

FINAL REPORT

TRC 1302

**USING CHEMICAL ADMIXTURES TO INCREASE THE EFFECTIVENESS OF SNOW/ICE
REMOVAL**

by

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ABSTRACT

Snow and ice removal typically is a considerable expenditure during winter months, imposing multiple and significant impacts to efficiently transport people and goods. Companies and manufactures alike market preventative products and treatments, assuring users of lower operational temperatures for extended durations with a formula less-corrosive and environmentally friendly compared to typical rock salt.

The Arkansas Highway and Transportation Department (AHTD) typically use a pre-wetting chemical variant with sand/salt mixtures or mixtures of rock salt brine and beet juice (de-sugared beet molasses). Another option uses high concentrated mixture of salt water (salt brine), because its adhesiveness and longevity on roadways permits easier snow and ice removal.

Another factor limiting reaction time is the ability to view remote areas during winter weather events. Incorporating weather monitoring systems in strategic areas could provide essential information in determining the most effective use of AHTD resources while informing the public of current roadway conditions.

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List of Abbreviation and Acronyms

- AASHTO – American Association of State Highway and Transportation Officials
- ADT – Average Daily Traffic
- AHTD – Arkansas State Highway Transportation Department
- FHWA – Federal Highway Administration
- ITS – Intelligent Transportation Systems
- LOS – Level of Service
- NCHRP – National Cooperative Highway Research Program
- RWIS – Road Weather Information System
- TRB – Transportation Research Board
- US DOT – U.S. Department of Transportation
- USGS – United States Geological Survey
- WTIC – Wisconsin Transportation Information Center

BACKGROUND

Agencies must consider factors such as performance, cost, availability, ease of use, corrosion impacts, environmental impacts and health effects when selecting an appropriate chemical for snow and ice control operations (Cuelho, Harwood, Akin, & Adams, 2010). Table 1 shows AHTD's overall annual amounts for snow and ice removal. The additional information relates to interrupted work schedules for non-essential AHTD employees from data collected from Human Resources.

Table 1: AHTD Annual Snow & Ice Removal Cost

Year	Amount	Late Start	Early Closure	8 Hour Closure
2015	Not Available	4	2	1
2014	\$18,064,699.90	1	1	2
2013	\$4,983,550.96	2	0	1
2012	\$1,612,364.18	1	0	2
2011	\$12,319,883.30	2	1	3
2010	\$11,572,338.88	2	1	3
2009	\$6,115,738.51	4	0	0
2008	\$4,750,376.87	0	2	0

(Source: Arkansas State Highway and Transportation Department: Winter Weather Legislative Briefing, March 2014, Arkansas State Capital, Little Rock, AR)

Deicing and anti-icing chemicals have been around for decades as most northern states have used some form of liquid deicing chemicals for winter weather maintenance. Using either liquid concoction or in combination with solid deicing materials, provides a better bond and extends the material's time to the pavement, which has become more popular in recent years. Transportation departments have recognized when trucks scatter solid materials like rock salt or sand, the material has a tendency to relocate from the roadway nullifying its purpose. Saturating the pavement with a liquid mixture application provides a more uniform and homogenous application, because the tactile bond with the pavement. Thus, a lesser amount of liquid material is required to achieve the equal concentration of solid material distributed on pavements and bridges.

There are several options for liquid deicing and anti-icing chemicals. The most common chemical products used for winter maintenance activities are sodium chloride (*NaCl*),

magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), calcium magnesium acetate [CMA], and potassium acetate [KA] (Cuelho, Harwood, Akin, & Adams, 2010). However, new mitigating products have become available and reported to work at lower temperatures compared to dry salt and salt brine. These products utilize natural sugars as additives to typical deicing compounds, such as Magnesium Chloride ($MgCl_2$) and are designed to be more environmentally friendly. Another environmentally friendly product, Potassium Chloride (KCI), was designed to be safer for animals and vegetation, but its melting quality tends to be inferior to calcium chloride. A further discussion on Anti-icing and Deicing working properties is covered in *Selected Chemicals and Properties*.

In 2004, the Clarus Initiative was developed to incorporate innovative weather observing for surface transportation, while the Clarus System is designed to allow various public agencies to assess weather and pavement conditions in an accurate and concurrent fashion. As weather events can impact agencies' operations, such knowledge is critical to effectively plan, conduct and evaluate activities as winter road maintenance, weather-responsive traffic management, traveler information dissemination, safety management, transit vehicle dispatching and flood control (FHWA, 2011). Through the Clarus Initiative, popularity for Road Weather Information System (RWIS) sites has grown, which has AHTD evaluating and testing RWIS systems for the Department. In conjunction with easier observation and data recording assistance, hosting RWIS sites would allow Arkansas to contribute more meteorological data to the Clarus Network, thus benefiting the traveling public within Arkansas and the rest of the United States.

OBJECTIVES

The primary benefit of this research was determining which anti-icing/deicing mixtures effectively perform for snow and ice removal on Arkansas' roadways and bridges. A cost/benefit analysis was generated to determine product effectiveness versus its cost point through the level of service data. Incorporating concentrated products similar to its counterpart requires lesser quantity for each batch or mixture, thus freeing funds for other maintenance concerns.

Another part of this research was installing Road Weather Information System (RWIS) within Arkansas and incorporating them into a single web-based interface and weather monitoring network. This could allow the Department to monitor current conditions and inform the traveling public through AHTD's website. RWIS could better serve Area Maintenance personnel, informing of current weather conditions for significant and secondary areas during weather events. This valuable information could then broadcast an early-alert system, assisting Area Maintenance personnel to assess current situations and delegate resources effectively based on degree of weather conditions. Situations could be managed through a Decision Tree to resolve questions as circumstances arise. Decision Trees should be modified for each Area Maintenance yard and include Alert times, Personnel notifications, Pretreatments mixtures, Treatment mixtures and snow and ice removal.

Rational decision-making guidelines are needed to assist winter maintenance managers in selecting the most appropriate snow and ice control materials for the conditions that exist in their jurisdictions. A transportation agency must consider a range of factors when assessing snow and ice control materials for use, including performance, cost, potential for the material to impair the natural receiving environment, and potential for the material to impair infrastructure. Each agency will have unique objectives and conditions that influence the importance of each of these factors in the decision-making process. The overall objective of this project is to develop guidelines for selecting snow and ice control materials based on their properties and common site-specific conditions near roadways on which these products would be used.

LITERATURE REVIEW

Every year, considerable quantities of snow and ice control products are applied to highways; environmental and regulatory agencies have questioned the environmental effects of these products. Transportation agencies are asked to use “environmentally friendly” or less toxic alternatives wherever possible, but there is no commonly accepted guidance for determining which products meet these criteria. The traditional use of road salt has been prohibited in some locations, leaving highway agencies uncertain about how traffic safety can be maintained in winter conditions.

Studies of the most common chemical alternatives—sodium chloride (salt, NaCl), magnesium chloride (MgCl), calcium chloride (CaCl), calcium magnesium acetate (CMA), and potassium acetate (KA)—have focused on performance and cost under various weather conditions without evaluating their relative effects on the environment. Several new chemical preparations, including some that are proprietary formulations, have entered the market as snow and ice control chemicals for use by transportation agencies, but there is limited information about the environmental effects of these preparations.

EQUIPMENT AND MANPOWER

Being effective against the elements is a fundamental duty for AHTD, requiring proper equipment and trained personnel. Increasing employee numbers on AHTD crews and equipment available when inclement weather occurs signifies target areas can be addressed and cleared in a timely manner. These are lessons learned from the previous winter season demonstrating how the level of service for the AHTD’s equipment fleet can be blindsided by a significant ice storm that Arkansas has not experienced in years. After a major storm cleanup, AHTD officials dedicated time to meet with other Departments of Transportation, District Engineers around the State and the Arkansas State Highway Commission to develop an exceptionally efficient strategy for battling the elements. The results have been a number of new components in the AHTD’s goal of keeping roads clear for motorists.

On July 1st, 2014, AHTD reallocated \$18 million to hire 200 additional full-time employees, purchase new equipment and provide each of the ten Districts money needed to purchase material such as sand and salt. New equipment included six new belly-plows (Figure 1) that are stationed in Central Arkansas to be dispatched wherever they are needed. A belly plow is a tandem-axle dump truck with the snow plow blade mounted underneath the truck between the front and rear axles. The truck also has a front mounted plow blade and a spreader bed to distribute snow and ice fighting materials. Another six belly plow trucks are to be delivered by 2016 (Nilles, 2014).



Figure 1: New AHTD Belly Plow

ANTI-ICING AND DEICING MATERIALS

To make winter roads drivable for motorists, maintenance personnel will apply chemical deicers to melt ice and snow or spread sand to provide traction. Since chemicals and sand can be costly and may have negative environmental impacts, it is important these materials are applied in the most effective and efficient manner. As Arkansas faces the inevitable winter season, the use of road salt can be an economic game changer, pushing innovation balancing safety, cost and the environment. According to FHWA, winter road maintenance consumes 20 percent of maintenance budgets nationally; state and local agencies spend more than \$2.3 billion on snow and ice control operations annually. Salt production in the United States rose 9 percent last year as municipalities have stockpiled for winter 2015. A 2015 report from the United States Geological Survey (USGS) revealed that salt production was a \$2.2 billion industry in 2014, in which 43 percent of all salt sales (about 19 million tons of the 44.1 million tons of salt produced in the U.S.) went to road de-icing (U.S. Geological Survey, 2015). This does not classify salt as a bad investment. According to the trade advocacy group, American Highway Users Alliance, road salt pays for itself within 25 minutes of being applied, reduces crashes by up to 88 percent, and injuries and accident costs by up to 85 percent (Balakrishnan, 2015).

Before winter weather arrives in Arkansas, all ten Districts coordinate preparation for road treatments with the needed materials and resources to alleviate poor road conditions. This preliminary groundwork allows major routes to be efficiently cleared, enabling AHTD crews to treat other routes before they become treacherous for the traveling public. Apart of this preparation is using rock salt pretreated with BEET 55c[®], a liquid organic accelerator. BEET 55c[®] is a natural agricultural product, featuring melting performance superior to traditional brines while lowering corrosion rates when mixed with chloride products and rock salt. BEET 55c[®] is multifunctional as products can be purchased pre-blended or in concentrate, allowing end users to develop their own custom blends that is environmentally safe and completely biodegradable.



Figure 2: SFG demonstrating road deicers containing beet juice (Source: www.sfgiowa.com)

Other strategies being implemented include higher material stockpiles and application on road surfaces. In northwest Arkansas, District Nine has been using a salt brine solution that has been beneficial and valuable. The solution is a blend by pouring water over rock salt, which is sprayed on highway surfaces prior to a winter weather event. This technique allows the salt brine to work from the bottom up as frozen precipitation accumulates. The result generally keeps the snow or ice from bonding with the pavement, allowing crews to clear the roadways with ease. Every year can be a learning curve for deicing applications, but it was noted that a mixture of 30% beet juice and 70% salt brine shows comparable results and less expensive than other previously used chemicals such as magnesium chloride and calcium chloride.

Figure 3: District 9 Super Brine Mixture Tank



Salt Brine Chemical Solution Production

Simple brine manufacturing became a necessity with the use of salt brine or pre-moistened salt for anti-icing treatments. Several DOTs have assembled their own simple brine plants. AHTD Districts Four, Eight and Nine have purchased or developed brine making machines as shown in Figure 6.

Currently, two manufacturing types used to prepare saturated brine are batch and continuous flow. Simple batch units for temporary or small scale production can be assembled using small tanks (Figure 6). Water passing through a bed of rock salt by gravity will produce a solution saturated at the water temperature. Production involves loading a tank with salt and running water through it, collecting the brine in a holding tank. Finally, brine is passed through a 10 μ m filter, being pumped into a storage tank or directly into a spreader truck. Production rates tend to be low with this process, about 600 gallons/hour.

Another detail to consider is checking the concentration during production with a hydrometer. This device measures the specific gravity of the solution, which will increase as the concentration increases. Table 3 lists hydrometer readings and the corresponding salt concentration for a solution temperature of 59°F. More efficient continuous flow units have been developed for high capacity production as water is forced under pressure through a salt

bed. The saturated solution then flows into a storage receptacle as salt and water are metered automatically and continuously.

The following items should be considered in specifying or designing a brine manufacturing plant:

- Future needs for additional capacity
- Adequate water inlet capacity
- Suitability of the proposed site from an operational and environmental standpoint
- Pump capacity requirement
- Possibility of using earth heat for storage tanks
- Overflow control requirement
- Containment of spills
- Use of noncorrosive material in the plant construction

Table 2: Hydrometer measurements of pure salt concentration

Percent Salt	Specific Gravity at 59°F	Percent of Saturation	*Weight of Salt (lbs./gal)
0	1.000	0	0
5	1.035	20	0.432
6	1.043	24	0.523
7	1.050	28	0.613
8	1.057	32	0.706
9	1.065	36	0.800
10	1.072	40	0.895
11	1.080	44	0.992
12	1.087	48	1.000
13	1.095	52	1.100
14	1.103	56	1.291
15	1.111	60	1.392
16	1.118	63	1.493
17	1.126	67	1.598
18	1.134	71	1.705
19	1.142	75	1.813
20	1.150	79	1.920
21	1.158	83	2.031
22	1.166	87	2.143
23	1.175	91	2.256
24	1.183	95	2.371
25	1.191	99	2.448
25.2	1.200	100	

*Note: *Weight of commercial salt required* = $\frac{\text{Weight of pure Sodium Chloride from Table}}{\% \text{ Purity}}$

Selected Chemicals and Properties

Information presented in Table 3 is referenced from FHWA, *Manual of Practice for An Effective Anti-Icing Program*, which is on the properties of five chemicals used for anti-icing treatments and instructions for preparing various liquid concentrations.

Table 3: Working Properties for Anti-icing and Deicer Treatments

Chemical	Optimum Eutectic Temperature (°F)	Optimum Eutectic Concentration %	Practice Working Temperature (°F)
Sodium Chloride (<i>NaCl</i>)	-5.8	23.3	15 – 20
Magnesium Chloride (<i>MgCl₂</i>)	-28	21.6	3
Calcium Chloride (<i>CaCl₂</i>)	-60	29.8	-10
Potassium Chloride (<i>KCl</i>)	12	19.75	20+
Calcium Magnesium Acetate [<i>CMA</i>]	17.5	32.5	18
Potassium Acetate [<i>KA</i>]	-76	49	2

(Source: FHWA-RD-95-202, June 1996)

Preparation of Liquid Calcium Chloride

Solid Calcium Chloride dissolves readily in water, requiring little agitation and radiates considerable heat when it dissolves. Two methods of mixing can be used to obtain a specific concentration of liquid Calcium Chloride (*CaCl₂*). Method 1 is used if mixing container volume is known, where Method 2 is used for an unknown volume. Each of these methods is described below. For both, the water temperature should be below 68°F.

Method 1:

1. From the “per volume solution” column of Table 4 determine the weight of solid Calcium Chloride required for making 1 gallon of solution at the desired concentration level. This value (multiplied by the volume of the container in gallons) gives the total weight of Calcium Chloride required.
2. Fill the container approximately 2/3 full of water, and then add the required Calcium Chloride gradually while stirring carefully with a paddle by hand, with a mechanical agitator, or with an air bubbler.
3. After the Calcium Chloride has completely dissolved, add water to the container to bring the level to the working volume. Agitate the solution slowly until a uniform mixture is obtained.

Table 4: Calcium Chloride Mixing Proportions

%CaCl ₂ actual	Weight CaCl ₂ 77% flake		Crystallization	Weight per unit
	per volume solution (Lbs./Gallon)	per volume water (Lbs./Gallon)	Temperature (°F)	volume of solution (Lbs./Gallon)
10	1.16	1.22	22.3	9.06
15	1.82	1.99	13.5	9.46
20	2.53	2.87	-0.4	9.89
25	3.31	3.93	-21	10.3
29.8* ¹	4.1	5.18	-67	10.75
30	4.16	5.23	-50.8	10.8

(Source: FHWA-RD-95-202, Manual of Practice for An Effective Anti-Icing Program, June 1996)

Method 2:

1. Put a measured volume of water in the container to no more than 2/3 of the container capacity.
2. Dissolve in it the required weight of Calcium Chloride given in the "per volume water" column of Table 5 for each gallon of water used. Add the Calcium Chloride slowly to the water with agitation.
3. When completely dissolved, the solution will have the desired concentration.

The following formula can be used to determine the volume of water required for a given level of concentration:

$$\begin{aligned} & \text{Gallons of Water required to make a solution of a desired concentration} \\ & = \left[\frac{\text{Dry CaCl}_2(\text{lbs.}) \times \% \text{ CaCl}_2}{\text{Desired \% Solution}} - \text{Dry CaCl}_2(\text{lbs.}) \right] \div 8.34 \text{ lbs./gal of water} \end{aligned}$$

Example: To make a 20% solution from 1000 lbs. of flake CaCl₂ (Typically 78% concentration)

$$\begin{aligned} & \left[\frac{\text{Dry CaCl}_2(1000 \text{ lbs.}) \times 78\% \text{ CaCl}_2}{\text{Desired 20\% Solution}} - 1000 \text{ Dry CaCl}_2(\text{lbs.}) \right] \div 8.34 \text{ lbs./gal of water} \\ & = 348 \text{ Gallons of Water required to make a solution of a desired concentration} \end{aligned}$$

¹ This is the Eutectic point, meaning the concentration that results in the lowest temperature (-67°F), which a solution can exist while remaining completely liquid.

It is important to be aware when dissolving Calcium chloride that it initiates an exothermic reaction. This exothermic process first causes the brine to increase volumetrically and then decrease as the solution cools. Due to this chemical reaction, Method 2 requires 1/3 free space of the container's volume. For example, additional tank capacity of approximately 23 gallons is required for every 1000 gallons of 20% solution and 26 gallons for 1000 gallons of a 34% solution. Another requirement is adding the Calcium Chloride to the water. If the water is added to a container of Calcium Chloride, the chemical reaction may form a solid mass, thus making it difficult to dissolve completely.

Preparation of Liquid Sodium Chloride

Sodium Chloride has been used as an ice-control chemical on roads since the early 20th century. It is produced by three methods:

- Rock salt which is mined by conventional hard rock mining equipment and techniques and is the most commonly used product for highway application. Naturally occurring rock salt is the mineral halite, and usually contains 1 to 4% impurities, mostly gypsum, shale, dolomite, and quartz.
- Solar salt which is produced by the evaporation of sea water and may contain only a small amount of impurities. This is produced in several western states and imported in eastern states.
- Evaporated or solution or vacuum salt, a very pure form made by drying under vacuum the solution resulting from injection of water into deep underground deposits.

Two methods of mixing can be used to obtain a specific concentration of liquid Sodium Chloride. Method 1 is used for a known volume of the mixing container and a desired volume of salt brine to be produced. Method 2 is used for an unknown volume of the mixing container.

Method 1:

1. From the “per volume solution” column of Table 7, determine the weight of dry salt required to make 1 gallon of solution at the desired concentration level. This value, multiplied by the volume of the container, gives the total weight of dry salt required.
2. Fill the container approximately 2/3 full of water, then add the required dry salt gradually while stirring with a paddle by hand, with a mechanical agitator, or with an air bubbler.
3. After the salt has dissolved, add water to the container to bring the level to the working volume. Agitate the solution slowly until a uniform mixture is obtained. Some insoluble precipitate from the impurities will remain in the bottom of the tank until it is physically removed.
4. Finally, the salt brine should be tested with a hydrometer to determine the percentage of concentration that has been produced. For anti-icing operations, the concentration of the salt brine should be as close to 23.3% as possible, but no more than 25%. If the concentration is more than 25%, some water should be added to the mixture to reduce the concentration to the desired level. If the concentration is less than 23%, salt should be added to the mixture to raise the concentration to the desired level. In Table 3, hydrometer readings versus percent concentration of salt given can be used for these tests.

ENVIRONMENTAL IMPACTS

In recent years, the cost of salt is not the only issue gaining attention as studies have shown the impact on soils, vegetation, water, highway facilities and vehicles from highly soluble deicing chemicals with the tendency to follow any water flow. A major concern using chemicals for winter road maintenance is the environmental impact effecting most soil and vegetation within 60 feet of the road and increases closer to the pavement (WTIC, 2005). The use of road salt has grown controversial for boosting sodium levels in water sources as well, which has DOTs experimenting with Best Management Practices for deicing and anti-icing. So, it is no surprise that Rochester, New York, (the third-snowiest city in the U.S.), have spent years experimenting with the best environmental practices for de-icing. Other cities, including Boulder, Colorado, and Anchorage, Alaska (the fifth- and sixth-snowiest cities), have switched from salt to magnesium chloride, partially to address environmental concerns (Balakrishnan, 2015).

Deicing chemicals can accelerate deterioration in concrete and steel structures. New construction methods are reducing this impact, but highways and bridges do suffer from chemical damage. Vehicle corrosion is also accelerated. Corrosion on vehicles and structures is estimated to be the largest cost impact of chloride-based chemicals. Even relatively small amounts of chloride will significantly accelerate existing corrosion.

A basic understanding of the characteristics, transport, chance and ecological impacts of each deicing material is necessary to make an informed decision on whether to adopt deicing alternatives. Each deicing material evaluated in this report contains one or more of the following components: chloride (Cl), sodium (Na), acetate (C,HsO,), calcium (Ca), magnesium (Mg), nitrogen (N), potassium (K), phosphorous (P), silicon (Si), sulfur (S), and zinc (2%). For each, a geochemical and toxicological evaluation is made. (The deicing materials and their primary components are listed in Exhibit 3.1.)

Information on the six primary components (chloride, sodium, acetate, calcium, magnesium, and potassium) as well as sand is presented in considerable detail. Information on the four secondary components (phosphorous, nitrogen, sulfate, and zinc), which may be

present in a deicer in very small amounts, is presented in less detail. Heavy metals-sometimes present in very small amounts on road surfaces and in roadside soils-also are discussed. Exhibit 3.2 presents a summary of the effects of each deicer on the environment.

Deicing with Salt

The primary method for snow and ice removal is deploying snow plows, but clearing roads to expose its surface usually requires deicing chemicals. The most widely used chemical is salt (Sodium Chloride), which has been crushed, screened and treated with an anti-caking agent. Rock salt is relatively light weighing approximately one ton per cubic yard, typically has a gradation of 3/8" granules to fine crystals and works to lower the freezing point of water.

Before a dry deicing chemical can operate it must dissolve into a brine solution. Employing a 23.3% concentration of salt water will remain liquid to -6°F as the brine uses moisture from water, snow or slush on the road surface. The other result comes from conduction through air, sun or pavement. Chemicals only lower the melting temperature as it takes heat transfer to change ice to water. Even when pavement is below freezing, it holds some heat which can help melt snow and ice.

Using Abrasives

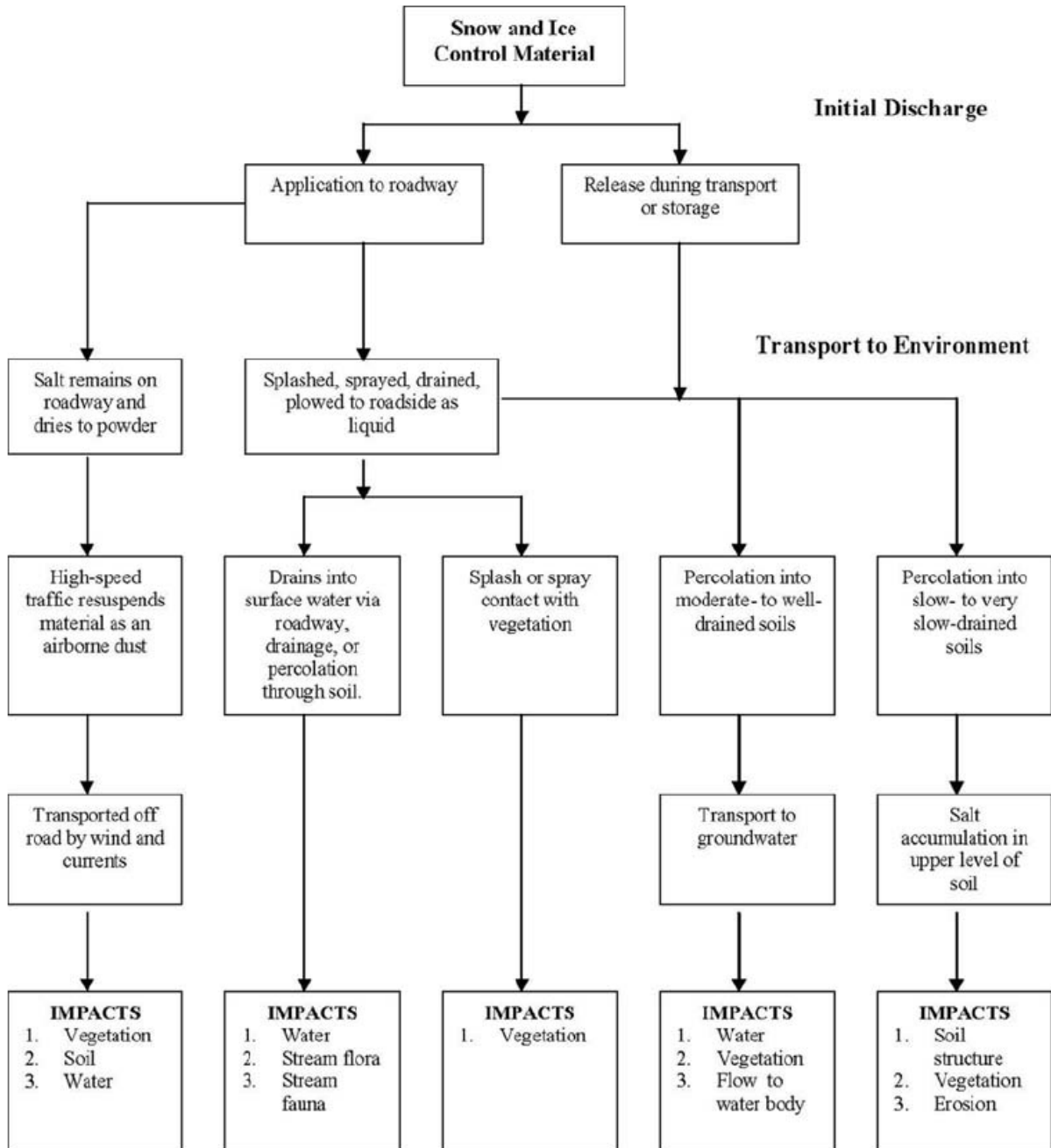
Sand, the most common abrasive, is versatile at all temperatures, improving vehicle traction on roadways, especially when temperatures are too cold for chemical deicers to work. Some sand and abrasives will provide better traction than other when using material with crushed or angular particles. Rounded particles are less effective and very small particles and dirt are actually harmful to traction. Material larger than the #50 sieve is most effective. To minimize windshield damage, use materials with particles having a diameter less than 3/8".

Some agencies mix more salt with their abrasives than is needed for freeze-proofing. This practice is often wasteful and ineffective as blending sand and salt does not produce a new material and often works against each other. Use straight salt when it will work best and apply freeze-proofed abrasive when salt is not effective or not needed. The reasons being:

- If the goal is for sand to stay on the surface for traction, the salt in the mix either blows off and gets wasted or does its job and melts the snow. However, tires can then push the sand down into the slush, making it ineffective for improving traction.
- If the goal is for salt in the blend to melt snow and ice so plows can clear the pavement, then the sand gets removed too, wasting it.
- Salt melts less ice when mixed with sand.

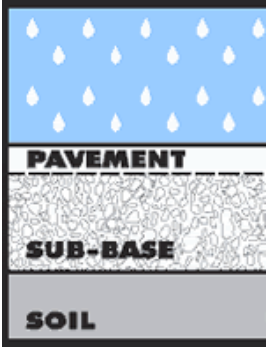
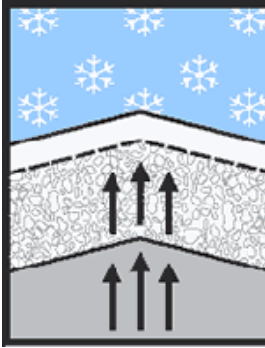
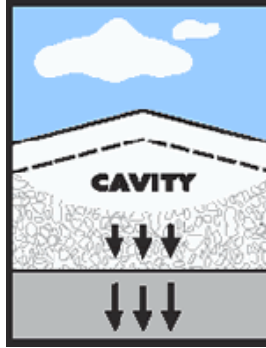

Abrasives used for winter road maintenance have some negative environmental impact. They can clog storm water inlets and sewers. Cleanup may be necessary in urban areas, on bridge decks, and in ditches. The materials may wash downstream and end up in streams and lakes which can have a negative impact on fish habitat.

Salt mixed with abrasives to keep them unfrozen and usable has the same potential impacts as described earlier. In particular, salt-treated abrasives can accelerate vehicle corrosion. Documented pollution from particles less than 10 microns (pm 10) has led to concern about the impact of winter abrasive use on air quality. As a result, cleaner abrasives and quicker cleanup after storms are being required in areas with severe air pollution.



Environmental Impact	Road Salt (NaCl)	Ca-Mg Acetate (CMA)	Calcium Chloride CaCl₂	Magnesium Chloride MgCl₂
Soils	Na can bind to soil particles, break down soil structure and decrease permeability. Cl may form complexes with heavy metals increasing their mobility.	Potential for Ca and Mg to exchange with heavy metals in soil and release them into the environment. Ca and Mg improve soil structure	Cl may form complexes with heavy metals increasing their mobility. Ca improves soil structure	Cl may form complexes with heavy metals increasing their mobility. Mg improves soil structure
Groundwater	Elevated levels of Cl can occur in groundwater during periods of low flow or spring thaws. Potential impact for drinking water, especially near heavily salted roadway or uncovered salt piles	Potential for heavy metals released from soil to make it to groundwater	Similar to NaCl, cation exchange action of Ca may increase potential for metal contamination	Similar to NaCl and CaCl ₂
Surface Water	Excessive chloride loading possible in small water bodies with limited potential for dilution or a high ratio of paved surfaces. Saline stratification in small water bodies resulting in anoxia in bottom waters. Limited evidence for ferrocyanide contamination.	Biological oxygen demand associated with acetate degradation can decrease oxygen availability in small water bodies.	Excessive chloride loading possible in small water bodies with limited potential for dilution or a high ratio of paved surfaces. Saline stratification in small water bodies resulting in anoxia in bottom waters.	Excessive chloride loading possible in small water bodies with limited potential for dilution or a high ratio of paved surfaces. Saline stratification in small water bodies resulting in anoxia in bottom waters.
Vegetation	Negatively effects through traffic spray, osmotic stress, and nutrient imbalance. Shown to influence vegetation up to 120 meters downwind from heavily traveled roadways. May influence spread of salt-tolerant or non-native species.	Little or no adverse effects, osmotic stress can occur at very high levels	Osmotic stress and leaf scorch, similar to NaCl. Ca is an important macronutrient for plant growth.	Osmotic stress and leaf scorch, similar to NaCl. Mg is an important element in plant physiology.
Wildlife	Linked to salt toxicosis in birds, may influence vehicle strikes in birds and mammals although the magnitude is unclear.	Little or no adverse effects	Little or no adverse effects	Little or no adverse effects
Automobiles and Highway Structures	Initiates and accelerates corrosion of exposed metal and concrete reinforcement bars. Exacerbates scaling.	Accelerate metal corrosion due to increased conductivity, less corrosive than chloride based deicers.	Similar to NaCl, surfaces stay wet longer, potential increasing corrosion rate	Similar to NaCl. Risk of cement paste deterioration due to Mg reactions.

Table 5: Courtesy of Tennessee DOT

The Birth of a Pothole - Step 1	The Birth of a Pothole - Step 2	The Birth of a Pothole - Step 3	The Birth of a Pothole - Step 4
			
<p>Potholes begin after snow or rain seeps into the soil below the road surface.</p>	<p>The moisture freezes when temperatures drop, causing the ground to expand and push the pavement up.</p>	<p>As the temperatures rise, the ground returns to normal level but the pavement often remains raised. This creates a gap between the pavement and the ground below it.</p>	<p>When vehicles drive over this cavity, the pavement surface cracks and falls into the hollow space leading to the birth of another pothole.</p>

FORECASTING WEATHER

Meteorology is the study of the atmosphere, atmospheric phenomena and atmospheric effects on earth's weather. Weather forecasting is the application of meteorology resulting from quantitative analysis of available and pertinent data, such as meteorological observations, and has direct application in many diverse fields, including transportation, engineering and construction. Comprehending atmospheric conditions along on a projected timeline is not only beneficial, but vital. Determining arrival times and locations are major advantages in battling winter weather in Arkansas. For that reason, AHTD has contracted with *Iteris*, a custom forecasting service using in-house meteorologists and state-of-the-art scientific and computing technologies, providing continuous and detailed weather information. A critical aspect of strategic planning and deployment of Department resources is accurate and timely weather forecasts during a winter weather event. At least 14 other State highway agencies are in agreement, having employed similar weather forecasting products.

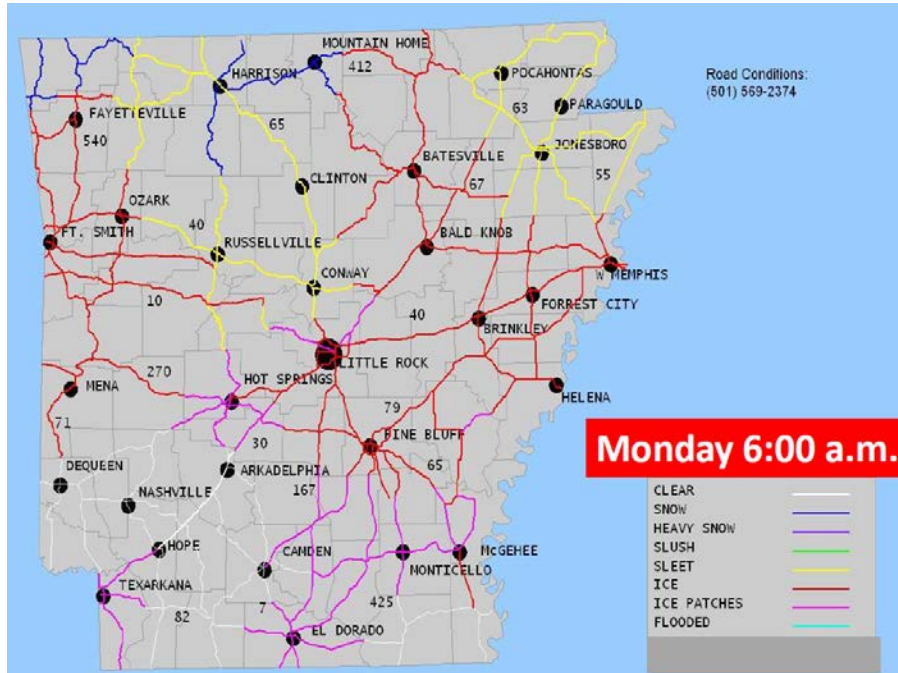
Iteris provides hourly, site-specific weather and road condition forecasting, enabling AHTD to coordinate snow and ice removal operations in a more cost effective and efficient manner over utilizing traditional forecasting information and methods. This weather information is provided online so all AHTD offices and Districts around Arkansas can access the information and make preparations. The information the service provides will be available online so that all AHTD offices and Districts around the State can access the information and make preparations. The result will be more timely and specialized weather information than has been available in the past (Nilles, 2014).

Implementing IDriveArkansas

The new winter-readiness plan will have more information available for the motoring public as well. The Department's IDriveArkansas website now contains more detailed weather information for motorists regarding winter road conditions and how frozen precipitation is affecting the Arkansas' highways. Figure 4 depicts AHTD's previous weather map that was instrumental and very popular with the media sources and the public. Over the years, it served

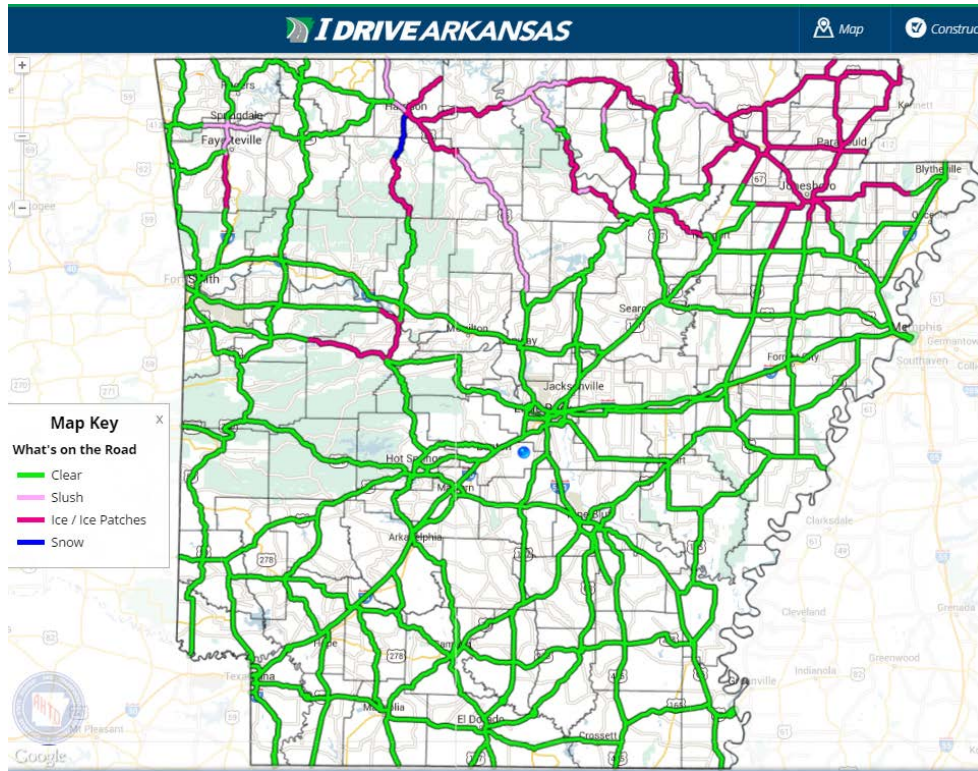
as a benchmark, but as the need for the most current road conditions expanded, the AHTD development team answered with its latest tool, *IDriveArkansas*.

Figure 4: AHTD Weather and Road Conditions Map (Previous Version)



Taking the *IDriveArkansas* website to the next level meant integrating new maps and being mobile friendly as shown in Figure 5. These new maps have been a coordinated effort between the Public Information Office, the Districts, the State Maintenance Office and AHTD’s development partner, Information Network of Arkansas. Maps are color-coded, showing mobile users precipitation type accumulating on Arkansas’ highways.

Figure 5: AHTD's IDriveArkansas Weather and Road Conditions Map (Current Version)



Another improvement allows mobile users to isolate a particular segment of a highway, showing conditions for specific sections, such as bridges and interchanges. This information will be more readily available as AHTD field crews update travel conditions through accessible internet connection via cell phone or tablet. The AHTD system allows road crews to update the state map and disseminate information to the public approximately every three hours.

Road Weather Information Systems (RWIS)

Another project was an initial Road Weather Information System (RWIS), which included installing specialized weather stations in remote areas in Arkansas. After site surveying possible selections, three locations were chosen within District Nine. (Figure 6) Siloam Springs Welcome Center was the first location selected, due to its close proximity to the Arkansas/Oklahoma state line.

Figure 6: RWIS located in Siloam Springs



Figure 7 shows the second location was Edward's Junction within the Ozark National Forest at the junction of Highways 21 and 16 and Figure 8 the third location was Cricket Creek along Highway 14.

Figure 7: Edward's Junction location



Figure 8: Cricket Creek Location



Table 6 shows the additional monitoring equipment sites included with this research project.

Table 6: Location Installations for Research Weather Cameras

Location	District	Highway
Brinkley	1	70 & 49
White River Bridge	1	64
Wynne	1	64 & 1
Lockesburg	3	371
Nashville	3	371
Danville	8	10
Hattiesville	8	213
Waveland	8	10 & 309
Decatur	9	102
Maysville	9	102 & 43
Monette	10	18

WINTER MAINTENANCE PROGRAM

The importance of a winter maintenance program should outline performance and product elements while focusing on the 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 everyone involved and should be in the design of any snow and ice control program as it pertains to climatic conditions.

The first of those new components is a newly published, forty-page “Snow and Ice Removal Guide” targeted primarily for essential AHTD personnel across Arkansas when winter weather arrives. One of the key topics of the ‘Snow and Ice Removal Guide’ is winter storms scenarios definitions and outlines preparation steps for a particular situation. Definition is based on historic winter storm data obtained from the National Weather Service (NWS) and results in dividing Arkansas into three zones, calculating the amount of material, equipment and personnel needed in each county. This information is also used to determine staffing levels, modernize equipment used for snow and ice removal, and increase salt storage capacities around Arkansas.

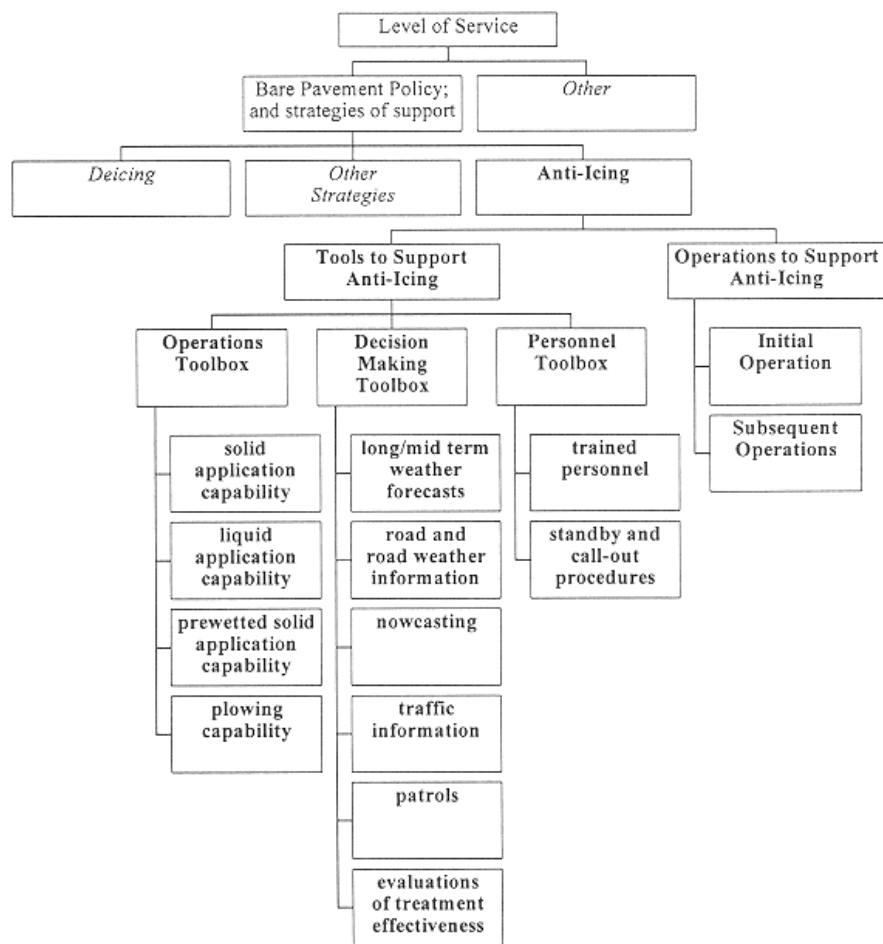
Level of Service

Typically, Level of Service (LOS) is a qualitative measure used to relate the quality of traffic services, to analyze highways by categorizing traffic flow and assigning quality traffic levels based on performance measures such as speed and density. The degree of LOS assigned to provide services for road sections is determined by maintenance personnel. In the case of winter maintenance, this requires establishing a prescribed post-storm road condition, what intermediate conditions will be acceptable to obtain the prescribed condition, or the frequency of snow and ice control maintenance operations. The LOS will largely be determined by the importance of the road as it concurs with average daily traffic (ADT). As a reflection of the desired bare pavement condition, high winter maintenance service levels are often generically called "bare pavement policies."

As defined in the Introduction, anti-icing is the snow and ice control practice of preventing the formation or development of bonded snow and ice by timely applications of a

chemical freezing-point depressant. A winter maintenance crew that is persistent in this practice is best able to support demanding road condition requirements set forth by a higher LOS. If the LOS requirements are in terms of operational frequency rather than road condition, a crew operating at higher frequency would find anti-icing practices to provide the best road conditions possible within a given set of operational constraints. Because of the proven compatibility between anti-icing and higher LOS, this manual presents anti-icing as a strategy for support of high service levels. Figure 9 depicts the components of an anti-icing program in the context of a winter maintenance program and the LOS assignment. It shows anti-icing as a support strategy for "bare pavement" service levels.

Figure 9: Typical Maintenance Outline Program for Snow and Ice Removal



RECOMMENDATIONS AND CONCLUSIONS

The maintenance of Arkansas' highways is increasingly challenged due to higher public expectations and increasing traffic that complicate daily operations. In order to maintain satisfactory levels of service, AHTD must strive for maximum effectiveness from its crews, equipment and materials, and incorporate new and innovative products and techniques. Acknowledging the necessity to prepare personnel for snow and ice removal and to implement weather and traffic management technology will maximize the Department's resources while providing safety of the traveling public, AHTD personnel and the environment.

Limitations

The primary factor that extended this research study was due to the inconsistency of winter weather seasons. Meteorology tends to be more of an abstract or theatrical science, calculating results with more predictability and probability than generating an answer through a formula alone. Topography, elevation, latitude and longitude are other variables that factor into weather.

Attempting to forecast precipitation amounts and weather duration in September to determine the number of personnel and amount of material needed in December to maintain and treat roadways is a challenging feat. One of the key components to understanding seasonal weather trends is reviewing annual data collected for a selected region. Historical weather data can be retrieved from weather sites, such as National Oceanic and Atmospheric Administration (NOAA) and National Weather Service (NWS).

The initial design for the RWIS had potential to provide crucial information to the 10 Districts and maintenance personnel. Unfortunately, the customized remote weather stations and cameras proved to be time consuming and inadequate data for the needs of the Department. Once the equipment was transferred from the Research section to Maintenance Division, the equipment was replaced with the more reliable *Iteris* system.

Maintenance Monitoring and Recordkeeping

To facilitate deicer materials environmental management, it is important to monitor environmental parameters and have sound recordkeeping practices. Such data will greatly assist in understanding the migration of deicer materials from maintenance sites to roadways and to the adjacent environment. Maintaining logs and records of equipment calibrations and deicer monitoring will also aid in assessing cost/benefit analysis of material, labor and equipment. Finally, consider documenting the following data on a regular basis:

- Salt stored under cover
- Storage sites with collection and treatment of wash water and drainage
- Inspection and repair records
- Stockpiling records
- Brine production quality control (e.g., concentrations)
- Pavement temperature trends in daily logs, along with pavement conditions, weather conditions and winter treatment strategy (TAC, 2003)

To enable benchmarking, Maintenance personnel may also consider obtaining baseline conditions of area maintenance yards and surrounding areas before applying deicers and anti-icing materials, which will provide guidance for future monitoring and comparisons. Also, the amount of material used annually should be monitored, possibly with advanced sensing devices, such as weight-in-motion - WIM sensors or scale sensors. Combining truckload tracking with routine monitoring could provide more accurate information for the Department. The Highway Deicing Task Force Report (2007) suggest the possible activities or conditions maintenance could report:

- Total length of road on which salt is applied
- Winter severity rating
- Total number of events requiring road salt application during the winter season
- Materials usage
- Description of non-chloride materials used for winter road maintenance
- State of calibration equipment

- Average chloride concentration and frequency of sampling at each sampling location, if available

A major component of deicer material monitoring is the tracking chloride levels in right-of-ways and nearby water bodies. While it may not be practical to monitor the chloride level in all the storm water runoff from roadways, consider monitoring of salt-vulnerable areas. Data obtained from the deicer material monitoring and record keeping can also be used to determine whether and how new maintenance techniques or weather events affect the natural environment. Duties should be assigned accordingly with monitoring what is brought to each maintenance area or yard, what is being discharged and any possible onsite or downstream contamination and environmental impacts.

Conclusion

AHTD has taken major steps towards maintaining a high level of service for Arkansas' roadways during the winter weather season. Deficient areas have been addressed and continue to be monitored as each winter season approaches. And though the Department may not be able to measure the severity of the next winter season, it is their mission to ensure motorists the best Level of Service is being provided by AHTD.

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