UPDATE OF THE AASHTO
GUIDE FOR SNOW AND ICE CONTROL

Requested by:
American Association of State Highway
And Transportation Officials (AASHTO)
Standing Committee on Highways

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Finally, the team acknowledges the National Cooperative Highway Research Program’s selection of the team which has put together these new chapters. The team looks forward to the potential of revising the remaining sections of the original Guide for Snow and Ice Control which are also dated.
ABSTRACT

In 1997 the National Cooperative Highway Research Program (NCHRP) initiated a project, NCHRP 2-7 (83) to develop an American Association of State Highway Transportation Officials (AASHTO) Guide for Snow and Ice Control. AASHTO published The Guide for Snow and Ice Control in 1998. After 10 years, this Guide became outdated in many areas, especially equipment, materials and weather information. This report provides updated chapters covering these three elements of snow and ice control.

The first chapter, which is chapter four of the Guide, Equipment, describes the latest in equipment technologies. The second chapter, chapter five of the Guide, Materials, describes the availability of various chemicals and mixtures and background research into their use for the prevention of ice bonding to pavement (anti-icing) and ice melting and removal. Finally, the third chapter, chapter six of the Guide, Weather Information, describes the latest weather forecast and observation capabilities, and the advances in Road Weather Information System and Environmental Sensor Station development to assist in the provision of tailored support to highway maintenance snow and ice control personnel.
EXECUTIVE SUMMARY

In 1997 the National Cooperative Highway Research Program (NCHRP) initiated a project, NCHRP 2-7 (83) to develop an American Association of State Highway Transportation Officials (AASHTO) Guide for Snow and Ice Control. AASHTO published The Guide for Snow and Ice Control in 1998. The Guide sold well, especially with catalogs like the AASHTO Publications Catalog and the American Public Works Association (APWA) Catalog and APWA displays and stores at conferences.

In the time since the Guide was originally published, highway winter maintenance has changed significantly. New technologies emerged in equipment used to plow roadways and apply snow and ice control materials. The science of snow bonding prevention and melting brought forth new chemicals and mixtures of chemicals for snow and ice control. At the same time, especially with the expansion of the use of the Internet, weather information availability and new technologies offered highway maintenance personnel the opportunity to make more efficient and effective decisions for snow and ice control operations.

Snow and ice control research generated a great deal of literature in the time since the first Guide was published. The project team started this effort with a detailed review the available related literature. This included documentation of new equipment, the use of snow and ice control materials and the types in use, and the availability and use of weather information.

In addition to the literature review, the team prepared a survey to gather the latest information related to winter maintenance practices and procedures, to include equipment and materials used and the availability and use of weather information. The team posted the survey on the Internet and received input via Email and faxed responses.

In addition to the survey, the project team attended the American Public Works Association North American Snow Conference and the Pacific Northwest Snowfighters (PNS) conference. Face to face discussions took place with snow and ice control practitioners. The team also gathered a great deal of applicable literature from vendors at these conferences. At the PNS conference, copies of the survey that had been posted on the Internet were provided to individuals who indicated they would complete the survey.

This report provides updated information on the three elements of snow and ice control described above. The first chapter, which is chapter four of the Guide, Equipment, describes the latest in equipment technologies.

The second chapter, chapter five of the Guide, Materials, describes the availability of various chemicals and mixtures and background research into their use for the prevention of ice bonding to pavement (anti-icing) and ice melting and removal.

Finally, the third chapter, chapter six of the Guide, Weather Information, describes the latest weather forecast and observation capabilities, and the advances in Road Weather Information System and Environmental Sensor Station development to assist in the provision of tailored support to highway maintenance snow and ice control personnel.
In keeping with the original guide format, all references to materials used in the development of the material can be found at the end of each chapter.
CHAPTER FOUR

EQUIPMENT

This chapter addresses mobile and special support equipment for snow and ice control, its acquisition and its maintenance. Equipment and special considerations for materials storage and handling are discussed in Chapter Five.

MOBILE SNOW AND ICE CONTROL EQUIPMENT

Agencies use a variety of mobile snow and ice control equipment on a routine basis. The most common types are trucks, plows (front mount or nose plow, wing, under-body, extension plows, and tow plows), material spreaders, liquid chemical applicators, wheel loaders, motor graders, snow blowers or rotary plows, sweepers (pick-up and broom), small utility vehicles, and melters (for melting hauled snow and ice). Each agency determines which types of equipment are appropriate for its needs.

Selecting Snow and Ice Control Equipment

To select appropriate equipment, primary consideration should be given to the types and varieties of tasks the equipment will be performing and the environment in which it will be operating. In some heavy snowfall locations, snow and ice control operations are the primary function of the equipment. In these cases, the equipment should be designed to perform this difficult function over much of its service life. In lighter snowfall areas, snow and ice control operations may only be incidental to other functions performed by the equipment, such as hauling equipment and personnel for non-snow-and-ice-control highway maintenance activities. In this case, the non-snow-and-ice-control activities will drive the design
features of the equipment. The key to successful equipment utilization is to balance the design so that even the least-common tasks can be accomplished adequately. By choosing multipurpose equipment appropriately, an agency can usually optimize its equipment budget.

Attachments provide an excellent way to make equipment more versatile. Front plows, "V" plows, wing plows, under-body plows, and snow blowers can be attached to trucks and motor graders. Snow blowers and plows can be attached to wheel loaders; materials spreaders can be attached to truck beds; and anti-icing tanks can be added to spreaders; and a variety of other equipment. Trailers can be outfitted with anti-icing tanks, spreaders, brine makers, and plows. Figure 3 shows one configuration of front and wing plows. Wing plows can also be mounted further back on the vehicle chassis or at the front of the vehicle. The working position of wing plows varies with the type of plow. Wing plows can be set to a fixed position, move hydraulically to vary the horizontal position, and move hydraulically in a vertical position for benching operations. Effective use of attachments can be achieved from uniformity of the attachment system (from vehicle to vehicle) and the ease of connecting and disconnecting attachments. The European DIN (German Institute for Standardization) mount system provides a universal mount that accommodates a wide variety of attachments for any truck or loader. No such universal mount system is currently widely accepted in the United States, in spite of the obvious benefits that such universality provides.
The load capacity of tires and axles must always be considered when outfitting a truck or trailer with attachments. The weight of materials hauled must also be considered when determining the capacity of spreaders and liquid tanks. Safety must be the primary concern.

Always consider the production rate of equipment, that is, how quickly a given piece of equipment can perform a specific operation. This is an important consideration in the equipment purchasing process as it relates to the overall efficiency of snow and ice control operations. This topic was discussed in Chapter Three, Personnel.

Snow and ice control equipment from European manufacturers is becoming more common in North America. Generally, European equipment is well engineered and designed to perform specific functions. Examples are material spreaders designed to deliver precise mixtures of solid and liquid chemicals, front plows that extend hydraulically to increase plowing width, front plows with hydraulic down pressure or weight control systems that lift a portion of the plow weight off the cutting edge, and cutting edges that run smoother, quieter, and are extremely durable. Consider the global market when the agency is looking for equipment solutions to problem areas.

**Specifying Snow and Ice Equipment**

Agencies commonly use two types of specifications to acquire snow and ice equipment - functional and technical. Functional specifications are primarily performance-based. They identify
performance requirements such as load-carrying capacity, maximum speed up certain inclines while loaded, stopping distance under various load conditions, and equivalent performance relative to a particular manufacturer and model. This type of specification places responsibility on the manufacturer/supplier. Agencies should exercise care when developing functional specifications to exclude prototype versions of equipment unless a prototype is desired.

Technical specifications stipulate particular components of the equipment; e.g., the hydraulic line shall be 3/8 inch inside diameter, constructed of stainless steel, and have a 1000 psi pressure rating. In this case, the purchaser assumes most of the liability and responsibility. Many agencies mix and match between the two specification types in order to assure they will be getting exactly what they want.

**Equipment Productivity**

When developing specifications, agencies need to consider equipment productivity. Equipment productivity depends on the system characteristics and the characteristics of the equipment itself. The productivity needs to be put in perspective with the tasks to be accomplished. For example, many agencies appear to be moving to larger vehicles to increase productivity, especially on high priority roads. Other items that need to be considered include:

- Fuel efficiency;
- Lower weight/horsepower ratio vehicles are less grade sensitive;

*Figure 5. Iowa DOT trailer-mounted anti-icing tank.*
Larger capacity spreading equipment will require less reloading and provide for longer cycle times;

Wider plow paths (the addition of wing plows, hydraulic extension plows, tow plows, or using long front plows) will often completely clear a lane in one pass;

Smaller, more maneuverable equipment may be more productive in some situations, especially in an urban environment; and

Underbody plows can assist in gravel/dirt rural road reconstruction following winter maintenance activities, which can damage the roadway.

Because of unusual demands placed on snow and ice equipment, particular attention should be given to the items listed in Tables 2 through 10 when specifying these types of equipment:

Table 2. Items to consider when developing specifications for trucks.

- Hydraulic system
- Gear ratios in transmission
- Electrical system
- Gear ratio in rear differential
- Suspension system
- Engine horsepower
- Single or double axle
- Mirrors (heated) and lighting package for snow plowing
- Tires and rims
- Frame (particularly if using wing plows)
- Cold and wet weather operation
- Automatic or manual transmission
- 2 or 4-wheel drive
- Gross weight
- Axle weight rating
- Diagnostic and information systems
- Corrosion protection
Quality heaters and defoggers
Comfortable, adjustable driver’s seat.
Ergonomic cab features and controllers

Power windows
Heated wiper blades
Wiper blade vibrators
Heated windshields

Table 3. Items to consider when developing specifications for wheel loaders.

- Reach
- Capacity
- Cold and wet weather operation
- 2 or 4-wheel drive
- Transmission type
- Attachment capability
- Articulation or straight frame
- Electrical system
- Weight and horsepower
- Power takeoff

Table 4. Items to consider when developing specifications for material spreaders.

- Type - liquid, granular or combination
- Capacity
- Application rate and speed ranges
- Uniformity of application rate & speed ranges
- Transverse spread pattern capability
- Zero velocity
- Front, side, or tailgate applications
- Belt, chain, or auger system
- Offloading capability and ease of cleaning
- Spread data and download capabilities
- Ground speed control
- Spread containment system
- Pre-wetting capability and method
- Tie-down/connect/disconnect requirements
- Lights & airfoils (if applicable)
- Hopper insert or bed
- Side, tailgate or insert prewet tanks
- Stainless steel construction
- Liquid/solid mix ratio capability
- Ease of calibration
Table 5. Items to consider when developing specifications for liquid anti-icing equipment.

- Tailgate tank
- Hopper tanks
- Trailer mount
- Nozzle type
- Overspray protection
- Ground speed control
- Frame mount or slide in
- Multiple tanks for different liquids
- Spread data and download capabilities
- Ease of cleaning
- Side mount
- Prewetting support
- Tanker truck
- Discharge pattern and controls
- Low to high application flow rate
- Poly or steel tank
- Off-truck storage method
- Off season usage
- Ease of calibration

Table 6. Items to consider when developing specifications for motor graders.

- Cold & wet weather operation
- 2 or 4-wheel drive
- Weight and horsepower
- Articulated
- Push blade
- Attachment capability
- Electrical system
- Transmission type
- Snow blowers
Table 7. Items to consider when developing specifications for plows.

- Length
- Type (reversible, one way, “V”)
- Hitching mechanism
- Moldboard material, thickness, reinforcing height & geometry [1 (SHRP H-206)]
- Shoes (if required)
- Underbody
- Hydraulic extension and variable shape
- Weight loading on truck
- Ease and speed for cutting edge replacement
- Tripping mechanism
- Height and location of wing mount
- Vertical and horizontal angle adjustments
- Cutting edge composition (steel, carbide insert, rubber, etc.)
- Laser guidance
- Type/brand of plow controls
- Tow plow
- Hydraulic down pressure and weight management system
- Casting distance

Table 8. Items to consider when developing specifications for snow blowers

- Production rate
- Number of steering axles
- Safety systems
- Number of drive axles
- Horsepower
- One or two engines
- Drive system
- Protection systems
- Electrical system
- Chute configuration(s) and height
- Casting distance
- Road speed
- One or two stage
- Speed control
Table 9. Items to consider when developing specifications for snow sweepers.

- Capacity (for discharge)
- Dump configuration
- Operating speed
- Transmission and drive mechanisms
- Dust control systems
- Personnel protection systems
- Pressurized cab, air filtration/conditioning
- Sweeping path width
- Broom bristle characteristic

Table 10. Items to consider when developing specifications for conveyors.

- Capacity
- Configuration
- Mobility

Table 11. Items to consider when developing specifications for snow melters.

- Capacity
- Fuel and safety consideration
- Type of fuel and method of combustion
- Environmental considerations related to the discharge system, including separation

SUPPORT SYSTEMS AND EQUIPMENT FOR SNOW AND ICE CONTROL OPERATIONS

A variety of systems and equipment supports snow and ice control operations, some of which may not be in general use throughout the snow and ice control community. These systems include voice and data communications, snow fences, equipment facilities, and mobile equipment servicing.
Voice and Data Communication Systems

Agencies use these systems to convey data and voice communications among operating equipment, between operating equipment and base stations, among base stations, between base stations and higher management units and among higher management units.

Wireless Systems

Many agencies use dedicated radio systems that provide dependable and secure wireless communication. Modern wireless systems are controlled by complex computer software that enables multiple radio transmissions nearly simultaneously on a single frequency. In addition to voice communication, wireless systems offer data communication capability and interoperability with police and emergency management organizations.

Depending on the area of use and terrain, radio systems may have to be supported by a system of towers and repeaters. Computer programs are available to determine optimum tower/repeater placement in almost any geographical location without extensive field trials. When acquiring a radio system, it is important to design the power, range, and repeaters to cover as much of the agency’s service area as possible.

Many agencies that do not have dedicated radio systems equip their base and mobile units with citizens band (CB) radios. CB radios are not the most efficient arrangement, but do offer some communications capability. Federal Communications Commission rules only prohibit the use of CB radios by federal government agencies. Non-federal government agencies, especially winter maintenance forces performing snow and ice control, should be able to use these radios legally. Many state, county, and local governments use CB radios for communications, but their use is subject to certain rules.
Agencies lacking radio communications can establish basic communications with cellular phones. Although pagers are most useful for call-outs, alphanumeric pagers can provide additional operational information. Cellular phones are not as user-friendly as a radio system and they have the same potential for dead spots. Many remote areas do not have cellular or pager service. In this case satellite telephones may provide the needed coverage. Coverage (or lack thereof), as well as agency policy, will determine their potential use.

**GPS and GIS Systems**

Global Positioning Systems (GPS) and Geographic Information Systems (GIS) are becoming increasingly popular and affordable. GPS employs a network of satellites and ground receivers to accurately determine positions. GIS is a computer-based system that stores information based on geographical coordinates. GPS and GIS can be combined into a system that provides Automatic Vehicle Locating. There are a number of safety and management benefits associated with knowing the location of snow and ice control equipment while it is in operation, such as:

- Ability to locate stationary vehicles, which in the absence of other communications, could indicate a problem;
- Reduce the need for communications traffic on radio systems;
- Equipment can be more effectively deployed to critical areas;
- Better data for public information and inquiries, including data that may limit agency liability;
- Data can be “played back” for analysis;
- Problems communicated by equipment operators can be precisely located; and
- Reduced opportunity for unauthorized work or other activities.
Additional benefits can be realized by incorporating other data into the GPS data stream. Sensors on equipment and attachments that report equipment functions, measured conditions, and vehicle health give managers information on the status and progress of winter maintenance operations. Sensor data can tell how critical equipment systems are performing and predict maintenance needs by monitoring some combination of the following:

- engine temperature
- plow position(s)
- material spread rate and distribution
- lights being used
- exhaust system characteristics
- safety belt engagement
- oil pressure
- voltage/current demand/output
- hydraulic pressure
- air and pavement temperature
- engine braking system use
- equipment loading characteristics
- vehicle speed
- automatic shutdown
- transmission temperature

Computer-based GIS systems are in wide use for identifying assets and physical features within defined geographic areas. Systems are increasingly used to support snow management decision making.
and measurement and evaluation processes. They are used in emergency management centers to provide near-real-time situational data and the location and numbers of various types of resources. The GIS systems are used by many highway agencies to pictorially define the location of roadways, gas lines, water lines, sewer lines, guide rail and safety appurtenances, signs, culverts, and maintenance facilities. When combined with GPS data, the GIS systems are very powerful tools.

Before acquiring such high tech systems, a thorough benefit cost analysis should be performed. Other units/divisions within the agency should be informed to see if they might be developing a GIS, since most GIS systems are department-wide in their application. If the decision is to acquire a system, a Request for Proposal (RFP) {purchase or lease} is an appropriate step as part of the acquisition process.

Snow Fence

Snow fences can be an economical means of collecting and storing snow and keeping snow off of roadways. Figure 7 shows an example of storage capacity behind a snow fence. There is a wide choice in fence material depending on considerations of cost, weight, aesthetics, performance, and snow load. Most snow fences are constructed of standard, readily available materials.

Although there is good snow fence design guidance available (1), some agencies use consultants to do site specific designs. Significant agency input is still required due to the value of local observations over time. In some cases, changing the shape of the roadside can help store snow along the road rather
than allow it to blow over the road. Blowing snow is particularly problematic if an agency conducts anti-icing and deicing where ice and snow can turn to liquid on the road surface and refreeze.

Special consideration needs to be given to land requirements for snow fences and the storage of snow behind them, and vehicle access. Blower fences are useful where space is limited. A blower fence is one that accelerates the wind as it passes through the fence, thus blowing the snow clear of the road. A vortex generator is a specialized example of a blower fence. In some cases, tree lines or unharvested crops such as stands of corn, can provide vegetative snow fences in lieu of constructing snow fences. Figure 8 shows a corn row snow fence in Iowa. Some agencies actually lease farmers’ land to use vegetation for living snow fences. For living snow fence examples, see the Iowa DOT cooperative snow fence program brochure (2).

**Facilities for Washing Snow & Ice Equipment**

Snow and ice control equipment should be washed frequently to minimize corrosion, improve operating efficiency, and extend its useful life. Washing facilities should be designed to minimize environmental impact. Pressure washers and hot water may be used for effective cleaning and water conservation. Washing equipment may be portable or fixed depending on an agency’s overall needs. Electric or internal combustion motors drive high-pressure pumps, and water-heating capability is available on some units. Items such as pressure washers and high-pressure pumps are relatively inexpensive and may be acquired through the procurement process.

Wash-water handling systems usually involve separation systems and underground piping and storage tanks. The facility should be capable of disposing sediment, oil and ice control chemical solutions.
to meet local environmental requirements. The design and construction of these systems may be accomplished through the contract process. Agencies should check state and local regulations when developing washing facilities and waste water systems.

Agencies should also consider sharing of equipment washing facilities with other agencies to minimize costs and adverse environmental consequences. The use of commercial equipment washing facilities, such as truck washing businesses, should also be considered since they are responsible for wash water collection and disposal.

**Mobile Equipment Servicing and Tow Trucks**

Snow and ice control equipment sometimes needs field servicing/repair to maximize up time. If the problem is relatively minor and can be corrected in the field, a mobile field service truck and qualified mechanic will expedite repair and minimize downtime. Vehicle diagnostic and prognostic systems can yield considerable efficiency savings minimizing equipment downtime and facilitating planned mechanic trips instead of reactive repair trips. Repair trucks should be large enough to provide locked tool and parts storage as well as carry larger items like jacks, tires and rims. The entire function may be outsourced using the contract process. If this function is outsourced, contract documents should give special consideration to response time.

A tow truck capability required to deal with stuck or disabled vehicles that impede snow and ice control operations, particularly in urban areas, should be identified. Generally, trucks should have appropriate towing capacity and cable and winch capability. Trucks should be stabilized with chocks, tire chains and abrasives. Pulling the vehicles to a cleared area for final hook-up and removal is often required.
Although this service is commonly outsourced, tow trucks may be acquired through the normal equipment procurement processes. Contracts intended specifically for snow and ice control equipment removal situations or for a more comprehensive mobility-oriented highway clearance operation should be pursued. Towing and moving of private vehicles should be allowed only if permitted by law.

EQUIPMENT MAINTENANCE AND FLEET MANAGEMENT REQUIREMENTS

Snow and ice control operations are very demanding on equipment. Cold weather, a corrosive environment, impact loadings, over-loadings, and collisions (with other vehicles or roadside features) are some of the factors that increase equipment stress. As a result, particular attention has to be given to maintaining and repairing mobile snow and ice removal equipment.

Equipment Maintenance Programs

The routine maintenance schedule recommended by the equipment manufacturer should be regarded as the absolute minimum requirement for mobile snow and ice control equipment. Fuel suited to the climate, such as winter blend diesel fuel for very low temperatures, should be used. More frequent lubrication and inspection schedules will usually result in greater up time. Strategic pre- and post-operational inspections every shift the equipment is used will help identify small problems that, if not corrected, can result in large or expensive repairs. Inspection checklists and electronic systems are helpful tools to perform effective inspections. Sensors attached or built into equipment systems and wear parts can provide automated maintenance data when linked to diagnostic and prognostic information systems. A thorough inspection and repair of equipment, if needed, prior to and after each snow and ice season should be performed. If chemicals are used for anti-icing or deicing, detailed inspections of brakes, wiring and underbody features, such as oil tanks and transmission housings are needed.
Measuring and reporting equipment and sensors should be calibrated prior to each snow and ice season and during the season as necessary. Solid material spreaders and liquid dispensing equipment that put out large quantities of materials should be calibrated on a regular schedule that meets the needs and capabilities of the agency.

A thorough cleaning, repair welding, repainting and lubricating of equipment is essential at winter’s end. Establishing an off-season repair and maintenance program is a good practice.

The value of highly trained, competent mechanics cannot be overemphasized. Acquiring skilled people at the entry level and providing comprehensive training throughout their career is essential for providing a high level of efficiency and effectiveness within the maintenance organization. Training topics should, at a minimum, include hydraulic systems; diesel engines; electrical systems; tires, rims and wheels; suspension systems; plows wings and material spreaders.

**Equipment Maintenance Facilities and Resources**

The number and type of equipment repair/maintenance facilities to service mobile snow and ice equipment depends primarily on fleet size and geographic distribution. Appropriately equipped repair/maintenance bays (including spare parts and routine maintenance items) and qualified mechanics should be available at work locations having mobile snow and ice equipment. In smaller agencies, only one repair facility may be available and thus will be used to perform most types of repairs and maintenance. In larger, more geographically diverse organizations, there is likely to be central repair facilities to perform more specialized, complex and time consuming repair procedures. Whatever facility arrangement is used, provisions for immediate repair of equipment during operations should be available.
Equipment Storage and Housing Facilities

Snow and ice control equipment operates in a very difficult environment. Most equipment is diesel powered, which does not start very well in cold weather. Storing equipment in heated garages will help cold weather starting. If such storage is not possible, electrical outlets should be provided for engine block heaters to aid in the cold weather starting process. In general, the practice of leaving vehicles idling to avoid issues with starting in cold weather is to be avoided. It wastes fuel and creates unnecessary pollution. Equipment stored and used outside during winter operations should be brought into a warm location to thaw out. Indoor storage should have proper drainage for melt water. Stockpile loaders should also be stored inside if at all possible. Equipment should be washed as often as possible after usage during snow and ice control operations.  

![Figure 9. Hanging hopper for easy mounting.](image)

Plows, wings and spreaders should be stored in a way that they can be quickly and safely attached to trucks. The specification of a suitable mounting system will reap considerable benefits at this stage of operations. If possible, hopper-type spreaders should be stored in covered racks, in an elevated position to allow trucks to back under the spreader. Figure 9 shows one method for storing material hoppers. Many hoppers now come with legs that fold up for easy mounting and storing. Front and “V” plows should be stored so they can be driven into and easily attached, and wing plows should be stored in stands and carts that allow easy, safe hook-up.
Maintenance and Repair Systems

Establish a system for identifying, scheduling, and documenting the performance of routine maintenance procedures for any size mobile snow and ice fleet. This system should also track the life-to-date repairs (type, cost, and hours), usage, up time, downtime, and availability for each piece of equipment. With small fleets, this can be done manually on paper. For larger fleets, computer programs are absolutely essential. Agency-created or commercially available computerized maintenance management software (CMMS) programs are available to perform this function. Commercial CMMS programs can be found by searching the Internet using “CMMS,” “fleet maintenance management software,” “equipment maintenance management software” etc.

Assigning Mobile Snow and Ice Equipment

Most snow and ice equipment is distributed on some type of level of service based formula. Generally two level of service criteria are used to assign equipment: minimum cycle time and allowable snow accumulation. Cycle time is the plow route length in lane miles divided by average truck speed. Equipment capacity and operating speed impact cycle time. Heavy tandem axle trucks with high capacity hoppers and/or chemical tanks spend less time replenishing materials thus have higher average operating speeds. Higher application rates lower average operating speed and reduce cycle time. The use of a cycle time level of service criterion does not exert much control over the amount of snow accumulating on the road so is often supplemented with allowable accumulation criteria. Average truck speed has a similar effect on productivity for allowable accumulation criteria. A truck with higher capacity and greater plowing width can spend more time on the route to keep snow accumulation within an allowable range. During high snow fall rates, more trucks must be assigned to the route to deliver the level of service. It should be noted that a third method of specifying level of service, namely specifying an allowable road condition (e.g. bare wheel paths, bare and wet road, and so forth) does not specifically translate into an
assignment of equipment. When such a level of service method is used, experience will have to dictate the appropriate level of equipment for a given route.

By analyzing the fleet’s use, availability, up time and downtime, and the use of route optimization studies, fleet reductions and optimization of the fleet size can be accomplished. Research conducted for Iowa DOT developed a snow route optimization program (3). Other efforts include Ohio DOT using GIS information and optimizing plow routes (4). A comprehensive survey of models is also available (5). Agencies can also partner with other jurisdictional units when possible to yield some fleet reduction. Also, agreements with adjoining agencies can result in having isolated pieces of roadway being maintained by the adjoining agency.

ACQUIRING SNOW AND ICE EQUIPMENT

Ways of acquiring new or used snow and ice equipment include non-contract purchases, contract (bid) purchases, auctions, military/government surplus, equipment use partnerships, and leasing.

Non-Contract Purchasing

Non-contract purchasing is relatively rare among governmental agencies. However, there may be situations where the cost of the equipment is below contract purchase thresholds, existing contract prices, or is otherwise available for a nominal cost (surplus and auctions). To the extent possible, several quotations for similar equipment should be obtained before purchasing.
Contract Purchasing

Contract purchasing, using a competitive bid process, is the most common method of acquiring snow and ice control equipment. Lower prices are generally associated with higher volumes of equipment. The pooled-agency bidding process for like or similar equipment might increase volume and assure lower prices. A few of the important features of the various bid processes are listed below:

Requests for Proposals (RFP).

The agency (requester) can use a RFP to specify important system operating characteristics and other features. The proposer has the freedom to use new and proven technology and offer options the requester may not have considered. As most RFPs are evaluated on a best value basis, the least cost proposal does not have to be chosen.

Turnkey Specifications. In the turnkey specification approach, completely assembled equipment, with all the systems necessary, unless mounted equipment is otherwise available, is specified.

Competitive Specifications. To assure larger pools of bidders, the specifications should be crafted to allow as many competent vendors as possible. If an agency chooses to specify particular manufacturers, as many dealers as possible should be allowed to bid. One way to assure that specifications are sufficiently broad is to have a pre-bid meeting with potential suppliers, and give the suppliers sufficient opportunity to review the proposed specifications. Exceptions to the specifications should be investigated thoroughly and changes to the final specifications should be made if required.
Bid Solicitation. The bid documents should be complete in terms of specifications, customer expectations, and payment. Some of the more important criteria include delivery time(s), assembly sequence, assembly timetables, warranties, routine maintenance, penalties, bonuses, price schedules for various quantities, payment terms, delivery time, and format for the bid.

Bid Evaluation and Award. Depending on the type of contract, bids should be evaluated for least cost or best value. The apparent low bidders should be thoroughly evaluated for facilities, materials, processes, personnel, and performance history. Prior to award there should be a meeting to thoroughly discuss the bid, clarify any open issues, and assure that all parties understand the contract. Once this process is complete, the contract can be awarded.

Pilot Model, Pre-Paint, and Final Inspections. Preliminary and pilot model inspections are best done before the unit is painted to allow for easier inspections and corrections if required. After the preliminary unit is deemed satisfactory, full-scale production can commence. Thorough and uniform inspections can be made prior to shipment (it is usually easier to correct deficiencies at this point) or after receipt by the owner.

Partnering

Some agencies have relatively little use for specialty equipment like snow blowers and sweepers. In this situation, agencies independently purchase equipment and agree to share it with, rent it to or exchange service with cooperating partners on a pre-determined priority basis. This reduces the individual agency cost for this type of equipment substantially. Partnering opportunities within and among agencies are almost limitless.
Leasing

Although leasing is more of a financing mechanism, it provides an opportunity to acquire equipment with far less up-front investment. The overall cost of leased equipment may be higher than purchased equipment due to finance or interest costs. Leases are particularly attractive when acquiring high tech electronic equipment that may become obsolete in a short period of time.

Maintenance and other services, and provisions for technical upgrades or equipment replacement cycles at negotiated or fixed prices, can be part of a lease. Leases can be relatively immune to governmental budget processes as they are usually considered to be a contract that cannot be altered.

Use of Rental Equipment and Personnel

Judicious use of rented equipment makes practical and economic sense. In areas where there are few snow and ice events, equipment rental (trucks and loaders) may be very cost effective, particularly if the agency does not need that type of equipment for other work. The agency may have to supply plows, plow frames, and material spreaders if there is not an adequate rental source of for this type of equipment. Infrequently used equipment is ideal for rental if a supplier is available, although there isn’t much of a rental market for snow blowers, sweepers, and similar equipment.

Areas having severe winters may yield attractive seasonal markets for items such as motor graders, trucks and loaders as most earthwork construction is shut down for the winter season. By limiting the rental period to the off-construction season or providing different rental rates for different time periods, rental rates can be kept low.
An increasingly popular strategy is to maintain sufficient agency staff and equipment to handle light snow and ice events and most material spreading needs. However, in more severe situations, strategies ranging from total privatization to total in-house capability may be used. For example, contracted personnel and equipment may be called-in and deployed as necessary. There are a variety of strategies in this area. Equipment may be rented during extreme storms, or private sector personnel (non-employees) may be hired to run agency equipment. Such equipment operators must have a Commercial Drivers License.

There are a number of issues to consider in cultivating a competitive marketplace and assuring performance in acquiring temporary equipment and personnel. For example,

- Carefully consider strategies to maintain some level of in-house capability versus dependency on the private sector.
- Consider long-term contracts (6-10 years or more) to allow the contractor to purchase and amortize the right kind of equipment. With such long-term contracts, provision for inflationary adjustments should be made.
- Consider providing a contract award payment to compensate contractors for start-up costs such as insurance and amortization of equipment.
- Consider payment for reasonable minimum annual hours, particularly in less winter-severe locations. Some spring non-snow or ice related tasks may exist where the agency can use up minimum hours.
- Be aware of the marketplace and be prepared to provide specialty items such as plows, plow frames, material spreaders, ice control chemicals and abrasives, communications equipment, and standard warning light configurations, as necessary.
- Enforce uniform performance criteria.
- Always require a performance bond.
Contracting Equipment Maintenance, Repair and Service

Some agencies contract all or portions of their equipment maintenance and repair to the private sector or other governmental agencies. Routine fluid changes and lubrication are increasingly being done by the various “quick-lube” vendors. Major repairs are also being contracted to truck and equipment repair centers on a time and materials/parts or flat rate basis, depending on agency needs. Agencies must be mindful of contractors’ response time. Contract provisions should stipulate expeditious repairs during snow or ice events, and on-call contracts with multiple service vendors should be considered. Contractors should be chosen on the basis of a cost and effectiveness analysis.

Economic Analysis of Alternatives

A cost and effectiveness analysis should be the basis for the agency’s decision regarding snow and ice control equipment. Keeping good routine cost and effectiveness data will help in making rational and informed decisions. The following data and assessments are useful in performing an economic analysis:

- Unit cost for various repair and equipment maintenance tasks (direct regular time labor and materials);
- Program area overhead (equipment) costs, including parts and inventory, supervision, management system, overtime, leave, benefits, pension, and social security;
- Life cycle ownership costs for various types of equipment (exclusive of financing);
- Costs to administer private sector contracts including moving equipment to and from vendors, supervision, contract management, and supplying specialized equipment;
• Financing Costs (should be identified in bids);
• Level of service (quality and performance) impacts; and
• Private sector unit cost.

REFERENCES


2. Iowa’s Cooperative Snow Fence Program, Iowa Department of Transportation, July 2002.


CHAPTER FIVE

SNOW AND ICE CONTROL MATERIALS

This chapter provides guidance on three major topics relative to snow and ice control materials: acquisition; storing, handling and inventory monitoring; and choosing and applying materials for various weather and road conditions. Other areas closely related to each of these three main topics are also covered. The materials discussed in this chapter include expendable items used in snow and ice control; liquid and solid chemicals, abrasives, and mixtures of the two.

A wide variety of chemicals has been and continues to be used in snow and ice control operations. Different forms of chemicals have also been used, including dry solids, pre-wetted solids (including slurries), and liquids. The chemicals include chlorides, non-chlorides, and blends of chemicals to enhance their performance or reduce their impact from corrosion or environmental effects.

Naturally occurring sand is, perhaps, the most prevalent type of abrasive used during winter maintenance operations. Others include stone chips or screenings (artificial sand), ground slag, bottom ash, various ore tailings, and cinders.

MATERIAL ACQUISITION

The use of chemicals and abrasives for snow and ice control operations represents a major expenditure area for many highway agencies. It was estimated in 1994 that application of snow and ice control chemicals (including material, labor and associated equipment costs) accounts for about one-third of highway winter maintenance expenditures in the United States (1). Over $2 billion are spent annually
on snow and ice control operations (2). According to the Salt Institute, almost $586 million was spent on salt alone for highway operations in 2007 (5)

Expenditures for sand and other abrasives may account for more than 10 percent of winter maintenance budgets (depending, of course, on how much sand and abrasives are used), excluding application and clean up cost (1). The use of these materials also has been shown to be costly in terms of damage to the infrastructure and motor vehicles, can produce harmful effects on the natural environment along the roadway, and creates the need for additional highway and drainage system cleanup operations.

Chemicals

There are two distinct snow and ice control strategies that make use of chemical freezing-point depressants: anti-icing and deicing. They differ in their fundamental objective. Anti-icing is the snow and ice control practice of preventing the formation or development of bonded snow and ice to the pavement surface by the timely application of a chemical freezing-point depressant. Anti-icing is a proactive strategy. Deicing, on the other hand, is the snow and ice control practice of destroying the bond between snow and ice and the pavement surface by chemical or physical means, or more likely, a combination of the two. Deicing is a reactive strategy. Anti-icing requires about one-half to one-third the quantity of chemicals as de-icing (4).

Chemicals have been used for highway deicing since early in the 20th century. Extensive use did not occur until the 1950s, following the introduction of the Interstate highway system and growing dependence on the motor vehicle for transportation. Ice control chemicals are frequently the application of choice because of the simplicity of their use, additional treatment range, and effectiveness. The most commonly used chemical for snow and ice control has been and still is salt (sodium chloride). From 1998 to 2007, between 10-20 million tons of road salt were used each winter in the United States (5).
Salt is widely used because of its effectiveness at moderate subfreezing pavement temperatures, relatively low cost, availability, and ease of application in the solid form with current spreader equipment. General practice limits the use of salt to circumstances when the pavement temperature is greater than about 15° to 20 °F (-10° to -7°C). In this temperature range, salt is extremely effective at preventing the formation of a bond between snow and ice and the pavement. Salt is also effective at breaking an existing bond under these conditions, although in general more salt will be required for this than for prevention.

Environmental concerns have created demands for more controlled salt use or even total prohibition in some states and communities. These actions have lead to experimentation with alternative chemicals that promise to be less harmful to highway facilities, motor vehicles, and the natural environment.

Highway agencies have been searching for many years for the most cost-effective chemical to use during snow and ice control operations. This quest has generated information pertaining to some interesting chemical compounds with varied physical characteristics. Though multi-faceted, the journey always seems to lead back to a small, group of chemicals that have both advantages and disadvantages. This result is not too surprising when we review some basic chemistry in conjunction with economic considerations. This issue is considered in greater depth in NCHRP Report 577 {6}.

Any chemical that dissolves in water will lower the freezing point of the solution. As more and more of the chemical is added to the water, the freezing point of the solution will decrease to a certain level and then begin to increase. This behavior can be represented graphically in what is termed a phase diagram. This has percentage of mixture as the x-axis and temperature as the y-axis, and is divided into the various phases that the two components form as a function of both concentration and temperature. In salt-water systems, for example, one such region is a liquid brine, while another represents the existence
of two phases - ice, and a liquid brine. The lowest temperature at which the chemical will melt ice (under steady state conditions) is known as the eutectic temperature. The concentration of the solution at this temperature defines a point of the chemical solution called the eutectic composition. The eutectic temperature needs to be considered when purchasing chemicals to meet the need of the expected pavement temperatures in the local environment. However, the eutectic temperature is not the only temperature related factor that should be considered when selecting an ice-control chemical.

When discussing the temperature related performance of ice-control chemicals it should first be noted that the critical temperature to consider is the pavement temperature, not the air temperature. There may be considerable differences between the two temperatures, and to use the air temperature as an operational guide is simply neither efficient nor effective. In terms of performance of an ice-control chemical, the key temperature related factor is how much snow or ice a given quantity of chemical will melt at a given temperature. A first-order calculation of this amount can be made from the phase diagram, and while the value of the eutectic temperature is important in determining the general shape of the phase diagram, it is also useful to consider at least one other point on the phase diagram as well. This issue of temperature performance has been considered in a number of publications recently (3, 4).

Other factors to consider when selecting an ice control chemical are cost, corrosion, availability, ease of handling, and the residual effect. The residual effect is the propensity for the chemical, when applied as a liquid, to remain on the roadway. Some chemicals dry on the roadway and are easily blown off by traffic, and other chemicals adhere to the roadway and remain effective for several days provided the application is not diluted by precipitation.

Many chemicals have been considered and tried for snow and ice control together with some degree of success. The five chemicals that have been used most commonly for roadway anti-icing and deicing treatments are sodium chloride, calcium chloride, magnesium chloride, calcium magnesium
acetate (CMA), and potassium acetate (KA). However, it should be noted that often ice control products are not simply a single chemical. In many cases, up to 10% of the product may be other materials designed to either improve the performance of the product or reduce the tendency of the product to cause corrosion, or both.

*Specifications*

Highway agencies that use chemicals during their snow and ice control operations should have bid specifications that govern the roadway chemicals they use. The degree of complexity of these specifications will vary depending upon the political and environmental constraints imposed upon the agency.

The specifications used by many highway agencies to purchase roadway chemicals are quite varied and range from a simple list of requirements to a very complete and complex set of guidelines. For solid chemicals, the simplest set of specifications might require the material to satisfy a specified gradation, have an upper bound on the maximum particle size, and have a maximum water content. The specification might also require a minimum level (percentage) of the active ingredient, a maximum level of other chemicals (in many cases such specifications limit the quantities of heavy metals, for example), and to be clean and free of foreign materials and dirt. For hygroscopic solid chemicals, such as calcium chloride, the specifications should require the material to be shipped in moisture proof containers or super bags.

For liquid chemicals, the simplest set of specifications might require a breakdown of the chemical composition together with a description of the eutectic composition. A more complete set of requirements would be similar to the chemical deicer specifications used by member agencies of the Pacific Northwest Snowfighters (PNS) organization. The PNS is made up of a group of western states and
provinces (7). This specification is included as Appendix C-2. Product vendors or manufacturers wishing to sell chemical deicers (both liquids and solids) to the five states and one Canadian province must submit their product(s) for a pre-approval process before the chemicals can be included on an approved deicer products list for bid considerations. The pre-approval process requires the vendors to submit samples of the product(s) plus an analysis of the supplied samples. The analysis must contain, as a minimum, the following information:

- Corrosion test data from an independent laboratory analysis according to a specified National Association of Corrosion Engineers (NACE) standard;
- pH (liquid products only);
- Analytical results of all constituents for which limits have been set by the specifications;
- Specific gravity chart (liquid products only) with correlating weight and freeze point information presented in 1% increments beginning with a five percent solution. Note: although not specified, the specific gravity properties should be provided for several temperatures in the normal storage range;
- A completed Material Safety Data Sheet (MSDS).
- Toxicity.
- Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).
- Friction.
- Stability or ability to remain in solution at specific temperatures.

Additional specifications are applied to chemicals that fall into one of nine deicer categories. These categories are:

1. Corrosion inhibited liquid magnesium chloride;
2. Corrosion inhibited liquid calcium chloride;
3. Non-corrosion inhibited liquid calcium magnesium acetate;
4. Corrosion inhibited sodium chloride;
5. Corrosion inhibited sodium chloride plus 10% magnesium chloride;
6. Corrosion inhibited sodium chloride plus 20% magnesium chloride;
7. Calcium magnesium acetate; and
8. Non-corrosion inhibited sodium chloride, with the following subcategories:
   8A-B Standard Gradation, Brining Salt, Insoluble Material less than 1%, Contains moisture less than 0.5%;
   8A-R Standard Gradation, Road Salt, Contains moisture less than 0.5%;
   8B - Contains moisture less than 5.0%;
   8C-B Fine Gradation, Brining Salt, Insoluble Material less than 1%, Contains moisture less than 0.5%; and
   8C-R, Fine Gradation, Road Salt, Contains moisture less than 0.5%
9. PNS Experimental Category - Approved Liquid Corrosion Inhibited Products

The above-described specifications required by the PNS are more the exception than the rule. Primarily workability, corrosion and environmental considerations have driven these elaborate specifications.

Finally, the Strategic Highway Research Program (SHRP) Report H-332 entitled "Handbook of Test Methods for Evaluating Chemical Deicers" (8) can be used by highway agencies in developing a set of test specifications for evaluating and approving chemicals for snow and ice control. The resultant specifications would fall somewhere between the two approaches discussed above.
Cost-Effectiveness Considerations That Influence Specifications

Stringent specifications for chemicals certainly carry an associated increase in cost. In some instances, these added costs are necessary to help protect the highway system and the environment in which they operate. Some liquid ice control chemicals, such as gas well brines, may be available at no cost. They may have to be enhanced with additional chemicals, and their use should include restrictions on the amounts of undesirable components. It should be noted, however, that less stringent specifications may result in an associated decrease in performance and inconsistent product characteristics. It is an issue of engineering judgment for any given agency to determine where their best balance of price and performance lies.

Pre-Season Inventory and Delivery of Chemicals

Comments made for solid chemicals on this topic also apply for abrasives. Solid chemicals should be ordered by mid-summer for late-summer or early fall delivery. This schedule provides some assurance of obtaining the material well ahead of winter. Some agencies have a practice or ordering 125% of their average winter use. Bids can require suppliers to guarantee delivery of a determined amount. It is also common to guarantee purchase of a minimum amount, e.g., 90% of the normal amount.

The demand for chemicals, especially salt, places great pressures on the shipping and hauling industry that delivers the material from the production point to the users. Transportation problems grow more complicated after winter begins. As a general rule, if an agency orders all their chemical for delivery prior to the start of winter, their price will be lower than an agency which requires chemical delivery throughout the winter. Of course, this savings in materials cost will be balanced by an increased need for safe and effective material storage.
It is generally impractical to store all of an agency’s liquid chemical due to the large volume of water in the mixture. Storage of heavily concentrated mixtures is also impractical because the material is susceptible to freezing due its position on the phase diagram. It is extremely important that the inventory of chemicals be monitored closely throughout the winter. Contracts should specify maximum delivery times and penalties for delivery delays.

It is important to remember that the agency’s chemical suppliers often must order their supplies weeks in advance of delivery to the maintenance storage site. This is especially common with liquid chemical supplies. Close communication between the agency and the supplier helps prevent shortages or late deliveries. Orders for replacement chemicals should be placed with appropriate lead times (as defined in the contract) so that the inventory will not be depleted during or before storm events. Also, rush orders for replacements should be avoided, if possible. Not only do these orders often carry premium charges, but the orders might be in competition with others such that longer-than-anticipated delivery times are incurred.

*Multi-Agency Purchasing Programs*

The same advantages and disadvantages of using multi-agency programs for the purchase of abrasives can also be stated for chemicals. There are economic and environmental advantages for multiple states and local agencies to have a common set of specifications for the purchase of chemicals and abrasives, especially if the states involved have similar chemical requirements. A specification for a multi-jurisdiction cooperative for acquiring salt is contained in Appendix C-1.
Abrasives

Abrasives are used primarily during snow and ice control operations to improve traction. The improvement gained may be short lived and depends on many factors such as precipitation type, pavement type and conditions, and traffic conditions. Abrasives are usually mixed with salt or other chemicals to prevent stockpiles from freezing, keep truck or hopper loads flowable, and “stick” the abrasives to the snow or ice surface. Abrasives are primarily used for treating snow-packed and icy roads in rural areas. They are also used on all types of roads when pavement temperatures are too low for chemical treatments to be effective. It must be remembered that abrasives are not snow and ice control chemicals, e.g. salt (sodium chloride), and will not support the fundamental objective of either anti-icing or deicing which is to prevent or destroy the bond between pavement and ice.

Specifications

Many highway agencies have established bid specifications for the acquisition of abrasives used for snow and ice control. In some instances, there may be more than one specification depending upon conditions at various locations. This is primarily an economic decision. More restrictive specifications are required for areas that have air quality concerns and regulations. Many local highway agencies (county and city) pattern their abrasive specifications around those used by the state. Also, many agencies still use “pit run” or passing-a-single-screen (sieve) size to limit initial cost.

The specifications for abrasive material should contain, as a minimum, the acceptable particle size gradation range. There is some evidence that the maximum aggregate size should be limited to 0.5 in (1.3 cm) to reduce damage to motor vehicles and injury to pedestrians (1, 8). Likewise, particles that pass through a number 50-mesh sieve (less than 300 micrometers diameter) should not be used as abrasives because they do not significantly increase the skid resistance of the surface (9). Significant amounts of
200-mesh (75 micrometers) material tend to make the abrasive material stick to itself, cause difficulty in handling, require more ice control chemicals for reasonable workability, and can be detrimental to air quality.

Other desirable components of specifications for abrasive materials include the following (8):

- Resistance to crushing, impact, and grinding by traffic;
- An angular particle shape to reduce blow-off from the roadway and improve skid resistance;
- Maximum limits on “flat” and “elongated” particles

Cost-Effectiveness Considerations That Influence Specifications

It is important to remember that whatever specifications are used or developed, they must satisfy a number of constraints. These include production, delivery, and storage costs, material supply and demand, effectiveness, and quality. An engineering assessment of each variable should be made to achieve a balance of the constraints. Abrasives are often obtained from local, or at least in-state, sources to minimize delivery costs.

Pre-Season Inventory and Delivery of Abrasives

In late spring of each year, a list of current stockpile locations and quantities of abrasive material needed for the next season should be prepared from inputs received from field supervisors. The maintenance headquarters office then processes the requests for next winter’s abrasives before forwarding them to a purchasing department. Purchasing then proceeds with the advertising and awarding of contracts for those materials requested that satisfy the agency’s specifications. Orders can then be placed for the necessary abrasives from an approved listing of successful bid suppliers.
If winter delivery of abrasives is an option, local maintenance supervisors should continually review the abrasive needs of the maintenance forces. This is necessary to ensure that materials required for snow and ice control operations are ordered and delivered, or will be delivered, in sufficient quantities and at appropriate times to ensure that adequate amounts of abrasives will be available for each storm. Adequate lead-time for deliveries should be given to the material suppliers for economical considerations; suppliers impose high surcharges when rush orders are demanded. Otherwise, a sufficient quantity of abrasives to handle the most difficult winter of record, plus a little more, should be acquired before winter arrives.

Multi-Agency Purchasing Programs

There are advantages and disadvantages of using multiple-agency programs for the purchase of abrasives. The advantages include possibly lower purchase costs per unit because of larger orders, reduced shipping costs, and more uniformity of abrasives used in a given area. These advantages are probably realized more by smaller highway agencies such as county, town and city maintenance departments rather than by state maintenance departments.

One disadvantage has to do with the need to have a common specification among the various agencies. Many times it is difficult for multiple agencies to agree on one common specification. A smaller highway agency might have to pay a higher purchase price for the abrasives, especially, if they have a less stringent specification than a dominant-purchasing partner does.

Another disadvantage has to do with the recharging of replacement supplies if winter resupply is available. It is likely that the agencies in a purchasing program will consume their supply of abrasive material at different rates. This means that one agency might need to reorder replacement supplies before another, thereby minimizing or eliminating any potential volume delivery cost savings associated with a
larger order. These disadvantages would need to be addressed during any negotiations concerning a multi-agency purchasing program.

**STORING, HANDLING AND INVENTORY MONITORING OF MATERIALS**

Properly locating material storage (stockpile) sites and the continued monitoring of material consumption are critical to an efficient snow and ice control operation. This section addresses these two major areas.

**Storing of Materials**

*Storage Location Requirements*

The material storage sites in a given maintenance area must be located where there is suitable access off and on the highway for maintenance and material delivery vehicles. Also, the location of the storage sites should minimize non-productive travel time by maintenance forces and be situated to maximize use by multiple crews. The number of material storage sites for a given roadway system is determined by a number of considerations including the following:

- The maximum cycle time allowed for a spreading operation;
- The level of service of the road segments to be treated;
- Special treatment features such as bridges, tunnels, and intersections; and
- The range of the spreaders as determined by capacity and typical application rates.
The range of the spreaders also determines the way the material storage locations are distributed geographically. The number and geographical distribution of material storage locations need to be reviewed periodically. This need is emphasized by the incorporation of new technology, such as anti-icing, into maintenance forces' snow and ice control operations. There is a possibility that the number of material storage loading points can be consolidated through the use of anti-icing operations. There is also the possibility that the type of material stored at some locations could be changed through enhanced operations and shared facility agreements with other highway maintenance jurisdictions. Finally, the material storage sites should be located to minimize possible environmental damage and not create a nuisance to adjoining properties.

The Salt Institute has developed a handbook that explains many aspects of chemical storage including site selection (11). The handbook describes six issues that need to be considered in selecting an appropriate storage site: safety, accessibility, legality, tidiness, economics, and drainage. Half of these issues concern the environmental aspects of the sites. The sites should be located to minimize possible environmental damage and not create a nuisance for adjoining properties. Silos and elevated material storage may have to be considered at some of these locations.

The other half of these issues concern the movement of truck traffic, both into and out of the storage sites. The agencies' trucks generate most of this traffic, though some results from large trailer trucks making deliveries of snow and ice control materials. Thus, the truck traffic flow at the entrance to

Figure 10. Dome building for storing salt.
the site and in the vicinity of the stockpiles must be carefully evaluated, monitored, and regulated for safety conflicts. The stockpiles should be located with enough room for the maneuvering of large trailer trucks. Some maintenance agencies have designed their storage sites for rail delivery of the bulk snow and ice control materials. At one storage site in Wisconsin, the cost of salt supplies delivered by rail was 1/3 less expensive than that delivered by truck (12).

Storage Site Issues

One common issue associated with storage sites is “How much material storage capacity should be provided?” In the United Kingdom and Europe, cities routinely stockpile up to one and one-half times their average annual material usage. In the United States, many agencies are fortunate to have storage room for at least 100% of the estimated average winter requirements. The costs to develop storage are a significant capital outlay thus some agencies opt to develop smaller storage sites and depend on re-supply as needed. Storage capacity in maintenance yards is often limited and the maintenance forces must improvise with what space they have available. A link to a handy stockpile calculator is provided at the Salt Institute’s web site (5).

Two types of snow and ice control materials are stored at maintenance facilities: abrasives and chemicals. Chemicals can be in both solid and liquid forms. Abrasives are normally stored in piles while solid chemicals are stored in bags or in bulk (piles). Liquid chemicals are stored in tanks. Storage requirements for each of these four items (abrasives, solid chemicals in bags, solid chemicals in bulk, and liquid...
Abrasives are normally treated with salt to prevent freezing in storage, to maintain flowability in the spreading truck, and as an aid to help keep the material on the road surface when spread. Normally, treated abrasives, or winter sand as it is sometimes called, consisting of three to five percent salt will provide a free flowing condition for distribution.

Treated winter sand is usually stored outside on an impermeable pad and covered to the extent possible. Leftover winter sand should be relocated to covered storage buildings during the summer season. Bulk chemicals should have the first priority for inside storage. Any winter sand that cannot be stored inside during the summer season should be placed on an impermeable pad and covered with a moisture-proof material.

Solid chemicals should be stored inside a building or under a moisture-proof cover, preferably on an impermeable pad. Figures 10, 11 and 12 show types of storage buildings. Chemicals stored in the open pick-up moisture, produce leachate that drains into watercourses and aquifers, and develop an outer crust that has to be wasted or reprocessed.

Solid chemicals shipped in bags should be stored in a dry place, preferably in an enclosed building. Storage for more than one year is not recommended. Storage should be arranged to utilize the older bags first. Outside storage is sometimes permitted, provided the bags are placed on an appropriate surface, covered with a moisture-proof material, and securely fastened down. Care should be taken when storing any hygroscopic chemicals such as calcium chloride. They will absorb moisture and corrode unprotected metal surfaces.
Some of the environmental problems associated with solid chemicals have resulted from improper storage of the bulk material. Bulk storage is necessary because highway maintenance agencies need to have enough chemicals to meet all their anticipated winter needs and then some. The potential danger from improper bulk chemical stockpiling comes from brine runoff caused by rain and snowmelt in sufficient quantities to harm surface water supplies, aquifers, and vegetation. Housing the material in a structure can minimize this danger.

Many types of barns or silos are in use for solid chemical storage, ranging from a simple roof over the stockpile to a complete building. These facilities may also house the spreader(s) under the same or appended roof. Storage within an enclosed building is the preferred method.

The Salt Storage Handbook (11) is probably the best resource for planning a storage facility for both bulk and bagged solid chemicals. This handbook explains the various aspects of sizing the facilities, land requirements, construction details, roof requirements, and ventilation needs. The storage building should be designed to meet the following criteria:

- Have a permanent roof;
- Provide protection from direct precipitation;
- Provide adequate space for loading and unloading;
- Provide shield from the prevailing wind;
- Have an impervious floor that slopes away from the chemical pile and out the building; and
- Provide a containment system for any chemically contaminated liquid runoff from the storage site.
Outside storage of bulk chemicals during the winter season is allowed in some states where covered storage is limited. In these cases, the stockpiles should be placed on impervious surfaces and covered with a moisture-proof material. The surface pads should be large enough to store the largest piles and provide sufficient room for loading and unloading operations. The moisture-proof covering should be tied down carefully and the bases sealed to prevent infiltration of wind-driven precipitation and surface water.

The bulk chemical storage requirements described above, if followed, should minimize any potential brine runoff. A containment system should be constructed around the bulk storage facilities if the maintenance agency wants to completely avoid the effects of brine or if a problem exists that cannot be solved by protective coverings. This containment system should be designed to receive all runoff from the stockpile area. After collection, the runoff can be reused for treating abrasives stockpiles or prewetting solid chemicals during snow and ice control operations. The collected runoff can also be disposed of by pumping and hauling to an appropriate waste disposal site. In general, preventing chemical pollution is preferred and more effective than any collection and disposal system.

The use of liquid chemicals during snow and ice control operations, in general, and specifically during anti-icing operations, has been gaining in popularity in the U.S. since the early-to-mid-90s. This period witnessed an increased awareness of the benefits of using liquid chemicals during anti-icing operations through the SHRP and FHWA funded research (12, 13).

The interest by winter maintenance agencies in using liquid chemicals during anti-icing treatments as either a straight liquid or to prewet solids has led to the addition of liquid chemical storage facilities in many maintenance yards. Some state highway agencies (SHAs) have expanded their commitment to using liquid chemicals by building and installing salt brine and CMA solution production facilities in selected maintenance yards. The production facilities require additional yard space, not to
mention the space needed for the extra liquid application equipment and containment systems. The SHAs have found it is more economical to produce brine on site rather than have it trucked to the storage site as brines are typically 75 percent water.

An excellent and complete discussion of liquid chemical storage, brine production equipment requirements, and chemical application equipment is given in the FHWA manual of practice for an effective anti-icing program (14). Some of the storage and production items covered in this reference include the following:

- Inside vs. outside storage;
- Agitation and circulation systems;
- Storage tank material;
- Containment systems;
- Batch and continuous flow production facilities; and
- Design items to consider for a brine production facility.

In addition to these factors relating to storage of chemicals, it is also important to consider how the liquids will be transferred from storage to the delivery systems mounted on the truck. If possible, the storage location should be such that trucks can pull along side the storage without having to reverse. Further, some sort of color coding system on hoses can help to ensure that the correct chemical is loaded into the trucks. Pump switches should be readily accessible, and the loading location should include some sort of containment system to catch any liquid spills.

Maintenance forces have used a number of approaches in the mixing of chemicals and abrasives. Sand and salt stockpiles for winter road use are usually mixed with front-end loaders and/ or motor
graders. This mixing is done on an asphalt or concrete surface with the intent of getting a uniform mix. Pockets of unmixed chemicals are still common with this method. Another approach, just as marginally successful, relies on the use of front-end loaders to dump alternating loads of sand and salt, or two different types of dry chemicals, into the bed of a spreader truck as it is being readied for snow and ice control operations. This second approach mixes the two ingredients on a volume basis. The densities of the two materials need to be known in order to achieve a desired mix that will be distributed on a weight per unit area basis.

Some SHAs have found they can achieve a more uniform mixture of sand and salt, or even two dry chemicals, by using a hopper blending method. Such a system consists of separate hoppers for each material, a stacking conveyor, and a power drive mechanism. Each material is metered onto the conveyor from its respective hopper and the resultant mix is distributed to a stockpile for later use. This method has successfully produced uniform sand/salt mixes with as little as three-percent salt.

"Outside" conical stockpiles are sometimes created with cranes. This provides fairly good distribution of the constituent materials. This is a fairly slow and expensive process.

The liquid chemical prewetting techniques and equipment are more sophisticated than that used to mix dry materials. Prewetting can be accomplished by one of three methods. First, a prewetting chemical can be injected into a material stockpile at a specified dosage. Second, a liquid chemical can be sprayed onto a loaded spreader or on the material in the loader bucket as it is being loaded into the spreader. Third, an on-board spray system mounted on the spreader and/or dump body can add a liquid chemical to the dry material at the time of spreading. (15). Of these three methods, the third is the most effective.
Material Handling

It is a good rule to handle snow and ice control material as little as possible. The more it is handled, the greater the chance for spillage and degradation to take place, for unwanted moisture to be picked up by the material, or for someone to be inadvertently injured. The loading of the spreader trucks should be conducted carefully to minimize spillage of the material on the outside of the truck or the surrounding surface. The road surface under the truck being loaded should be impervious and allow for easy cleanup after truck loading has ceased for a given storm. A containment system should be constructed around the loading area to receive and collect any brine runoff from the loading operations.

The Swiss federal highway office recommends storing salt in silos. The silos enable faster filling of spreaders because they permit several trucks to be filled simultaneously and drivers can load without additional help or equipment (1). This system also helps alleviate unnecessary spillage of chemicals and allows for accurate monitoring of the quantity of material loaded on each truck. This use of silos appears to be common in Europe.

When practical, winter sand should be mixed and placed in the stockpiles prior to the start of winter. Material mixed after this period will potentially contain excessive moisture and will present more handling problems than material that is mixed before winter. Swedish research also indicates that abrasives from “aged” (where the chemical has a chance to dissolve and coat sand particles) stockpiles are more effective in terms of friction improvement and treatment longevity.
There are many potential hazards involved in loading material in spreaders. The following general guidelines should be kept in mind when working in the loading area:

- Load vehicles on a level surface;
- Do not overload trucks;
- Load and distribute loads evenly;
- Do not drop the material into a truck bed using an elevated loader bucket (Figure 13 shows one method of loading materials using an elevated loader platform);
- Avoid striking the truck, box, warning lights, or flags with the loader or loader bucket;
- Never leave a vehicle idling unattended;
- Conform to Occupational Safety and Health Administration (OSHA) and state regulations.
- Keep the loader bucket as low as possible all of the time;
- Never allow people on the truck body or hopper during the loading process.
- Avoid spilling on vehicles;
- Clean up after a loading operation;
- Don't leave material hanging on the sides, front, or back of the spreader.

**Inventory Monitoring of Materials**

Accurate and timely records of materials used on the roadway are an absolute necessity for material inventory and control. The records kept should be entered into a computerized database for analysis to assist in management decisions. Ideally, this entering of information should be a fully automated procedure, thus both minimizing extra tasks for equipment operators, and ensuring optimal accuracy and completeness of the data record.
Many highway agencies use a system to keep track of daily material usage by maintenance area. Sample data elements that are recorded include date, route number, amount and type of material used, and source of material (stockpile location). Additional elements may include the type of storm event and the amount of precipitation accumulated. The information should be entered into a computerized database on a weekly basis, as a minimum. Some agencies manually record the material usage data while other agencies are moving towards more automated systems using onboard data logging systems. The latter is greatly preferable.

Various systems for estimating materials use are employed. These include:

- Known loader bucket volume;
- Known hopper or truck body volume,
- Counting the drive shaft revolutions of spreader augers or drive shafts and relating that to materials delivered at various gate openings.

Solid chemical/abrasive spreader control systems are available now that provide extensive data logging capabilities which keep track of the vehicle’s activity records. These records can be downloaded in a number of different ways. Some GPS based systems allow data to be recorded and stored on a quasi-continuous basis (e.g. once every fifteen minutes) via wireless communication systems, others transmit data automatically when they enter a storage yard, while others rely on regular downloads from a “smart card.” This approach minimizes human recording errors prevalent with the manually based record systems. The newer spreader control systems are also compatible with GPS, allowing the spreader activities to be spatially related. This makes it possible to know, within limits, what happened and where it happened. Automated material inventory systems are now available that combine the spreaders’
activities through GPS with a geographical information system containing the highway network and material storage locations (16).

The amount of materials in stockpiles can be estimated by segmenting them into geometric shapes whose volume can be calculated. The density of the piles will generally increase over time. This must be considered when estimating the weight of the stockpile.

CHOOSING AND APPLYING MATERIALS FOR VARIOUS STORM CONDITIONS

Almost all highway agency maintenance managers and field personnel are faced with the selection and application of appropriate snow and ice control materials for various storm conditions. Many maintenance agencies have, over time, developed general guidelines to address these issues. These guidelines have been established mainly through trial and error and are generally directed towards deicing operations. These guidelines should be continually reviewed and revised in light of what information is learned about the potential benefits that can be achieved through anti-icing operations. Sufficient evidence has accumulated from two years of SHRP and two years of FHWA anti-icing testing to demonstrate the effectiveness of U.S. anti-icing practices (15). The six issues discussed in this section are listed below.

- The design of a state-of-the-art winter maintenance program;
- Guidelines for material and application rate selection;
- Role and use of abrasive/chemical mixtures;
- Test and evaluation procedures for comparing materials and application programs;
- Environmental considerations related to material application; and
- Economic evaluation of material alternatives.
Design of a State-of-the-Art Winter Maintenance Program

A state-of-the-art winter maintenance program consists of several elements that have varying degrees of importance depending on the size of the operational jurisdiction it covers and the complexity of its road network. One element, level of service (LOS), is important for all jurisdictions. It must be considered, along with the climatic conditions, in the design of any snow and ice control operation. Both deicing and anti-icing strategies are part of an overall winter maintenance program and, as such, are influenced by both LOS and climatic conditions. A detailed discussion of the process of developing a winter maintenance program is given in NCHRP Report 526 (17).

Deicing and anti-icing strategies differ in their fundamental objective. Anti-icing operations are conducted to prevent the formation or development of bonded snow and ice for easy removal. Deicing operations are performed to break the bond of already-bonded snow and ice. Both deicing and anti-icing can be used to support higher service level objectives. Because deicing is reactionary, it cannot support strict requirements for reasonably safe road conditions during a winter storm. Anti-icing can improve an agency’s ability to meet such requirements successfully and efficiently, but the maintenance manager must ensure that the timing of the operations is consistent with the objective of preventing the formation or development of bonded snow and ice. The appropriate timing of the operations requires the use of judgment in making decisions, that available information sources be utilized methodically, and that the operations be anticipatory or prompt in nature. In short, it requires a systematic or engineered approach.

Deicing operations are discussed in Chapter 8. The elements of a systematic anti-icing program are summarized briefly below and discussed in more detail in Chapter 9. The supporting tools of an anti-icing program can be organized according to three toolboxes: operations, decision-making, and personnel.

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These toolboxes are further broken down according to capabilities, information sources, and procedures that may be available for a given operation.

The operations toolbox for anti-icing includes capabilities for applying solid chemicals, liquid chemicals, or prewetted solid chemicals, and for plowing. The decision-making toolbox includes long- and mid-term weather forecasts, road and road weather information, nowcasting, traffic information, patrols providing information on weather and pavement conditions, and evaluations of treatment effectiveness. The personnel toolbox consists of personnel trained in anti-icing practices and use of information sources for decision-making, and stand-by and call-out procedures.

In the development of an anti-icing program, each toolbox should be viewed as a critical component of a systematic operation or practice. The required elements of the toolboxes will differ from site-to-site, jurisdiction-to-jurisdiction, or agency-to-agency, depending primarily on levels of service, highway agency resources, and climatic conditions. Thus, the selection of the tools will differ in each program design. The toolboxes will expand and their elements will improve as newer technologies become available and as more effective operational techniques are identified. It will always be important that the maintenance manager select and maintain effective anti-icing tools in the areas of operations, decision-making, and personnel.

**Guidelines for Material and Application Rate Selection**

A number of studies have considered what approaches to take in using anti-icing for winter maintenance. In general, these approaches are based upon the weather forecast. The approaches generally consider pre-storm treatments and in-storm treatments, although some also consider how treatments should modify toward the end of a storm, if appropriate (for example, if temperatures are predicted to drop rapidly, together with an increase in wind speed).
These various approaches are now being incorporated in a number of different ways into Maintenance Decision Support Systems (MDSS). The purpose of any MDSS is to suggest maintenance actions based upon known chemical performance, rules of practice, and the weather forecast. Such systems can be extremely complex, but at their core they rely on three factors: pavement temperature, cycle time on a given route, and the type of storm or weather event being encountered.

One particularly effective and simple form of operational guidance or decision support system has been developed by Iowa Department of Transportation. It is a laminated card that is placed in every truck. The card indicates for each operator what the application rate should be as a function of the three factors described above. Such a system does not address pre-storm and end-storm activities, but nonetheless provides a very useful and accessible guide for operators. Table 12 shows the information on the card as used by Iowa DOT.
Table 12: Iowa Department of Transportation recommended chemical application rates.

<table>
<thead>
<tr>
<th>Surface Temperature (° Fahrenheit)</th>
<th>Prewetted salt @ 12' wide lane (assume 2-hr route)</th>
<th>32-30</th>
<th>29-27</th>
<th>26-24</th>
<th>23-21</th>
<th>20-18</th>
<th>17-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>lbs of salt to be applied per lane mile</td>
<td>Heavy Frost, Mist, Light Snow</td>
<td>50</td>
<td>75</td>
<td>95</td>
<td>120</td>
<td>140</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>Drizzle, Medium Snow 1/2&quot; per hour</td>
<td>75</td>
<td>100</td>
<td>120</td>
<td>145</td>
<td>165</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Light Rain, Heavy Snow 1&quot; per hour</td>
<td>100</td>
<td>140</td>
<td>182</td>
<td>250</td>
<td>300</td>
<td>350</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface Temperature (° Fahrenheit)</th>
<th>Prewetted salt @ 12' wide lane (assume 3-hr route)</th>
<th>32-30</th>
<th>29-27</th>
<th>26-24</th>
<th>23-21</th>
<th>20-18</th>
<th>17-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>lbs of salt to be applied per lane mile</td>
<td>Heavy Frost, Mist, Light Snow</td>
<td>75</td>
<td>115</td>
<td>145</td>
<td>180</td>
<td>210</td>
<td>255</td>
</tr>
<tr>
<td></td>
<td>Drizzle, Medium Snow 1/2&quot; per hour</td>
<td>115</td>
<td>150</td>
<td>180</td>
<td>220</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Light Rain, Heavy Snow 1&quot; per hour</td>
<td>150</td>
<td>210</td>
<td>275</td>
<td>375</td>
<td>450</td>
<td>525</td>
</tr>
</tbody>
</table>

The Iowa DOT guidance suggests the appropriate application rate for pre-wetted salt on a two or three hour route for a given precipitation or icing event. Each action is defined for a range of pavement temperatures and associated temperature trend. Most of the maintenance actions involve the application of a chemical in either a dry solid, liquid, or pre-wetted solid form. Recommendations for application rates should consider pavement temperature, dilution potential for the type of weather event, the cycle time for the route, and local experience with the chemical and roadway conditions. An excellent discussion of pavement temperature, dilution potential, and cycle time is found in NCHRP Report 526, Snow and Ice Control: Guidelines for Materials and Methods (17). The Salt Institute’s “Sensible Salting” report (5) is another useful reference for application rates.
Roadway traffic affects pavement conditions in a number of ways. Traffic redistributes solid materials toward the edge of lanes, shoulders, and off the roadway. Traffic spreads liquid chemical applications forward in the direction of traffic flow, and across the lane when liquid is applied in a streaming pattern. Heat from tires assists melting to create wheel tracks. High traffic volumes impede snow and ice control operations by slowing or, in the worst case, blocking snow and ice removal equipment thus increasing cycle time. NCHRP Report 526, Snow and Ice Control: Guidelines for Materials and Methods (17) advises that dilution potential is affected by traffic volume greater than 125 vehicles per hour. The recommendation in Report 526 Table A-4 is to raise dilution potential by one level, thus increasing the chemical application rate.

Whatever chemical is used by an agency, it is important to note that there will be a pavement temperature below which the effectiveness of the chemical is significantly reduced. This temperature is different for different chemicals. For salt (sodium chloride) it is about 15°F (-9°C). For calcium chloride, the temperature at which effectiveness diminishes is about -5°F (-20.5°C). This temperature cannot be obtained directly from the phase diagram for the chemical, but is rather a reflection of field experience. This limitation in the usage of chemicals is because the application of a chemical below its effective low temperature may create a problem by causing a wet pavement surface. Once a wet surface develops where it was previously cold and dry, the dry snow can adhere and begin to build up.

Role and Use of Abrasive/ Chemical Mixtures

The use of abrasives or a mix of abrasives and chemicals is common to many snow and ice control operations. The sole function of abrasives is to improve traction. This increase may be short lived because traffic will rapidly disperse abrasives and additional frozen precipitation will cover an application treatment.
Abrasives are used routinely for treating snow-packed and icy lower-volume roads in rural areas. They are also used on medium- and low-priority roads in many non-rural areas and on all types of roads for traction when pavement temperatures are so low that chemical action is slow. Thus, abrasive treatments can be an important tool to supplement deicing operations to help improve traction. Abrasives are not ice-control chemicals and, as such, will not support the fundamental objective of either anti-icing or deicing operations.

The disadvantages of abrasives are significant and must be understood. The advantages cited are that abrasives:

- Have low first costs;
- Offer some immediate, although temporary, increased traction on slippery surfaces;
- Can be used at low temperatures when some chemicals are ineffective; and
- Provide visible evidence of road crew actions.

The disadvantages cited for the use of abrasives include the following:

- Low distance of coverage per truckload of material, requiring frequent reloading;
- Reapplication required due to traffic and precipitation;
- Adverse effects on cars such as damage to windshields and body finishes;
- Significant cleanup efforts of roads, culverts, and other drainage facilities following storms and the winter season;
- Negative impact on the air quality through increased airborne particulate matter (PM$_{10}$ problem); and
- Negative impact on watercourse ecosystems.


- Must be mixed with small amounts of chemical to prevent stockpile freezing.

The problem resulting from the use of mixtures of abrasives and chemicals is equally challenging. The Ontario Ministry of Transport concluded that mixing salt with abrasives above the level needed to prevent stockpile freezing improves neither the abrasive qualities of straight sand nor the deicing qualities of straight salt (2). In addition, they found the highway sections treated with straight salt required fewer applications than sections treated with salt/abrasives mixtures, while achieving the same level of service.

The FHWA Test and Evaluation (T&E) 28 study found that a mixture of abrasives and chemical will usually be no more effective as an anti-icing treatment during snow storms than the same amount of chemical placed alone (14). The study findings suggest that the use of abrasives in the mix can be detrimental to the effectiveness of the chemical. It is certain that a truck delivering a chemical abrasive mixture will need to reload more often than a truck delivering just the chemical (in the same, per lane mile, amount) and will thus be significantly less efficient and effective. The study also states that abrasives applications should not be routine operations of an anti-icing program because of all the negative attributes associated with its use.

**T&E Procedures for Comparing Material and Application Programs**

The SHRP Contract H-208 (13) and T&E Project 28 (14) contained study elements for comparing and evaluating snow and ice control material and associated applications during anti-icing operations. Both of these studies used an experimental design together with a "test and control" section concept. The experimental designs were developed to provide data that would allow the effectiveness of the treatments to be statistically analyzed, differences between the effectiveness of treatments to be quantified, and the conditions under which anti-icing is effective to be established. The test and control section concept was
used to help control some of the independent test variables. Personnel interested in conducting evaluations are encouraged to review the results of both contracts.

Another FHWA-sponsored T&E project is currently being performed to determine the advantages of using prewetted finely-graded salt during anti-icing operations (18). The test and control section concept is being utilized in this study without heavy dependence upon a statistically based experimental design to reach some qualitative conclusions relative to advantages of prewetted finely graded salt.

**Economic Evaluation of Material Alternatives**

A number of studies involving an economic evaluation of material alternatives have been conducted. Possibly the most publicized study is the one sponsored by the Transportation Research Board (TRB) that compared salt and CMA usage (19). That study examined the economic impact of salt usage on motor vehicles and the infrastructure, the environment, and drinking water. These were compared with the health and environmental effects of CMA together with its compatibility with automotive and highway materials. The study concluded that road salt usage will continue to be the predominant highway chemical for many years. The study also reflected on continued research aimed at reducing salt use by the development of anti-icing technology, improving salt application techniques, and exploring alternatives to salt besides CMA.

Part of the MINSALT project sponsored by the Swedish Ministry of Transport and Communications involved looking at new methods for snow and ice control (20). Included in this study were economic evaluations of chemical alternatives, such as CMA, to the use of salt. The findings of the study relative to CMA usage were similar to those of the TRB report.
The NCHRP Synthesis 207 on managing roadway snow and ice control operations includes a discussion on estimating winter maintenance benefits and costs (1). The discussion covers much of the same information on salt as is covered in the above TRB publication. It does go into some detail on a Nevada DOT sponsored study involving an economic analysis of five alternatives for removal of snow and ice from highways in the Lake Tahoe Basin. The alternatives considered included the following:

- No change in the use of salt;
- No chemical use;
- Singular use of CMA;
- Use of salt with state-of-the-art technology; and
- Use of alternative chlorides (magnesium chloride) with state-of-the-art technology.

The costs of the last two alternatives are about equal and less than the other three.

Some studies of the effectiveness of anti-icing technology have also included economic evaluations of material alternatives. A Washington DOT study reported that traditional winter maintenance operations using a sand/salt mixture cost about three times as much as anti-icing methods using liquid CMA (21). Also, a traditional winter maintenance operation using straight sand costs between 11 and 14 times as much as anti-icing methods using liquid magnesium chloride. Similar findings were also achieved by the Oregon DOT (22).

The SHRP study on anti-icing technology showed that savings of up to 50 percent in chemical usage and up to at least 74 percent in abrasive usage are possible through anti-icing operations in comparison to conventional (reactive) snow and ice control operations (13). The final report from the FHWA T&E 28 project provides a cost analysis of anti-icing operations from data provided by five states:
California, Nevada, New Hampshire, New York, and Wisconsin (14). Of the 40 test events for which cost date were obtained, only 7 showed test section costs equal to or below control section costs. The level of service attained in these test events is not readily apparent. The report does provide a framework for evaluating the costs and effectiveness of an anti-icing program using various material alternatives.

Those interested in performance and issues related to the use and effects of various snow and ice control chemicals can be found in a compendium of seven papers prepared for the TRB (23).

REFERENCES


CHAPTER SIX

WEATHER INFORMATION SYSTEMS

INTRODUCTION

Weather impacts nearly every facet of our lives. Knowing what weather to expect, whether it is winter weather such as depicted in Figure 14, or severe weather, allows us to make decisions to take part or not take part in some activity or perform certain tasks. Every person responsible for roadway snow and ice control also knows how important weather is in determining what will happen to his or her roads, when it will happen, and where it will happen. Good weather information is critical to making timely, effective, and efficient decisions to employ frequently limited but costly resources.

The need for snow and ice control results from weather and its effect on pavement conditions. Weather and pavement conditions can vary greatly over regions as small as a few square miles, while pavement conditions can vary over distances of tens or even hundreds of feet. Although weather conditions can essentially be similar over an entire state, pavement conditions are more likely to vary over much smaller regions due to changes in earth surface or pavement characteristics.

Figure 14. Scene in Portland, Oregon, January 2004. Photo courtesy of the National Weather Service Portland Office.
Elevation, latitude, sources of moisture (lakes, rivers, ponds, streams, cooling towers, etc.), and exposure to the sun all influence pavement conditions under certain weather conditions. Highway characteristics also play a role, especially when considering preferential icing of bridge decks.

Because of this variance in circumstances, accurately determining pavement conditions, even at known problem areas, can be difficult. Weather information systems improve the data gathering process and provide decision makers with more accurate, timely data for managing snow and ice removal. The proper installation and use of weather information systems requires an understanding of how weather affects pavement conditions.

### Weather and Pavement Conditions

It is important for snow and ice control practitioners to recognize how certain meteorological variables, such as temperature, humidity or dewpoint, wind speed and direction, cloud cover (or lack thereof), and precipitation dilution potential, can and do influence pavement conditions and the performance of snow and ice control materials. Precipitation dilution potential is the combined effect of precipitation type and rate (5). Precipitation types, as defined in the Manual of Practice for an Effective Anti-Icing Program (4), are as follows:

- Light snow storm;
- Light snow storm with periods of moderate or heavy snow;
- Moderate or heavy snow storm;
- Frost or black ice;
- Freezing rain storm; and
- Sleet storm.
Pavement conditions resulting from any level of precipitation can vary greatly depending on pavement temperature and maintenance treatments. Knowing the existing and forecasted pavement temperature and precipitation dilution potential can greatly enhance the ability to determine or anticipate pavement conditions and appropriate treatments.

The bonding of snow or ice to pavement results from pavement temperatures at or below freezing and an insufficient presence of ice control chemicals. If pavement temperatures are above freezing (32°F (0°C)) or chemicals are present in sufficient quantity, snow or sleet can melt on contact with pavement. With pavement temperatures below freezing and insufficient chemicals, rain can freeze on contact (freezing rain).

Even without precipitation, moisture from the air can condense on pavement and then freeze with pavement temperatures below 32°F (0°C) producing black ice. Moisture can also deposit as frost if the pavement temperature is below freezing. These situations occur when the pavement surface temperature is below the dewpoint of the air. It is analogous to water condensing on a pitcher of ice water. Knowing that conditions will occur that can produce black ice or frost allows for the proactive use of ice control chemicals to prevent the ice formations.

Climatology

The averaging of weather conditions over time is climatology. Different geographic areas tend to have different weather patterns and hence their climatologies are different. Reviewing climatology is helpful in ascertaining those areas more prone to the kinds of weather which result in snow and ice control needs.
Certain road segments or geographic areas are also more prone to adverse pavement conditions than others. Experienced snow and ice control personnel generally know these problematic locations. It is important to include these people in the process of determining the operational procedures and allocation of resources for snow and ice control. This process includes determining the amount and types of equipment, number of people and call out procedures, the selection of materials to use, the amounts to stockpile, and the distribution of storage facilities. This “road climatology” is also important for determining the locations of weather and pavement monitoring equipment.

ROAD WEATHER INFORMATION SYSTEMS (RWIS)

Since the early 1970s, instruments have been used to monitor conditions in and around runways at airports to aid in the selection of appropriate snow and ice control measures. In the early 1980s, this technology began to be used in the highway environment. In the late 1980s, the term Road Weather Information Systems (RWIS) was developed. RWIS refers to:

- A set of atmospheric and pavement condition monitoring equipment (sensors), called Environmental Sensor Stations (ESS);
- The data collection and distribution systems for measurements from the sensors;
- Equipment for the display and presentation of the measurements;
- Forecasts of weather and pavement conditions based partly on the measurements from the sensors; and
- All other weather data available from sources including weather service providers such as NorthWest Weathernet, Inc. or Meridian Environmental Technologies, Inc., the National Weather
Service (NWS), the Weather Channel, other media, satellite broadcast systems such as Data Transmission Network (DTN/Meteorologix), and the Internet.

Enhanced Decision Making

Weather and pavement condition information is useful for making decisions regarding snow and ice control. For instance, understanding the relationship between the current weather conditions and pavement temperature and future conditions can enable appropriate decisions on applying or not applying chemicals, selecting the appropriate chemicals, and determining an application rate.

![Graph showing temperature and precipitation forecast]

Figure 15. Twenty four hour site specific pavement and air temperature forecast from the University of Washington-developed Automated Realtime ROad Weather System, ARROWS.

If pavement temperatures are above freezing and are expected to remain so, usually no chemicals need to be applied. Therefore, in order to make informed decisions, managers and supervisors should use the most current information and forecasts of weather and pavement conditions. Knowing what is expected to happen arms the decision-maker with information that provides for proactive decision making, rather than having to react to conditions. Figure 15 shows a 24-hour forecast of pavement temperature and dewpoint which can help decision makers determine the strategies, if any, required during the period.
Be sure to pay attention to bridge decks and the potential for icing due to cold air cooling the bridge pavement more rapidly than surrounding road surfaces. During transition periods, like Autumn, relatively warm subsurface temperatures can help prevent road surfaces from freezing, while bridge decks can cool down due to temperatures below freezing beneath the deck as well as above.

Forecasts of weather and pavement conditions should be tailored for individual agencies, locations and their practices and procedures. Such forecasts generally require contracting with value added meteorological services (VAMS). VAMS can provide the forecast detail, such as forecasts of pavement temperature and within storm and after-storm conditions, necessary for decision-makers. Such detailed forecasts are not available from media or public forecasting services.

Road Weather Information System Components

The discussion of RWIS in the previous section described system components in general terms. The following section provides more detail for each of the components.

Environmental Sensor Stations (ESS)

Environmental Sensor Station (ESS) sensors can be divided into two categories: pavement (both surface and subsurface) and meteorological. Pavement sensors are generally installed at the pavement surface or are implanted at some depth below the surface. The surface sensors typically measure surface temperature, determine the surface characteristics (wet, dry, frost, frozen), provide a measure of the amount of deicing chemical on the surface, and some give an indication of the ice content of the chemical solution on the surface. Figure 16 shows one kind of surface sensor that is embedded in pavement.
There is a growing trend for sensors to no longer be placed in the roadway, but record information safely from the side of the road. This type of measuring of conditions is commonly known as non-intrusive. This non-intrusive trend began with the traffic sensors as customers have moved away from loops and tubes to microwave and laser technologies that can analyze traffic from the side of the road. RWIS are also beginning this trend towards non-intrusive. The big advantage of non-intrusive is the ease of installation, repair, and maintenance from the side of the road vs. from performing traffic control to perform these actions. The one major drawback of nonintrusive technologies is that they are not as accurate as sensors placed directly in the road surface, which is also true of traffic sensors as well. The current non-intrusive road weather sensors available include one that detects pavement temperature and another that detects the pavement condition.

Pavement temperature can be measured non-intrusively by using infrared technology. Infrared sensors look at an object (such as the road) and measure the radiation emitted from the surface. The amount of radiation is related to the temperature of the road surface. This method works very well for wet roads, slushy roads, and damp roads during most all temperature conditions. The technology does not perform as well during dry pavement and clear nights, during heavy snow or ice on the road, or when...
there are major variations between the air temperature and the pavement temperature. Pavement temperature is very important in snow and ice operations especially at the beginning of an event, because it can assist in determining whether the winter precipitation will freeze to the pavement and require anti-icing or deicing operations.

The condition of the pavement can be measured in a variety of ways, but the most common is by using different wavelengths of light (may not be visible to the human eye). The sensor bounces the light off the pavement and by viewing what is reflected the sensor can tell what is on the pavement. This is an excellent way to measure pavement condition because it tells you the true condition of the pavement. An in-pavement sensor measures road temperature, moisture values, and chemical values and then calculates the pavement conditions. At times conditions can fool the sensors, which then report an incorrect condition. Non-intrusive pavement conditions sensors can report road condition status, water depth, snow depth, and surface friction, which are critical values during events as they report on whether the maintenance activities are effective at that time.

Pavement temperature can also be measured using hand-held devices such as infrared radiometers, although care needs to be taken to obtain accurate measurements. Mobile pavement temperature measurements using truck-mounted sensors are also available but require the same care and understanding as hand-held devices. The biggest problem is the field of view of the sensors. The greater the field of view, which results from the height of the sensor above the pavement, the greater the potential error. However, the sensors still provide insight into the trends of pavement temperatures. It is also advisable to correlate truck-mounted sensors with actual in pavement sensors or the nonintrusive types discussed above. Older thermocouple technology still provides an inexpensive
short range (readout less than about 1000 ft (300 m) from the sensor) means of measuring pavement temperature.

Subsurface temperature sensors may also be installed 16-20 in (0.5-0.6 m) beneath the pavement surface. These subsurface temperatures are important for determining whether or not heat will flow to or away from a pavement surface. If the subsurface is warm, which typically occurs in Autumn, it takes longer for a surface to cool. Conversely, if a subsurface is cold, especially in early Spring, the pavement surface can freeze more rapidly or warm up more slowly.

ESS meteorological sensors are typically installed within the highway right-of-way to measure atmospheric parameters in the highway environment. Typical measurements include air temperature; relative humidity (for determining dewpoint); wind speed and direction; the occurrence of precipitation; type and amount of precipitation; atmospheric (barometric) pressure; amount of sunlight; and meteorological visibility. Care needs to be taken when installing and using any measuring devices to ensure that the measurements are representative and meaningful. Managers should review the FHWA RWIS ESS Sensor Siting Guidelines for help in determining proper installation locations and procedures (6).
Weather Observations

Monitoring weather conditions, especially upstream from a location of concern, is important to understanding not only what weather might be coming, but how well forecasts are behaving. Weather observations can be obtained from many sources. An agency with an RWIS in place typically has access to all ESS within the system. The FHWA is sponsoring an initiative called Clarus, which is being designed to collect data from all RWIS ESS around the country and provide quality control and easy access to the data. One thing Clarus will also do is provide metadata for ESS locations. Metadata is data about an installation, such as its detailed location, elevation, types of instruments, representativeness of observations, etc. The metadata will assist in determining how meaningful certain parameters are from each ESS.

Observations can be obtained from local NWS Internet sites. Local NWS forecast offices can be found by going to the NWS forecast office locator page, http://www.weather.gov/organization.php. By clicking on the location, that office’s Web page will appear and users can click on the map that appears to find observations. Figure 20 shows the statewide surface observations page for the state of Washington. Users can click on a site and find the latest observations.
Some universities also provide special access to collected weather observations. These include the University of Utah (MesoWest: [http://www.met.utah.edu/mesowest/](http://www.met.utah.edu/mesowest/)) and the University of Washington (Northwest Net: [http://www.atmos.washington.edu/data/](http://www.atmos.washington.edu/data/)). The National Oceanographic and Atmospheric Administration (NOAA) is currently developing the capability to provide a central location for weather observations. This effort, entitled the Meteorological Assimilation Data Ingest System (MADIS), is described at [http://madis.noaa.gov/](http://madis.noaa.gov/). NOAA may incorporate Clarus functionality as it transitions MADIS from a research to an operational environment. Some private sector data are also being incorporated in MADIS. The AWS/WeatherBug school net sites represent the private sector.
Weather forecasts, on the other hand, give insight into what is expected to happen rather than observations that tell you what is happening or has happened. Forecasts come in different forms, but the two major categories of forecasts are general forecasts and tailored forecasts.

*General Forecasts*

NWS forecasts and many private sector forecasts, such as those presented via various media, provide information that relates to areas or zones. The forecasts are general in nature, but are tending to become more focused. More detailed NWS information sometimes can be found in weather advisories, weather watches or weather warnings and special weather statements. The NWS is responsible for the safety of life and property and when bad and/or severe weather is expected, the information becomes more detailed.

NWS forecasts can be obtained via the Internet and going to the local NWS forecast office Web site as described above. The forecasts, in general, are valid for up to seven days and over a daytime and nighttime time frame. These forecasts will provide a good insight into the general weather conditions that are expected across a large geographical area.

You can also receive NWS information anywhere/anytime using a wireless device. This means data for supervisors/decision makers may be available in a vehicle. All you need is a wireless device that can access the Internet along with a wireless Internet service provider. You can use either of the following URL's to access your complete weather forecast:

- **HTTP** enabled wireless devices: mobile.weather.gov
- **WAP** enabled wireless devices: cell.weather.gov
Once you enter your "City, St" or zip code, you will receive your current weather information and links to the following...

- **Forecast-at-a-Glance** - a quick word or two describing the weather and a forecast temperature for the next 36 hours.
- **Detailed forecast** - The complete forecast text issued by the local NWS weather office for the next seven days.
- **Doppler Radar Image** - This is the same image available you are used to seeing from the NWS website, just transformed into the best possible image that your wireless device can display.

**Tailored Forecasts**

Proactive decision making requires the use of forecasts of weather and pavement conditions. Forecasts of weather conditions can be obtained from a number of sources, either free or for a fee. Free forecasts can be obtained from the National Weather Service and media. These forecasts are intended for the general public, are provided for rather large areas, and tend to be general in nature. For proactive decisions, forecasts must be tailored to the decision-maker’s needs, hence the term “tailored forecasts.” Tailored forecasts are developed in a consultant-type fashion based on decision-maker parameters and thresholds provided to a forecasting service.

Tailored forecasts are usually obtained by contracting with a VAMS. For snow and ice control decision-makers, these forecasts should include pavement temperature since that is the key to whatever pavement conditions result from the weather. VAMS typically provide a 24-hour forecast of pavement temperatures in a graphical format. The forecasts are site-specific and are based on pavement and
atmospheric measurements and forecasts for that site (the agency may have to supply pavement measurements). In some cases, pavement temperature forecasts can be provided for road segments rather than specific sites (see Thermal Mapping, below).

Tailored forecasts should also include forecasts of expected road conditions. These conditions can be very different from standard weather forecasts. The forecast conditions should include the type and amount of any snow or ice accumulations expected over time. The forecasts are generally site-specific and again are based on pavement and atmospheric measurements and weather forecasts for that site.

The tailored forecasts should also include forecasts of weather conditions that are critical to the decision-maker. For the decision-maker to make proactive decisions, these forecasts should be based on the critical thresholds agreed to between the decision-maker and the VAMS. Some forecasting service can also be provided “by exception.” If a certain threshold is not to be exceeded, then a forecast may not be needed.

Service from a VAMS should be acquired using a Request for Proposal (RFP) process similar to acquiring other professional services. SHRP H-351 provides an example of such an RFP. The FHWA Road Weather Management (RWM) Website (http://www.ops.fhwa.dot.gov/weather/index.asp) provides a list of VAMS and other road weather service providers. At the RWM Website, click on Private Sector Providers, then select RWIS, MDSS, and Thermal Mapping.
Communications

Communications can be separated into two categories: electronic and human. Electronic communication involves the collection and dissemination of data from sensors and the issuing of tailored forecasts. Sensors are typically connected directly to some form of data logger, usually called a remote processing unit (RPU) or outstation. Data can also be collected from "wireless" sensors. Occasionally sensors are sited to take advantage of existing communications or power. This can detract from the utility of the observations, as sites should be selected for their representativeness of specific problem areas or wide general areas. This includes in-pavement sensors, which can report wirelessly to an RPU at least 0.5 miles away. This allows for more representative atmospheric observations while a roadway trouble spot is monitored.

Data from the data loggers are then transmitted via a combination of telephones including cellular, fiber optic, or radio links to a centrally located collection computer, referred to as a central processing unit or instation. Agencies installing RWIS outstations need to work closely with vendors and other nearby communications users to maximize effectiveness and minimize costs.

Additionally, AASHTO, the Institute for Transportation Engineers, and the National Equipment Manufacturing Association jointly developed a standard communication protocol for RWIS as part of the National Transportation Communications for ITS Protocol (NTCIP) project (NTCIP 1204, NTCIP Environmental Sensor Station Interface Standard), available from the NTCIP Website. Agencies should consider language in RWIS requests for proposals that requires successful responders to use the standard communication protocols rather than proprietary protocols to ensure competitive bidding, effective interagency data exchange, and that communication networks are not compromised.
Decision-makers may use remote connections via telephone modem (wire or wireless) or a computer network to access data from the central computer. Field supervisors can access data via laptop computers; managers and supervisors in offices can use either laptop or desktop computers. If central processors are tied to an agency computer network, network terminals can be used. Data can also be distributed over and accessed via the Internet.

Display Systems

Vendors of RWIS hardware and tailored forecasts generally provide web-based displays or software packages for use in retrieving and displaying sensor data, weather data, and forecast information. These display packages provide user-friendly access to RWIS information. In many cases, only the information needed by the decision-makers needs to be displayed. The information may also be displayed in a user-selected, color-coded display for enhancing the decision process.

Thermal Mapping

Thermal mapping is a process of measuring pavement temperatures over a roadway network in order to create profiles of pavement temperatures under various atmospheric and pavement conditions. The process involves an instrumented vehicle that measures the pavement temperature using an infrared radiometer and computerized monitoring equipment that also measures the distance traveled and/or the precise geographical location of particular temperature measurements. In some cases, atmospheric measurements are also made. Observations of important topographical features, highway construction features, and roadside features are usually annotated.

Thermal mapping was developed in the United Kingdom in the mid-1980s specifically to address frost or black ice problems. It is usually conducted under varying atmospheric conditions in order to
develop representative profiles. This is done because under clear night skies, pavement temperatures can cool more in low-lying areas: whereas under cloudy night skies, temperatures tend to decrease with increasing elevation. To be totally effective in the more severe winter areas, profiles should be developed in late fall/early winter, mid-winter, and late winter/early spring.

Thermal mapping has been used for selecting RWIS sites, establishing a basis for forecasting pavement temperature profiles, and for developing optimized plowing and deicing chemical routes based on expected conditions. Refer to SHRP H-350 for a discussion of thermal mapping (1).

OTHER SELECTED TOPICS

RWIS is a portion of a larger weather information system. Special forecasting software and services plus other available data can complement existing RWIS information and help to provide for more effective decision making. Some of these other areas of the weather information system are listed below.

Acquiring and Using Nowcasting Support

Advances in atmospheric monitoring capabilities and refined computer models allowed for the development of nowcasting, the production of short-term forecasts for a variety of weather and pavement conditions in the zero to four-hour range. Many treatment decisions are made with the intent that they be executed in this time frame. Examples include whether to load spreaders, attach plows, begin anti-icing, or cease activities. Sometimes the most cost-effective decision may be to do nothing with the confidence provided by a nowcast.
Nowcasting gives a more precise understanding of what weather, highway, and traffic conditions to expect in this short time frame. The weather component can be provided by exception. For instance, frequent short-term weather forecasts are not needed when no significant weather is expected that would require implementation of snow and ice control procedures. If a 24-hour forecast indicates that weather or pavement conditions that will warrant snow and ice control are expected, nowcasting can be implemented in a time frame to enhance near-term decision-making.

Nowcasting service can be obtained from many providers of weather forecasts. Expect to pay more for nowcasting support than for more typical 24-hour forecasts (twice a day). These forecasts should be integrated with in-house traffic and resource data to be of maximum value.

**Decision Support Systems**

Data from ESS and forecasts from providers can feed decision support systems. For snow and ice control operations, Maintenance Decision Support Systems (MDSS) have been developed under the FHWA RWM Program and led by the National Center for Atmospheric Research. Commercial decision support systems continue to evolve to serve agencies of all sizes. Commercial products are available and more are under development.

Detailed MDSS discussion can be found in Chapter 7, Operations, and Chapter 8, Total Storm Management.
Obtaining and Integrating Ancillary Meteorological Data

Pavement condition measurements, atmospheric measurements, and forecasts of pavement and weather conditions are crucial for making informed snow and ice control decisions. Additional help can come from monitoring the progress of weather phenomena.

A number of services are available for obtaining ancillary weather data, such as radar and satellite observations. Some data are available through subscription to services, though in some cases, the same data are available from the Internet. Note that some of the “free” data on the Internet are provided at a significant time delay. Links to weather information can be added relatively easily to agency web pages. Agency personnel and the traveling public can access local weather data readily. Figure 21 shows a radar image which provides an indication where precipitation is occurring. Observing a sequence (loop) of images will show the movement (speed and direction) of the precipitation.

In addition to free weather radar access form the NWS, special radar products can be purchased from companies like Accuweather. These products may be more tailored to an agencies needs. However, radar data must be used carefully. First, especially winter precipitation, which can be low level, may be below the radar field of view. Because of earth curvature, the beam may go over the top of clouds as the distance from the radar increases (Figure 22). Also, especially in mountainous terrain, the beam may be blocked and clouds and precipitation cannot be seen.
Many road maintenance agencies use satellite broadcast dissemination systems that provide near real-time satellite and radar imagery to a computer-based display that can be located in any facility as long as there is electricity. The display, sold by DTN/Meteorlogix and others, can be set to continually update desired images automatically and display them in a looped sequence. The information displayed can be used to time the arrival and departure of storms, and show regional and local variations in storm conditions. The storm and precipitation coverage is limited to standard radar coverage that is limited in some areas. These systems can also be programmed to receive RWIS data from roadside stations, site-specific forecasts.

A third option for obtaining weather information is a satellite radio-based system by Baron Services Inc. called Mobile Threat Net. The system requires an XM satellite radio antenna, a portable WxWorks receiver, and a laptop. The system provides localized storm tracking. It automatically displays warnings from the National Weather Service, providing that information in the mapping display. The system can also post estimated rainfall totals—information derived from Baron’s own in-house hydrologic models. The system is frequently use by storm spotters and can be used even if telephone service and internet connectivity fail. Further information can be obtained from the Baron Services Website, http://www.baronservices.com/index.php.

Sharing Weather Information with the Public

Any weather information acquired by an agency can theoretically be shared with the road users. This can be done in many ways. Data from RWIS sites and ancillary data are typically made available via the Internet. Although most people are aware of wind socks to advise motorists of wind conditions, wind
sensors are being connected to variable message signs to warn motorists as are visibility sensors. Some agencies are experimenting with ice warning signs using RWIS pavement sensors. Some agencies also make NOAA Weather Radio broadcasts available in rest areas, while others use Internet weather sites and DTN/Meteorlogix kiosks. Ideally, forecasts of road conditions over a period of time would be provided motorists through such systems. Road and weather data can also be accessed through some 511 systems.

Each agency needs to determine to what extent data are made available. Some agencies prefer not to provide pavement information because of perceived liability issues. Some provide only pavement temperature data. Washington State DOT (WSDOT) provides computer generated road condition forecasts via the Internet for certain road segments. See figure 23 below.

![Forecast Conditions](image)

**Figure 23. Example of WSDOT route forecast for Interstate 90.**
Archiving Site-Specific Weather Data and Information

RWIS data provide observations of weather and pavement conditions. These observations have obvious value for decision making. They also have value for other purposes, for example:

- Winter storm reconstruction and post analysis;
- Development of training exercises;
- Reconstruction of events for legal purposes;
- Development of a road climatology; and
- Assistance in developing better forecasts.

Because of their utility, RWIS site-specific data and information (including both sensor measurements and forecasts) should be archived. Select a representative surface sensor for each site. Use vendor-provided backup devices, internal or external computer disks, or CDs/DVDs to archive data. Be sure to retain copies of forecasts along with logs of maintenance activities. This is necessary for post-storm and post-season analyses of the effectiveness of maintenance actions. This can also provide support for the agency in the event of liability issues.

REFERENCES


3. *Atmospheric Technology Directory and Buyer’s Guide*, Meteoquest, P.O. Box 10360, Bedford, NH.

4. FHWA Manual of Practice for an Effective Anti-Icing Program, 1996


ABBREVIATIONS, ACRONYMS, INITIALISMS, AND SYMBOLS

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<tr>
<th>Acronym</th>
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<tr>
<td>AASHTO</td>
<td>American Association of State highway and Transportation Officials</td>
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<td>APWA</td>
<td>American Public Works Association</td>
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<td>ARROWS</td>
<td>Automated Realtime ROad Weather System</td>
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<td>BOD</td>
<td>Biological Oxygen Demand</td>
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<td>CB</td>
<td>Citizens Band</td>
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<td>CMA</td>
<td>Calcium Magnesium Acetate</td>
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<td>CMMS</td>
<td>Computerized Maintenance Management Software</td>
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<td>COD</td>
<td>Chemical Oxygen Demand</td>
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<td>DIN</td>
<td>German Institute for Standardization</td>
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<td>DOT</td>
<td>Department of Transportation</td>
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<td>ESS</td>
<td>Environmental Sensor Station</td>
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<td>GIS</td>
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<td>ITS</td>
<td>Intelligent Transportation System</td>
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<td>KA</td>
<td>Potassium Acetate</td>
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<td>LOS</td>
<td>Level of Service</td>
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<td>Meteorological Assimilation Data Ingest System</td>
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<td>Maintenance Decision Support System</td>
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<td>Material Safety Data Sheet</td>
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<td>NACE</td>
<td>National Association of Corrosion Engineers</td>
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<td>NCHRP</td>
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<td>OSHA</td>
<td>Occupational Safety and Health Administration</td>
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<td>PNS</td>
<td>Pacific Northwest Snowfighters</td>
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<td>RFP</td>
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<td>RPU</td>
<td>Remote Processing Unit</td>
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