PB99-100398

PASCON: An Expert System For Passive Snow Control on Highways

DARRELL F. KAMINSKI

SATISH MOHAN

SPECIAL REPORT 98

ENGINEERING RESEARCH AND DEVELOPMENT BUREAU

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

Mario M. Cuomo, Governor/Franklin E. White, Commissioner

REPRODUCED BY: NTIS
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

PASCON: AN EXPERT SYSTEM FOR PASSIVE SNOW CONTROL ON HIGHWAYS

Darrell F. Kaminski, Civil Engineer II, Design
New York State Department of Transportation Region 5
Buffalo, New York

Satish Mohan, Associate Professor
Department of Civil Engineering
State University of New York at Buffalo

Special Report 98
April 1991

PROTECTED UNDER INTERNATIONAL COPYRIGHT
ALL RIGHTS RESERVED.
NATIONAL TECHNICAL INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE

Reproduced from
best available copy.

ENGINEERING RESEARCH AND DEVELOPMENT BUREAU
New York State Department of Transportation
State Campus, Albany, New York 12232

ABSTRACT

Blowing and drifting snow are common problems on roadways in cold regions, causing reduced visibility and/or snow drifting onto the roadway, resulting in partial or total road closure and hazardous road conditions. 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. Its techniques include snowfences, shelterbelts, and design of aerodynamic roadway sections. Currently, no widely accepted algorithmic methods exist for passive snow control on highways.

This project's main objective was to provide a tool for highway design and maintenance personnel 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 called PASCON (PAssive Snow CONtroller) has been developed on an IBM PC microcomputer. It incorporates information from a nationally recognized expert in passive snow control and from the literature and, it includes five external programs for design procedures, computations, and graphics. Several consultations on the expert system gave results that agreed with the domain expert or with solutions worked out manually.

(This report has been submitted to the Transportation Research Board for publication in their 1991 Transportation Research Record series.)

CONTENTS

INTRODUCTION

Blowing and drifting snow are common problems on roadways in cold regions, causing reduced visibility and/or snow drifting onto the roadway, resulting in partial or total road closure and hazardous road conditions. 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 is in contrast to mechanical methods of snow control by plowing and deicing that are in predominant use today. Passive snow control techniques include snowfences, shelterbelts, and the design of aerodynamic roadway sections. Although this technology to mitigate or even eliminate many 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 non-existent in most areas of the world.

Also, snow control measures are often used only reluctantly due to 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 report presents an expert system for passive snow control, PASCON (Passive Snow CONtroller), incorporating domain knowledge available in the literature and the experience and knowledge of a leading expert on the subject. This system is intended to provide an effective mode for transfer of technology from those who possess knowledge to those who need it.

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 snowfences along a 77-mile section of Interstate 80 in southeast Wyoming in 1971. This new highway section was closed ten times during its first winter in service due to severe problems with blowing and drifting snow. To alleviate this hazardous and somewhat embarrassing situation, the Wyoming State Highway Department was willing to install several miles of snowfence designed almost exclusively from untested research studies (3). 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, snowfences, 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 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 seeking 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 snowfences 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 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 is 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. This is accomplished by using a regression model to determine the potential for drifting. If drifting is indicated, the roadway is 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 of 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 equal to or flatter than 4:1 (6). Guiderail often causes drifting onto the roadway at locations that would otherwise be drift-free (6). This results from corrugated-beam guiderail acting as a miniature snowfence, inducing snow deposition downwind. It 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, reducing 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 negligent in a lawsuit resulting from an accident caused by this ramping effect (7). For these reasons, at locations where drifting or poor visibility can be attributed to guiderail it should be eliminated if possible. If not, use of cable guiderail is recommended, but corrugated-beam guiderail is discouraged.

Although good road design is effective in preventing drifting onto the roadway, it 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 re-design can be evaluated as an alternative to solving drifting problems.

Snowfences

The basic function of a snowfence is to produce a reverse air flow area that will cause wind-driven snow to be deposited upwind of the area requiring protection. Although the history of snowfences dates back to their use by railroads in the 1800s, modern engineering criteria for design of snowfence installations have existed for less than 25 years. Tabler was the first to design snowfences for a specific snow storage capacity, based on seasonal snow transport (8). His method for estimating snow transport at a given location depends 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 this 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 following equations are used to estimate seasonal snow transport are as follows:

Precipitation-Dependent Seasonal Snow Transport:

$$Q = 0.5\ k\ P\ T\ [1 - 0.14^{(F/T)}] \quad (1)$$

where Q = total snow transport (cu ft of water/ft of width),

k = transport coefficient (0.5 - 0.7, % of snowfall that is relocatable, expressed as a decimal),

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:

$$Q = 0.004895\ \Sigma\ [Di\ \Sigma\ (Fij)\ (Uj^{4.04})] \quad (2)$$

where Q = total snow transport (lb/ft of width),

Di = number of snow 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 the wind-based equation to be valid for fetch distances of 1000 ft or more. For this reason the precipitation-based transport equation should be used exclusively for locations with a fetch distance less than 1000 ft. In locations where this distance is greater, 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 snowfence required to store this volume of snow.

There are several different snowfence types and shapes, constructed using materials ranging from steel to paper. The expert system presented here uses four types: 1) "Wyoming-type" wood-slat, 2) synthetic (plastic), 3) wood-picket, and 4) 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 in use today. Because they have different porosities, their storage capacities and different drift profiles also vary (10).

Shelterbelts

Also referred to as "living snowfences," these 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 snowfences to protect highways dates from the 1920s. Many states currently have formal living snowfence programs. Living snowfences have many advantages over 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 to reach effective heights, but snowfences 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 will be sure 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 they 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.

The first four phases are independent of each other and are in no particular order. Phases 5 through 9 are in logical order.

Identification and Acquisition of Domain Knowledge

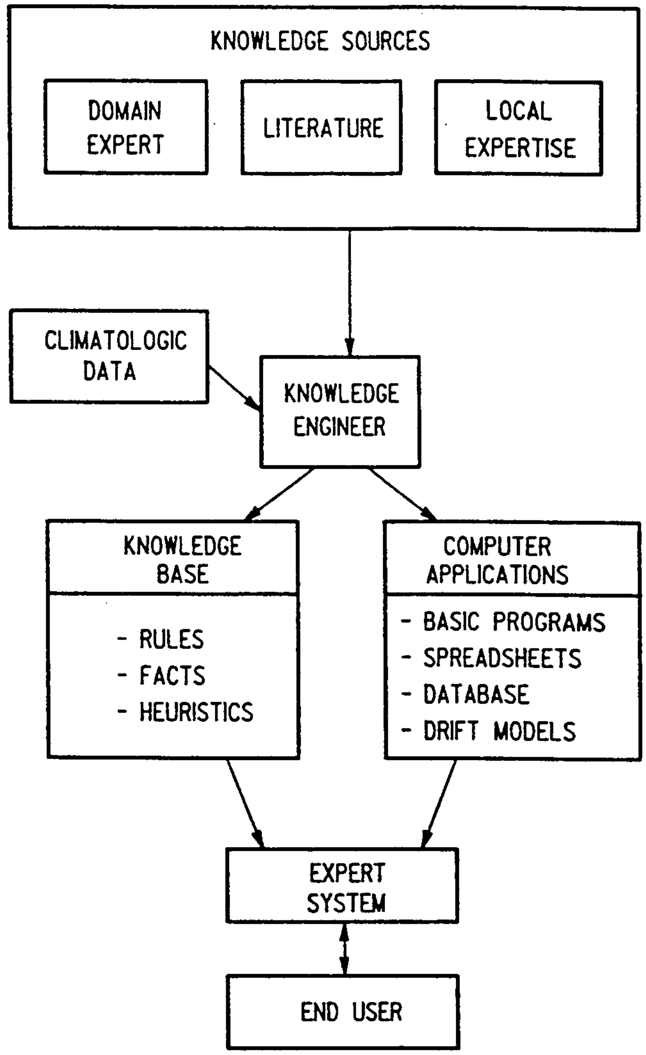
Knowledge Sources

Several databases were searched for information about passive snow control on highways in cold regions. The Transportation Research Information Service (TRIS) database provided 72 references, and the U.S. Army Corps of Engineers database listed 16. New York State Department of Transportation (NYSDOT) files provided results of 1983-84 research to solve a severe blowing snow problem in Western New York. Finally, Tabler & Associates of Colorado, who specialize in passive snow control, provided many current research papers.

The literature survey identified Ronald D. Tabler of Tabler & Associates as a leading expert on passive snow control. Based in Colorado (formerly in Wyoming), he has been working on the subject since the late 1960s, and has developed several new methods successfully adopted on Wyoming highways. Because most post-1970 literature cites his work, he was approached for domain expertise, and agreed to serve as domain expert. Several state, county, and local officials within New York State were also identified al having some knowledge of the subject. This expert system has incorporated knowledge in three basic areas: 1) history of passive snow control methodologies, 2) current practices in Western New York, and 3) global knowledge of the domain.

Data on evolution of passive snow control techniques was largely obtained from available literature. Knowledge of current practices in Western New York was obtained from several state, county, and local officials with experience in snow

Figure 1. Schematic representation of knowledge transfer.



control on roads. They also provided information on why they do not employ 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 correctness of the system's output. Knowledge transfer from these sources is diagrammed in Figure 1.

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, one such recurrent characteristic for drift control, although there was no consensus regarding proper height, was that many references suggested 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. Selection of these persons was based on addressing various levels of government and different classes of highways. Although the types of information obtained from them differed from that found in the literature, the underlying concept was the same. 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 snowfences was that they were not considered cost-effective. This is validated by modern snow control technology, which shows that this type of fence as generally ineffective. Information from Tabler was obtained over several months through spoken and written communication providing answers on applicability of various analytical techniques, research findings, and the current state-of-the-art. He also 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 shell. This is an expert system development tool with predefined syntax for knowledge representation and inferencing procedures. These shells are generally easier to learn and use than knowledge representation languages such as Lisp or Prolog. A microcomputer-based system was desired to ensure portability within a user agency. The selected expert system had to satisfy three major requirements:

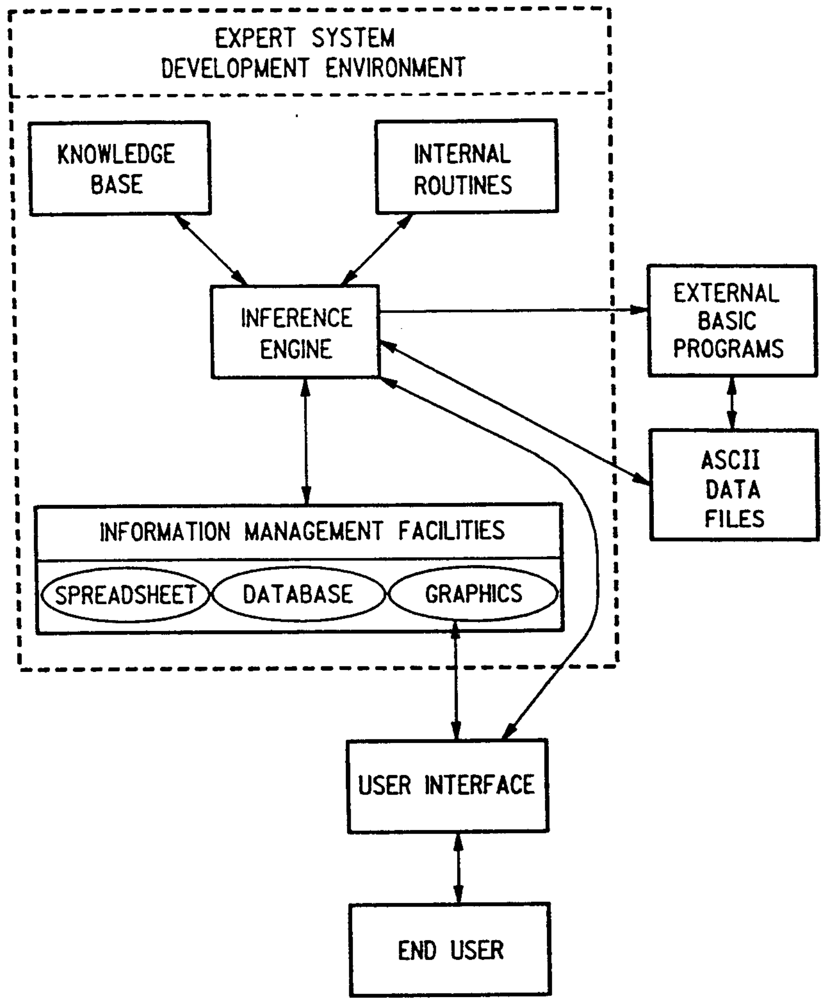
1. Ability to execute the necessary external program easily,

2. Graphics capability so that predicted drifting could be displayed and/or plotted, and

3. Ability to handle advanced mathematical functions necessary to perform required calculations.

After a study of several medium-size expert system shells, GURU from Micro Data Base Systems, Inc., was selected because of its extensive information management capabilities, ability to handle complex mathematical functions, excellent graphics capabilities, and ability to execute external programs with simple one-line commands. Although GURU is more expensive than several other shells, it also includes several accessory features making it a good selection. Because it includes spreadsheet, database, text processing, and graphics capabilities, no peripheral software is necessary with the exception of BASIC software. All GURU's features were used in 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 through the database utility. The text processor was used 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.

Figure 2. Architecture of expert system for passive snow control.



Development of Computer Programs

As discussed previously, regression models to predict snowdrift profiles created by topographic features and by snowfences have been developed by Tabler. Computer algorithms using an incremental application of these models were developed for this study. Other support programs were also written, as will now be briefly described. All were written in BASIC for two reasons: first, this language was resident on most NYSDOT Region 5 microcomputers and thus no additional expense was incurred. Second, programs required for system development are relatively small, and no significant savings in execution time would have been realized by using a more powerful language. Data transfer between the expert system and external programs is accomplished with ASCII files.

Other Support Programs

Five support programs have been developed for the various procedures required by the PASCON expert system. All have been written in BASIC programming language and can interface directly with one other as well as with the expert system. A complete listing can be found in Kaminski (12).

1. XSECTION: this program stores cross-section points of the road by offset and elevation, and plots a cross-sectioned profile of a road section. A maximum of 50 points along a cross-section can be input. Other inputs include pavement width, shoulder width, and total number of lanes. The XSECTION program can plot four types of roadway sections: embankment, cut, at-grade, and side-hill cut. More sections can be added to the program if needed.

2. ROUGHXS: this program is used to approximate a cross-section when a detailed survey is not available. It constructs a cross-section based on user responses to general questions about the problem site. The program has been developed for an undivided road, and thus a divided highway must be treated as two separate roads. Each of the four cross-section types, as listed in the XSECTION program, has a different set of questions.

3. OGSNOW: this program draws road cross-section data from either XSECTION or ROUGHXS and predicts existing snowdrift formation.

4. FNCDRFT: this program computes predicted drift profile leeward and windward, as created by a snowfence. It correlates fence drift elevations with terrain, and then using the parameters for the desired fence type computes fence storage capacity..

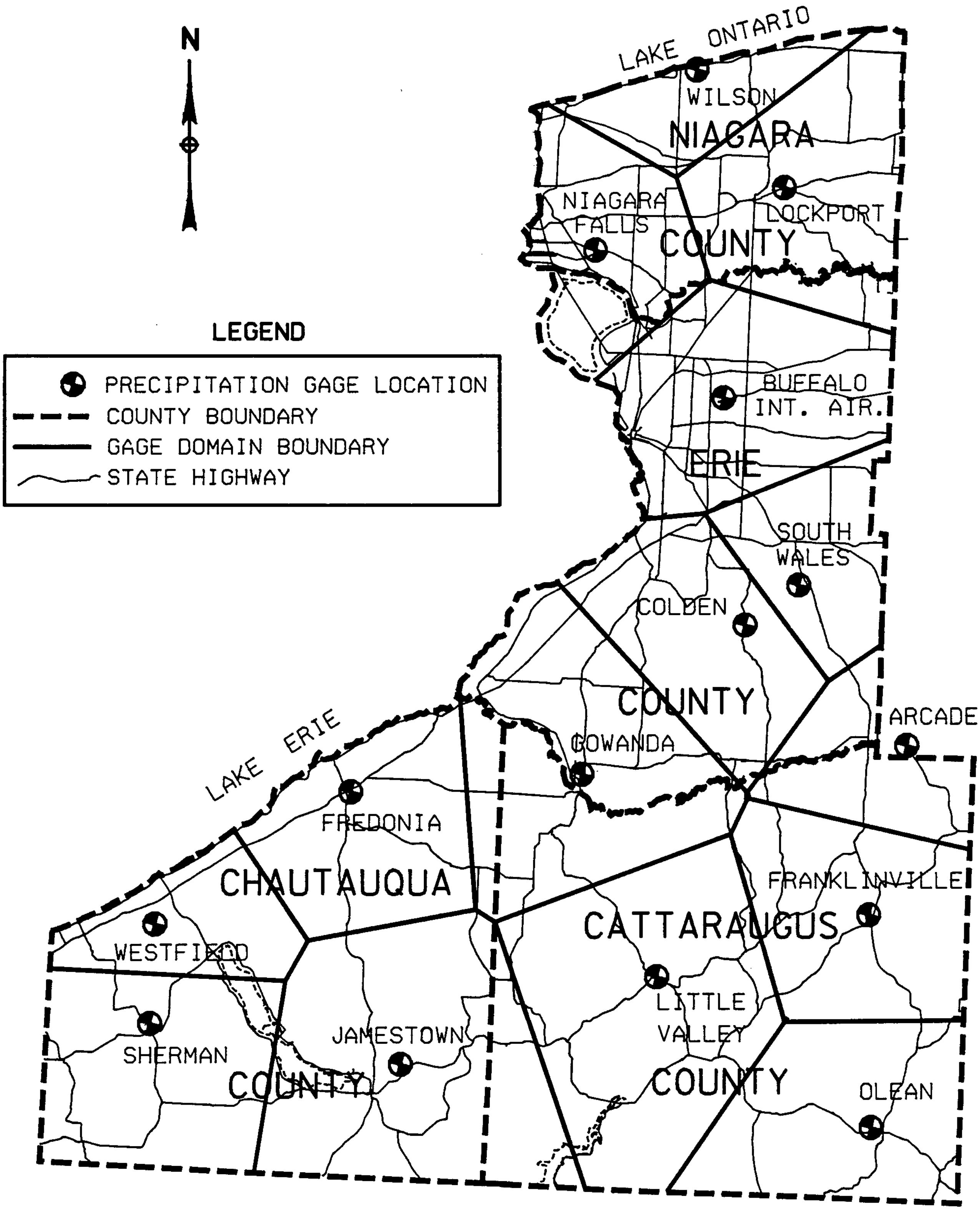
5. U33COMP: this program determines a composite wind speed for a range of given wind speeds for use in the wind-speed-based snow transport equation. The user inputs the height of the wind instrument, and the wind speed group maximum and minimum values.

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 for the Niagara Falls, Greater Buffalo, and Erie (Pa.) international airports were available as part of 10-year airport climatological summaries, and were obtained from the National Climatic Data Center in Asheville, N.C. The data consist of tables of wind direction versus wind speed (percent frequency of observations). These data are tabulated for nine 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 from the three airports were taken at a height of 20 ft, which required adjustment to the standard height. Wind speeds were adjusted by assuming that the velocity profile can be approximated by

Figure 3. Precipitation gage domain boundaries for western New York as determined by the Thiessen method.



$$\bar{U} = 2.5\ u* \ln [(z + h')/h'] \tag{3}$$

where U = wind speed at height z,

u* = friction velocity, and

h' = aerodynamic roughness height.

(This theory is included in most fluid mechanics textbooks and will not be reiterated here).

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 since roughness will vary 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. A computer program was written to compute composite wind speed for any wind speed group and measurement height. After converting knots to miles per hour and determining the speed at 33-ft height, if necessary, composite speed for a speed group is given by:

$$U = \frac{[ul^{4.04} + (ul + 0.5)^{4.04} + \ldots + uh^{4.04}]^{(1/4.04)}}{[2(uh - ul) + 1]} \tag{4}$$

where U = composite speed for speed group (mph),

ul = low speed of speed group (mph),

(ul + 0.5) = intermediate speeds at 0.5-mph increments, and

uh = high speed of speed group (mph).

Monthly precipitation normals are used to estimate precipitation-dependent snow transport. Precipitation data for 15 Western New York gage stations were obtained from the Northeast Regional Climate Center at Cornell University. The Thiessen method of polygons was then used to determine domain boundaries for these gage stations, as shown in Figure 3. Each town in four Western New York counties (NYSDOT Region 5) was then assigned to a specific gage station. Minor adjustments in gage station assignments were made to account for the fact that seasonal snowfall adjoining Lakes Erie and Ontario is less than inland snowfall. This is generally referred to as the "lake effect." Adjustments were made by assigning towns adjoining lake to a more representative gage station nearer that lake, when it was believed that the assigned station as determined by the Thiessen method would significantly overestimate local precipitation. The system's database management facility stored precipitation data. This 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 were unknown (or the name misspelled). Only data for November through March were used since these are the months of snow accumulation for Western New York.

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

Formulation of Rules

The expert system software used here 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, as all the design algorithms and computations were executed outside of the PASCON expert system. The total rule base is given in Kaminski (12).

A typical rule in GURU's syntax includes rule name, comment, priority, IF-THEN clauses, reason, and # 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 = FGETL(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 as follows 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 1000 ft or less should be based on precipitation, while design transport for fetch distances greater than 1000 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's logic was completed in stages by directing it to seek specified subgoals -- 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 was accomplished by assigning a priority order to competing rules that seek values for the same variable. The premise of a rule with a higher priority rating (0 to 100) would be tested before rules with a lower priority rating. Inferencing was controlled by GURU's capability to define the rigor with which a goal or subgoal is sought. This 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 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 based on 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 employs a goal-driven approach, with the goal of providing a recommended solution to the identified snow problem. The system performs three basic tasks: 1) problem identification, 2) problem evaluation, and 3) problem solution, as shown in Figure 4.

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 is accomplished by a combination of evaluating cross-section elements for their potential to cause problems, and estimating drift profiles if needed.

When evaluation of the problem is completed, the system then tries to find solutions that will mitigate or eliminate it. Possible solutions are 1) do nothing, 2) redesign the roadway, 3) install snowfence, and 4) plant shelterbelts.

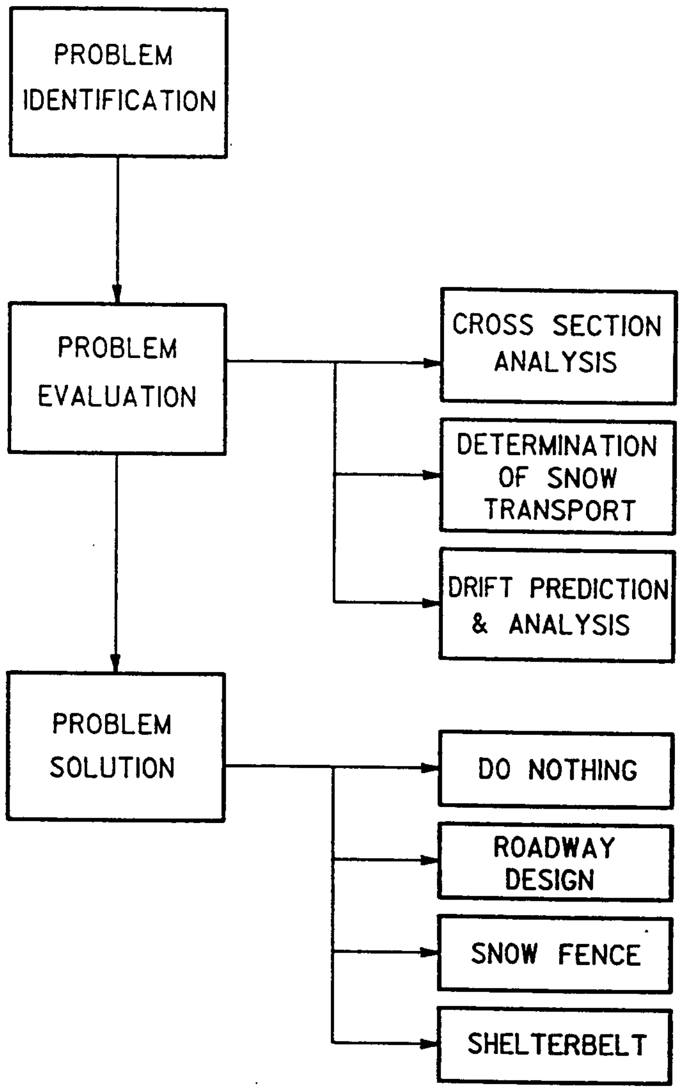
Snowfences will be recommended only if they can store at least 50 percent of the total design transport. (This may be overridden by the user if desired.) This is based on the authors' opinion that a fence should store a minimum of half the estimated seasonal snow transport.

System Organization and Formulation

The system can be divided into three major phases:

1. Initialization,

Figure 4. Basic tasks of the expert system.



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 database 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. Snowfences are then evaluated by estimating fence height necessary to store the anticipated snow transport, and executing the external fence drift-prediction model. 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. He has shown screen plots of the roadway before and after implementation of the recommendations, which if desired may also be routed to a line printer.

Testing and Verification

The five external programs were tested for accuracy by comparing results with computations by hand. After debugging the final organization, all the external programs performed accurately. Spreadsheet and database manipulations were also compared to hand calculations and found to give accurate results. Flow of the PASCON expert system was verified by using the tracing facility of GURU. This 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 the New York State Department of Transportation for statewide use, and a user interface friendly to NYSDOT engineers is being written. It is planned to include several graphical help screens, as in Figure 5, to answer questions that may arise during consultation sessions.

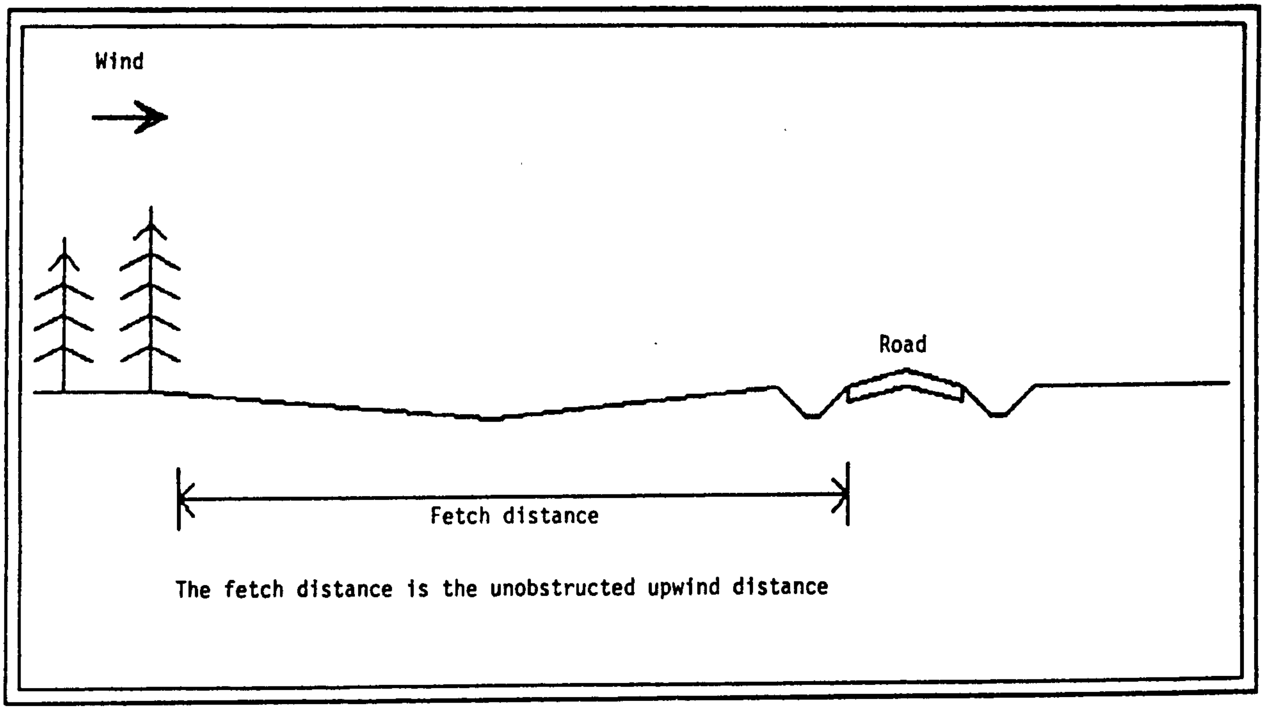
EVALUATION

Comparison to 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 snowfence as part of the Strategic Highway Research Program (SHRP) to illustrate effectiveness of snowfence 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

Figure 5. Sample help screen illustrating fetch distance.



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 caused 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 since the problem was poor visibility. It found that drifting was not a problem by directly asking the user. This 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 snowfence. 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. Since this site was on an embankment and not on level terrain, the system did not rule 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 onto the roadway. It was found that a 9-ft fence would not create drifting onto the road as the fence approached capacity. The system did not evaluate a taller

Figure 6. Consultation listing.

```
Before we begin it is inportant 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 ....
```

```
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
```

fence since 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 expert Tabler. Consultation for this problem location is shown in Figure 6. 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 are 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 was shown 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 was extremely useful since 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 (variable name is PBASEDQ). This was easily accomplished by invoking the command "consult direct to seek PBASEDQ." This verified whether proper precipitation values were used and that necessary rules were evaluated. Although the trial problems were designed to be simple in order 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 shown that it can provide good results, within constraints of the rule set. It illustrates 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 due to 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 snowfence installation. A proposed road design or fence installation can be evaluated in a very short time. Analysis of drifting is nearly impossible without a computer program. These programs can also be used as "stand-alone" options and 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.

In the authors' opinion 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 most conceivable problems, but is capable of addressing most typical problems.

In summary, 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.

ACKNOWLEDGMENTS

The authors wish to express their deep appreciation to Dr. Ronald Tabler of Tabler & Associates in Niwot, Colorado, who provided the domain expertise through several long interviews and written communications. The contents of this paper reflect the views of the authors and do not necessarily reflect the official views or policy of the New York State Department of Transportation.

REFERENCES

1. R. D. Tabler. "New Engineering Criteria For Snow Fence Systems." Transportation Research Record 506, Transportation Research Board, 1974, pp. 65-78.

2. R. D. Tabler. "Predicting Profiles of Snowdrifts in Topographic Catchments." Proceedings, Western Snow Conference (Coronado, Ca., April 1975), Vol. 43, pp. 87-97.

3. R. D. Tabler. Snow Fence Handbook (Release 1.1). Niwot, Colo: Tabler & Associates, 1988.

4. M. Mellor. Blowing Snow. CRREL Monograph, Part III, Section A3c. U.S. Army Cold Regions Research and Engineering Laboratory, 1965.

5. S. L. Ring, J. D. Iversen, J. B. Sinatra, and J. D. Benson. Wind Tunnel Analysis of the Effects of Planting at Highway Grade Separation Structures: Final Report. Report HR-202, Iowa Highway Research Board, 1979.

6. F. W. Cron. "Snowdrift Control Through Highway Design." Public Roads, Vol. 34, No. 11 (December 1967), pp. 227-234.

7. J. C. Vance. Supplement to Liability of State and Local Governments for Snow and Ice Control. Legal Research Digest 14, June 1990, p. 7.

8. "Problem Of Blowing Snow In Wyoming Under Attack By Highway Department." Highway Research News, No. 47 (Spring 1972) pp. 52-56.

9. R. D. Tabler, C. S. Benson, B. W. Santana, and P. Ganguly. "Estimating Snow Transport from Wind Speed Records: Estimates Versus Measurements at Prudhoe Bay, Alaska." Paper presented at Western Snow Conference, Sacramento, Ca., April 1990.

10. R. D. Tabler. "Geometry and Density of Drifts Formed by Snow Fences." Journal of Glaciology, Vol. 26, No. 94 (1980), pp. 405-419.

11. D. L. Shaw. Living Snow Fences: Protection That Just Keeps Growing. Colorado Interagency Living Snow Fence Program, Colorado State University, 1989.

12. D. F. Kaminski. An Expert System for Passive Snow Control in Western New York. Master of Engineering Project, State University of New York at Buffalo, May 1990.

13. R. D. Tabler. "Estimating Dates of the Snow Accumulation Season." Proceedings, Western Snow Conference, (Kalispell, Montana, April 1988) Vol. 56, pp. 35-42.