National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

April 1999—Number 238

Subject Area: IIIC Maintenance

Responsible Senior Program Officer: Edward T. Harrigan

Report on the 1998 Scanning Review of European Winter Service Technology

This digest summarizes the findings of an international technology scanning review conducted with the support of NCHRP Project 20-36, "Highway Research and Technology—International Information Sharing." The scanning review team consisted of representatives from U.S. federal, state, and private sector agencies. This digest was prepared by David A. Kuemmel, report facilitator for the review.

CHAPTER 1

Introduction

This digest describes the findings of the 1998 International Scanning Review of European Winter Service Technology organized jointly under the auspices of FHWA's International Outreach Program and the American Association of State Highway and Transportation Officials (AASHTO) through the National Cooperative Highway Research Program (NCHRP). The review was undertaken to examine several Japanese and European technologies for winter maintenance originally identified by the 1994 International Winter Maintenance Technology Scanning Review as prime candidates for further, detailed investigation, viz, new sensor developments, integration of winter service road condition in IVHS technology, and pavement anti-icing and deicing systems *(1)*.

The Strategic Highway Research Program (SHRP) (1987-1993) opened up new areas of research on winter service technology. Research on ice bonding and dis-bonding, snowplow edge design, road-weather information systems (RWIS), winter snow fencing, and anti-icing was launched. This was the first time substantial resources were allocated in the U.S. to researching winter service technology.

The SHRP anti-icing experiments coupled with expansion of RWIS demonstrated the potential to improve service and reduce costs and environmental impacts from deicers. This led FHWA to expand the field testing of various chemicals and procedures with Test and Evaluation Project 28 that included field trials in 18 states during the winters of 1992 to 1994.

Objectives

The 1998 European scanning review (conducted from March 6 to March 22) was organized to enable team members to do the following:

- Discover, understand, publicize, and assist with the marketing of state-of-the-art developments in winter maintenance technology and techniques;
- Focus on methods, equipment, and processes to improve customer service and awareness;
- Make recommendations on the development and implementation of customer-based performance measures; and
- Assist state and local agencies to implement state-of-the-art technologies and techniques by using the resources of FHWA, AASHTO, the National Association of County Engineers (NACE),

CONTENTS

the American Public Works Association (APWA), and TRB.

The technology scanning review team met before the scanning review to plan its itinerary around eight topic areas identified by the sponsoring organizations:

- Public information systems and driver training programs;
- Use of studded tires;
- RWIS;
- Snow removal in urban areas;
- Performance measures for winter service;
- Automated dispatch, control, and traffic management systems (split into "Automated Dispatch and Technology Applications" and "Traffic Management Centers" in Chapter 3);
- Avalanche prediction and control; and
- Equipment, materials, and methods in winter maintenance.

These topics were selected to avoid overlap with technology evaluated in the 1994 scanning review. The itinerary was developed so that team members would interact with a range of host agencies and staff with similar expertise and experience.

(Note: The term "winter service," often used in European countries, describes the customer-oriented services provided to the motoring public; this term was adopted by the team and used throughout this digest.)

Sponsoring Organizations

The 1998 Scanning Review of European Winter Service Technology was conducted under the auspices of the FHWAs International Outreach Program, AASHTO, and NCHRP, in cooperation with APWA and NACE. Appendix A provides biographical information on the scanning review team members. Appendix B contains the itinerary. Appendix C provides a bibliography of Permanent International Association of Road Congresses (PIARC) and Standing International Road Weather Commission (SIRWEC) papers.

CHAPTER 2

Country Summaries

Switzerland

In Switzerland, the team met with officials of the Canton (State) of Fribourg, the Canton of Vaud (Lausanne) and the Canton and City of Geneva. The team also visited one of Fribourg's maintenance equipment centers. On the way to Geneva, the team viewed the operation of an in-pavement automated liquid chemical dispensing system on Highway A9 (Lausanne "Ring" road) and a maintenance center in the Geneva Canton.

The maintenance of national roads in Switzerland is performed by the cantons, with 80 percent of the cost paid for by the national government. The agencies visited

- Have specified levels of service and include some public information programs,
- Rely heavily on contractors and use an innovative equipment amortization system,
- Have an extensive RWIS with an advance pavement freeze alarm that activates an automated pager system,
- Experimented with global positioning satellites (GPS) for automatic vehicle location (AVL),
- Use a very fine grade of salt and load spreader trucks using an inclined conveyor,
- Address avalanche problems with extensive construction of wire fabric and steel fencing, and
- Have implemented some of the innovative equipment ideas discussed in Chapter 3.

France

France has a national traffic management system consisting of a central center and seven regional centers; the system provides complete integration of winter service, police, traffic management, and public information programs. In France, the team met with officials from the French Ministry of Infrastructure, Transportation and Housing (DDE) in the Savoie Department (similar to a county in the United States). The team members visited the Organization of Security, Information and Road Itineraries (OSIRIS) Traffic Management Center (TMC) built for the Albertville Olympics in 1992. A maintenance district in the French Alps was also visited for demonstration of an automated, site-specific device that detonates a propane-oxygen mixture to initiate controlled avalanches. The team visited the Center of Operations, Safety and Road Assistance (CESAR) near Chambery (operated by the Society of Auto Routes in the Rhone-Alpes Region [AREA]) to meet with officials of several of the privately operated toll highway authorities in France. The team toured the Regional Center for Information and Coordination of Routes (CRICR) in Lyon, which is jointly directed by the DDE, the Gendarmes, and the national police. This is one of seven regional TMCs operating under France's national TMC near Paris. The team also visited a new winter service training facility operated by the Autoroutes in the South of France (ASF) toll highway authority at Les Salles near Clermont-Ferrand (the facility is the only one of its kind in Europe for training winter service personnel from all levels of government).

Key findings are as follows:

- RWIS centers are integrated with the TMCs and co-operate with the police and media, as well as highway maintenance personnel within these TMCs.

- The DDE pays the French Meteorological Service (Meteo France) for surface transportation forecasts.
- The DDE has developed a vocabulary describing winter highway travel conditions for the public.

These and other innovative ideas are discussed fully in Chapter 3.

Norway

In Norway, the team met with officials of the Norwegian Public Roads Administration (NPRA) in the Oslo area and the Contracts Director for the City of Oslo. The team also visited the Romerike maintenance area (Akershus County) of the NPRA.

Key findings are as follows:

- There is a national 3-digit phone number for road information, including winter conditions.
- The NPRA is working to reduce studded tire use from 80 percent to 20 percent in the four largest Norwegian cities in just 4 years.
- RWIS equipment uses a common data and communications protocol in order to integrate data from throughout the country.
- The NPRA uses thermal mapping to improve service and reduce costs.
- The NPRA uses friction testing for performance evaluation of winter service.

These and several unique equipment ideas are discussed in Chapter 3.

In the City of Oslo, efforts to reduce environmental concerns associated with snow dumping and the use of definitive performance standards for public forces as well as contractors were examined. Oslo is working under a mandate of forced competition for government maintenance services. These concepts are discussed in Chapter 3.

Sweden

In Sweden, the team members attended the PIARC's Xth International Road Congress in Lulea, Sweden, March 16–19, 1998. Key technical papers are referenced in Chapter 3, as are technical reports presented at the 9th SIRWEC conference in Lulea preceding the PIARC meeting. (Note: See the end of this digest for information on obtaining copies of the proceedings for SIRWEC and PIARC.)

Following the Congress, team members met with officials of the Swedish National Road Administration (SNRA) at the Stockholm TMC and visited a nearby maintenance and operations center.

Key findings are as follows:

- RWIS data collection and winter service operations are integrated within the TMCs, and road condition information is available on the Internet.
- Sweden has no plans to abolish use of studded tires.
- Sweden has conducted extensive research on the benefits and costs of studded tires. As a result of research on and development of both lightweight studs and hard pavement aggregates, pavement wear caused by studded tires has been reduced from 300,000 tonnes per year to 100,000;
- SNRA RWIS software integrates the best components from several RWIS manufacturers.
- Sweden has many RWIS stations and shares data with Norway and Finland.
- SNRA mandates contracting out for all winter service, and its own forces compete in the bidding.

These and other innovative equipment ideas and methods are discussed in Chapter 3.

CHAPTER 3

Observations, Discussions, and Recommendations

Public Information and Education Programs

Data Collection. Motorists are encouraged to use cellular phones to report road conditions as well as traffic incidents directly to TMCs in Switzerland and Sweden. Road authority personnel use radios to report winter road conditions in France and Sweden, as do the police. French toll highways have emergency callboxes at 2-km intervals, even in rural areas. France is also using aircraft in larger metropolitan areas for incident management monitoring.

In Sweden, private contractors gather information, and radio broadcasters pay motorists to call in road and traffic conditions. The SNRA uses its own road assistance patrol in Stockholm to keep the TMC informed and integrates information from numerous ferry and lift bridge operators at its TMC.

Data Distribution. Before the start of the winter season, newspapers in Fribourg, Switzerland, carry information from road authorities on actions required of the public during winter travel, such as tire requirements and safe driving practices. Police announcements are carried on radio when necessary. Drivers in Switzerland can switch to roadside radio frequencies for current conditions, and roadside electronic speed limit signs are used to reduce speed limits when conditions warrant.

Every household in the City of Geneva is notified annually about what residents can do to minimize the effect of snow on their lives, and citizens are reminded of their responsibility to remove snow from sidewalks adjacent to their property.

French national road authorities recently launched a newspaper campaign to educate the public about the uniform vocabulary describing road conditions. More than one million copies of a brochure were distributed to the public, and posters were placed in locations frequented by motorists (e.g.,tire shops, roadside rest areas, tourist offices and ski resorts) (*2*). French tire manufacturers relate tire performance to standard terms in this vocabulary (*3*). Part of the brochure discussing this vocabulary is shown in Figure 1. The conditions described by the four standard terms are as follows:

- Normale—snow on the shoulders or non-driving portion of the road, the absence of slippery conditions, and no ice formation or drifting snow;
- Delicate—melting snow on the road, localized slippery spots because of frost formation, or possible icy or slippery pavements;
- Difficile—road covered with a thin layer of snow or a thin layer of ice or slippery pavements everywhere; or
- Impossible—road covered with heavy snow accumulation or thick ice layers or slippery pavements everywhere.

National broadcasts of weather conditions use this same vocabulary to notify the public about road conditions in terms they will understand. French road authorities plan to solicit feedback on the public's perceptions of this undertaking.

The team observed outstanding efforts to integrate RWIS into TMCs. Great emphasis is placed on getting road information to the public by using familiar terms with meanings standard throughout the country as well as a wide variety of technologies (from standard radio to the Internet).

Driver Education Programs. No formal winter driving training was reported by any of the four countries visited.

Recommendations for U.S. Highway Agencies: (1) Give the public preseason information on winter service operations and what behavior is expected of motorists; provide the public with the vocabulary used by road officials to describe driving conditions expected as a result of a particular storm condition. Emphasis should be placed on informing the public when to stay at home and off the highways. (2) Develop partnerships with the media and other techniques for getting real-time information on road surface, traffic, and weather conditions to the public, both in advance based on forecast and during the event. (3) Introduce winter driving techniques into driver training programs.

Use of Studded Tires

Various regulations and practices govern studded tire use in the four countries visited. In Switzerland, the team was provided with a summary of European regulations. In southern Europe, studs are prohibited entirely in some countries. Austria, Belgium, Denmark, France, Italy, Luxembourg, and Switzerland have limits on time of year and use on certain highways with lower speed limits. In northern Europe, studded tires are allowed (with some exceptions by time of year and use on certain highways with lower speed limits). The prohibitions are an attempt to reduce pavement and bridge deck wear, as well as air quality problems.

European countries are working with tire manufacturers to improve studless and studded tire design for improved winter traction. At least two major tire suppliers (Nokian and Bridgestone) are selling a softer rubber, studless winter tire. Both suppliers believe that this type of tire is an acceptable option to studs in most situations.

In Switzerland, studded tires may only be used on Canton roads with speed limits under 80 km/h. No studded tires are allowed on freeways. Snow tires are mandatory from November to April on drive wheels. In mountainous areas, either studs or chains are required. Because studs are banned on freeways leading to the mountain ski areas, chains are usually used on mountainous roads. At accidents, police will issue a citation for tire violations. In other situations, a warning will be issued.

In France, studded tires are not allowed, but snow tires are required. In mountainous areas, chains also are required when it is snowing, but are not allowed at other times. In the French alpine ski areas, special roadside areas, much like U.S. Interstate rest areas, provide motorists with safe places to pull over and install tire chains.

Studded tire policies in Norway and Sweden differ significantly. Because of air pollution, the Norwegian government has mandated a reduction in studded tire use from 80 percent of all vehicles to 20 percent by the year 2002 in the four largest cities. No guidelines were given as to how this will be accomplished. The older, full-weight studs produce roughly twice as much pavement wear (forming dust particles) as that of the newer lightweight studs. A socioeconomic model developed by Krodeborg (*4*) comparing benefits and costs of studded tire use shows there is a benefit in reducing studded tire use in the largest cities, but not in Norway in general.

Sweden has done more research than any other European country on the following:

- Development and testing of studded tires,
- Durable pavement aggregates, and
- The socioeconomic effects of various policies.

Sweden allows studs and is considering mandated use of winter tires (studded or studless) in slippery conditions.

During the 1980s, problems related to studded tires increased as a result of increasing traffic density. Research (*5*) has led to development of studs that are durable and less damaging to pavements, pavements that are more resistant to stud wear, and cost-based policies for studded tire use.

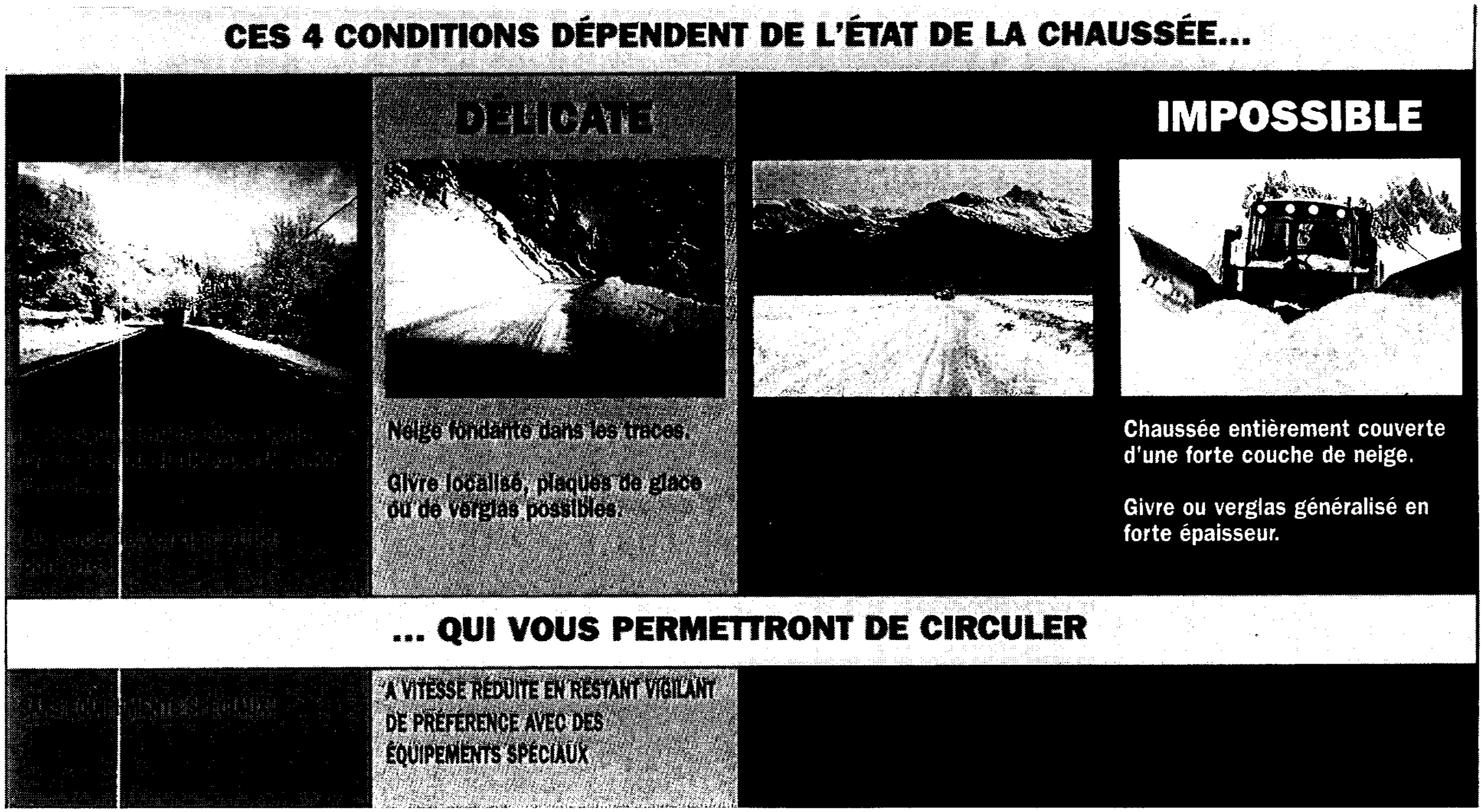

Figure 1. Portion of French brochure "Winter Service."

Research on stud durability and pavement wear are reported by Gustafson (*6*). For many years, it was realized that studs directly affect traffic safety, but the basic design of studs has remained a metal pin enclosed in a mantle of steel, with each stud weighing about 2 g. In recent years, both manufacturers and the SNRA have tested plastic studs and lightweight steel studs. The new lightweight plastic studs result in roughly 50 percent of the pavement wear of traditional steel studs. Lightweight steel studs yield only a 35 percent reduction in pavement wear. Both speed and stud weight increased pavement wear, with the pavement wear from plastic studs being less sensitive to speed than that from steel. The increased use of more durable stone mastic asphaltic (SMA) surface courses is also factored into these estimates.

The SNRA has also experimented with the effect of studs on various aggregates used in asphalt concrete pavements. This is quantified by the SPS index (a Swedish abbreviation for specific wear) reported by Jacobson (*7*); he predicts that by the year 2001 the index will be reduced from 24 g/km to 10 g/km. The report concluded that "the problem of wear caused by studded tires has been mastered on the Swedish road network and is currently not particularly urgent. The deep ruts, more a rule than an exception on the large traffic routes 5–10 years ago, are mainly gone" (because of the switch to lightweight studs and harder aggregates).

Extensive studies of the relative wear of different aggregates used in Sweden found that three factors affect pavement wear: the quality (wear resistance), the content, and the size of the coarse aggregate. Porphyry and quartzite wear least, the granites next, and gneiss the most. Larger size (16 mm) coarse aggregate had less relative wear than the 12-mm size (*7*).

Studies of the socioeconomic effects of differing regulations on studded tire use were undertaken in the winter of 1993–1994 by the SNRA (*8*) because of concern about high road salt use and the potential to reduce chemical use with expanded studded tire use. This work led to discussions on changing rules about winter service to use less salt and leave more ice- and snow-covered roads. Calculations of cost were made for the winter of 1993–1994 and projected conditions in 1999–2000, assuming only a switch to lightweight studs and the greater availability of wear-resistant pavements. Economic costs included those of the following:

- Accidents, both directly (because of slipperiness) and indirectly (because of pavement wear),
- Road wear costs (including pavement marking wear and sign cleaning),
- Car maintenance costs, and
- Car washing costs.

Two sets of calculations are reported (*8*). In the first, a comparison of the effect of increased, voluntary use of winter tires showed decreased cost by the year 2000, primarily because of a reduction of 7,500 accidents annually from the number occurring in 1994. A second set of calculations looked at a policy of requiring winter tires (lightweight studs or studless) in slippery conditions. This second set of calculations showed a further reduction of 1,000 to 1,400 accidents annually. On the basis of the estimated reduction over the 7 years of 9,000 winter accidents, the SNRA has recommended the mandatory use of winter tires during slippery conditions. A decision has yet to be made (1998) by the government because of political concerns.

Because of these advancements, specifically the increased use of plastic or lightweight steel studs and harder asphaltic pavement surfaces, pavement wear as a result of studded tires has now been reduced from 300,000 tonnes per year to 100,000 tonnes per year. In all of Sweden, studs are allowed from November 1 to the first Monday in April.

Recommendations for U.S. Highway Agencies: (1) Prohibit the use of studded tires in high-speed and high-volume areas. Where very hard aggregates are available, allow lightweight studs in mountainous or remote areas where low traffic volumes do not warrant higher winter service levels. (2) If allowed, permit only 0.9-g lightweight studs. (3) Work through AASHTO and FHWA with the tire industry to improve tire tread design for winter service. Tire/pavement noise, friction, and pavement wear should be the controlling criteria. The tire industry can provide tread design alternatives for differing service levels.

RWIS

Observations and Status of RWIS in European Countries Visited. European countries are moving quickly and with confidence to implement and expand RWIS. Thermal mapping is used as a strategy, not only to determine locations for remote, roadside weather stations, but to alert agencies to pavement temperature variations between stations affecting operations. The emphasis is on prediction of black ice—as a result, a much greater density of weather stations exists in Europe than in the United States. RWIS information and pavement forecasts are integrated into their TMCs and into their public information programs. RWIS alarms are linked to automatic pagers that trigger a winter service alert to key personnel (see "Automatic Dispatch and Technology Applications" section).

In Fribourg, Switzerland, on the national system of highways (freeways) there is one RWIS Remote Processing Unit (RPU) or remote weather station for every 3 to 4 km of freeway. The oldest systems are about 10 years old. Annual maintenance and operation costs run approximately \$275 to \$500 per station, depending on the number of sensors and detectors. These stations use an active type of sensor that provides a 2°C warning time before ice formation (see "Sensors" section below). At the CESAR TMC in Chambery, France, there is an RWIS station density of approximately one for each 15 km of national highways. There are 150 sensors in Norway, with just 3 in Oslo. These employ a mix of equipment manufactured in three different countries. These have different protocols for data transmission but seem to operate satisfactorily with the mix of manufacturers, using the Icecast system of Vaisala. The advantage of using the Icecast system is that it does not require a network; its disadvantage is that it allows only one user at a time. Norway has added cameras to some of its RWIS stations. There are 648 RWIS stations in Sweden, with 43 in the Stockholm area. Some British and some Swedish components are used, and the Swedish meteorological service wrote its own presentation software, called PT100. This allows the agency to use components best suited to its applications and ensure interchangeabilty among system components (*9*).

Optical cameras are used in Sweden to detect the amount and type of precipitation, and some can detect the presence of fog. This information is relayed to the TMC along with other camera and RWIS information.

Sensors. Switzerland uses Boschung's active/passive sensor system in some Cantons and the Vaisala system in others. These systems use a common data and communications protocol to promote communication between systems. The Boschung system measures snow depth, wind speed and direction, relative humidity, dew point, air temperature, freezing point of residual brine, and subgrade temperature. The system measures the temperature at which liquid on the surface will freeze on the basis of the residual chemical present. This system provides a 2 °C warning time before ice formation—typically about a ½- to 1-hr lead time, depending on the weather. The system accuracy is reported to be "pretty accurate" for 12-hr forecasts.

The Boschung active sensor principle uses a combination of an active and passive sensor (probe) in an RWIS station to predict the imminence of ice formation with a 2°C lead temperature and measures actual protection imparted by the residual chemical (*10*). The principle of the active sensor is based on the variation of enthalpy (latent heat of fusion) associated with the solidification of an aqueous solution. To artificially freeze the solution on the road surface, it uses a thermoelectric cooler (TEC) in the sensor (shown schematically in Figure 2). Heat is pumped through a metallic conductor and dispersed through a heat sink. An insulator isolates the cold and hot parts of the probe. The temperature of the aqueous solution is measured by a platinum-resistive temperature detector (RTD) located close to the sensitive surface of the probe (not shown in Figure 2). The active sensor measures the thickness of the aqueous solution (which, when the freezing temperature is known, can be used to compute the salt content of the solution). A nearby passive sensor measures the pavement temperature. When the pavement temperature gets within 2°C of the temperature of the active sensor or freezing point for a given residual chemical, the RWIS triggers an alarm, so that appropriate action may be taken.

Personnel at the Les Salles training center described the evolution of the French selection of RWIS. The Vaisala and Boschung sensor systems were the finalists selected after extensive testing in the early 1980s. At that time, the Vaisala system was believed more accurate than that of the Boschung, on the basis of the statistical analysis and the experience of the operators. However, because a meteorologist would be needed to interpret the data provided by the Vaisala system, and because the French believe the Boschung system "best fits the culture of the country," they standardized on it. Training in the use of the Boschung system and sensors is provided in a training center (See "Equipment, Materials and Methods in Winter Service, Employee Training" section). Boschung is developing a new prototype that will have a 2-hr warning time instead of the 2°C advance warning.

Thermal Mapping. Thermal mapping of a road network consists of measuring pavement surface temperatures along all or part of a road network under varying atmospheric and solar conditions to determine pavement temperature differences, which can affect winter service strategies and tactics. The pavement surface temperature recording is conducted using hand-held or vehicle-mounted radiometers. Networks that integrate RWIS data with historical pavement surface temperature (thermal) mapping are used to develop a pavement surface temperature forecast for an entire highway network.

The NPRA reported it uses extensive thermal mapping throughout Norway to aid in forecasts of pavement surface temperature. Because buildings, bridges, and forests can significantly affect road surface temperature, maps for four different winter weather conditions have been developed. Road surface temperature maps are available for a section of road in each condition. As an example, a map of approximately 200 km of highway, with rugged terrain, showing changes in road surface temperature under an extreme condition, has approximately 150 road segments with different temperature categories. Five categories of temperature change are used, showing deviations from 1.5°C above average to 2.0°C below average. When the average is at the freezing point, the data become very important in determining winter service strategies. Norway is very mountainous—pavement temperature changes can be extreme.

Weather Forecasting. All European countries visited have national forecast systems specifically designed to provide forecasts for surface transportation as well as forecasts for other transportation modes (i.e., water, air). These forecasts grew from the cooperation of road and meteorological personnel to develop the necessary data gathering and dissemination systems. As a result, specific forecast information geared to highway transportation is paid for out of highway funds, just as the Federal Aviation Administration (FAA) pays for forecasts geared to air transportation in the United States. The same is not done for forecasts geared to surface transportation in the United States; however, a White Paper describing steps to be taken to encourage a dialog between FHWA and the NWS has been prepared (*11*).

French highway officials explained their relationship and operation with Meteo France. Meteo France is a public corporation and works together with the DDE. Meteo France provides special forecasts for the road network, just as for air and water transportation. Meteo France implemented an agreement with the DDE and spent 10 years developing the kind of product needed for winter road service. The DDE pays for any special forecast data needed for winter service. Forecasts provided to the public are free of charge. Meteo France provides a wallet-size card with a toll-free number to the public to obtain weather conditions for anywhere in the country. Other numbers on the card can be called for modal forecasts and information on avalanche risk.

At the CESAR TMC, officials reported that the accuracy of Meteo France weather forecasts is about 90 percent for the 12-hr forecasts.

Communication of Real-Time Pavement Conditions to the Public. Road officials in the TMC in Stockholm, Sweden, place road surface conditions from RWIS networks on the Internet, indicating snow, black ice, and wet and dry conditions throughout the region by a color-coded map. As of March 1998, the information was only available to SNRA, but the agency expects to make this information available to the public in the future.

Recommendations for U.S. Highway Agencies: (1) Because of the growth of RWIS in the United States and anti-icing strategies that depend on accuracy in forecasts, the dialog between FHWA and the NWS (*11*) should be accelerated to determine a strategy to use NWS data and integrate such data with the states' RWIS data to provide surface temperature forecasts without limitation of state or regional boundaries. The national ITS framework in the United States provides the opportunity for this to occur. Currently, public agencies own the RWIS hardware, but, in some cases, the data are privately provided and owned. This situation requires input and cooperation from current private providers and is much more complex than the systems in operation in Europe. Although states have made substantial investment in systems (often with FHWA funds), they may not be able to communicate with one another, and the NWS does not use or recognize the availability of the hundreds of RWIS stations now in operation. FHWA funds could be used to integrate these weather systems and provide a true national and regional scope to these forecasts. (2) Develop a state and/or regional strategy for full use of RWIS data, by integrating pavement forecasts with TMC, variable message signs, ITS strategies, and public information on winter service programs. Such a long-range strategy should include ultimate use of non-proprietary RWIS components and the availability and distribution of real-time weather and road conditions to the public. RWIS should be linked to automatic notification of duty personnel. (3) Encourage training of winter service personnel to include understanding of basic meteorological phenomena and the action of the RWIS. This training should be statewide and offered to all levels of government. (4) Pursue thermal mapping, beyond just its application for location of remote weather stations, to further improve operating efficiencies from pavement forecasts.

Snow Removal in Urban Areas

Pedestrian Mobility. Property owners in Geneva, Switzerland, are required to remove snow on sidewalks adjacent to their own property, but no time limit is set. Transit routes and pedestrian paths receive a higher priority for winter service in Geneva. In Oslo, Norway, it is the owner's responsibility to prevent slippery sidewalks and remove snow 1 day after a snowfall. The city highway agency removes windrows of snow between the sidewalk and road or behind the sidewalk. If too much snow accumulates, it is removed and hauled to a disposal site. In Sollentuna, Sweden, a Stockholm suburb, property owners are notified of their responsibilities for snow removal through the newspaper.

Snow Storage and Dumping. The City of Geneva has snow dumps on two rivers and two on Lake Leman. Both the City and Canton use liquid and a fine-graded salt for deicing, which ultimately ends up in fresh water.

Snow disposal in Oslo, Norway, is a very sensitive issue because liquid and solid forms of road salt are used for deicing. Snow once was dumped into the sea, but this was stopped to avoid polluting the sea with trash from the streets. Now a search is on for land disposal areas for as much as 350,000 m^3 of snow annually, requiring 10 to 15 land sites. Only two or three firm sites are available as of 1998, because of neighborhood resistance to disposal areas. The cost estimate for development of all necessary sites is approximately $6 million, including drainage. The City Council approved a return to ocean disposal but this has been blocked by the Port Authority. Because snow remaining by the roadside for 3 or more days is defined as polluted, snow was hauled to the sewage treatment plant for disposal on three occasions during the winter of 1997-1998.

Recommendations for U.S. Highway Agencies: (1) Ensure that winter service planning provides environmentally and politically acceptable urban dumping and storage sites for snow removed from streets. (2)

Develop winter service plans for bicycle and pedestrian paths and public transit routes in urban areas.

Performance Measures and Contracting for Winter Service

Performance measures established in both urban and rural areas by European road authorities are both measurable and output-based. They consist of maximum deterioration of road conditions tolerated before action is taken and minimum level of service conditions required before action is terminated. The measures also include time frames for reaching these levels of service under varying weather conditions.

Level of Service Objectives. Most of the countries visited had a bare pavement policy on main roads, with the exception of rural areas in Scandinavia. Switzerland has a bare pavement policy throughout the arterial highway system. Anti-icing in Switzerland is used only on the Canton highways, not on local arterials, nor in the City of Geneva. Geneva gives first priority to clearing transit routes. Specific quantifiable service levels were provided in the City of Oslo. Table 1 shows sample service level details.

The NPRA requres plowing to begin when accumulations reach 1 cm. A friction level of service of 0.4 (coefficient of friction) has been established across all of Norway. Achievement is checked with a friction meter. In the winter of 1997-1998, the friction standard of 0.4 was also applied for the first time to private contractor operations.

In Sweden, performance is described in standards for different highway classes, with class based on function and traffic volume. The standards, called operating rules, are tied to roadway surface temperature, precipitation, and how the road looks under different conditions. Friction testing is done with a Corabla friction tester by a supervisor traveling in a separate light truck, not on the production truck. Two examples of service levels are shown in Table 2, one for a high volume arterial and one for a low volume road.

Customer Point of View. Except in Sweden, there was little observed being done to link customer expectations to performance measures. The SNRA does obtain a systematic customer service response. A total of 14,000 people are surveyed annually at the end of winter, with 2,000 people surveyed in each of the seven regions. Questions are asked about how the SNRA manages snow (50 to 88 percent satisfied, depending on the region), how it manages slipperiness (49 to 73 percent satisfied) and how it manages slush (50 to 67 percent satisfied). Attitude toward salt is also surveyed. In the last survey, those in favor of salt use ranged from 22 to 42 percent, 20 percent had no opinion, and between 40 to 58 percent were dissatisfied. The variation results from regional differences, with people in the north of Sweden generally opposed to salt and those in the south in favor of its use. The sampling is statistically valid, and there is good correlation between lack of road slipperiness and the percent surveyed who are satisfied with the use of salt.

Contracting for Winter Service. All countries visited contract some portion of their winter service. In Europe, contracting is politically driven, with mixed and sometimes questionable results. No systems were in place in the countries visited for true comparison of benefits, relative quality of service, and costs of public versus private service delivery.

In Fribourg Canton, Switzerland, all winter service is contracted for Canton highways, but not for city streets. The Canton purchases the plow and spreading equipment (at a cost [1997–1998] of approximately \$58,600), gives a discount of approximately \$4,100, and charges the balance to the contractor at a cost of \$5,450 annually. The Canton charges no interest, and the contractor buys the truck and owns the plow and spreader after 10 years. Materials are paid for by the Canton. The following rates (1998) are paid the contractors in all Cantons in Switzerland, as part of a 10-year contract that expires in 2002 and is adjusted annually for inflation:

- Standby fee—\$40 per month,
- Salt spreading only—\$121 per hour,
- Snow plowing only—\$150 per hour, and
- Plowing and salting—\$182 per hour.

The minimum call out rate is 3 hr, the second call out in a day pays an additional 3 hr and subsequent call outs are paid at an hourly rate only. Sunday, holiday, and overtime rates are higher. The owner/operator is guaranteed \$6,000 annually.

The AREA Toll Road Company in France has some plows contracted in each district and pays a standby fee of \$1,000 per week. Contractors buy their own truck, blade, and spreader and are paid \$75 per hour (1997–1998) for truck and operator.

The French DDE officials discussed contracting and the pressures to reduce the work force. In the last 15 years, they have reduced their work force from 50,000 employees to 30,000 employees. They must either improve productivity or contract work out. French labor laws limit rehiring of temporary employees in successive seasons, and they often need more staff in winter in the Alpine regions than in summer, so the best alternative is contracting. The French consider winter service to be of equivalent value as police and fire protection in terms of public safety. The French don't have the systems in place to compare costs and levels of service—only direct costs between contracting and in house work.

In Oslo, Norway, winter service is contracted and city forces must compete against private contractors for work.

In Sweden, competitive bidding is mandated for winter service and the SNRA competes along with private contrac-

TABLE 1 Service levels, city of Oslo, Norway

Facility	Weather Event	Time of Weather Event	Treatment or Activity	Begin Activity	Complete Activity
Main Roads	Snow	0200-0700 hrs.	Plowing	Latest 2 hrs. after 5 cm accumulation	8 hrs. later
		0700-1500 hrs.	Plowing	At once, after 5 cm accumulation	8 hrs. later
		1500-0200 hrs.	Plowing	At once, after 5 cm accumulation	0600 hrs.
Secondary Roads	Snow	0200-0700 hrs.	Plowing	Latest, 0700 hrs. weekdays, 0900 hrs. weekends	1500 hrs.
		0700-1500 hrs.	Plowing	At once, after 5 cm accumulation	2300 hrs.(most important roads)
		1500-0200 hrs.	Plowing	At once, after 5 cm accumulation	0700 hrs. weekdays 0900 hrs. weekends
All Roads	Slippery	all	Salt/Sand	within 1 hr. after slippery	4 hrs. later
Intersections	Snow	all	Removal		2 days after end of snowfall
Sidewalks	Snow	all	Plowing	when starting roads	24 hrs. later
	Slippery	varies	sand/gravel	latest, 1 hr. after slippery	24 hrs. later

TABLE 2 Swedish National Road Administration (SNRA) service level examples

Highway Class	Volume, ADT	Temp.	Weather	Action	Treatment	Condition	Completion
Standard Class A-2	8,000-16,000	>8 °C[1]	Fair			Black pavement	
			Snow	Plow		Maximum accum. 4 cm loose snow 2 cm slush	4 hrs., except major storms
				Deicing	10-15 g/m^2 typical, 20 g/m^2 maximum Multiple applications in major storms		
				Anti-icing	liquids or pre-wet 3-5 g/m^2		
Standard Class B-2	<500	all	Fair		Sand only, no salt	Snow Covered	
			Snow	Plow and sand, (salt 2-4%)		Maximum 8 cm loose snow f[2] = 0.15	8 hrs. after end of snow, minimum

[1] Contractors may go below 8 °C
[2] f = coefficient of friction

tors. When the government mandated the competition, they split the field organization of the SNRA into production (delivers service) and administration (supervises and administers service) units. Competition will cover 100 percent of all winter service (and other maintenance) by the year 2000. A fixed amount per person required for winter service is provided to all successful bidders, covering all costs (i.e., labor, material, and equipment) on an hourly basis. A fixed lump sum per winter period is also paid. The production unit does not know from year to year how many employees it needs until service is bid. In some years, the unit must find other private or government customers to retain workers. Currently, 20 percent of its total work is for private businesses or for other governments.

The staff of the administrative unit came up through the ranks of the production forces and average 25 years of experience each. There is concern about the long-term availability of in-house expertise if the production unit continues to lose work to outside contractors. In order to bid competitively, the work force has been reduced by 30 percent. Although quality is rated by the SNRA as one selection factor, there are concerns about the long-term effect of competitive bidding reducing quality. When asked if contracting was a good solution for a public safety function, SNRA staff stated they believed that the production unit renders a higher level of service for an equivalent cost. The mandate was intended to increase the number of contractors bidding, but has resulted in just the opposite. In the beginning, eight contractors bid, but now there are only four, because of contractor consolidation.

Recommendations for U.S. Highway Agencies: (1) Implement management information systems that will provide sufficient information on costs, productivity, efficiencies, and outcomes to allow relevant comparisons across public and private work units. This includes use of outcome-based standards for comparative purposes. (2) Assess the long-term implications of contracting for winter service on organizations in order to determine relative efficiencies. For example, contract supervision requires agency personnel with knowledge of weather, equipment, and the desired strategies of winter service. The availability of personnel with this training in the organization needs to be recognized.

Computer-Assisted Dispatch and Other Technology Applications

The scanning team witnessed extensive application of new technology in all the countries visited.

Computer-Assisted Dispatch. An automatic pager system is used in the Fribourg Canton to mobilize personnel. It is triggered by the remote ice detection system, which relays information back to the communications center, where the RWIS central processing unit is located. When the center is unoccupied, the RWIS is connected to a modem, which triggers an auto pager. The pager is left with the center chief who carries a lap top and modem connection to the RWIS, so the system can be entered and monitored remotely. The police can trigger the alarm through the same pager system. Mobilization takes about ½ hr during the day and between ½ hr and 1 hr at night or on weekends.

The SNRA reported use of the ENERA (Swedish trademark) automatic dispatch system. Its use is especially suited to sites that have more than 5 to 10 persons requiring call out. The SNRA units are generally smaller, so the system is used in only three locations. At the three locations, the time required to call out and dispatch crews has been reduced by a factor of 20 to 30. Theoretically, 1,200 people can be contacted in 25 min through 48 outgoing phone lines (approximately 1 person per minute per line). In Sweden, the larger cities use the system, and some 60 systems are installed serving both the public and private sector, as well as utilities. The system is marketed under the trademark "Rapid Reach" in the United States and Europe.

An automatic call out system linked to RWIS with both phone and fax notices is used as a combined winter warning and winter administration system in Denmark (*12*). The turnout system is described as follows:

> "Vinterman contains an advanced turnout system in which all activities in progress can be constantly followed. The actual initiation of activities may be triggered by pre-defined action plans. An action plan describes a number of standard activities, which ought to be implemented in a given situation, e.g. salting of 12 vehicular routes, 5 pedestrian routes, notification to a number of authorities and call-outs to salt depot workers. In turnout situations the system also assists automatically with telephone calls and sending of faxes and carries out continuous monitoring of turnout hours spent on the individual activities, issuing reminders if an activity is taking significantly longer than anticipated."

Other Technology Innovations. One of the highlights of the tour was a roadside visit and demonstration of a large, in-pavement chemical distribution system near Lausanne, Switzerland. It was constructed during 1997 on the A9 Ring Road around Lausanne, adjacent to Lake Leman, near Geneva, Switzerland, shown on the map in Figure 3 (marked N9), and lies between the Villars-St. Croix interchange and the Vennes junction. The highway carries 70,000 to 80,000 ADT and about 5,000 trucks daily. The 8.3 km of pavement on the A9 Highway was constructed with drainage (porous) asphalt for reduction of spray during wet weather but primarily for noise reduction. The location and pavement used were natural choices for this type of chemical distribution system for the following reasons:

- Porous asphalt normally requires more chemical application to maintain safety in winter weather.

- This stretch of A9 is difficult to reach from the maintenance headquarters, resulting in excessively long trip times or ineffective applications because of timing.
- It is often congested during rush hour, making ice control difficult.
- It complied with the Federal Highways Office directives covering cost reduction measures as follows:

"In certain cases the installation of a system for the spreading of chemical melting agents can reduce the use of salt and hence the winter service costs. Such an installation is primarily beneficial for bridges or particularly exposed sections located at the extremities of the maintenance sector. They permit the avoidance of additional interventions for spreading chemical melting agents. Cost-effectiveness of such an installation must be analyzed by a comparison of the costs of the two methods independent of the geographic location." (*13*)

The earliest systems of this type were installed in Germany in 1977, but the system in Lausanne is much advanced. The section of highway has 25 RWIS stations on 8 km of highway plus several bridges and two interchanges. Experience has been limited because of its completion in 1997 and little use the winter of 1997–1998 because of low snowfall, but it has worked as planned when needed. The Swiss believe the system allows just-in-time delivery of chemical, reduces the amount of chemical, and reduces accidents, thereby improving safety.

A central storage system for liquid salt holds 64,000 liters, which is sufficient for 2 days of extreme use of ice control chemical. There are eight substorage systems, each holding 2,000 liters each (at about 1 km spacing). A computerized system controls all elements of the system from the Vaud Canton headquarters. The computer contains 30 pre-programmed distribution plans, depending on precipitation and temperature, including anti-icing, with rates as low as 1 g/m^2. It can be programmed to activate sequentially, simultaneously, or intermittently. The system can be activated by RWIS warning or by radio control from a truck, or manually, from the substation. The RWIS sensors used are those of the active and passive Boschung system described previously.

The spray distribution system is located in the middle of the concrete barrier, shown in figures 4 and 5. Chemical is stored in a small pressure vessel (in the median) with a membrane to control pressure. The vessel can serve multiple heads. The quantity and pressure required for each sprinkler head are preset and depend on precipitation and other factors. A pipe (13 mm diameter) is laid into a slot cut in pavement (at a depth of 3 cm to the bottom of cut in new pavements or 4.5 cm in retrofits). Pressure in the pipe is 10 bar, and in the heads, 4 to 10 bar (again depending on the requirements of a storm). The spray heads are generally plastic and about 4.5 cm in diameter. Figure 6 shows the spray head in action, and Figure 7 shows salt residue several hours after an application.

The heads can be in the concrete barrier or between guard rails (the latter has proved difficult to maintain and is no longer recommended). They can also be recessed into the pavement. A single, in-pavement nozzle can cover two lanes with one head on the side of the pavement. In three-lane sections, the nozzles are placed in line with the right lane line, so a single head covers two left lanes and one right lane. The heads are spaced about every 12 m. There are more than 1,000 heads in this section in Lausanne. If the system is not on porous asphalt or bridges, it can be spaced as follows:

Width	Short bridges	Longer highways
2 lane	15 m	25 m
3 lane	12 m	17 m

Head spacing is closer on the porous asphalt, because liquid chemical drains down and freezing of the top surface is possible. Also, some pumping up of liquid occurs after spraying stops, and the liquid can refreeze. Hence this system especially lends itself to problems with deicing caused on porous asphalt. Traffic can carry spray as much as 100 m. This system uses NaCl at a maximum concentration of 22 percent. Other systems have been designed for use with $CaCl_2$ at a 29 to 30 percent concentration where colder temperatures predominate.

In case of power outage, an alert is received in the center. After the season is over, the chemical solution is drawn back to storage, and water is flushed through the system and left pressurized within it. The system cost about 1 million Swiss Francs per km ($1.1 million per mile, 1997). Maintenance costs are reported to be nominal.

On a system in Germany, the activation of the spray system is linked to a symbolic variable messsage sign, which displays a spray nozzle on the pavement. The German Federal Highway Research Institute (BASt) performed a cost-benefit study (including maintenance costs) on such a system in 1993 (*14*). The 6-km section installed along Highway A45 in Germany (Sauerland autobahn) was the longest installation of its kind at the time in Germany. The system was installed at altitudes ranging from 285 m to 412 m within a climatically critical region. In the winter season, road conditions often change rapidly because of the transition from rain to snow or rising to falling temperatures. Numerous accidents caused by slippery road conditions had occurred, leading to long traffic delays. To improve this situation, the spreading system was installed and began operation in the winter of 1984-1985.

After the installation of the spreading device, accidents under wintry road conditions decreased by more than 50 percent on this autobahn segment (*14*). The accidents involving minor injuries decreased by an even greater degree (85 percent) compared with a decrease of 60 percent in the accidents involving minor property damage. Studies undertaken by BASt have confirmed the economy of the deicing chemical spreading device. Cost data included yearly operating costs for traditional deicing and for the automated system, including energy costs. A one-time major repair cost was included because of a change in design, following installation, along with typical annual maintenance costs. Accident costs before and after were calculated, as well as improvements to the operating speed of different classes of vehicles because of the installation of the spreading system.

A cost-benefit ratio of 1.9 to 1 resulted, considering amortization of the 1.52 million DM (cost of construction and modification, in 1985 German Marks) over the 15-year estimated life of the system. The report recommends that this type of system is best suited to combat black ice and support conventional winter service where black ice or heavy snowfall is common. It further suggests cost-benefit analyses for each individual case in question. Corrosion costs of vehicles were not included. The installation uses less deicer than typical application of salt and $CaCl_2$, so installations in areas where typical winter service includes those chemicals is considered beneficial to the environment (*14, 15*).

Experimentation with in-vehicle GPS receivers in winter service vehicles was mentioned by several agencies, but no cost-benefit data were available.

Several agencies, including the Fribourg Canton, are laying their own fiber-optic cables to connect RWIS stations to TMCs.

Recommendations for U.S. Highway Agencies: (1) Evaluate the use of call out systems triggered by RWIS alarms, especially if RWIS stations are equipped with active sensors that provide accurate real-time pavement conditions. This is especially important when unforecast weather events occur. (2) Fund, through FHWA and AASHTO, an in-pavement chemical dispensing system and document the benefits and costs of such an installation. The benefit-cost calculations should include environmental considerations related to less chemical use and reduced corrosion. The pilot installation should be located where traffic volumes are heavy and the area is subject to frequent black ice and/or heavy snows. The installation should be of sufficient length on a highway with numerous accidents related to winter weather in order to form a good statistical comparison of accident costs before and after installation, or comparing the installation with a comparable control section treated manually during the same periods.

TMCs

The team spent substantial time in France, Norway, and Sweden, visiting five different TMCs. All three countries have national traffic management systems that integrate winter service forecasts and conditions within the TMC. In France, the team saw centers at three levels of government (county, toll highway authority, and National Defense District).

The Organization for Security, Information and Road Itineraries (OSIRIS) TMC was built for the Albertville Winter Olympic Games in 1992. Numerous incidents are related to winter weather, because of avalanches, rock slides, and the large influx of skiers (especially on weekends); these incidents are handled by this TMC. The DDE, the police, railroad, civil protection, and other civil officials are all involved as necessary in dealing with incident management.

National road responsibility in France is divided into defense districts, regions, departments (DDEs or counties), and local cities and towns. OSIRIS is the TMC for the Savoie department, one of the 100 DDEs in France. It is the DDE with the largest snow removal budget, because of its alpine location and the great traffic load because of skiing. There are 3,200 km of highways in Savoie, and there are 71 surveillance cameras, 57 belonging to the DDE and 14 to the toll highways (toll facilities are semi-private in France, built and operated privately, but by charter or license from the national government, through its regions). There are 45 traffic count stations and 16 variable message signs. The TMC manages the Alpine tunnels and has 71 emergency roadside phones. There are four RWIS on national highways in the DDE. The cameras can pan to watch for mud slides and avalanches. There are 650 radio sets for employees. The center communications backbone is fiber-optic cable.

Before the TMC (Figure 8) was put in operation 20 years ago, 20,000 vehicles per weekend reached the ski areas beyond Moutiers, experiencing 10 hr of congestion (10 hr of delay over normal travel time). After the center was built, the congestion was reduced to 2 hr for the same number of vehicles. At a peak of 35,000 vehicles, the congestion extends over 5 hr.

Savoie has a population about 300,000, and, in addition, can have as many as 300,000 tourists at any one time. Normal traffic volumes on Friday and Sunday on the four-lane highway to Moutiers run 10,000 to 15,000 ADT, and traffic flows relatively well. At Moutiers, there is a funnel effect, as the traffic splits in three directions onto narrow mountainous highways climbing up to end at the Alpine ski resorts. On Saturdays, the road to Moutiers experiences over 30,000 ADT, and the narrow two-lane roads cannot accommodate the traffic. The divided highway leading to the city can carry 2,200 per hour, but the three roads leading out can only carry 1,100; 600; and 400 vehicles per hour, respectively. The arterial highways are controlled by signals and the freeways by ramp metering. The tollbooths are also used to slow traffic (tollbooth workers slow manual toll collection). Because all traffic is regulated, delay affects the residents, especially from the two cities on each side of Albertville. Moving the metering up to Moutiers is being considered, to free up the road through Albertville. Roads

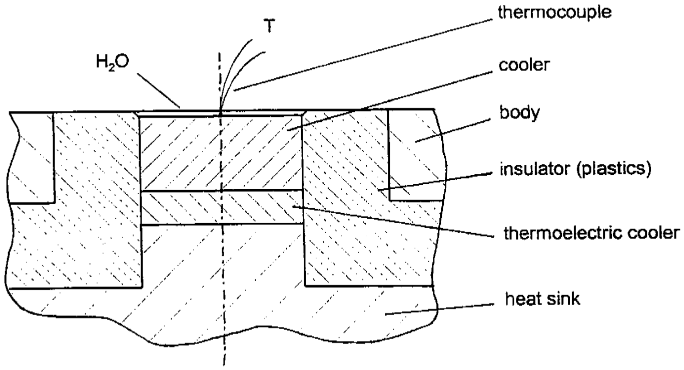

Figure 2. Active pavement sensor (10).

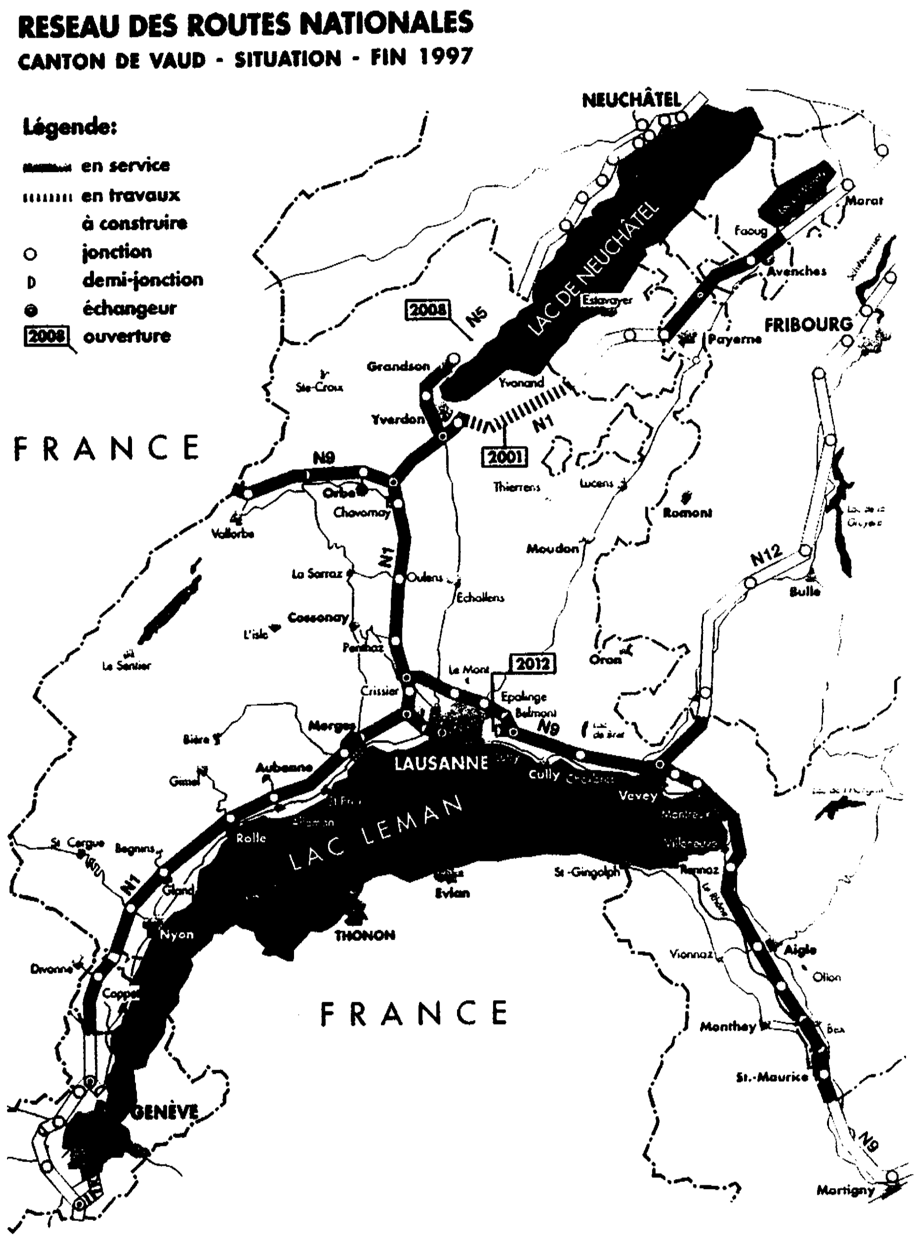

Figure 3. Map of Lausanne, Switzerland, showing location of A9 (N9) Ring Road.

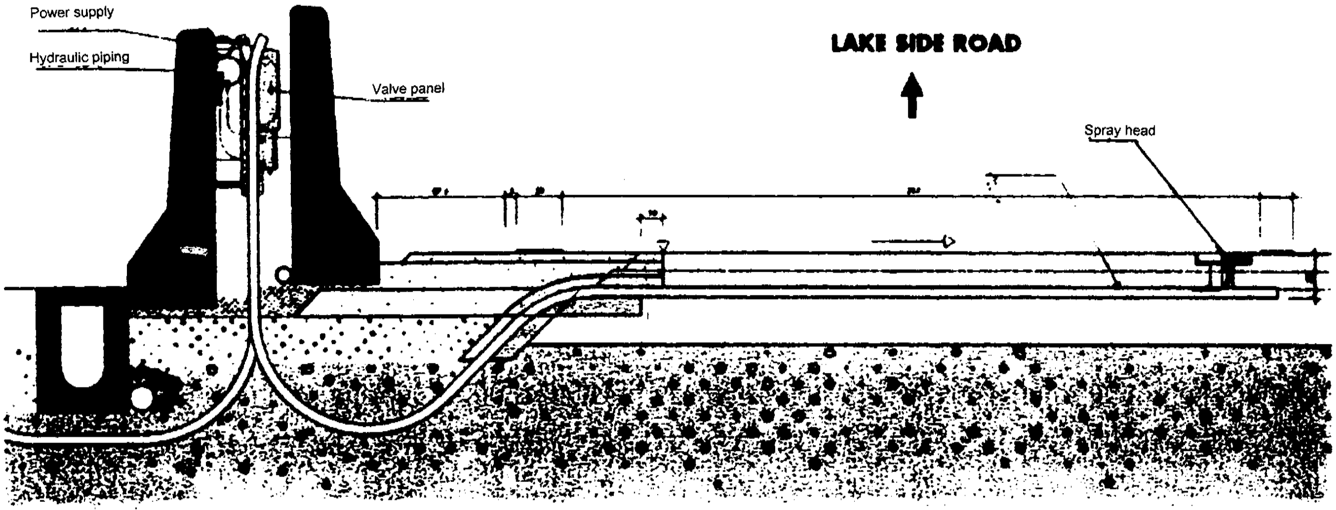

Figure 4. Nozzle and valve arrangement showing the typical elevation of piping for automated spray system in concrete barrier.

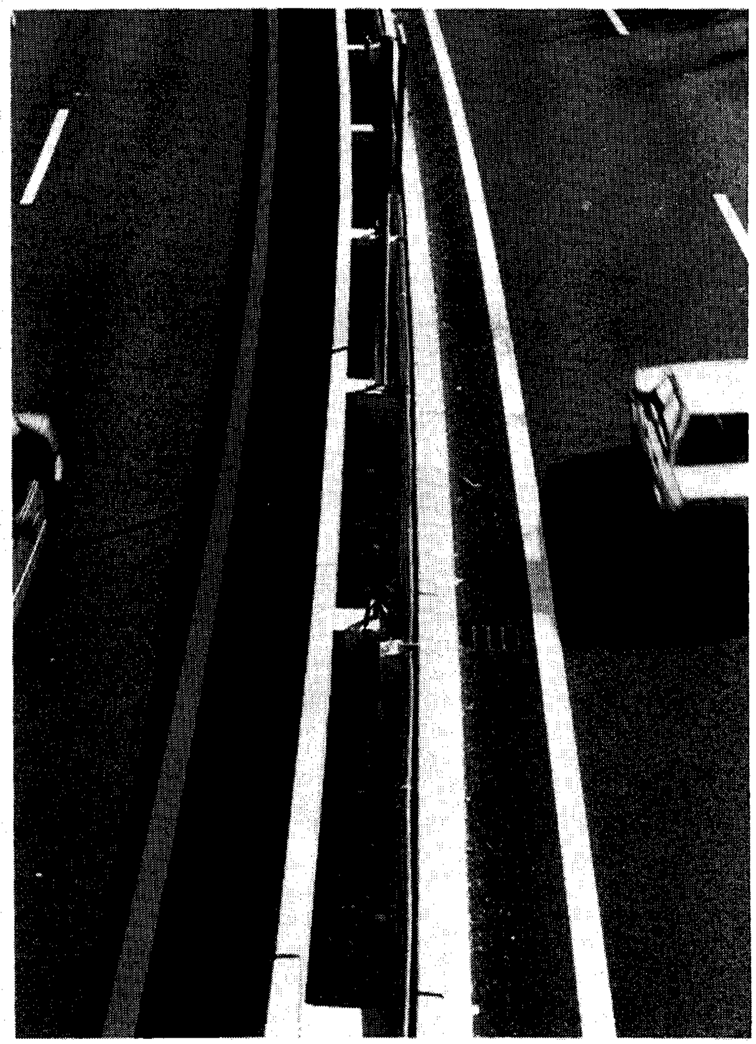

Figure 5. Looking down at piping for automated sprinkler system in concrete barrier.

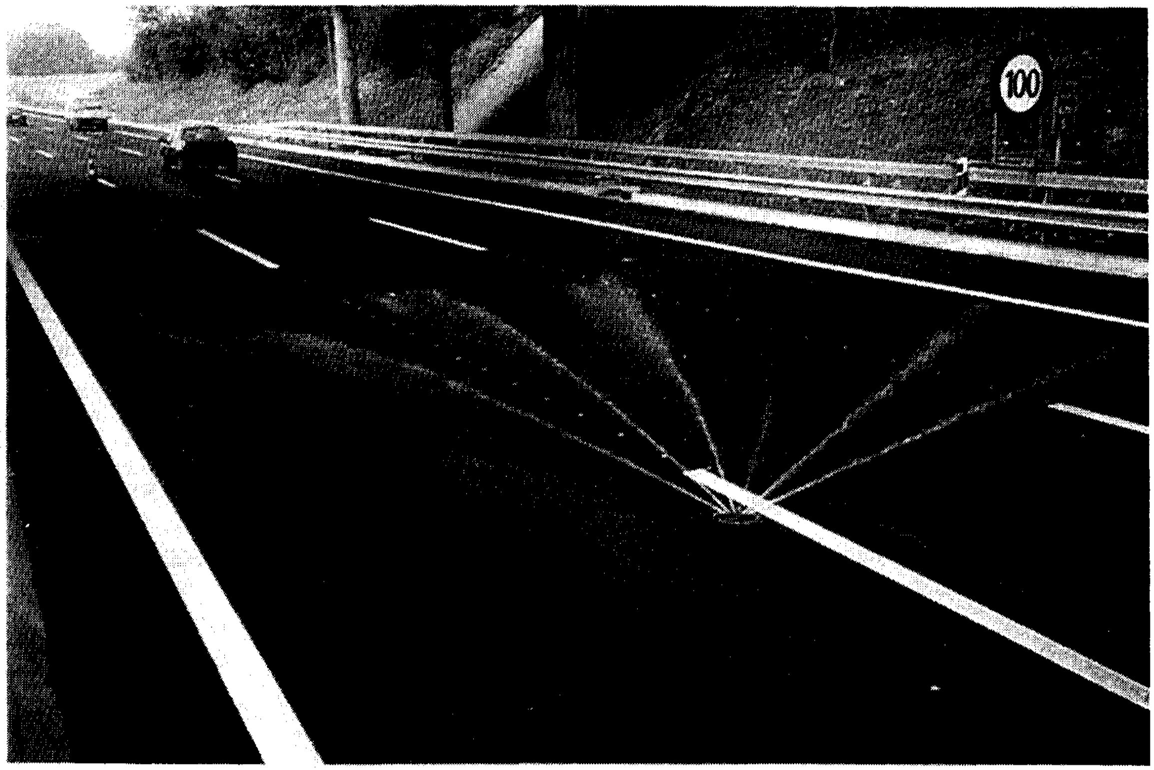

Figure 6. Spray head in action, automated salt spraying system, Lausanne, Switzerland.

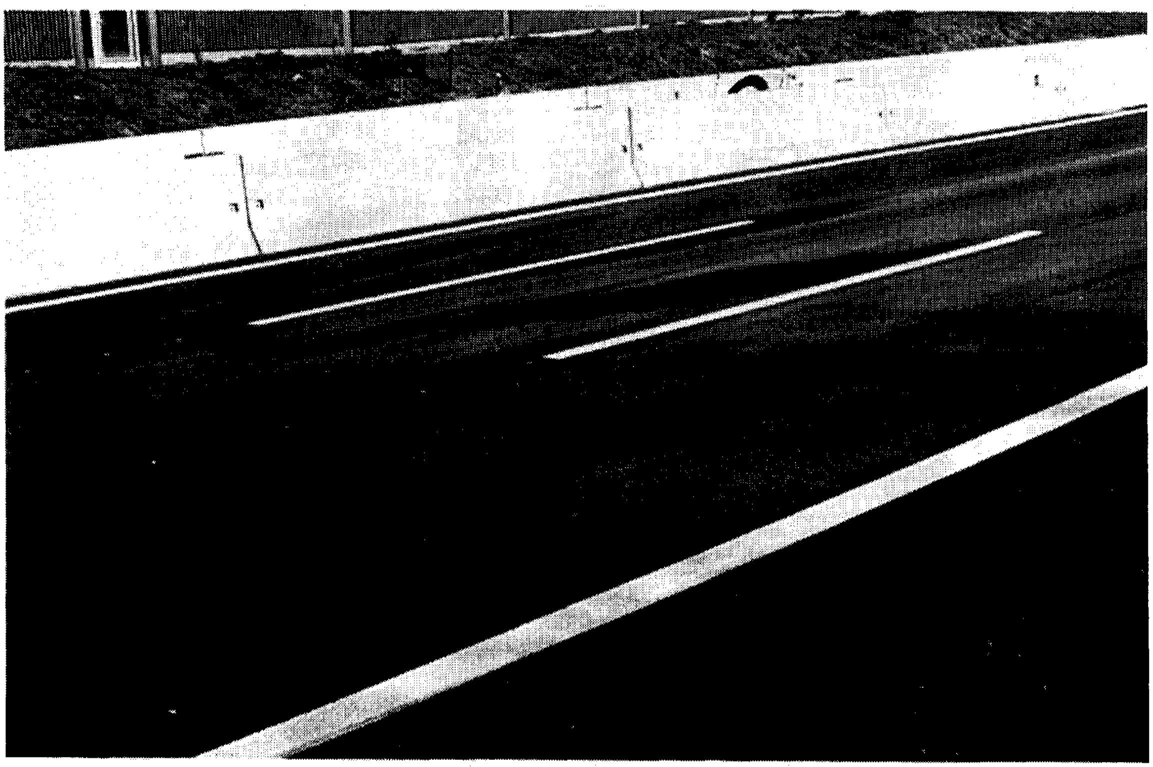

Figure 7. Salt residue on pavement after earlier activation of automated salt sprayers.

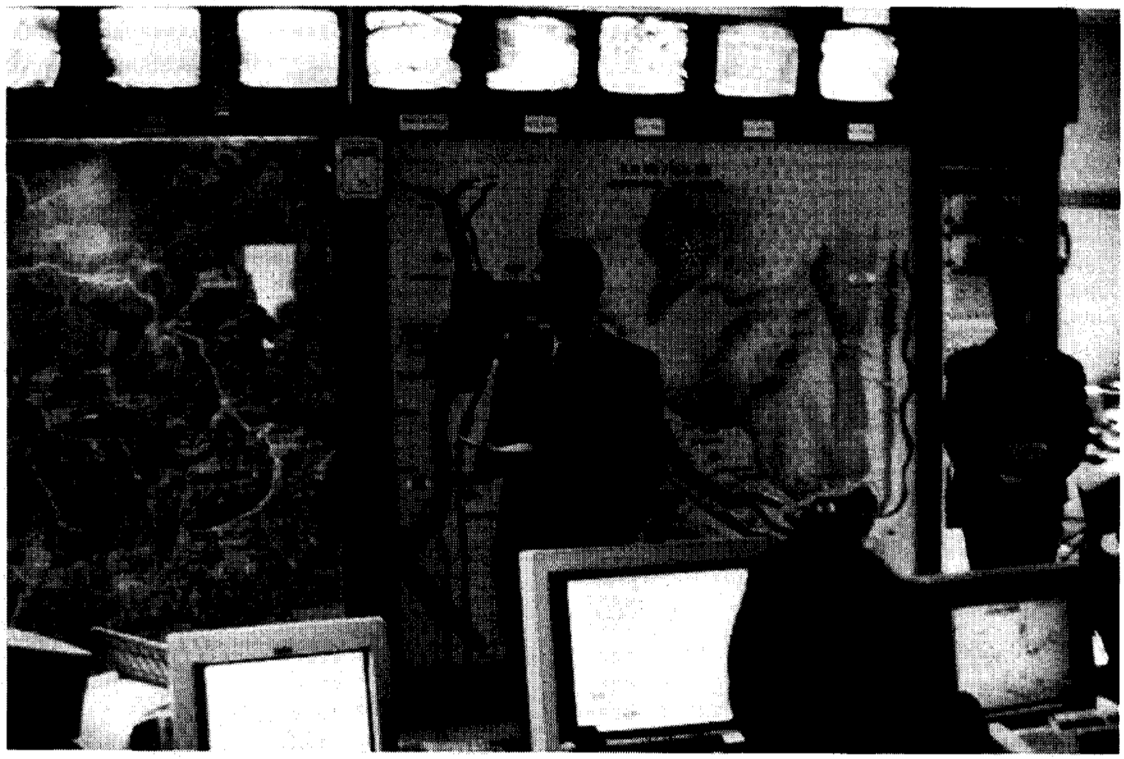

Figure 8. OSIRIS TMC Control Center.

to the ski resorts cannot be further improved because of mountain switchbacks.

The team visited the AREA Toll Highway Authority TMC in Chambery, known as the Center for Operations, Safety and Road Assistance (CESAR). The toll highway company operates in the Rhone-Alpes region of France and the center was built in 1992. The company manages 368 km of freeway and has seven maintenance centers under its direction. One of the maintenance centers is next to the TMC. Maintenance employee housing is immediately adjacent to the center (see "Materials, Equipment and Methods"). There is close coordination with the media, with a media room next to the TMC. All data are shared with the DDE TMCs in the area. There are 70 cameras and 36 variable message signs in the system. This TMC is another example where RWIS data and traffic data are routed to the same center, and the TMC and maintenance centers are at the same physical site.

The final French TMC visited was the Regional Center for Information and Coordination of Routes (CRICR) in Lyon, France, one of seven TMCs organized along the lines of the seven defense regions of France. CRICR serves two economic regions of France—the Rhone-Alpes and Auvergne regions. This center is unique because it is operated by three separate ministries, with three separate offices and three chiefs: the Gendarmes (war office or military), Home Office (civilian police and urban areas) and Transport Office (Ministry of Infrastructure, Transport, and Housing or DDE). Leadership is rotated weekly. All decisions are made jointly. The Gendarmes patrol rural areas and the privately operated toll roads, the Home Office patrols the national roads and free motorways, and the Ministry of Transport (DDE) is responsible for overall traffic management.

Traffic management has had a long history in France. The first TMC opened in the Paris region in 1968, with national and regional TMCs following between 1969 and 1972, when CRICR and the other seven defense region centers opened under the triple direction. There are 1,450 km of motorways; 2,753 km of national roads; and 46,554 km of DDE roads (there are very few roadside call devices on DDE roads). The regions collect data from and disseminate data to and from various traffic and weather agencies. They have 15 cameras and 91 traffic count stations under CRICR direction. They do not use fiber-optic cables but rely on telephone lines; therefore, expense dictates infrequent use except during emergencies.

There are two modes of operation: regular and crisis. Traffic is not managed in the regular mode. When crises occur, the cameras and telephones are used. The mission of CRICR during emergencies (caused by weather, strikes, protests, and so forth) is as follows:

- Respond to alarms to the TIGER computer system (managed by CRICR), triggered by cameras or count stations (see description following);
- Prepare traffic forecasts and traffic management plans for the seven military defense regions;
- Develop a public relations program with the code name "Clever Buffalo," for application during the tourist season and holidays. The program's aim is to convince 10 percent of the vacationers (skiers) to delay their departure. Results are reported to be positive.

CRICR defines and disseminates plans and assesses traffic flow performance resulting from the plans. Holiday travel and snow plans are examples. Center staff are developing a plan for hazardous spills. The toll authority requests intervention by CRICR if necessary and CRICR intervenes only with the agreement of the toll authority.

The team was shown a video of the Treatment of Geographic and Road Information (TIGER) system. The TIGER system's goal is to identify, validate, localize, and adapt to road crises. All road information, including RWIS data, comes into the road center. The TIGER system forecasts events and has synoptic maps in real time for the entire country. CRICR is working with the private sector to develop a Radio Data System (RDS) GPS. The French government wants uniform information available. The European Union wants free data transmission between member countries.

The team was told that both Britain and Germany are interested in establishing national traffic management systems and that the French may abandon theirs. National networks, with integrated RWIS information, and linked with maintenance centers and the media, are thought to have many advantages in the United States by the team. In the United States, more likely a regional grouping of states is feasible. Currently, sharing of RWIS data and other winter weather information across state lines is the exception, not the common practice, and requires the same vendor in adjacent states.

The team visited the Oslo TMC, one of five regional TMCs in Norway. The centers are linked to the single 3-digit telephone number, 175, to both report and receive traffic and weather situations daily. The center is an example of another country with national traffic management. The center includes RWIS data and is linked to maintenance centers as well as public safety departments (*16*).

Oslo has three to four events requiring intervention daily. The center uses cameras with automatic detection in tunnels. Using a software algorithm, the camera automatically detects a stoppage or slowing of traffic, providing real-time traffic control. The Center uses an RDS interruption capability for those vehicles so equipped and, in tunnels, can interrupt certain radio channels with tunnel evacuation plans. Police are co-located in the TMC and can coordinate with other incident management personnel. Oslo has many variable message signs as well.

The team visited the greater Stockholm, Sweden, TMC, a relatively new facility being developed regionally to cover all emergency service, including winter service. An overhead lane control system spaced every 500 m starts working when traffic drops to 45 km/hr, and the signs change automatically as conditions change. Spacing of sensors and signs are sometimes closer depending on ramp locations. Stockholm uses inductive loops, and the studs reportedly have no effect on the inductive loops, because they are too deep (7 to 8 cm) in the pavement.

Recommendations for U.S. Highway Agencies: (1) Promote better coordination among law enforcement, emergency service providers, winter service personnel, and public communications in TMCs in the United States. (2) Integrate RWIS into TMC operations and establish closer working relationships between incident management and winter service personnel (through co-location within the facilities), link variable message signs and ITS technology with TMC technology, and establish permanent regional data interchanges.

Avalanche Protection and Control

Physical Barriers and Restraints. The team was given plans and a description of a Swiss installation (in the Fribourg Canton) that uses metal grates and nets to control snow and rock avalanches. The installation includes a system of permanent markers (snow probes) to determine if snow is moving. The installation is on a highway that was a regular problem area. The protection cost $3.45 million (in 1993) and has eliminated the problem—there have been no avalanches in the 5 years since its installation.

In the Savoie DDE in the French Alps, more than 50 permanent snow sheds have been constructed to provide protection over sections of roads leading to the ski resorts. Both reinforced concrete and steel culvert installations are used. This handles all but approximately 10 avalanches per year, which must be monitored and/or triggered by explosives as conditions determine.

Explosive Devices. In the French Alps, standard plastic explosives have been used in the past with a conventional fuse and a controlled cable delivery system automated to time out the delivery of the charge above the impending avalanche and trigger the event. These systems are being replaced because they are too time-consuming and not sufficiently accurate, as well as to avoid handling explosives. France is moving toward permanently installed site-specific exploders (GAZ.EX) that include an automated system to fire propane/oxygen mixtures in corridors experiencing potential slide activities. The DDE have determined that the permanent exploders are safer and more effective than conventional explosives.

Chambers, like large nozzles (Figure 9), are installed above roadways and ski slopes and are discharged (fired) by computer control and ignited electronically from below via a radio link from a vehicle. The explosion is channeled out of the nozzle toward the buildup of snow. A building houses equipment that charges each device with the gases used (propane and oxygen). The gases are exploded in a controlled fashion to achieve the desired effect. The DDE in Savoie has a full-time demolition expert on its staff. Turnkey installations cost about $89,000 per site (1998), including all the infrastructure, and about $35 per site to fire. This is comparable to U.S. installations, which cost from $70,000 to more than $100,000 for turnkey installations (*17*).

Prediction and Public Protection. A surveyor with binoculars monitors markers placed in the avalanche zone in Fribourg, Switzerland. In addition, snow probes record the temperature and depth of snow. The height and temperature conditions dictate road closure policies, which are handled by the police. Maximum closure period is limited to 3 days.

France is actively modeling avalanche scenarios for diversion and control purposes. Meteo France provides forecasts of risk to authorities responsible for public protection in both the Alps and Pyrenees mountains (*18*).

Recommendations for U.S. Highway Agencies: (1) Increase the use of permanently installed site-specific exploders for avalanche protection. AASHTO, FHWA, and academia should work with industry to reduce the cost of such tools. (2) ITS technology should be used to inform the public of potential avalanche risks and forecasts. Automated monitoring systems should be linked to automated road closure devices to protect motorists from avalanches.

Other Equipment, Materials, and Methods

Although the scanning team saw various innovative ideas in the area of winter service, only those deemed most applicable to the United States are discussed in this section.

Innovative Equipment. Industry and maintenance workers are actively involved in developing equipment innovations. Government and industry partnerships were commonly seen in the four countries visited. French officials described their program as beneficial to both government and industry. They recognize the great gap in most highway organizations between what is shown on the floor at equipment shows and what is being used by the rank and file in winter service.

Vehicle-Mounted Radiometers. In Fribourg Canton, an experimental, vehicle-mounted radiometer that measures pavement temperatures every 2 min was provided by Boschung for testing by the Canton forces.

Global Positioning Satellites for Automatic Vehicle Location. Fribourg Canton is using several units on a trial basis and expects to expand the number of units in the future.

Figure 9. GAZ.EX Avalanche Exploder, Val Thorens, France.

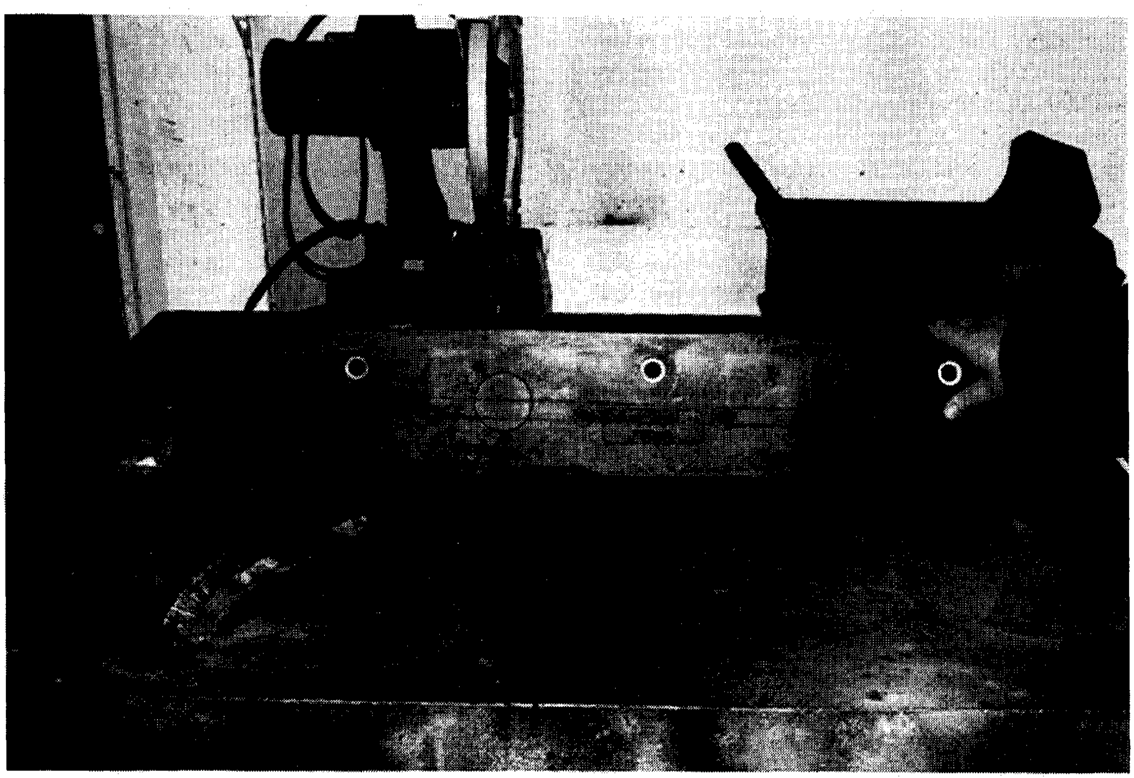

Figure 10. Rubber/steel composite plow cutting edge used in the Stockholm area by the SNRA.

The SNRA is experimenting with several units in the Stockholm area and also expects to expand their number in the future.

Snow Plows and Blades. Unusual plow blades and cutting edges were seen. Rubber blades or rubber/steel composite cutting edges are being used in Fribourg Canton. In the Stockholm area, a composite blade of steel coated with thick rubber, which is manufactured in sections 1 m wide, is being used by the SNRA; reportedly, the blade wears six times longer than that of regular steel (and is about equal to that of tungsten steel). The advantage is that blades are not changed for varying snow/slush conditions. A blade with a 3.6-m-wide cutting edge cost about $1,530 (in 1998). Each 1-m section has three pieces of steel dividing the blade in three sections, with a few cm of rubber in between and surrounding the steel plates. The cutting edge is shown in Figure 10.

Fribourg Canton is using a 5-m-wide plow on freeways, with two plows in tandem to cover both of the 3.5-m-wide lanes. A plow with a narrower blade is used for plowing the shoulder. In the French Alps, the Savoie DDE demonstrated an Alpine Crab with a blade about 7.5 m wide when opened capable of plowing an entire roadway in one pass. Other agencies were using blades with movable sections that can expand 6 to 7 m. Sweden is using a segmented plow blade that conforms to the curvature of the pavement surface.

The Geneva Canton is using a Swissliner plow with the operator seated on the righthand side of the vehicle so that the operator can see better while plowing. It is equipped with a plow 5 m wide and an extension 1 m wide.

Salt Loading Conveyor System. Switzerland and parts of France use a fine grade of salt, finer than granulated sugar, and Switzerland uses a conveyor system to load its salt spreaders (Figure 11).

Chemical Spreading. Several countries use air foils on the back of salt spreaders to keep salt spray off the various light systems mounted on the back of the spreader truck. This is very effective and is considered a safety device, because the continuous air flow down the rear of the truck improves visibility for following motorists. A spreader from Switzerland is shown in Figure 12.

Friction Testing Equipment. Friction trailers are used in Norway to measure compliance by contractors with the winter service level friction requirement established by NPRA. Sweden is developing a vehicle with state-of-the-art equipment to measure friction and temperature in order to determine compliance with level of service requirements. The vehicle, shown in Figure 13, includes a brine sensor.

Other Equipment. Most of the countries visited had salt brine storage tanks, and either manufactured their own brine or purchased liquid salt for anti-icing or pre-wetting.

At the PIARC equipment show, Enator demonstrated a vehicle-mounted sensor cylinder about 5 cm in diameter and 10 cm long (Enator's new active "Frensor" sensor). A depression in the middle of the sensor "cups" a sample of solution that is lifted from the pavement by the vehicle's tire. An air actuated cover lowers over the sample while the sample is cooled to freezing. It then heats the sample and records its melting point. Air lifts the cover off, blows out the top of the sensor, and allows another sample to be collected. It can cycle every 30 sec. With these data and the chemical type, the solution concentration can be determined.

Blue strobe lights are used on snow plows in France to give the snow plow the status of an emergency vehicle.

A steel broom mounted on a trailer with a liquid spreader (Figure 14) is used in Norway to minimize the amount of chemical required in conditions of light snow or slush (*19*).

Materials. In Switzerland, salt is stored in a dehumidified, permanent building. The salt is very fine, much like flour, and has no anti-caking agent. No problems with caking of the salt have occurred. The Canton also has a sealed storage tank for liquid $CaCl_2$. It produces its own liquid $CaCl_2$ for use when the temperature is below – 5°C.

The use of very fine salt (seen in Switzerland and France), although unusual, is economical, because it is readily available from mines where it is produced by running water through salt and drying it for shipping or shipping it as a concentrated liquid. Fine salt can be applied at very low rates and can be converted to liquid conveniently.

In France, three different gradations of salt are used:

- Fine (0 - 2 mm),
- Medium (0 - 5 mm), and
- Large (0 - 8 mm).

Different climates and regions require different grades. For example, on ice, the finest grade (largest specific surface) is used. On snow, most regions use the largest, because it remains to melt what is left after plowing. A maximum percent of moisture allowed in each gradation is specified.

Surprisingly, the team did not witness any other chemical use, and no regular use of other chemicals beside salt (NaCl) and $CaCl_2$ was reported by the agencies in the four countries visited. The application rates of chemical are as little as 3 to 5 g/m^2 , and anti-icing is the standard operation. Agencies visited mix their own brine solutions, and their standard practice includes extensive pre-wetting with salt brine. There is use of pre-wet sand on lower volume roads.

Methods. Employees of the AREA Toll Highway Company (private) in France are required to live within 5

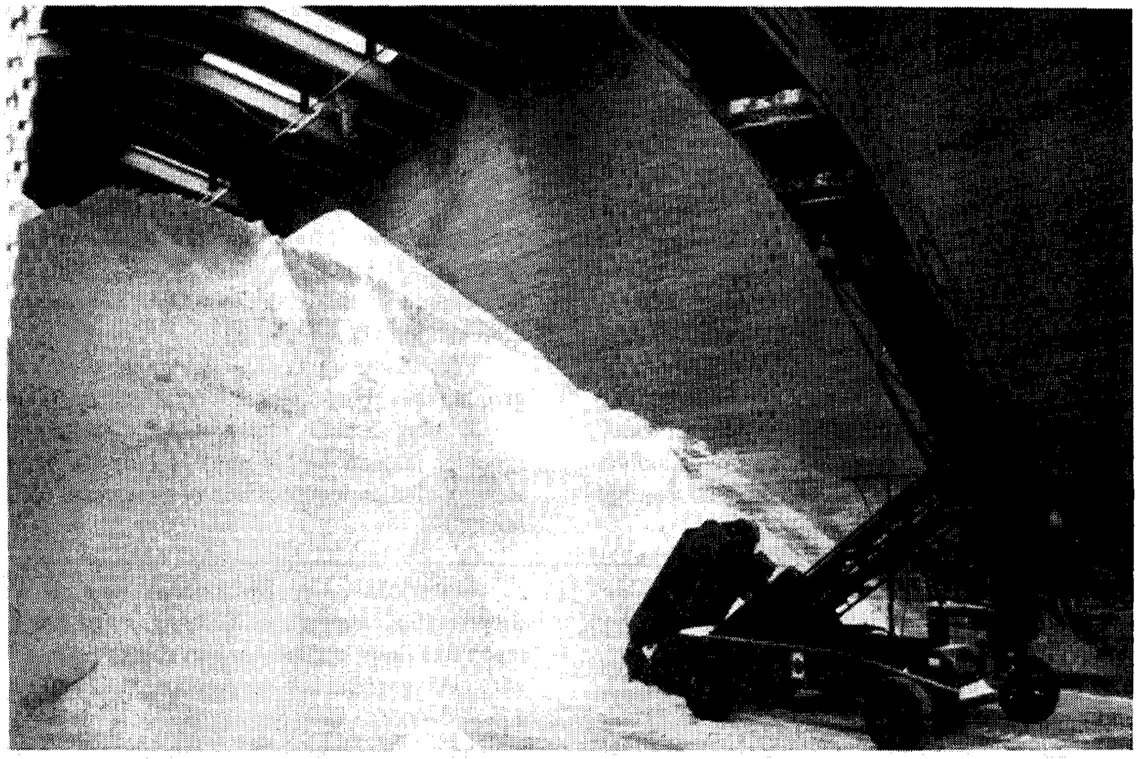

Figure 11. Conveyor Salt Loader in Switzerland.

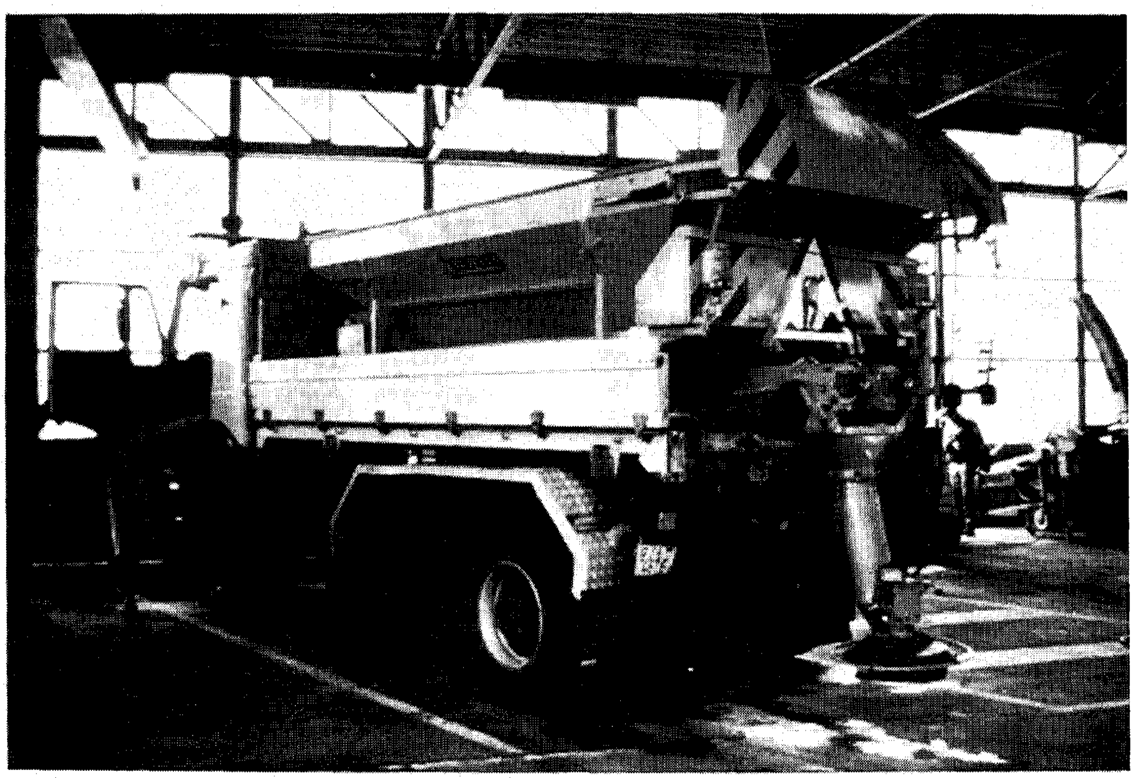

Figure 12. Air foil on rear of salt spreader, Switzerland.

Figure 13. SNRA experimental Winter Road Condition Monitoring Vehicle.

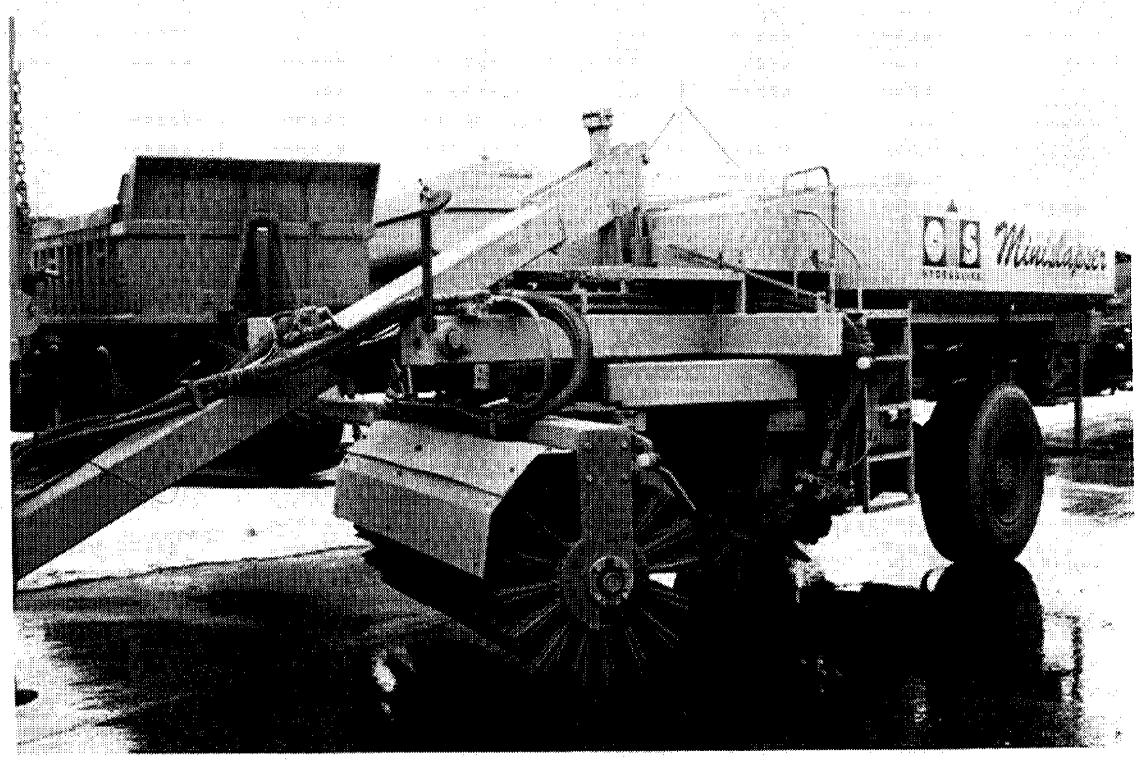

Figure 14. Steel Broom and Liquid Spreader-Trailer (Norway).

km of the maintenance center. Ten of the 28 employees in the AREA district headquarters next to the CESAR TMC in Nance must live closer and are provided housing as part of their fringe benefits. However, the employees must be on standby for duty 1 week out of 4, must remain in housing provided by the company on site, and must remain at home or at work around the clock during their week of duty. In the Stockholm area, some emergency personnel are housed in construction shanties so that they are readily available when on standby.

During heavy snows in the French Alps, police stop trucks and form them into caravans behind plows, in order that the trucks do not impede plow progress.

In Norway, in 1998, a 5-year winter friction testing program was begun in order to explore ways to improve friction and reduce studded tire use. Different mechanical, chemical, and abrasive means (including heated sand) for improving friction without using more salt will be evaluated. Testing will include both test track and field experiments. A new truck-mounted friction tester is being used. The goal is to develop a friction standard with variations reflecting weather and location (e.g., urbanized or mountainous).

Also in Norway, the NPRA has begun to use various means to reduce collisions between automobiles and elk. It increased fence height to 2 m along freeways and built elk crossing culverts beneath the freeways at problem sites. In one location in Akershus County, motion detectors have been installed along the freeway, connected to an illuminated elk crossing sign, to reduce collisions. The initial report is that the devices have helped reduce collisions.

Employee Training. Meteorological training of all employees involved in winter service is required every 3 years in Switzerland. Re-training occurs before each winter.

The most unusual facility for employee training was in Les Salles, near Clermont-Ferrand in France. It was built and is operated by the ASF. All toll highways are owned by the government; all but one of the eight are operated privately. The area chosen for the facility is at an altitude of 700 m, to permit training under winter conditions. The center is the only one in all Europe built especially for training winter service personnel at all levels, from drivers to management. Although operated by the private toll highway company, personnel of other companies, DDEs, cities, tunnels, and bridges may also attend. The philosophy of training is that personnel must not only understand the equipment they are using, but must understand meteorology and how equipment, personnel, and management are organized to deliver winter service. The improvements in training were developed because of expansion of the freeways into mountainous country and the large amount of winter tourism that depends on accessible winter highways. To control cost, a better understanding of winter service strategies by all personnel is needed, and this is provided by the center.

The center's trainers are meteorologists, supervisors, and network operators who have practical experience in the winter service area for which they provide training. Manuals are prepared by user groups. New employees are trained for 3 days and retrained at 3- to 5-year intervals. Training is geared to specialties and conducted between October and March, except for the winter holidays. Subjects taught include the following (*20*):

- Levels of winter service on freeways,
- The specifications of the toll highway companies,
- Winter service events,
- Means of providing winter service treatments,
- Traffic effects on the road during winter events,
- Equipment used in winter service, and
- The organization of winter service.

Training emphasizes both the purpose and the methods of winter service operations. Trainers receive instruction in teaching techniques and technological advances.

A laboratory attached to the training room has equipment demonstrating RWIS sensor action, chemical action under traffic, the effect of pavement porosity on anti-icing and deicing functions, and a fog/humidity chamber to simulate frost. The training equipment is shown in figures 15 through 18. There are common modules for training different levels of personnel, (i.e., chemicals, weather, and regulations) (*20*). The computers provide the information from Meteo France weather, including real-time satellite images and evaluation of RWIS data to determine storm-fighting procedures.

In 1998, attendees were charged 3,000 French francs ($532) to recover costs. The center was constructed at a cost of more than $700,000 in 1996. Training takes roughly 10 to 20 percent of the director's time. Eight trainees can work on computers at one time, while 15 is the maximum at other sessions. The center trains about 300 persons annually.

Training emphasizes the development of tools for individual decision making and an understanding of everything from equipment to chemicals and weather. Work is underway to assess the training procedures and design a new course on communications with media, police, and the public. Work is also underway to prepare an interactive CD-ROM training program.

Recommendations for U.S. Highway Agencies: (1) Involve winter service personnel with industry to optimize winter service equipment by using state-of-the-art technology advances to improve efficiencies. (2) Develop cost analyses based on winter level of service outcomes (service levels provided), not just on the direct costs of in-house or contract work (this may require the assistance of AASHTO). (3) Develop and implement winter service training for all personnel at all levels of government. In-depth training programs similar to those in France should be

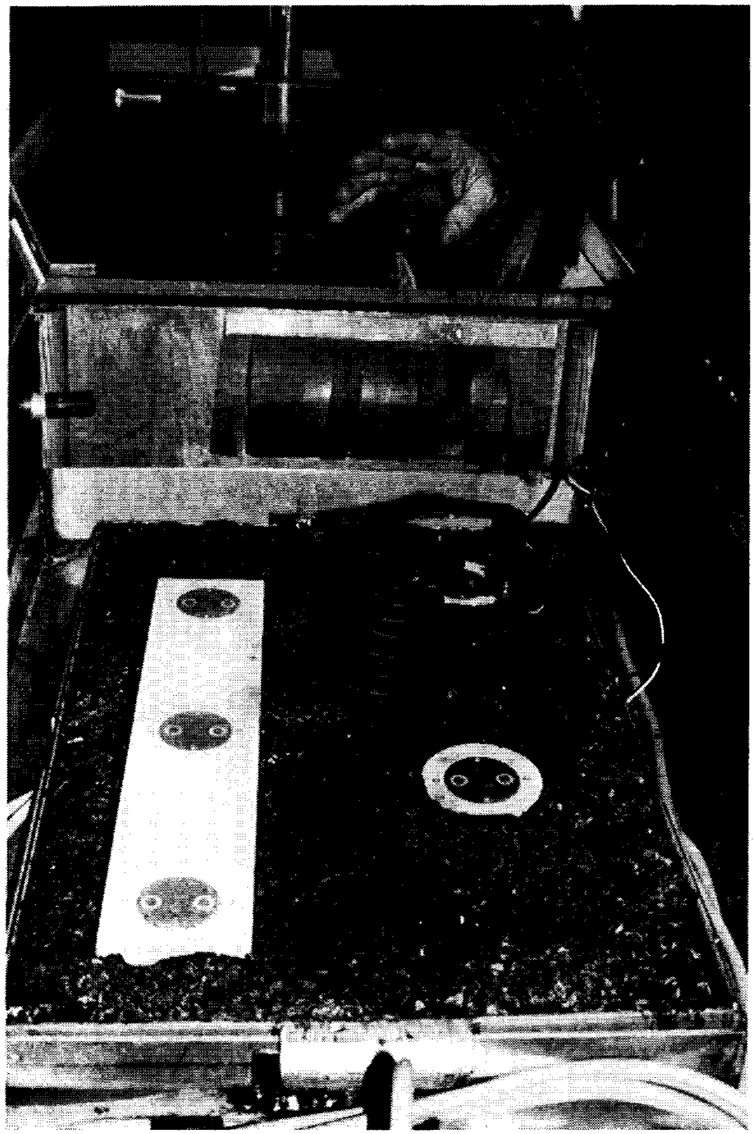

Figure 15. RWIS Sensor Demonstration, Les Salles, France.

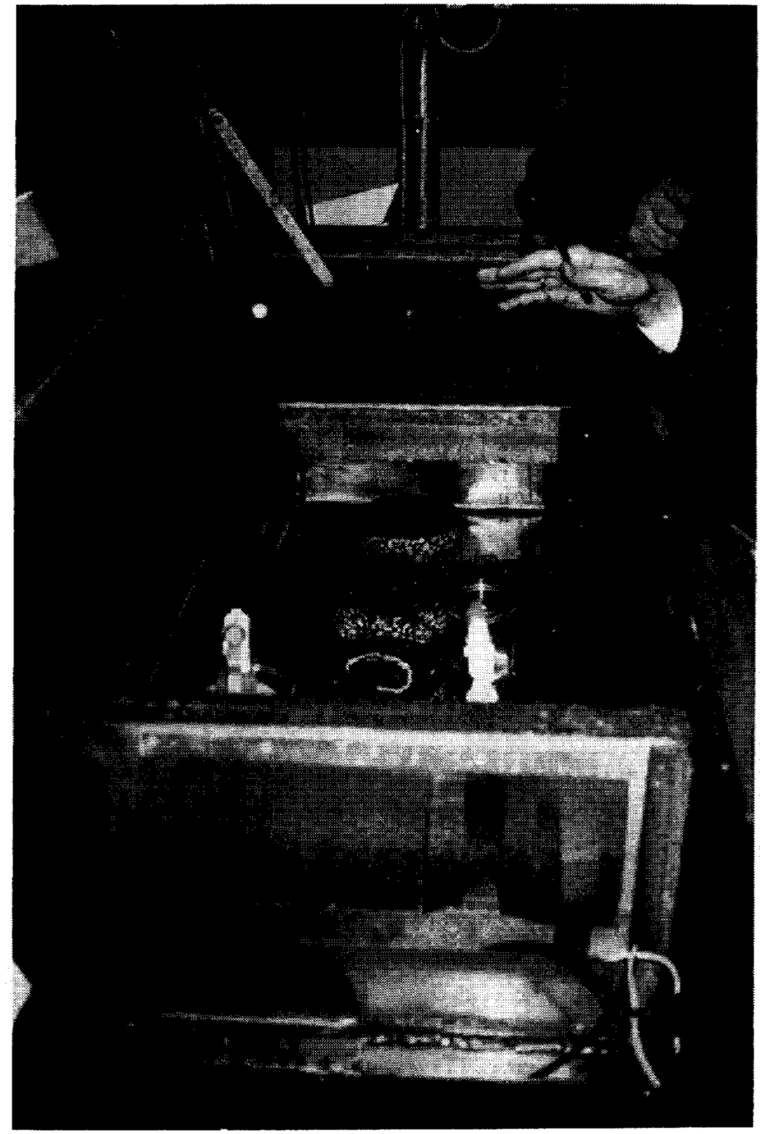

Figure 16. Ice Control Chemical Demonstration, Les Salles, France.

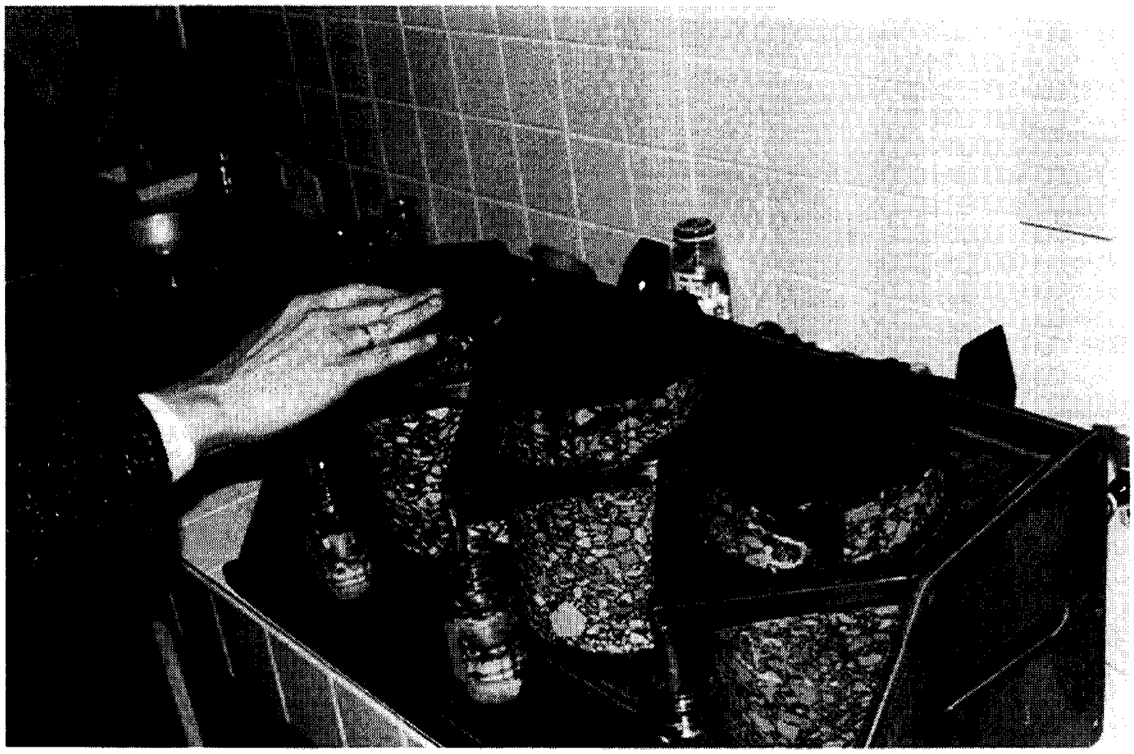

Figure 17. Pavement Porosity Demonstration, Les Salles, France.

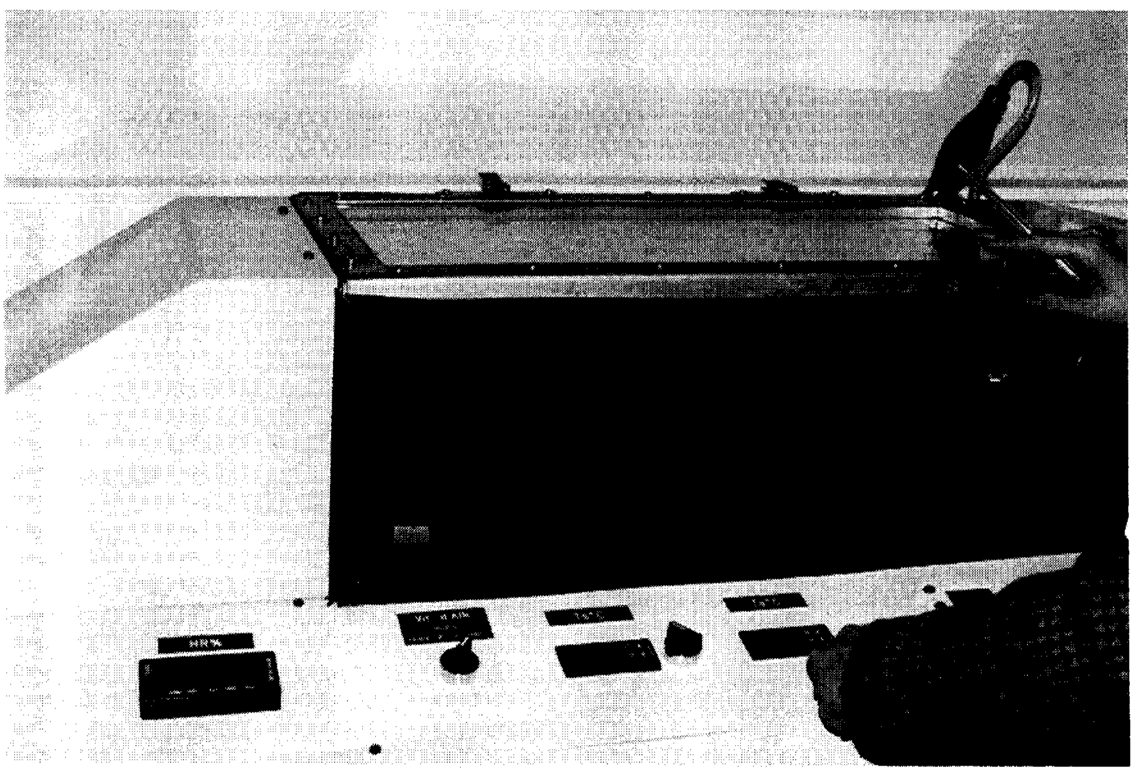

Figure 18. Pavement Frost Simulator, Les Salles, France.

developed, for regional application, that provide more instruction in meteorology and climatology as they relate to RWIS data.

ACKNOWLEDGMENTS

The team members thank their colleagues in Switzerland, France, Norway, and Sweden for sharing their time and experiences. The team members also thank the Transportation Technology Evaluation Division of American Trade Initiatives, Inc., of Alexandria, Virginia, for providing travel arrangements and other coordination. The team members thank, in particular, Mr. Joseph N. Conn and Mr. John O'Neill for their able assistance throughout Europe. Donald Steinke (FHWA) and Pat Hughes (Minnesota DOT), team co-chairs, provided a structure for the 1-day meeting that led to the team's recommendations. Photography was provided by the reporter, team members, host countries, and agencies.

REFERENCES

1. "Winter Maintenance Technology and Practices—Learning from Abroad," *NCHRP Research Results Digest 204,* Transportation Research Board, National Research Council, Washington, D.C. (January 1995).
2. Roussel, J, "General Political Context of Winter Service in France," *Technical Report*, Vol. 1, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 59–67.
3. Cabanes, A, "Winter Serviceability," *Technical Report*, Volume 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 967–976.
4. Krokeborg, J, "Studded Tyres and Public Health—The Road Grip Project," *Technical Report*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 611–620.
5. Gustafson, K, "Pavement Wear from Studded Tyres—The Swedish Solution," Summary Paper from the Fifth International Symposium on Cold Region Development, Anchorage, Alaska, Swedish National Road and Traffic Research Institute, Linköping, Sweden (May 1997).
6. Gustafson, K, "Tests with Light Weight Tyre Studs in the VTI's Pavement Testing Machine," Summary of report in Swedish, Swedish Road and Traffic Research Institute, (VTI), Linköping, Sweden.
7. Jacobson, T, "The Wear Resistance of Bituminous Mixes to Studded Tyres—the Swedish Experience," Summary Paper from the Fifth International Symposium on Cold Region Development, Anchorage, Alaska, Swedish National Road and Traffic Research Institute, Linköping, Sweden (May 1997).
8. Oberg, G, "Winter Tyres—Socio-Economic Calculations," Summary Paper from the Fifth International Symposium on Cold Region Development, Anchorage, Alaska, Swedish National Road and Traffic Research Institute, Linköping, Sweden (May 1997).
9. Frimodig, L., "Road Weather Information System," *Proceedings*, SIRWEC 9th International Road Weather Conference, Lulea, Sweden (March 1998) pp. 87–91.
10. Bornand, E., "Physical Bases of Freezing Point Measurement Using Active and Passive Probes," *Proceedings*, SIRWEC 9th International Road Weather Conference, Lulea, Sweden (March 1998) pp. 273–286.
11. Pisano, P. and G. Nelson, "Integrated Weather Information Systems: White Paper Findings," *Proceedings*, Vol. 1, SIRWEC 9th International Road Weather Conference, Lulea, Sweden (March 1998) pp. 92–106.
12. Knudsen, F., "The Danish Winter Management System," *Proceedings*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 805–816.
13. Zambelli, M et al, "Motorway A9, Lausanne Ring Road Is Equipped with a Revolutionary Salt Solution Spreading System Combined with a Porous Asphalt Surfacing," *Revue Generale des Routes,* English supplement, Paris, France (January 1998) pp. 40–45.
14. Wirtz, H., and K. Moritz, "Effectiveness and Economy of a De-icing Chemical Spreading Device," German Federal Highway Administration (BASt), Bruderstrasse 53, D-5060 Bergisch Fladlbach 1, Germany (April 1993) (German, with limited English translation by Marquette University, Center for Highway and Traffic Engineering, Milwaukee, Wisconsin, 1998).
15. Moritz, K., "Effectivity and Economy of De-icing Agent Spraying Systems," *Proceedings*, Vol. 2, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 297–306.
16. Leirin, K., "Road User Information Service in Norway," *Proceedings*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 947–956.
17. Western Association of State Highway and Transportation Officials (WASHTO) Subcommittee on Maintenance, Minutes of Spring Meeting, Galveston, Texas (1998).
18. Naaim, M. and Cligniez, V., "Avalanche Study and Modeling: Application to Road Protection," *Proceedings*, Vol. 2, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 345–352.
19. Andersen, O., "Equipment for Removal of Snow and Slush," *Proceedings*, Vol. 2, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 317–324.
20. Pigeon, M., "Training Staff for Winter Service: The Salles Training Centre," *Proceedings*, Vol. 2, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 243–256.

Note: See the end of this digest for information on obtaining copies of the proceedings for SIRWEC and PIARC.

APPENDIX A

Team Member Biographic Sketches

The team consisted of representatives of the U.S. federal, state, and local governments as well as academia. Information about team members, at the time of the review, follows.

Patrick C. Hughes, Co-Chairman of the team, is Assistant Commissioner for Operations for the Minnesota Department of Transportation (MnDOT). He provides overall management and direction to the Operations Division, which is responsible for planning, design, construction, and maintenance of all trunk highways in Minnesota outside of the Twin Cities Metropolitan Area.
He is responsible for integrating all other transportation modes into the district's operations. Mr. Hughes chairs MnDOT's Quality Council and is a member of the Transportation Investment Program. He is also on the Board of Directors for the MnRoad Research Facility and chairs the MnRoad Technical Committee. He is active in AASHTO and is a member of AASHTO's Committee on Quality. He chairs the AASHTO Winter Maintenance Policy Coordinating Committee. Mr. Hughes' degree in Civil Engineering is from the University of Minnesota.

Donald P. Steinke, Co-Chairman of the team, is Chief, Highway Operations Division, Office of Engineering for the FHWA in Washington, D.C. He is responsible for the nationwide administration and direction of the highway operations phases of the FHWA's programs covering construction, maintenance, contract administration, materials, and quality activities. Mr. Steinke has nearly 30 years of program administration and technical experience with the FHWA. He has held assignments in the states of Colorado, North Dakota, Illinois, Louisiana, Utah, and Texas in positions ranging from being a project engineer on construction, to directing the federal-aid highway program within a state, to his current national position. Mr. Steinke has a B.S. degree in Civil Engineering from the University of Nebraska-Lincoln. He is a licensed Professional Engineer in the state of North Dakota. He is a member of the AASHTO Winter Maintenance Policy Coordinating Committee and is Secretary of AASHTO's Subcommittee on Construction. He is also the Chairperson of the FHWA Asphalt Technical Working Group and the Chairperson of the FHWA Highway Operations Research and Technology Coordinating Group.

Andrew V. Bailey, II, as the State Maintenance Engineer for the Virginia Department of Transportation, is responsible for operations and maintenance of the third largest state-maintained highway system in the United States. Mr. Bailey has more than 12 years of experience managing winter maintenance operations, ranging from oversight of a two-county residency to his statewide responsibilities. He is sponsoring research in the technology applications of Global Positioning Systems (GPS) and Computer-Assisted Dispatch (CAD) in the management of snow removal operations, Road Weather Information Systems (RWIS) for assisting in decision making, and the use of anti-icing and alternative chemical approaches for snow and ice control practices. He has a B.A. degree from Virginia Polytechnic Institute and has completed various programs in leadership and management.

D. John Blacker, the Administrator of the Maintenance Division for the Montana Department of Transportation (MDT), is responsible for developing and issuing statewide budgets, policies, and procedures for all maintenance, equipment, facility, and motor pool programs. He also has a responsible role in MDT's Management Team, which sets direction and policy for the department. Mr. Blacker has 27 years of progressive experience with MDT in the highway maintenance field. He also serves on numerous state and national committees and was recently appointed the Task Force leader for the AASHTO Maintenance Committee for Safety, Snow and Ice. Mr. Blacker attended Western Montana College and Carroll college.

Ivan Corp is a Senior Research and Development Engineer for the Missouri Department of Transportation (MoDOT) in Kansas City, Missouri. Mr. Corp has 35 years of service with MoDOT. He has worked in maintenance operations for the last 23 years, 16 of which as a District Maintenance Engineer. He wrote a best practices operator's manual for anti-icing and a video for making salt brine. Mr. Corp was recently appointed a Friend of the Committee for Winter Maintenance for TRB. He is active in implementing best practices with regard to all maintenance activities, but particularly winter maintenance. He has a B.S. degree in Civil Engineering from Finlay Engineering College.

Joyce Curtis is the Director of Engineering and Operations for the Regional Office of the FHWA in Baltimore, Maryland. She administers programs, policies, and procedures and provides technical assistance, technology transfer, and training to state and local governments to preserve and improve the safety and efficiency of the federal-aid transportation system. Ms. Curtis has more than 15 years of planning and engineering experience and was involved in developing the *Washington Metropolitan Winter Storm Travel Guide*. She was also the main author of the after-action report on the Blizzard of 1996 and developed numerous innovative ideas to improve the Washington metropolitan area's response to snow removal. Ms. Curtis holds a B.S. degree in Civil Engineering from Villanova University in Pennsylvania. She has been Secretary of a TRB subcommittee and is a member of numerous technical committees and task forces, including the Lead States Team for SHRP Technology Implementation on Anti-Icing and Roadway Weather Information Service.

J. Michael Dooley is Director of Highways and Traffic for St. Louis County, Missouri. In this capacity, he directs and administers the annual construction, maintenance, repair and reconstruction, and traffic control of 3,100 lane miles of highways, streets, and roads. Mr. Dooley also oversees construction of major capital improvement projects on St. Louis County road systems. His experience includes 18 years as Director of Public Works and/or Highways and Traffic, 8 years in highway construction/maintenance management, and 2 years as a professional consultant. He is a member of the American Public Works Association (serving as state president), the American Society of Civil Engineers, and the Iowa Highway Research Board and is Chair of MPO Transportation Planning. He has a B.S. in Civil Engineering and a Master's degree in Public Administration.

Ed Fahrenkopf, the Director of Transportation Maintenance for the New York State Department of Transportation, is responsible for budgeting, policy, and quality assurance for all maintenance activities of highways and bridges in the state. He has more than 30 years experience in the department. Mr. Fahrenkopf has served on numerous committees for TRB. He attended New York State University at Morrisville.

David A. Gravenkamp, the Director of Public Works for Siskiyou County in northern California, is responsible for road and bridge maintenance and construction, solid waste administration, building inspection, building maintenance, public transit, airport administration, and flood control. Mr. Gravenkamp has more than 30 years of experience in winter road maintenance. He served on the Steering Committee for the 6th International Conference on Low-Volume Roads held in Minnesota in 1995. He was president of the County Engineers Association of California in 1992 and was the regional vice-president of the National Association of County Engineers in 1994. He has a B.S. degree in Civil Engineering from Iowa State University and a Master's degree in Public Administration from California State University at Chico. He has been a licensed Professional Engineer in California for 34 years.

William Hakala is the Construction, Maintenance & Special Programs Engineer for the FHWA in their Denver Region office. In this capacity, he provides technical and program assistance to the FHWA's Region 8 division offices and state transportation agencies. He received a B.S. degree in Civil Engineering from Colorado State University and is a registered Professional Engineer in the states of Colorado and Texas. He has 16 years of service in the highway arena and has worked as a construction engineer and project manager with the mining industry and as a field engineer with a rural electric cooperative. In addition to his knowledge of highway construction and maintenance activities, he is familiar with federal-aid highway contract administration and specifications.

David A. Kuemmel is conducting research at the Center for Highway and Traffic Engineering at Marquette University in Milwaukee, Wisconsin. He joined the faculty at Marquette University in 1989 after 35 years of transportation engineering experience with the City of Milwaukee in the field of transportation and public works management. He founded the Center in 1992 and served as its first Director until October 1995. From 1992 to 1995, he drafted *NCHRP Synthesis of Highway Practice 207*, "Managing Roadway Snow and Ice Control Operations" for TRB; this was published in 1994. Mr. Kuemmel's research interests include an extensive 6-year project on the accident characteristics of deicing, and he has completed a pilot project to develop a chemical-demand index for the MnDOT. He is studying the noise impacts of pavement surface texture and the public's perceptions of the Midwest's pavements. He is an active member of TRB's Committee on Winter Maintenance and of the FHWA's Technical Work Group on Highway Operations. He served on the Strategic Highway Research Program's Highway Operations Advisory Committee, dealing with winter maintenance issues, from 1988-1993. He has a B.S.C.E from Marquette University and an M.S.C.E. from the University of Wisconsin and is a Fellow of ASCE and ITE and a member of APWA. He is a registered Professional Engineer in Wisconsin.

Salim Nassif is the Winter Maintenance Program Manager for the FHWA in Washington, D.C. He is responsible for the dissemination and implementation of the winter maintenance technologies and strategies developed under the Strategic Highway Research Program. He is also responsible for FHWA's Snow & Ice Control Test and Evaluation Program with the objective to develop and assess the effectiveness of new and innovative winter maintenance technologies, methods, and materials. Mr. Nassif is a licensed Professional Engineer with 21 years of transportation experience within the private sector, the U.S. Army, and the FHWA. He holds a Bachelor's and a Master's degree in Civil Engineering from the University of Texas and a Master's degree in Engineering Management from Northwestern University.

APPENDIX B

Itinerary

Team members met with national, regional, county, and local government officials as well as officials from the private toll highway authorities and several winter service business officials from Switzerland, France, Norway, and Sweden. In addition they attended the PIARC Xth International Winter Road Congress in Lulea, Sweden. The itinerary was as follows:

Switzerland

March 8, 1998	Team Meeting, Fribourg
March 9, 1998	Fribourg Canton Officials
	Canton Operational Center

	Officials, Department des ponts et chaussees
	Swiss National Government
March 10, 1998	Canton de Vaud Officials
	Site visit to Lausanne, Highway A9
	Canton Maintenance operations center
	Geneva Canton and Geneva City Officials
France	
March 11, 1998	DDE, Savoie
	Savoie - OSIRIS TMC
	Moutiers Maintenance Center
March 12, 1998	Societe des Autoroutes Rhone-Alps (AREA)
	CESAR TMC and Maintenance District, Nance,
	CRICR Regional TMC, Lyon
March 13, 1998	Autoroutes du Sud de la France (ASF)
	Les Salles Training Center
	ASF maintenance center
March 14, 1998	Paris
Norway	
March 15, 1998	Team Meeting, Oslo
March 16, 1998	Norwegian Public Roads Administration (NPRA) officials
	Oslo TMC, NPRA
	City of Oslo, Contract Officer
	NPRA Romerike Production Operations Center
	Akershus County, (NPRA)
Sweden	
March 17–19, 1998	PIARC Xth International Road Congress, Lulea
March 20, 1998	Swedish National Road Administration (SNRA) officials
	Stockholm TMC
	Stockholm area maintenance operations center
March 21, 1998	Team post review meeting, Stockholm

APPENDIX C

Bibliography of PIARC and SIRWEC Papers Not Referenced in Text (Related to and Arranged in Order of the Topics of Chapter 3)

Studded Tires

Takaga, H. and A. Tsutae, "Winter Skidding Accidents on Road Surfaces Covered with Snow and Ice Under Studded-Tire Regulation," *Technical Report*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 621–633.

RWIS

Burtwell, L., "Assessment of Road Surface Freezing Point Sensors for the UK," *Technical Report*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 767–778.

Sahlin, L., "RWIS Development in Sweden," *Proceedings*, SIRWEC 9th International Road Weather Conference, Lulea, Sweden (March 1998) pp. 260–266.

Thornes, J., "The Verification of Road Weather Forecasts and Performance Related Road Weather Contracts," *Proceedings*, SIRWEC 9th International Road Weather Conference, Lulea, Sweden (March 1998) pp. 62–69.

Thermal Mapping

Gustavson, T., "A Critical Review of Thermal Mapping Techniques," *Proceedings*, SIRWEC 9th International Road Weather Conference, Lulea, Sweden (March 1998) pp. 25–31.

Levels of Service

Jaquet, J. and K. Prahl, "Road Standards for Winter Services," *Proceedings*, Vol. 1, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 23–24.

Queyrel, G., " To Salt? Not to Salt? That is the Question," *Proceedings*, Vol. 2, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 419–427.

Contracting for Winter Service

Brochner, J., and A. Johansson, "Winter Road Maintenance—A Swedish Typical Case," *Proceedings*, Vol. 1, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 209–218.

Danielson, U., "A Way to Optimize Winter Maintenance," *Proceedings*, Vol. 1, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 53–58).

Norlander, J. et al, "Greater Efficiency by Making Road Maintenance Competitive in Sweden," *Proceedings*, Vol. 1, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 181–186.

Technology Developments

Dahl, T., "Winter Management System," (automated telephone progress reporting by NPRA) *Proceedings*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) p. 887.

Schlup, U. and J. Schatzmann, "Solar Energy for Ice Control," *Proceedings*, Vol. 2, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 365–374.

Integration of RWIS and TMCs

Leviakangas, P., "Improving Winter Road Management under the Euro-regional Project "Viking," *Proceedings*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 755–762.

Avalanche Prediction

Randeu, W. and H. Schreiber, "Winter Road Management Support by Pulsed Doppler Avalanche Radar," *Proceedings*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 817–826.

Equipment

Durth, W. et al, "Intensified Snow Removal," *Proceedings*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 635–646.

Masuda, Y. et al, "Development of a Mobile Winter Road Surface Information Collection System," *Proceedings*, SIRWEC 9th International Road Weather Conference, Lulea, Sweden (March 1998) pp. 10–23.

Pani, B. et al, "A Radiometric System for Road Surface Condition Monitoring," *Proceedings*, Vol. 3, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 779–785.

Materials

Ihs, A., "Test and Evaluation of Alternative Deicing Methods and Materials in Sweden," *Proceedings*, Vol. 2, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 287–296.

Methods

Fraser, G. and J. Drew, "Route Selection and Salt Management in Northern Ireland," *Proceedings*, Vol. 1, PIARC Xth International Winter Road Congress, Lulea, Sweden (March 1998) pp. 41–52.

Note: Both 1998 proceedings of SIRWEC and PIARC are available from

Swedish Road and Transport Research Institute
SE 581 9
95 Linköping, Sweden
e-mail: vti@vti.se

These **Digests** are issued in order to increase awareness of research results emanating from projects in the CRP. Persons wanting to pursue the project subject matter in greater depth should contact the Cooperative Research Programs Staff, Transportation Research Board, 2101 Constitution Ave., NW, Washington, DC 20418.

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, DC 20418