that cause reduced visibility and snowdrifts on the roadway, resulting in hazardous road conditions and partial or total road closure. Consequences include longer travel time, greater maintenance and snow control costs, and more vehicle accidents involving property damage, personal injury, and, in extreme cases, loss of life. Passive snow control is the name given to methods offering some control over where wind-driven snow will or will not be deposited. Passive snow control techniques include snow fences, shelterbelts, and design of aerodynamic roadway sections. Currently, no widely accepted algorithmic methods exist for passive snow control on highways. The main objective of the project was to provide a tool for highway design and maintenance personnel to use in evaluating snow problem locations and identifying possible solutions, without requiring an extensive knowledge of passive snow control methods. To this end, an expert system, PAssive Snow CONtroller (PASCON), was developed on an IBM PC microcomputer. PASCON incorporates knowledge from a nationally recognized expert in passive snow control and from the literature. PASCON includes five external programs for design procedures, computations, and graphics. Several consultations with the expert system yielded results that agreed with the domain expert and with solutions worked out manually.

Blowing and drifting snow is a common occurrence on roadways in snow regions, causing reduced visibility and snowdrifts on the roadway, resulting in hazardous road conditions and partial or total road closure. Consequences include longer travel time, increased maintenance and snow control costs, and more motor vehicle accidents involving property damage, personal injury, and, in extreme cases, loss of life. Most state highway departments consider snow control primarily a maintenance responsibility, with little attention given to snow-related problems during the highway design process. Also, there are currently no widely accepted preventive methods of snow control. Passive snow control is the name given to methods offering some control over where wind-driven snow will (or will not) be deposited. This method contrasts with mechanical methods of snow control by plowing and deicing that are in predominant use today.

Passive snow control techniques include snow fences, shelterbelts, and the design of aerodynamic roadway sections. Although this technology to mitigate or even eliminate many of the problems created by blowing snow has been available for many years, it is seldom put into practice. One reason is the fact that expertise in passive snow control is virtually nonexistent in most areas of the world. In addition, snow control measures are often not used because of reluctance resulting from past experience with improper designs, lack of information on proper techniques, inadequate right-of-way, insufficient funds, or absence of a passive snow control policy to address these problems. This paper presents an expert system, PAssive Snow CONtroller (PASCON), that incorporates domain knowledge available in the literature and the experience and knowledge of a leading expert on the subject. It is intended that this system will prove to be an effective mode for transfer of technology from those who possess the knowledge to those who need it.

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PASSIVE SNOW CONTROL TECHNIQUES

Although passive snow control techniques have been in use for more than a century, engineered passive snow control is a relatively new technology. Modern techniques have been in existence only since the early 1970s (*1,2*). This new era began with successful installation of engineered snow fences along a 77-mi section of Interstate 80 in southeast Wyoming in 1971. This new highway section was closed 10 times during its first winter in service because of severe problems with blowing and drifting snow. In an effort to alleviate this hazardous and also somewhat embarrassing situation, the Wyoming State Highway Department was willing to install several miles of snow fence designed almost exclusively from untested research studies (*3*). The success of these fences has greatly aided development and acceptance of passive snow control as an attractive and economical alternative. There are three basic categories of passive snow control—drift-free roadway design, snow fences, and shelterbelts.

Road Design

The idea of preventing snow drifting on roadways by providing an aerodynamic cross section was pioneered by E. A. Finney in the 1930s. One of his most significant findings was the conclusion that the length of a snowdrift was 6.5 times the embankment height (or cut depth) for heights (or depths) of 2 to 10 ft (*4*). This rule of thumb for predicting snowdrift lengths was a useful tool for highway designers desiring to provide a drift-free cross section. Finney's work gained wide acceptance and was not seriously challenged until R. D. Tabler's research in the early 1970s. His studies of snow fences along Wyoming highways led to the observation that the slope of snowdrifts in roadway cut sections did not agree with Finney's research or other derivative literature.

Tabler developed a regression model based solely on topographic data to predict drift formation (*2*). The model was compared to existing drift locations and found to give reliable results. The significant difference between Finney's and Tabler's research was that while Finney found drift length to be directly proportional to embankment height, Tabler's regression model shows that it varies exponentially with height. For example, the length of a drift created by a 4-ft roadway cut will extend about 195 ft beyond the top of the cut—nearly 50 times the depth of cut.

The reason given for the disparity between Tabler's and Finney's findings is that Finney's wind tunnel experiments did not satisfy modeling similitude requirements, with the likely result that embankment heights tested were much higher than intended. This explanation is supported by the fact that the two theories converge for embankments of considerable height. Tabler's work provides a method for dynamic design and analysis of roadway cross-sections with respect to their potential for drifting. If drifting is indicated, the roadway may be redesigned in an iterative fashion until the model indicates that the roadway will remain drift-free.

The Wyoming State Highway Department uses a computer algorithm based on this theory to design drift-free roadways and redesign existing roadways where drifting is a problem (*5*). Redesign options for roadway cut sections include flattening upwind and downwind cut slopes, widening ditches on both sides of the road, and raising the road's profile above the ambient snow cover. Embankments may be made drift-free by providing leeward fill slopes that are equal to or flatter than 4:1 (*6*).

Guiderail often creates drifting onto the roadway at locations that would otherwise be drift-free (*6*). The process results from corrugated-beam guiderail performing as a miniature snow fence, inducing snow deposition downwind. The guiderail also tends to catch snow plowed off the road and prevent it from being thrown farther from the road. This further exacerbates the problem by creating a new snow berm at the guiderail, which may cause blowing snow to cross the road near driver eye level, resulting in reduced visibility. This snow berm may also act as a ramp that can direct a vehicle into the same obstacle from which the guiderail is designed to protect the motorist. The New York State Thruway Authority was found to be negligent in a lawsuit that resulted from an accident caused by this ramping effect (*7*).

For these reasons, at locations where drifting or poor visibility can be attributed to guiderail, the guiderail should be eliminated if possible. If elimination is not possible, then use of cable guiderail is recommended. Use of corrugated-beam guiderail is discouraged. Good road design, although an effective method for preventing drifting onto the roadway, will not obviate the need for other measures if improved visibility is also an objective. Also, because of the significant work involved, road design may not prove to be a cost-effective solution for existing roadways, but road redesign can be evaluated as an alternative to solving drifting problems.

Snow Fences

The basic function of a snow fence is to produce a reverse airflow area that will cause wind-driven snow to be deposited upwind of the area requiring protection. Although the history of snow fences dates back to their use by railroads in the 1800s, modern engineering criteria for design of snow fence installations have existed for less than 25 years. Tabler was the first to design snow fences for a specific snow storage capacity, on the basis of seasonal snow transport (*8*). He developed a method for estimating snow transport at a given location that depended on seasonal precipitation and unobstructed upwind distance, referred to as the "fetch" (*1*). Another method for estimating snow transport, which Tabler derived from work by Pomeroy, depends on wind speed (*9*).

The underlying premise of the precipitation-based method is that sufficient wind exists to transport all the relocatable snow—i.e., there is "more wind than snow." Conversely, the wind-based method assumes that the amount of snow relocated is limited by the available wind—i.e., "more snow than wind." The equations used to estimate seasonal snow transport are as follows:

Precipitation-Dependent Seasonal Snow Transport

$$Q = 0.5kPT[1 - 0.14^{(F/T)}] \tag{1}$$

where

Q = total snow transport (cubic feet of water per foot of width);
k = transport coefficient, percent of snowfall that is relocatable, expressed as a decimal (0.5 to 0.7);
P = seasonal snowfall (water equivalent, ft);
T = maximum transport distance (usually 10,000 ft); and
F = fetch distance or upwind open distance (ft).

Wind-Dependent Seasonal Snow Transport

$$Q = 0.004895 \sum_i [D_i \sum_j (F_{ij}) (U_j^{4.04})] \tag{2}$$

where

Q = total snow transport (pounds per foot of width),
D_i = number of now accumulation days in Month i,
F_{ij} = frequency of occurrence for wind speed Group j for Month i, and
U_j = composite speed for wind speed Group j.

Tabler believes that the wind-based equation is valid for fetch distances of 1,000 ft or more. For this reason, the precipitation-based transport equation should be used exclusively for locations with a fetch distance less than 1,000 ft. In locations where fetch distance is greater than this, total snow transport to be used for design and analysis should be the limiting value from the two equations. The design snow transport is then used to determine size and location of the snow fence required to store this volume of snow.

There are several different types and shapes of snow fences. They have been constructed using materials ranging from steel to paper. The expert system presented here uses four types of snow fences: (a) Wyoming-type wood-slat, (b) synthetic

(plastic), (c) wood-picket, and (d) chain-link. Although chain-link fence is not recommended, it is included to evaluate its placement adjoining the roadway. The other three are the most common types of highway snowfence in use today. Because they have different porosities, they have different storage capacities and different drift profiles (*10*)

Shelterbelts

Also referred to as "living snow fences," shelterbelts are rows of trees or shrubs planted to provide protection from blowing snow. The known history of shelterbelts in this country dates from the early 1900s when they were used by railroad companies (*11*). Use of living snow fences to protect highways dates from the 1920s. Many states currently have formal living snow fence programs.

Living snow fences have many advantages compared with fabricated ones, including roadside beautification, environmental benefits, little or no maintenance costs after they become established, long service life, and possible lower life-cycle costs. A disadvantage is that they generally require 5 to 10 years before beginning to reach effective heights, although snow fences may be used during the establishment period if immediate protection is desired.

Proper design of shelterbelts depends on many factors, including design snow transport, height of plantings, plant type, number and spacing of rows, and available upwind distance. No quantitative methods now exist for design of living snowfences (*11*). Designs are based on experience and planting schemes that are certain to provide some degree of protection.

An important consideration in shelterbelt design is change in drift pattern with growth and densification of the plantings. A living fence will perform like a porous snow fence during the first few years. As the plantings become more dense with crown closure they will perform more like a solid barrier. Change in drift pattern with growth must be considered during design. Also, an effective seasonal shelterbelt could be achieved in some areas by leaving several rows of cornstalks standing through the winter (*6*).

PROTOTYPE EXPERT SYSTEM DEVELOPMENT

Nine distinct phases of system development were identified for this project:

1. Identification and acquisition of domain knowledge;
2. Selection of expert system development environment;
3. Development of computer algorithms to compute predicted drift profiles before and after implementation of recommended control measures, and development of other support programs;
4. Acquisition, tabulation, and manipulation of climatological data;
5. Formulation of rules;
6. Development of system reasoning behavior;
7. Organization and formulation of the system;
8. Testing, verification, and fine tuning of the system; and
9. User interface development.

These phases are described in the following sections.

Identification and Acquisition of Domain Knowledge

Knowledge Sources

Several data bases were searched for information about passive snow control on highways, including those of the Transportation Research Information Service (TRIS), the U.S. Army Corps of Engineers, and (files of) the New York State Department of Transportation (NYSDOT). The literature survey identified Ronald D. Tabler of Tabler & Associates, Colorado, as a leading expert on passive snow control. He has developed several new methods that have been successfully adopted on Wyoming highways. He agreed to be the domain expert. Several state, county, and local officials within New York State were also identified who are known to have some knowledge of the subject.

The expert system has incorporated knowledge in three basic areas: (a) history of passive snow control methodologies, (b) current practices in western New York, and (c) global knowledge of the domain. Data on evolution of passive snow control techniques was obtained in large part from available literature. Knowledge of current practices in western New York was obtained from several state, county, and local officials who had experience in snow control on roads. They also provided information on why they did not use certain methods, which helped focus the PASCON expert system on addressing problems existing with some of the current techniques.

Much of the domain knowledge for the PASCON expert system was provided by Tabler, who offered general guidance during system development, pointed out several idiosyncrasies, explained unclear principles, advised on proper application of research, and judged the correctness of the expert system's output.

Flow of knowledge transfer is shown in Figure 1.

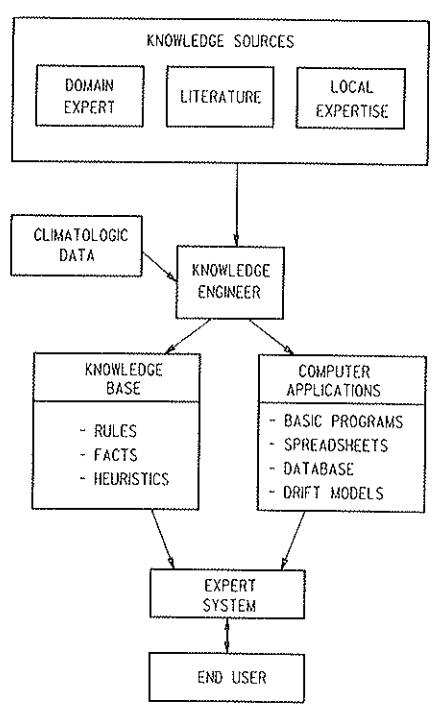

FIGURE 1 Schematic representation of knowledge transfer.

Knowledge Acquisition Methods

Available literature was examined and relevant domain knowledge was noted. Methods described throughout the literature were evaluated with an eye toward identifying common ideas and basic rules. For example, although there was no consensus regarding proper height, a recurrent characteristic for drift control was that raising the roadway profile a few feet above the surrounding terrain would help alleviate the problem. Experience and knowledge from various highway officials were obtained through informal personal communication. Discussions were conducted in an attempt to collect knowledge on techniques in general use and also to gain insight as to why certain methods are not used.

For example, one common reason for not using 4-ft picket-type snow fences was that they were not deemed cost-effective. This is validated by modern snow control technology, which shows that this type of fence is generally not effective.

Information from Tabler was obtained over several months through spoken and written communication. He was asked questions on applicability of various analytical techniques, research findings, and the current state-of-the-art. Also, he provided completed analyses that were used to validate various system subprograms.

Selection of Expert System Development Environment

It was decided to develop the expert system using a commercially available microcomputer-based expert system shell. The selected expert system was required to satisfy three major requirements:

1. Ability to execute the necessary external program easily,
2. Graphics capability so that predicted drifting could be displayed or plotted, and
3. Ability to handle advanced mathematical functions necessary to perform required calculations.

GURU® from Micro Data Base Systems, Inc., was selected because it includes spreadsheet, data base, text processing, graphics capabilities, mathematical functions, and simple external interfacing. All of GURU®'s features were used in the PASCON expert system development. The spreadsheet utility was used to store wind speed data and to perform wind-dependent snow transport computations. Precipitation data for 15 gage stations were stored and accessed by means of the data base utility. The text processor was used to provide user instructions and to present results. Graphs of existing and predicted profiles and several help illustrations were prepared through the graphics utility. System architecture is shown in Figure 2.

Development of Supporting Computer Programs

Computer algorithms were developed using an incremental application of Tabler's regression models to predict snowdrift profiles created by topographic features and by snow fences. Four support programs were written in BASIC language for the various procedures required by the PASCON expert system. A complete listing can be found in Kaminski (*12*).

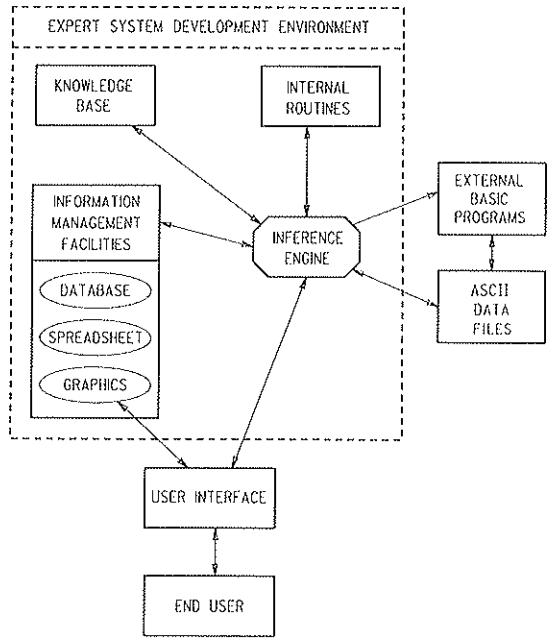

FIGURE 2 Architecture of expert system for passive snow control.

1. XSECTION stores cross section points of the road by offset and elevation, for use in plotting and analysis of cross section drift potential.
2. ROUGHXS is used to approximate a cross-section when a detailed survey is not available. It constructs a cross section on the basis of user responses to general questions about the problem site.
3. OGSNOW draws road cross section data from either XSECTION or ROUGHXS and predicts existing snowdrift formation.
4. FNCDRFT computes predicted drift profile as created by a snowfence and determines the fence storage capacity.

Climatological Data

Surface wind data are used to determine prevailing wind direction with respect to snow transport, and to estimate wind-dependent snow transport. Wind data are available as part of 10-year airport climatological summaries from the National Climatic Data Center in Asheville, North Carolina. The data consist of tables of wind direction versus wind speed (percent frequency of observations). These data are tabulated for 9 wind speed groups and 16 compass points. Because of the tabular format of the wind data, manipulations have been managed by the expert system's spreadsheet mode. A composite wind speed was required for each of the nine speed groups. Also, the wind speed transport equation requires that the wind speed be that at the standard height of 33 ft. Wind speed measurements taken at other heights require adjustment to the standard height. Wind speeds are adjusted by assuming that the velocity provide can be approximated by

$$U = 2.5u_* \ln [(z + h')/h'] \quad (3)$$

where

U = wind speed at height z,
u_* = friction velocity, and
h' = aerodynamic roughness height.

(This theory is included in most fluid mechanics textbooks.)

Wind speed at 33 ft was computed by solving for friction velocity at the given wind speed and height. This friction velocity was then used in the equation to determine U at z = 33 ft. An average roughness height of 0.05 in. was assumed because roughness varies depending on vegetation and snow cover. An additional consideration is that the wind-based transport equation is exponential, which means that composite speed is not the median of the wind speed group.

After the conversion of knots to miles per hour and determination of the speed at height of 33 ft, if necessary, the composite speed for a speed group is given by:

$$U = \frac{[u_l^{4.04} + (u_l + 0.5)^{4.04} + \ldots + u_h^{4.04}]^{(1/4.04)}}{[2(u_h - u_l) + 1]} \quad (4)$$

where

U = composite speed for speed group (mph),
u_l = low speed of speed group (mph),
$(u_l + 0.5)$ = intermediate speeds at 0.5-mph increments, and
u_h = high speed of speed group (mph).

Monthly precipitation normals are used to estimate precipitation-dependent snow transport. Precipitation data for cooperative gage stations were obtained from the Northeast Regional Climate Center at Cornell University. The method of polygons was then used to determine domain boundaries for these gage stations. Each town is then assigned to a specific gage station. The system's data base facility managed the precipitation data. This procedure allows the system to select proper precipitation values easily for the problem location. An average snowfall water equivalent of 11 in. was selected as the default value to be used if the town was unknown (or the name misspelled).

Use of wind and precipitation data depends on the duration of the snow accumulation season. Tabler's method for estimating dates of the snow accumulation season on the basis of latitude, longitude, and elevation has been incorporated into this project (*13*).

Formulation of Rules

The expert system software used in this work permits calling external programs by one-line commands such as RUN "BASICA OGSNOW" or #dskout = "RUNFENCE.ASC." These commands link the support program OGSNOW and the data file RUNFENCE.ASC, respectively, to the expert system. This facility allowed compressing the large knowledge base into 45 rules, because all the design algorithms and computations were executed outside the PASCON expert system. The total rule base is provided by Kaminski (*12*).

A typical rule in GURU®'s syntax includes rule name, comment, priority, IF-THEN clauses, reason, needs, etc., as in the following example:

```
RULE:     RUNFENCE
IF:       TRYFENCE & REQHT < 10
THEN:     e.odsk = true
          #dskout = "RUNFENCE.ASC"
          output designq
          output foffset
          output reght
          e.odsk = false
          e.wfu = false
          run "basica fncdrft"
          e.wfu = true
          HANDLE1 = FOPEN("FDIMENS.ASC," "R")
          FTYPE = FGETL(HANDLE1)
          FH = FGELT(HANDLE1)
          FCLOSE(HANDLE1)
          FHEIGHT = TONUM(FH)
          RUNFENCE = TRUE
NEEDS:    SECTYPE
          ROWWIDTH
          DESIGNQ
          FOFFSET
          TRYFENCE
CHANGES:  FTYPE
          FHEIGHT
```

A simple example of how rules are used to represent knowledge can be illustrated by the following rules to determine the design snow transport:

```
Rule X: IF FETCH <= 1000
        THEN Q = PBASEDQ
Rule Y: IF FETCH > 1000
        THEN Q = MINIMUM(PBASEDQ,WBASEDQ)
```

where

Q = design snow transport,
FETCH = Fetch distance,
WBASEDQ = precipitation-dependent transport, and
WBASEDQ = wind-dependent transport.

These rules represent knowledge that design transport for fetch distances of 1,000 ft or less should be based on precipitation, whereas design transport for fetch distances greater than 1,000 ft should be the limiting value found by the precipitation-based method or the windspeed-based method.

Use of rules to control system logic can be most easily explained by use of an example:

```
Rule a: IF: SURVEY
        THEN: RUN "BASICA XSECTION"
              AND XSECTION = TRUE.
```

The English translation of this rule is "if you have a survey of the site, then input the data points using the BASIC program 'XSECTION'." The "XSECTION = TRUE" clause represents knowledge that the cross section has been stored.

System Reasoning Behavior

Development of the system logic was completed in stages by directing it to seek specified subtotals, for example, requesting

the system to seek the beginning and end of the snow accumulation season. As individual segments were verified, they were added together to form larger segments. After the system was found to work properly from a mechanical standpoint, the next step was to program it to verify rules and take actions in the desired manner. This procedure was accomplished by assigning a priority order to competing rules that seek values for the same variable. The premise of a rule with higher priority ratings (0 to 100) would be tested before rules with lower priority ratings.

Inferencing was controlled by GURU®'s capability to define the rigor with which a goal or subgoal is sought. This process allows the system either to stop seeking a value for a variable after one is found, or to seek all possible values until all pertinent rules are tested. This process is used, for example, to allow the system to seek multiple solutions to the problem. It can be controlled dynamically within the system by setting the inferencing rigor on the basis of the initial value. Thus, if the system quickly determines that no solutions are feasible, it will not seek additional values for recommended solutions. However, if it determines that road redesign is a possible solution, it will continue to seek other permissible solutions.

The system uses a goal-driven approach, with the goal of providing a recommended solution to the identified snow problem. The system performs three basic tasks: (a) problem identification, (b) problem evaluation, and (c) problem solution, as shown in Figure 3.

Problem identification involves entering cross-section data and providing other site-specific information. The system then uses this information to determine the type of problem that exists. Once identified, the system will then evaluate it to determine its probable causes and estimate its severity. This result is accomplished by a combination of evaluating cross-section elements for their potential to cause problems and estimating drift profiles if needed.

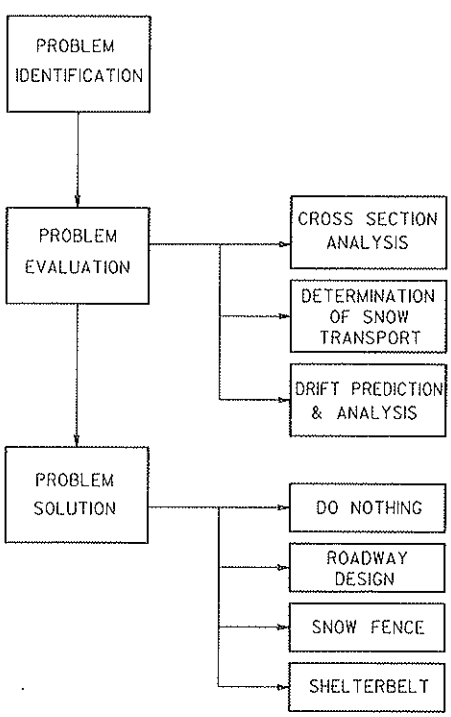

FIGURE 3 Basic tasks of expert system.

When evaluation of the problem is completed, the system then tries to find solutions that will mitigate or eliminate it. Possible solutions are (a) do nothing, (b) redesign the roadway, (c) install snow fences, and (d) plant shelterbelts.

Snow fences will be recommended only if they can store at least 50 percent of the total design transport. (This recommendation may be overridden by the user if desired.) This decision is based on the opinion that a fence should store a minimum of half the estimated seasonal snow transport.

System Organization and Formulation

The system can be divided into three major phases:

1. Initialization,
2. Evaluation, and
3. Completion.

Initialization defines the system goal, introduces the user to the system, initializes all variables, and ensures that the user is prepared to enter the consultation phase.

Evaluation or consultation is the main part of the system. All reasoning and evaluation are performed during this phase. The user is asked for information needed to evaluate the problem, which is then used to infer new information by validating rules and using the information to execute external programs.

As described earlier, historical wind data are stored on a spreadsheet. They can then be accessed and manipulated to determine the wind-dependent snow transport for the determined snow accumulation season. Precipitation data from November through March from 15 precipitation gage stations across western New York are stored in the data base facility. Existing roadway cross section is input using a survey cross section or the user's knowledge of the site to rough in the cross section.

The roadway is then evaluated for its susceptibility to drifting by executing the external roadway drift prediction program. If a significant drifting or whiteout problem is indicated, control measures are investigated. Snow fences are then evaluated by estimating fence height necessary to store the anticipated snow transport and executing the drift prediction model for the external fence. Road redesign options are evaluated within the system and then checked by executing the roadway drift prediction program OGSNOW using the redesigned roadway cross section.

Completion is the end of the consultation in which the recommended snow control measures are delivered to the user. Screen plots of the roadway before and after implementation of the recommendations are displayed to the user. These plots may also be routed to a line printer if desired.

Testing and Verification

The four external programs were tested for accuracy by comparing results with computations by hand. After debugging and final organization, all the external programs performed

accurately. Spreadsheet and data base manipulations were also compared to hand calculations and were found to give accurate results.

Flow of the PASCON expert system was verified by using the tracing facility of GURU®. This procedure allowed dynamic analysis of the order in which rules were selected for testing. Also, different methods could be quickly and easily checked for their effects on reasoning behavior.

User Interface

This expert system is being considered by NYSDOT for statewide use. A user interface friendly to NYSDOT engineers is being written. It is planned to include several graphical help screens, as shown in Figure 4, to answer questions that may arise during consultation sessions.

EVALUATION

Comparison with Human Expert

An example consultation was performed for a snow problem location previously analyzed using traditional methods. This location is along Route 219 in the town of Boston, New York, where a severe whiteout problem exists. Because this road section is on an embankment and no guiderail is present, drifting is not a problem. It was selected for installation of a demonstration snow fence as part of the Strategic Highway Research Program (SHRP) project to demonstrate the effectiveness of the snow fence on a full-size scale. It was chosen primarily because of the wide right-of-way which allowed the fence to be installed within the state right-of-way. Design of this installation was assisted by Tabler under auspices of SHRP, and was completed in 1989.

The final design was an 8-ft synthetic fence placed near the right-of-way line 160 ft west of the southbound lanes. The total design snow transport would normally require a 10-ft fence for a site on level terrain. This specific site is aided by a small ravine just upwind of the road, which provides additional storage capacity. Also, a fence taller than 8 ft would have to be placed farther from the road to prevent it from potentially casting a drift onto the pavement. The drift predicted by the fence's traditional design indicated that drifting cause by an 8-ft fence would not encroach onto the roadway. The calculations also indicated that it would not be adequate to store the total design snow transport. However, the expected storage indicated that the installation would provide protection for most of the winter months.

The PASCON expert system was used to analyze this location and results were then compared with the original completed design. The system properly determined that road redesign was not a viable solution because the problem was poor visibility. The system found that drifting was not a problem by directly asking the user. This fact was also verified by the system after it determined that the road was on an embankment and that the fill slopes were aerodynamic with respect to snow drifting. The system then analyzed the location for suitability for installation of snow fence. On level terrain, the right-of-way would only be adequate for a 5-ft fence, but that would not provide the declared minimum storage capacity of 50 percent of the total design snow transport. Because this site was on an embankment and not on level terrain, the system did not rule out the placement of fence. The PASCON expert system selected an initial fence height of 8 ft as the minimum allowable that would provide the required minimum 50 percent storage. This fence was then analyzed to determine if the predicted drift would encroach the roadway. It was found that a 9-ft fence would not create drifting onto the road even as the fence approached capacity. The system did not evaluate a taller fence because the predicted drift elevation near the road was found to be within 0.1 ft of the edge of shoulder elevation.

In summary, the system recommendations were very close to the previously completed design. The system recommended that a 9-ft fence offset 160 ft from the road would be a viable long-term solution. This agreed with advice from domain ex-

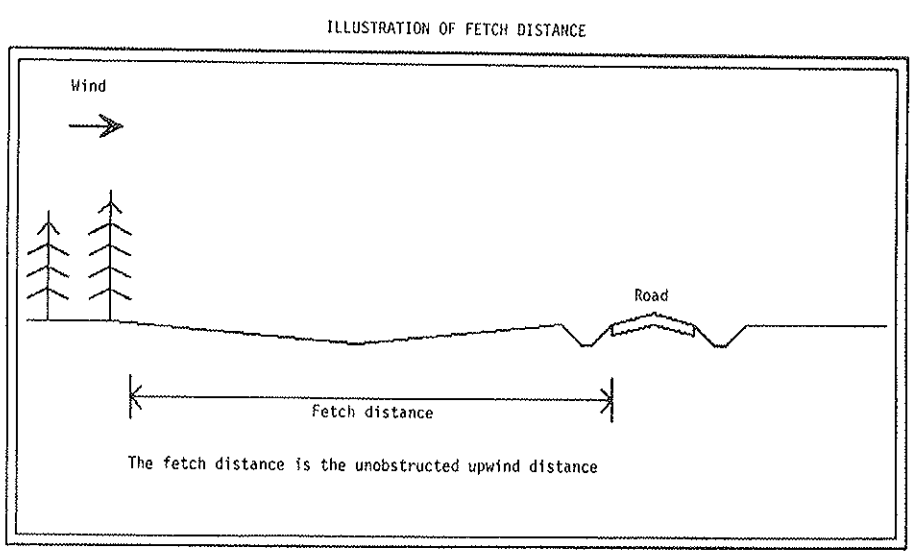

FIGURE 4 Sample help screen.

pert Tabler. The consultation for this problem location is shown in Figure 5. The time required to evaluate this problem site with the expert system was considerably less than that spent for the original manual design. The major time savings were in analysis of potential drifting and in fence drift prediction.

Several typical road sections and problems were analyzed to determine accuracy of the system and evaluate its reasoning behavior. The sections chosen were relatively simple problems whose solutions were easily determined beforehand. For example, the solution for a whiteout problem at an at-grade highway location with no right-of-way restrictions would be to install a fence of proper height at the proper distance upwind of the road. Use of several typical examples provided opportunities to observe system logic and determine if the rules were evaluated as intended.

Also, the system followed intended reasoning paths. This behavior was indicated by the observation that the expert system did not ask for information pertaining to impractical solutions, and further, all expected options were evaluated as desired.

GURU® also allows a rule set to be consulted to determine a specific subgoal or variable. This feature was extremely useful because it allowed reasoning behavior and system execution to be checked without going through an entire consultation. An example of this technique was to have the system seek the value for the precipitation-dependent design snow transport whose variable name is PBASEDQ. This operation was easily accomplished by invoking the command "consult direct to seek PBASEDQ." Running this command verified

```
Before we begin it is important that you are prepared to answer
general questions relating to cross-section and general topography
of the problem location.  This information can be from a survey,
record plans, or your personal knowledge of the site.  You should
also
have a USGS map available.
Keep in mind that the accuracy of any recommendations will be a
reflection of the accuracy of the information that you provide.
ARE YOU PREPARED TO BEGIN?
Enter Y or N  ===>  Y

Is drifting snow a problem at this location?
Enter Y or N  ===>  N

Are 'whiteouts' a problem at this location?
Enter Y or N  ===>  Y

The following figure illustrates the various types of cross
sections.  After viewing the figure you will be asked to identify
the type of cross section that approximates your problem site.
     [WIND IS FROM LEFT TO RIGHT]
(Press any key to see figure)

1.  EMBANKMENT SECTION
2.  CUT SECTION
3.  AT-GRADE SECTION
4.  SIDEHILL CUT WITH WINDWARD SIDE ON FILL
5.  SIDEHILL CUT WITH WINDWARD SIDE IN CUT
Enter the NUMBER of the section type that corresponds
to your problem site :  ===>  1

Is there guide rail along the problem section?
Enter Y or N  ===>  N

Have you already entered the cross-section of this site ?
Enter Y or N ===>  Y

The snow accumulation season is partly a function of ELEVATION
(above sea level), LATITUDE, and LONGITUDE.  This information is
easily obtained from USGS maps and some commercial maps.

Enter the ELEVATION of this site (feet)   1560
Enter the LATITUDE of the site, to the nearest .25 degree.   42.5
Enter the LONGITUDE of the site, to the nearest .25 degree.  78.75

LOADING WIND DATA !

Wait ....

DETERMINING PREVAILING WIND DIRECTION
                  &
   ESTIMATING TOTAL SNOW TRANSPORT

Please be patient ....
```

FIGURE 5 Consultation listing.

```
The upwind ground terrain has a significant effect
on the amount of snow transported.
1.  PAVED SURFACE
2.  FROZEN LAKE
3.  LOW VEGETATION ( 1'' -  6'' )
4.  CULTIVATED FIELD
5.  TALL VEGETATION ( > 6'' )
6.  NATURAL FIELD OR MEADOW
Enter the NUMBER of the terrain type that most closely corresponds
to your problem site : ===>  5

The unobstructed distance upwind of a site is referred to as the
'fetch' distance.  The beginning of the fetch is essentially any
barrier across which there will be no blowing snow.  This includes
woods, unfrozen bodies of water, deep ravines, etc.
The following figure illustrates the fetch distance.
(Press any key to see figure)

Enter the fetch distance (feet):  3000

What TOWN is the site located in?  BOSTON

The ROW may not be adequate for passive snow control measures.  Is
an easement at this location possible (Y/N)?   N

Please enter the right-of-way width from the centerline
of the roadway to the windward boundary.  --->  170

Is road redesign an alternative?
Enter Y or N  ===>  N

THE FOLLOWING FIGURE SHOWS THE DRIFT CREATED
BY A  9.0' TALL FENCE

PLOTTING FENCE DRIFT

Please wait ....

PREDICTED SNOW BARRIER DRIFT PROFILE

SUMMARY OF RESULTS:
The snow accumulation season begins on NOVEMBER  30
and ends on MARCH 18
The prevailing wind direction is  WSW
The design snow transport =  939 FT^3/FT

BASED ON THE INFORMATION PROVIDED, I THINK THAT
YOU SHOULD INSTALL A SNOW FENCE
FENCE HEIGHT =            9.0
OFFSET FROM CL =            170
press any key to continue
```

FIGURE 5 *(continued)*

whether proper precipitation values were used and that necessary rules were evaluated. Although the trial problems were designed to be simple to accommodate system evaluation, the system performed as intended and all recommendations were valid.

Problems Encountered in System Development

Some difficulties surfaced during development of the PASCON expert system, but most obstacles were eventually overcome. Controlling reasoning behavior posed a particular challenge. As with traditional methods, the extent and type of analysis changes as more information is found about the problem. The GURU® expert system environment offers many options to control system reasoning behavior, including forward, backward, or mixed chaining. Also, the order in which rules are selected for evaluation can be controlled by assigning a priority order to different rules that can determine values for the same variable. In addition, many system environment controls may be used to control whether a goal or other variable should continue to be sought. The difficulty was in determining how to use these options properly in a manner that would enable the system to closely emulate a human expert.

CONCLUSIONS AND RECOMMENDATIONS

Testing the prototype expert system has indicated that it can provide good results, within constraints of the rule set, and

that expert systems for technical applications can and do work. The system is limited only by accuracy of the information used to develop it. Limitations caused by uncertain information will exist whether the problem is analyzed with traditional methods or with an expert system.

The computer algorithms developed for drift prediction are a powerful tool for analysis of current drift potential and for predicting effects of road redesign or snow fence installation. A proposed road design or fence installation can be evaluated in a short time. Analyses of drifting is nearly impossible without a computer program. These programs can also be used as stand-alone options or in an iterative analysis for design of a snow-free roadway, similar to those of the Wyoming State Highway Department. Snowdrifting problems should be addressed at the design stage, where opportunity for alternative designs is at a maximum. This expert system provides a tool for analysis and solution of these problems. It will generally not recommend infeasible solutions. Recommendations it offers will be based largely on information supplied by the user.

This system should not be expected to replace the expert. It offers expert advice to the designer, who must use experience and judgment in accepting and applying each consultation to the problem at hand. It is designed to assist users in solving typical everyday problems, thus freeing the expert to spend time on advancing the technology and solving difficult problems. For this reason, it was not developed to solve all conceivable problems, but is capable of addressing most typical problems.

This project has fulfilled its objective of providing a tool to assist design and maintenance engineers in finding solutions to blowing and drifting snow problems. The system illustrates the effectiveness of expert system technology as a medium for transfer of knowledge to those who can use it. It allows users who do not have knowledge of passive snow control analysis and design to find real solutions to real problems.

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