Expert System for Winter Road Maintenance

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The advantages and limitations of an expert system for winter road maintenance in Sweden, as well as how to create an expert system that is effective, are discussed. An expert system will support the decision making of the maintenance manager in real time. It is primarily intended for inexperienced maintenance management personnel. An effective expert system must render advice on what action should be taken, when it should be carried out, and, if necessary, how much and what type of chemical should be used on a road. Another important use for an expert system is the education and training of maintenance managers. Information for developing an expert system was gathered in part from literature studies, but the main informational source was interviews with experts. In-depth interviews with six experienced maintenance managers concerning winter maintenance activities took place during February, March, and April 2000. The interviews were based on examples in which present and forecast weather were given along with the time of day. The setting was the managers' actual area of operation along with the actual available equipment. Based on these examples, the managers were asked what action they would take and why. In order to obtain the best possible result, a follow-up was conducted, documenting what actions had been taken during conditions that matched the weather examples used in the interviews. A short discussion then took place as to why particular decisions were made. After the interviews were concluded, information was compiled and key parameters identified. Rules of best practice could then be formulated stating what action should be taken under conditions defined by temperature, wind, precipitation, and forecast. Actions were placed into three categories: plowing, sanding, and salting. Three types of salting were defined: dry, prewetted, and brine. The best practice rules also prescribe the correct amount of salt for spreading over a road. Preliminary results show that brine spreading is preferred over prewetted salt in most situations. Dry salt should never be used. For preventive salting, normal recommended amounts are 10 g of brine/m^2 (124 lb/lane-mi) or 7 g of prewetted salt/m^2 (87 lb/lane-mi). These best practice rules will later be incorporated into the expert system.

To assess the possibilities and limitations of an expert system for winter road maintenance, a number of studies have been conducted. Although most of these studies were not primarily designed for assessing the suitability of an expert system, parts of the studies are nevertheless useful for that purpose.

Methodology

Assessing the suitability of an expert system for winter road maintenance is a part of a Ph.D. project entitled "Expert System for Optimal Winter Road Maintenance." The first study was a literature study of winter road maintenance, expert systems, and computer-based support systems for management of winter road maintenance (*1*). The literature study revealed that there are no expert systems currently in use anywhere in the world. One system, called VVEXP (*2*), was developed in Sweden at the begin-

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ning of the 1990s. A rule-based expert system that assisted maintenance managers with preventive salting actions, VVEXP was tested as a prototype during two winter seasons but was never fully developed. A survey (*3*) found that users were mainly receptive to the system; however, development was stopped because of financial reasons. Another system, the Deicing Anti-icing Response Treatment (DART) program, is under development in Canada and has been tested over two winters. The information available from the DART project is very limited, but the system appears to be a success and will be further developed.

Subsequent to the literature study, a problem description was developed using information from the literature study, interviewing persons experienced with winter road maintenance, and interviewing users of the finished expert system. These users were winter road maintenance managers with limited experience.

The number and geographical location of the experts, as well as the types of questions and techniques to be used for the expert interviews, were determined based on problem description results. The specific set of questions to be used for the expert interviews were developed based on actual weather situations occurring during January and February 2000.

The type of expert system to be used will be determined after the interview results have been processed. A rule base will then be created.

One significant conclusion from the problem description is that an expert system for winter road maintenance in Sweden has possibilities for success. Sweden already has an advanced support system for maintenance managers, but with an advanced expert system the country could make use of information that is difficult to employ today.

PROBLEM DESCRIPTION

Background

In 1985 the Ministry of Communications gave the Swedish National Road Administration (SNRA), the Swedish Association of Municipalities, and the Swedish Road and Transport Research Institute (VTI) the task of creating a detailed research program with the goal of reducing the negative effects of salt in winter road maintenance practices without reducing traffic safety. The research program, MINSALT (*4*), was carried out from 1985 to 1991 and resulted among other things in the development of new methods and strategies for limiting the negative effects of salt applied to roads to reduce their slipperiness. The main findings of the research program were that (*a*) salt should be used preventatively (i.e., before slipperiness occurs) and (*b*) prewetted salt or brine should be used on roads. The program estimated that employing its proposed methods and strategies could reduce salt consumption by 20 to 40 percent.

For reasons partly related to a change in winter road maintenance procurement, the strategies proposed in MINSALT have not been fully implemented. In practice, winter road maintenance methods and strategies have remain unchanged despite the knowledge gained from MINSALT.

Sweden now has full competition for all road maintenance activities (personal communication, G. Henrysson, 2000). The Swedish state road network is divided into 144 road maintenance areas. A contractor is responsible for maintenance activities in each area during the contract period, which usually runs 3 to 6 years. A number of private contractors and the SNRA Produktion, which is handled as a private contractor, have been awarded contracts since the start of competitive bidding in 1993. SNRA Produktion is the largest contractor in winter road maintenance and has approximately 75 percent of the market.

Competitive bidding means that the contractor for a maintenance area can change at the next procurement. This in turn means that detailed knowledge about a particular area can be lost. An expert system, however, can assist the new contractor in expeditiously acquiring area knowledge.

Traffic safety analyses show that the number of accidents varies very little on main roads during winter, despite the weather during this same period varying from very cold to very mild. However, the amount of salt spread over winter roads varies greatly, without any measurable differences in traffic or traffic safety.

During winter there are occasions when road maintenance has failed, resulting in serious accidents. During two winter seasons, from 1993 to 1995, a failure study on winter road maintenance was conducted (*5*). For the study, the SNRA commissioned the VTI to determine, under conditions of failure, what actions the maintenance operator had taken and why the road surface condition was poor. Police-reported accidents were used as a basis for identifying failure conditions. However, the information gathered to answer the key questions was insufficient. But one observation indicated that on a remarkably high number of occasions the salting actions were carried out too late (i.e., after the road had become slippery) although failure conditions could have been foreseen with the information available from the Road Weather Information System (RWIS).

In the light of such circumstances, there exists a need to review strategies and methods in order to provide better support for the road authority concerning strategy selection and for the maintenance manager (foreman) concerning the choice of method.

With an expert system or decision support system, choosing the most appropriate and efficient strategy, action, and time can be made easier, thereby helping to reduce the amount of salt spread required while also lowering the risk of winter road accidents.

Goal

The goal of this project is to develop an expert system that will aid the maintenance operator in choosing the right winter road maintenance method, at the right time, for different road classes, traffic volumes, weather conditions, road surface conditions, and other factors. The expert system should also contribute to SNRA goals for winter road maintenance. This means that traffic safety should be increased while salt consumption and cost are reduced.

This development of an expert system will focus on choice of method, spreader type, material type and quantity, and other factors, all at the winter road maintenance operator level.

Decision Situation Today

Maintenance area managers in Sweden are responsible for ensuring that the roads they oversee meet the maintenance standards prescribed in the procurement. A maintenance area in Sweden normally consists of 500 to 1000 km of roads. The roads are categorized into six classes of maintenance standards, depending on traffic volume and importance.

The road surface standard is prescribed by a set of rules known as Drift 96 (6), which is maintained by the SNRA. The requirements for action times, friction levels, and snow depth vary depending on the class of maintenance standard for the road. Figure 1 is an excerpt from the Drift 96 rules for one standard class.

The number of maintenance vehicles available to the maintenance manager may vary between different areas depending on the distribution of standard classes in the areas. Areas containing a large proportion of roads with high traffic volumes may have as many as 20 vehicles equipped with salt spreaders, while an area with primarily low-volume roads may have as few as 2 or 3 salting units. The number of vehicles used for snow clearance does not vary greatly. Twenty to thirty snow-clearing units is normal. It should be noted that in the most northerly part of Sweden no salting is carried out.

The available information on which a maintenance manager bases his or her decisions consists of weather information from VViS, the Swedish road weather information system, and SMHI, the Swedish Meteorological and Hydrological Institute. VViS measuring stations are placed along the Swedish road network (7). There are currently about 650 stations, an example of which is shown in Figure 2. In the figure, "Vindriktning" refers to wind direction, "Vindhastighet" to wind speed, "Nederbörd" to precipitation, "Temperatur/fuktighet" to temperature/humidity, "Elektronik/CP" to electronics, "Fryspunkt" to freezing point, and "Yttemperatur" to surface temperature. The most important weather-related parameters measured by the stations from the standpoint of a maintenance manager are as follows:

- Road surface temperature;
- Air temperature;
- Dew point;
- Precipitation, type;
- Precipitation, intensity;
- Wind, force; and
- Wind, direction.

Because the VViS presentation is Internet-based, maintenance managers can access the information from anywhere. A typical VViS screen showing different station locations is shown in Figure 3. Figure 4 shows the temperature information that is available at each station. The x-axis denotes the time of day for a 24-h day, and the y-axis represents the temperature in °C.

From SMHI, the maintenance manager receives weather prognoses in both text and pictures. Satellite images, radar images, and precipitation forecasts are also

Standard Class A2 (8000–16000 AADT)

The driving lane shall:

- During snowfall and up to four hours thereafter not have a greater snow depth than four cm of loose snow or two cm of slush
- Continuously be salted during rain that causes slipperiness
- Be free from ice within two hours after the rain that caused the slipperiness has stopped
- When there is no precipitation, during other times than stated above, be free from snow and ice

FIGURE 1 Excerpt from Drift 96 rules for winter road maintenance (6).

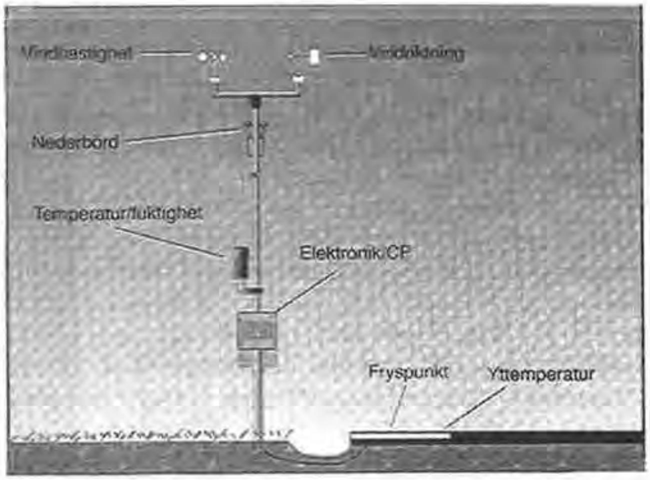

FIGURE 2 Swedish RWIS station (8).

available. The satellite pictures are used to predict the movement of fronts and determine whether or not cloud cover is dissipating. Radar images are used to predict the occurrence and intensity of precipitation. A satellite image is shown in Figure 5 and a radar image in Figure 6. (The white lines in Figure 6 represent boundaries. Precipitation is represented by colored pixels of green, yellow, and red, which appear as the lighter-colored areas in this black-and-white representation.)

It is difficult for a beginner to manage all this information, and making the right decision concerning the appropriate action to be taken, and when, is no easy matter. In addition, conditions within an area also vary as a result of differences in topography.

Other Factors

Besides weather information, data for the proposed expert system consist of information about the area, including available vehicles and equipment. A temperature profile for all roads in the area is also included. At Gothenburg University, a local climatological model (LCM) that can determine temperature variation along a stretch of road has been developed (9).

Although many experienced persons are employed in winter road maintenance, none can be regarded as a leading expert because conditions vary among different areas and locations. In addition, decisions about the same problem may not be the same. Acquiring knowledge from experts is therefore problematic. On the other hand, knowledge about winter road maintenance is relatively stable over time. As a result, the knowledge database only has to be updated once a year, primarily because of changes in SNRA rules (Drift 96).

For an expert system to be accepted by the user, it has to provide suggestions that the user does not discover on his or her own or that is already in use. For example, when salting takes place today, the whole road network in an area is salted because measurements from RWIS stations

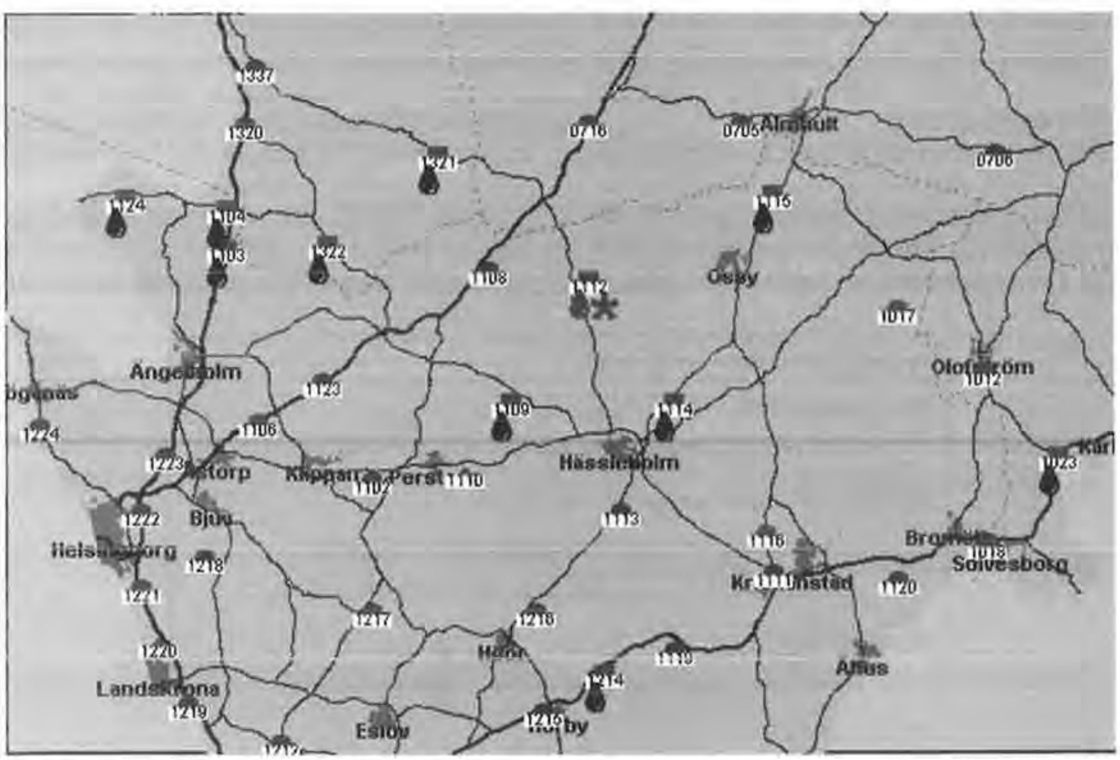

FIGURE 3 VViS screen capture (source: SNRA).

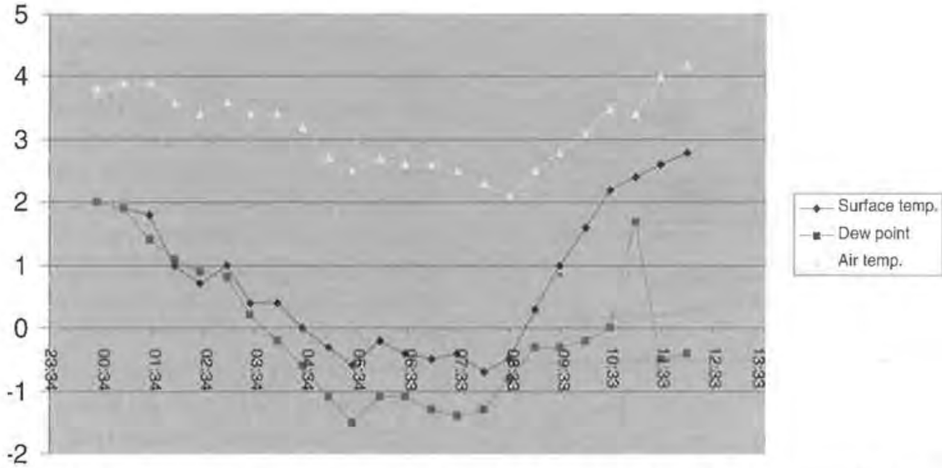

FIGURE 4 Temperature measurements from RWIS Station No. 646, February 11, 2000 (source: SNRA).

do not represent stretches of road between stations. With information from an LCM and an experienced maintenance manager, the expert system could recommend actions on those stretches where information is otherwise absent.

Proper assessment of the amount of residual salt on a road surface is an important factor for the success of an expert system. Although residual salt is difficult to measure, a theoretical model is under development (*10*), and measurements of residual salt have been carried out as part of this project. The results of these measurements are shown in Figures 7*a* and 7*b*. (In Figure 7*b*, "Prewetted" and "Slurry" are indicated by the same line.) If this measurement model were implemented in an expert system, the effectiveness could be substantially increased.

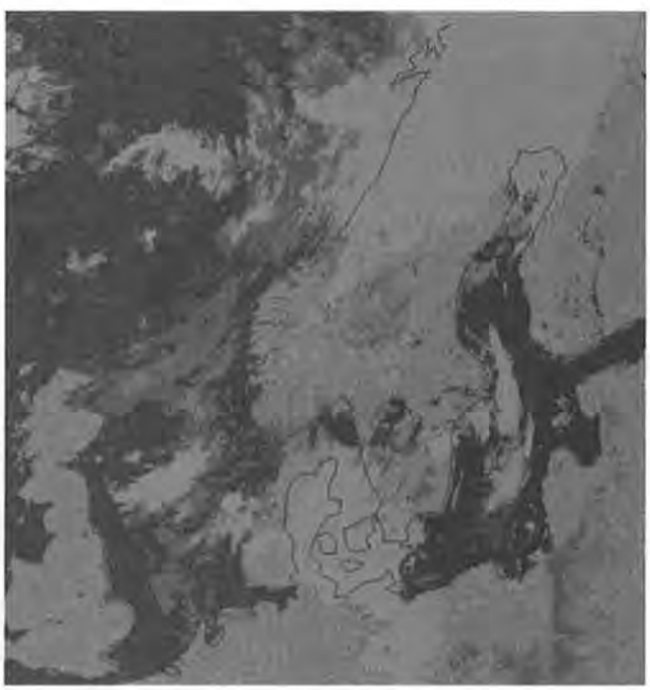

FIGURE 5 Satellite image of Sweden showing cloud cover (source: SMHI).

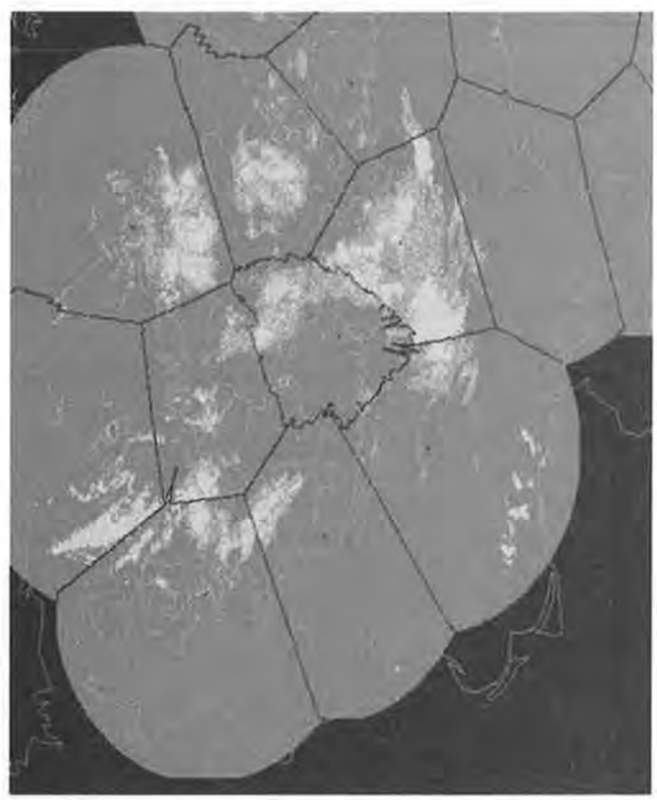

FIGURE 6 Radar image showing precipitation (source: SMHI).

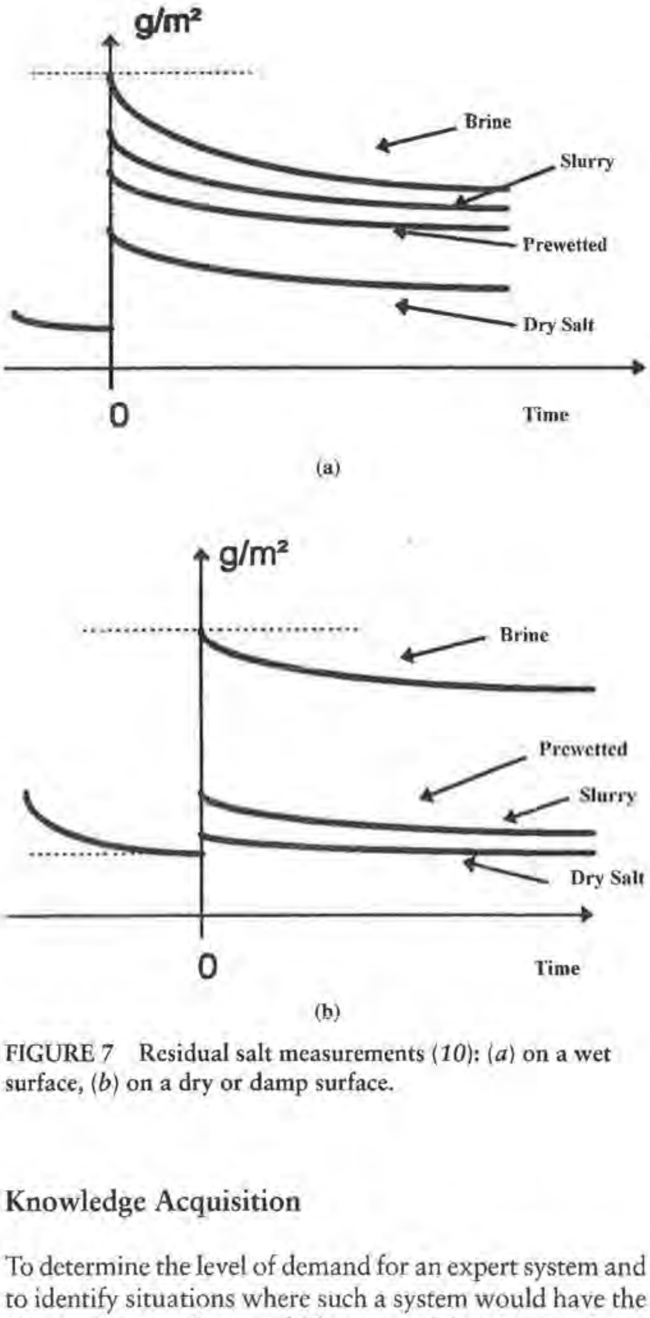

FIGURE 7 Residual salt measurements (*10*): (*a*) on a wet surface, (*b*) on a dry or damp surface.

Knowledge Acquisition

To determine the level of demand for an expert system and to identify situations where such a system would have the greatest impact, five would-be users of the completed system were interviewed. The users were new to the position of winter road maintenance manager (foreman) and had limited experience in the road maintenance field. The interviews were recorded and were based on a questionnaire concerning the managers' working situation and decision circumstances.

In selecting suitable experts for the interviews, a number of persons with extensive experience and wide connections in their industry were asked to recommend persons whom they considered to be experts in winter road maintenance. A criterion for selection as an expert was employment as a winter road maintenance manager (foreman) during the winter season the study was performed.

To obtain desired results from the interviews, it was important to follow a predetermined interview method. In *An Introduction to Knowledge Engineering* (*11*), Smith lists various methods for conducting effective knowledge acquisition interviews and provides guidance for the expert interviews conducted in this research.

A frequent problem encountered in making decisions on winter road maintenance is whether to perform an action immediately or to wait. It was therefore important to choose an interview method that took into account this problem. An introspective method, together with a retrospective method (*11*), was used. The introspective method presented the expert with an example of a situation where a decision was required. The expert was instructed to argue both for and against the decision that would be made. The retrospective method required the expert and knowledge engineer to discuss a decision after the actual decision was made.

Several other methods exist for interviewing for an expert system, including identifying extreme situations and documenting decisions based on them, and conducting studies in which the expert is observed at work. Drawbacks to using extreme situations are that such circumstances are inherently rare, and actions carried out during such situations are not paid for in the same way as in normal weather situations. An important drawback to on-the-job observations is that the reasoning behind decision making is not explored as well as with introspective methods. Another disadvantage is that identifying a variety of situations necessitates making observations over a long period of time.

Based on the results from interviews with five beginner road maintenance managers and discussions with six experienced managers, a number of weather examples were compiled for use during the expert interviews. The examples, which consisted of data from the Swedish RWIS, radar images, satellite images, and weather forecasts from SMHI, were intended to reflect the typical situation under which an expert would make a decision on winter road maintenance.

Results from Knowledge Acquisitoin

General

Beginners and experts were equally receptive and cooperative during the interviews. Their answers appeared earnest and candid, and they did not hesitate to talk about subjects that could be interpreted as negative for them.

Not surprisingly, there was a knowledge difference between beginners and experts. The beginners had less knowledge about winter maintenance methods and equipment, and they were more uncertain than the experts in making decisions. This is a prerequisite for further development of the expert system.

Beginner Interviews

All beginners indicated a need for a decision support system. The following reasons for this assistance were identified:

• Uncertainty concerning where road slipperiness first appears in their area.
• Very little knowledge about different maintenance methods and their effects. (The amount of salt used by beginners varied less compared with that used by the experts.)
• The need for a reliable forecast of road surface temperatures at least four hours in advance so that preventive salting could be completed before road slipperiness occurs.
• A request for residual salt measurements.

Beginners indicated they did not require assistance with snow clearance and sanding; however, they indicated that the assistance of an extra maintenance manager (foreman) would be required during heavy snowfalls because of problems associated with keeping track of numerous snow clearing trucks and the large number of reports that have to be sent to the traffic information center.

In general, beginners indicated they were dissatisfied with their level of compensation for being on call during the winter season. They said they would not accept being on call were it not an obligatory part of their job. Most beginners said they felt the pressure of responsibility for accidents, as well as anxiety if they should fail to observe a situation in which slipperiness has occurred.

Two out of five beginners said they intend to give up working in winter road maintenance because of the heavy workload and pressures of responsibility.

Expert Interviews

The primary purpose of the expert interviews was to create a knowledge database of maintenance practices for use in compiling a rules-based best practice manual for winter road maintenance in Sweden. Rules will be based mainly on road surface temperature, dew point, precipitation, residual salt, and the amount of water on the road surface.

In most cases the experts agreed on situations that require some form of maintenance action. Recommended salt amounts varied among the experts and according to different situations. Even though all experts interviewed had extensive experience (an average of more than 15 years in the field) in winter road maintenance, the amount of deliberation behind salting actions, method choice, and potential method effects varied greatly.

In general, the experts strive to use as little salt as possible while maintaining the prescribed standard. There are three reasons for this goal:

1. Lower salt costs,
2. Lower environmental impact, and
3. Faster-drying road surfaces.

The only chemical used in winter maintenance in Sweden is sodium chloride (NaCl). Other salts or chemicals that could be used are either too expensive or have an excessively negative impact on the environment or on bridges. In this study, salt is defined as sodium chloride.

There are two different methods for spreading salt, defined by the type of salt use. One method uses prewetted salt, and the other employs brine. Dry salt should never be used, according to the experts, because it does not stay on the road (Figures 7*a* and 7*b*), and it is much slower than prewetted salt and brine. Prewetted salt is dry salt that is wetted with 30 percent by weight of brine at the time of spreading. Brine is a saturated 23.8 percent salt solution of salt and water and is the method preferred by the majority of the interviewed experts in most situations. The advantages of brine over prewetted salt are as follows:

1. Total salt consumption is lower.
2. The melting effect is faster.
3. Road surfaces dry faster, in part because of lower salt quantities.

The disadvantages of brine over prewetted salt are as follows:

1. Maintenance areas must have equipment for spreading prewetted salt, as brine is not suitable for use during heavy snowfalls.
2. If the road surface is very wet or precipitation is ongoing, there is a risk that the brine will be excessively diluted and the liquid will refreeze.

All new spreaders purchased by SNRA Produktion over the last 4 years are combined spreaders (personal communication, G. Henrysson, 2000). A combined spreader can spread both pure brine and prewetted salt.

For normal preventive salting on dry or nearly dry surfaces when light hoar frost is expected, the recommended spreading salt amount is 10 g of brine/m^2. If the maintenance area does not have any brine spreaders, the recommended amount is 5 to 7 g of prewetted salt/m^2.

If the road surface is wet, the amount of brine should be doubled, to 20 g/m^2, and the amount of prewetted salt increased to 10 to 15 g/m^2.

In some situations, some of the experts use as little as 5 g of brine/m^2 (62 lb/lane-mi) for preventive salting.

To reverse or prevent slippery road conditions at low temperatures (less than −10°C), very small amounts of brine (less than 5 g/m^2) or prewetted salt (2 to 3 g/m^2) may be spread.

If a snowfall is expected, it is important to spread salt before the snowfall begins in order to prevent the snow from bonding to the pavement. The amount of salt spread should be 20 g prewetted salt/m^2. If the road surface is dry and colder than −7°C, the road surface temperature is not expected to rise significantly, and the dew point is below the surface temperature, the risk of snow bonding to the pavement is small and salting should be avoided. During snowfall, the spreading of extra salt should be avoided.

Experts indicated no reservations concerning sanding. Over the last few years there has been a change in the type of material used. Earlier, almost all sanding was performed with sand fraction (0 to 8 mm with 3 percent added salt). Salt was added to prevent freezing in stockpiles. Today, most sanding is done with grit (2 to 4 mm).

The situation cited as most difficult by most of the experts, which therefore constituted a situation in which an expert system would be useful to them, was the sky clearing suddenly. When this happens, the temperature on the surface can fall several °C in an hour.

Another situation where the experts indicated they would want more information is when determining whether the amount of residual salt on the roads is enough or if extra salt is needed to prevent freezing.

Proposed System Design

There are a number of parameters that cannot automatically be read by the expert system: weather forecasts, satellite images, radar images, and surface moisture. To obtain this information, the system must ask the user for input. Based on results from the literature study, a decision has been made to construct an expert system that is rules-based, using forward chaining and induction.

A rules-based system was chosen because it makes possible the ability to follow the reasoning behind decisions. The system is therefore transparent and enables a fuller understanding, a critical element of this project. A system based on neural networks or on case-based reasoning could also have been chosen if a full understanding of the system had not been as paramount. [A neural network system would probably have been easier and quicker to build (*12*).]

Forward chaining is suited to the selected type of expert system because it resembles process management (*13*). Induction is used on the rule base to create a decision tree in which the most important parameters for making decisions in different situations are revealed.

Figure 8 shows the schematic design of the proposed expert system.

Timetable and Recommendations

Timetable

The knowledge-gathering phase of this project was completed in April 2000. Creation of the rules database took place between May and November 2000. A prototype expert system will be completed by January 1, 2001.

Recommendations

Results from interviews with winter road maintenance personnel show a clear need for an effective expert system. The interviews were also valuable in assisting with the development of the prototype system. The critical factor

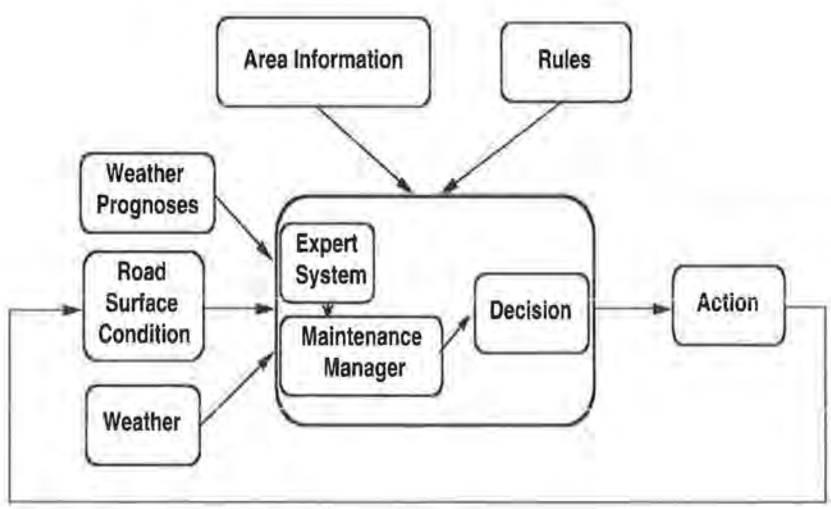

FIGURE 8 Schematic design of proposed expert system.

for success will be user acceptance. The system must be able to forecast situations in which slippery roads will occur and must also take into account possible amounts of residual salt. Recommendations provided by the system must be applicable to specific parts of a maintenance area, and the user's input to the system must be quite limited.

After testing of the system over one season, it should be evaluated to decide whether further development is warranted or if instead it should be abandoned. The evaluation should be performed as a user survey. A comparison with a similar maintenance area should be made to control for economic and salt consumption effects.

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