PROCEDURES FOR WINTER STORM MAINTENANCE OPERATIONS

Final Report 461

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16. Abstract

The purpose of this research is to review ADOT's existing snow and ice control practices and procedures and to make recommendations to improve snow and ice control. The research uses the level of service (LOS) goals from a maintenance management system (MMS) to make recommendations for improving procedures and acquiring resources in order to attain the LOS goals. The main recommendations in applying de-icing and anti-icing chemicals include

- Where level of service goals and site conditions allow, ADOT should implement anti-icing as a standard strategy.
- The reasonable amounts of chemicals in anti-icing operations should be based on current and expected conditions
- The concentration of chemicals applied can change over time, i.e., become diluted, with the interaction of the chemicals, precipitation and accumulated snow or ice. Care should be taken in applications of chemicals when the dilution potential is medium or high.
- The recommended treatment strategy for localized icing conditions is pre-treating with a liquid ice control chemical 6 to 66 hours before the potential event. Liquid ice control chemicals are also effective in treating black ice that has already occurred if the pavement temperature is above 23°F (-5°C).

The research has found that the current ADOT snow and ice fleet size, character, and associated support resource are not adequate to provide the level of service desired. It is recommended that 30-50 additional snow and ice trucks should be acquired. ADOT also should conduct a route-by-route analysis to realign existing resources to be compatible with highway priority and cycle time.

In order for ADOT to successfully attain its level-of-service goals, it needs to adopt a chemical priority policy for the use of chemicals in snow and ice control where possible. This policy would apply to both anti-icing and deicing strategies. This will require additional cost for chemicals and reduced cost for cinders.

It is also recommended that ADOT should establish a formally programmed, user driven, and continuous technical training program for snow and ice control. The training goals and objectives should be established. By establishing such a program, consistent practices and procedures can be implemented effectively and efficiently.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	Inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	Feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	Yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	Miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	Square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	Square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	Square meters	1.195	square yards	yd^2
ac	Acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	Gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	Cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	Cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	Ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	Pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or “metric ton”)	mg (or “t”)	Mg	megagrams (or “metric ton”)	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
$^{\circ}F$	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	$^{\circ}C$	$^{\circ}C$	Celsius temperature	1.8C + 32	Fahrenheit temperature	$^{\circ}F$
		ILLUMINATION					**ILLUMINATION**		
fc	foot candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	Poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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ACRONYMS

ACRONYMS	DEFINITION
AASHTO	American Association of State Highway and Transportation
ADOT	Arizona Department of Transportation
ADT	Average Daily Traffic
APWA	American Public Work Association
ASOS	Automated Surface Observing System
CDL	Commercial Driver License
CMA	Calcium Magnesium Acetate
CPU	Central Processing Unit
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration
FTE	Full Time Employee
GVWR	Gross vehicle Weight Rating
LOS	Level of Service
LTAP	Local Technical Assistance Program
MMS	Maintenance Management System
NTCIP	National Transportation Communications for ITS Protocol
NWS	National Weather Service
OJT	On-the-Job Training
PM	Preventive Maintenance
RPU	Remote Processing Units
RWIS	Road Weather Information System
SBWIS	Satellite-Based Weather Information System
SHRP	Strategic Highway Research Program
UDOT	Utah Department of Transportation
VAMS	Value-Added Meteorological Services

EXECUTIVE SUMMARY

The Arizona Department of Transportation (ADOT) is responsible for snow and ice control on Interstate highways, as well as US and State Route numbered highways, in Arizona. The primary snow and ice control strategy employed by ADOT is the mechanical removal of snow and ice along with friction enhancement. Friction enhancement involves the application of abrasives (mostly cinders in Arizona). The mechanical removal of snow is primarily accomplished by plowing, although in some areas snow blowers may be used when accumulations of snow are significant.

ADOT has also begun to test anti-icing, including the pretreatment of roadways before or during the onset of a winter weather event with liquid or prewetted solid chemicals. The purpose of the pretreatment is to prevent snow or ice from bonding to the pavement. This can facilitate the mechanical removal of snow or ice from the roadway and help provide the motorists with a higher level of service during winter weather events. Currently, ADOT doesn't have the resources to use this strategy in many areas where it could be very beneficial.

ADOT recognized in the early 1990s that technology may help them perform their winter maintenance operations more effectively and efficiently. Seven Road Weather Information System (RWIS) sites were installed along Interstate 40 (I-40) from east of Kingman to the New Mexico border. In addition, ADOT contracted for site-specific forecasts of weather and pavement conditions associated with these sites in order to improve the level of service (LOS) provided to motorists traveling in this corridor during winter weather.

These current procedures frequently fail to provide the LOS desired by ADOT and its public and commercial road users. ADOT also had no established LOS goals for snow and ice control, which are necessary in order to determine if ADOT meets performance goals, and if not, what resources are required in order to meet the goals.

In 1997, ADOT contracted with a team of snow and ice control experts to review existing winter maintenance practices and procedures and to make recommendations to improve snow and ice control. The review process included investigating the following:

- ADOT's use of weather information;
- The location of RWIS sites and plans for new sites;
- Maintenance of the existing RWIS;
- Existing resources and procedures for snow and ice control;
- Maintenance of snow and ice control equipment; and
- Training of personnel involved in winter maintenance.

The research team was to use the LOS goals from a maintenance management system (MMS) in order to make recommendations for improving procedures and acquiring resources in order to attain the LOS goals. The team gathered information from ADOT personnel through the use of surveys and interviews. It also participated in meetings with management personnel, conducted literature searches, reviewed current ongoing research, and provided assessments based on their personal expertise.

Following the information gathering and analysis, the team provided ADOT with a number of recommendations in several key areas that needed to be implemented in order to improve the LOS for snow and ice control.

OPERATIONAL RECOMMENDATIONS

First, operational recommendations for applying de-icing and anti-icing chemicals include:

1. Where LOS goals and site conditions allow, ADOT should implement anti-icing as a standard strategy, recognizing that the actual implementation is a case-by-case operation dependent upon the current and expected road and weather conditions.

2. In addition to anti-icing, in areas where LOS requirements suggest that because of current resource limitations the goals are unattainable, ADOT should implement a deicing strategy. Deicing can improve the efficiency and effectiveness of snow and ice removal in those areas and help to maintain or attain a higher level of service.

3. The implementation of anti-icing and deicing strategies should be based on tactics using reasonable amounts of chemicals based on current and expected conditions

4. The concentration of chemicals applied can change over time, i.e., become diluted, with the interaction of the chemicals, precipitation and accumulated snow or ice. Care should be taken in applications of chemicals when the dilution potential is medium or high. For instance, the application of liquid chemicals on bonded or packed snow or ice is not recommended. However, very thin pack/ice (<1/16 in [1.6 mm]) may be treated with liquids if post-treatment dilution potential is low. When the dilution potential is medium or high, application should be made more frequently. If the cycle times don't allow for an increase in frequency, applications should be either at greater rates, or the strategy should change to mechanical removal if refreeze is expected.

5. Localized icing conditions occur when the pavement (or bridge deck) temperature is at or below 32°F (0°C) AND below the dew point temperature. It is common for bridge deck surfaces to develop frost (preferential icing conditions) when the adjacent highway surfaces do not. The recommended treatment strategy for this condition is pre-treating with a liquid ice control chemical 6 to 66 hours before the potential event. Liquid ice control chemicals are also effective in treating black ice that has already occurred if the pavement temperature is above 23°F (-5°C).

The research has found that the current ADOT snow and ice fleet size, character, and associated support resource are simply ***not adequate*** to provide the level of service desired. It is recommended that 30-50 additional snow and ice trucks should be acquired. ADOT also should conduct a route (beat)-by-route analysis to realign existing resources to be compatible with highway priority and cycle time. Opportunities for cooperation and efficiency with adjoining Districts and Orgs should also be explored at this time. Other efficiencies to reduce cycle time should also be explored. These include stockpile siting and cooperative arrangements with other governmental entities and possibly the private sector.

In order for ADOT to successfully attain its level-of-service goals, it needs to adopt a chemical priority policy for the use of chemicals in snow and ice control where possible. This policy would apply to both anti-icing and deicing strategies. This will require additional cost for chemicals and reduced cost for cinders.

Current research and the majority opinion of snow and ice professionals indicate that a chemical priority policy is less costly (materials) than the abrasives priority policy currently being used by most of ADOT. After start-up costs there should be no additional cost for chemicals and there will probably be an over all savings in the total cost of snow and ice control operations.

INFORMATIONAL RECOMMENDATIONS

The following informational recommendations relate to equipment and software procurements or upgrades that will improve access to and use of weather and road condition forecasts.

1. Procure from Integrated Financial Solutions remote access software for downloading weather information from the SBWIS to PCs or laptops.

2. Participate with the University of Utah's Cooperative Institute for Regional Prediction in its development of a mesoscale weather information acquisition capability that would include access to RWIS and weather data in Arizona and surrounding areas.

3. In coordination with the National Weather Service in Bellemont, AZ, procure additional weather stations to fill in meteorological gaps. Whenever possible, coordinate this same effort with the RWIS Plan.

4. Procure up-to-date portable computers for Org decision makers in order for them to access weather and other information resources.

5. Provide all snow and ice control decision makers with access to the Internet for acquiring weather information and forecasts.

6. Provide Org decision makers who have laptop computers with portable telephones that have appropriate jacks for using laptop computers in vehicles or away from the office to access the ADOT Intranet, SBWIS, the ADOT RWIS and forecast products, and Internet weather.

7. Provide all personnel who have or will have Internet access Internet browser software that is Java-compatible. This will permit users to see and use the latest advances in visualizing weather information, such as regional radar loops.

8. Contract with the University of Arizona, for the development of mesoscale forecast products that will enhance the forecasting of winter weather along the transition zone, the Mogollon Rim, and the high country in Arizona.

9. Conduct thermal mapping on state roads to help provide better information for pavement temperature forecasting, especially in areas where no RWIS data exist. Thermal mapping data can help improve pavement temperature forecasting for snow accumulation, freezing rain events, and frost.

10. Begin a library of weather- and snow-and-ice-control-related materials at each Org. Include books at the introductory level.

11. Develop a guide to the availability of weather information in Arizona.

12. If the AASHTO Winter Maintenance Policy Coordinating Committee votes to develop a computer-based training program for snow and ice control, contribute to the pooled fund study.

It is also recommended that ADOT should establish a formally programmed, user driven, and continuous technical training program for snow and ice control. The training goals and objectives should be established. By establishing such a program, consistent practices and procedures can be implemented effectively and efficiently.

All snow and ice control training should fall under the guidance of and be monitored by the ADOT Technical Training Coordinator. To effectively conduct the training, it is recommended that ADOT develop training modules. For instance, snow and ice control training modules should be developed for:

- plowing and spreading techniques;
- operational decision making;
- strategies and tactics;
- communications;
- equipment operations and personal safety;
- equipment inspection and operator maintenance (by type); and
- pre-and post-season snow and ice control activities.

The following is a recommended minimum set of On-the-Job Training topics:

- CDL Acquisition
- ADOT Safety Policies
- Equipment Operation
- Snow and Ice Control Equipment Operation
- Operator Equipment Maintenance Requirements and Procedures
- Snow and Ice Control Operational Procedures
- Route Familiarization Demonstration
- Radio Operations and Procedures
- Personnel Procedure

1. INTRODUCTION

ADOT is responsible for snow and ice control on Interstate highways, as well as US and State Route numbered highways, in Arizona. The processes and procedures for conducting winter maintenance in Northern Arizona have evolved from the early days of just providing snow removal. These current procedures frequently fail to provide the LOS desired by ADOT and its public and commercial road users.

ADOT managers recognized in the early 1990s that technology may help them perform their winter maintenance operations more effectively and efficiently. Seven RWIS sites were installed along Interstate 40 (I-40) from east of Kingman to the New Mexico border. In addition, ADOT contracted for site-specific forecasts of weather and pavement conditions associated with these sites in order to improve the LOS provided to motorists traveling in this corridor during winter weather.

The primary snow and ice control strategy employed by ADOT is the mechanical removal of snow and ice along with friction enhancement. Friction enhancement involves the application of abrasives (mostly cinders in Arizona). The mechanical removal of snow is primarily accomplished by plowing, although in some areas snow blowers may be used when accumulations of snow are significant.

ADOT has also begun to try new snow and ice control strategies in order to increase the level of service for winter maintenance. Anti-icing, including the pretreatment of roadways before or during the onset of a winter weather event with liquid or prewetted solid chemicals, has been tested in some of the maintenance Orgs. The purpose of the pretreatment is to prevent snow or ice from bonding to the pavement. This can facilitate the mechanical removal of snow or ice from the roadway and help provide the motorists with a higher level of service during winter weather events. Currently, ADOT doesn't have the resources to use this strategy in many areas where it could be very beneficial.

ADOT's ability to efficiently and effectively remove snow and ice from roadways is limited due to a lack of snow and ice control operations capability. This is due to both a lack of resources and constraints from outside the agency on the use of chemicals for snow and ice control. Appropriate chemical applications can help break the bond of accumulated snow or ice to the pavement and facilitate the removal of the accumulations.

ADOT also had no established LOS goals for snow and ice control. These are necessary in order to determine if ADOT meets performance goals, and if they don't, what resources are required in order to meet the goals. ADOT, through the MMS contract, attempted to determine the LOS currently provided and the LOS that is desired by the traveling public. The MMS contract described a set of road conditions that are perceived to be currently provided and that are desired. Unfortunately, the contract didn't specify LOS goals, which require the time to attain the pavement conditions, minimum acceptable pavement conditions and their duration, or the spatial distribution by road segment of the desired pavement conditions.

In 1997, ADOT contracted with a team of snow and ice control experts to review existing winter maintenance practices and procedures and to make recommendations to improve snow and ice control. The review process included investigating the following:

- ADOT's use of weather information;
- The location of RWIS sites and plans for new sites;
- Maintenance of the existing RWIS;
- Existing resources and procedures for snow and ice control;
- Maintenance of snow and ice control equipment; and
- Training of personnel involved in winter maintenance.

In addition to these initial tasks, the research team was to use the LOS goals from the MMS contract in order to make recommendations for improving procedures and acquiring resources in order to attain the LOS goals.

The research team gathered information from ADOT personnel through the use of surveys and interviews. The team also participated in meetings with management personnel, conducted literature searches, reviewed current on-going research, and provided assessments based on their personal expertise.

Following the information gathering and analysis, the team provided ADOT with a number of recommendations that needed to be implemented in order to improve the LOS for snow and ice control. These recommendations include new strategies and tactics that will require the use of chemicals to prevent the formation of ice and frost on highways and bridges, prevent the bonding of snow and ice to the roadway surface, and enhance the ability of limited resources to provide more effective snow and ice control.

The information gathered was documented in four initial working papers that dealt with weather information access, ADOT snow and ice control procedures, decision-making processes, and the maintenance infrastructure for snow and ice control in Northern Arizona. Recommendations were documented in six additional working papers.

This report provides the original statement of the research problem and its objective; summarizes the research findings, and documents the recommendations delivered to ADOT that are designed to improve snow and ice control in Northern Arizona. Special attention is also given throughout the analysis and recommendations to the special needs for snow and ice control in the transition zone, the region between the desert valley and the high country of Arizona.

2. PROJECT OVERVIEW

2.1 ORIGINAL PROBLEM STATEMENT

The Arizona Department of Transportation highway maintenance personnel, both decision makers and equipment operators, face difficult weather and road conditions in the wintertime in Northern Arizona. The Interstate 40 (I-40) corridor is a main east-west route for commerce, travelers, tourists, and recreation enthusiasts. From Phoenix to Flagstaff I-17 also is heavily used during the wintertime. Keeping roads open and safe under adverse winter weather conditions has become extremely important.

I-40 from near Kingman in western Arizona to Flagstaff and to Lupton on the East goes through elevation changes of nearly 4000 feet (1200 m). With significant sunshine frequently available, pavement temperatures frequently rise above freezing during the daytime and drop below freezing at night. Moisture on roads, deposited by precipitation, condensation, or melting of snowpack and ice, can freeze back at night. Conditions similar to those on I-40 can also exist on I-17 south of Flagstaff.

Northern Arizona can also be characterized by its significant snow and ice control challenges during the winter. Storms from the west can be extremely moisture laden and produce significant accumulations in the higher elevations. Under cloud cover, pavement temperatures tend to mirror atmospheric temperatures, and significant accumulations of snow can occur on the roads where pavement temperatures are at or below freezing. Some nearby roads may be delayed.

ADOT's highway maintenance personnel in northern Arizona have many challenges in dealing with the weather and road conditions. Snow plow and spreader routes frequently cover long distances, and deadhead times can also be long. The crews apply large amounts of abrasives and chemicals on both I-40 and I-17.

As is the case in most areas, knowledge of existing conditions, as well as forecasts of impending weather and road conditions, are key to successful snow and ice control. In the early 1990s, ADOT installed seven Road Weather Information System (RWIS) pavement and meteorological sensor sites along I-40 between milepost 91 in the west and near the New Mexico border in the east. No systems were installed on I-17.

Data from these sites are collected at a Central Processing Unit (CPU) in Flagstaff. The RWIS provider who currently issues daily pavement and atmospheric forecasts for the seven RWIS sites accesses the RWIS data. Forecasts provide weather and road conditions, including a 24-hour forecast of pavement conditions. The forecasts are provided in textual and graphical presentations to the RWIS CPU in Flagstaff. These forecasts, plus historical and current weather and road conditions are available to maintenance personnel via telephone calls and telephone facsimile. Each Maintenance Foreman that has an RWIS site in his/her area of responsibility has a laptop computer for access to the CPU.

The ADOT Flagstaff District office also receives forecasts from the National Weather Service (NWS) in Bellemont near Flagstaff. The NWS at this time did not have access to the ADOT RWIS data or forecasts. Maintenance personnel also acquire data, especially Doppler weather radar data from the WSR-88D radar in Bellemont, through Internet access. These may be up to an hour or more out of date.

The Kingman and Flagstaff Districts receive weather information from a satellite-based weather information system (SBWIS) feed of NWS information. The weather radar and satellite information can also be slightly out-of-date (up to 30 minutes), but may be useful as decision tools with more continuous monitoring.

When the weather conditions dictate, maintenance personnel typically call District headquarters for daily forecasts first thing in the morning. They request updates every four to eight hours. District personnel will provide pavement temperature information from the RWIS sites to help maintenance personnel decide appropriate actions.

Some maintenance personnel on road patrol also use vehicle-mounted temperature gauges (radiometers) for determining pavement temperatures to assist in determining when and what type of snow and ice control strategy to implement.

However, it is likely that full use of road and weather information is not being made in the decision-making process for planning and implementing snow and ice control strategies. There are a number of reasons this could be true, mostly related to a lack of proper RWIS maintenance and training. Without recurring performance-based training, or following long lapses in RWIS use, personnel forget how to access data and information. Personnel are frequently transferred or promoted and training needs to be conducted all over again for replacements. And, once they have information, they may have forgotten how to integrate it into the decision-making process.

Forecasts being provided by the RWIS provider and the NWS require some interpretation. Without a clear understanding of the message, there is a tendency to “shoot the messenger.” Frequently, a forecast is perceived to be in error when in fact the interpretation of the forecast was not correct. Also, when forecasts are “bad,” users may be turned off and have a tendency to reject future forecasts.

Currently unknown sources of meteorological/environmental information may be available which the maintenance personnel are not using. Such information might also prove to be a valuable source of information for weather forecasters. In a similar vein, the current RWIS installations may not provide the best possible information. Additional RWIS sites might also prove beneficial.

The installed RWIS also requires maintenance. The manufacturer charged over three times per year what ADOT is now paying its own staff to maintain. This current maintenance arrangement may or may not be sufficient to ensure the quality of data required for ADOT decision makers.

ADOT in northern Arizona needs to take advantage of and implement state-of-the-art snow and ice control practices. ADOT needs to combine these practices with the best possible environmental information and appropriate management initiatives in order to provide the best possible level of service to the road users for the chosen ADOT financial investment.

2.2 OBJECTIVE OF THE PROJECT

There was one primary objective of this project. As stated in the Request for Proposal, the "objective of this research is to develop procedures to effectively and efficiently plan and use resources before, during, and after storm events to optimize roadway conditions for safe and efficient travel in northern Arizona. The study will determine the necessary infrastructure, equipment, organizational structure, operational procedures, and training necessary to meet these objectives."

In order to satisfy this objective, there were a number of underlying objectives that had to be met. There are basic resource components (in house and contractual) for snow and ice control: information, labor, equipment, and materials. This research needed to look at these components, along with decision support tools, available to assist ADOT. More specifically, the research needed to:

- Define for ADOT a road weather information system, including operating procedures, which will optimize the decision making process for implementing efficient and effective snow and ice control procedures. RWIS, for the context of this project, considers ALL available weather information from pavement and roadside sensor systems, ancillary data sources, general and tailored forecast support, communications for information exchange, and training of users (decision makers);

- Outline information and procedures that can help improve forecasting of weather and pavement conditions in Northern Arizona.

- Describe the current maintenance, organizational, and cultural structures that exist and recommend policies and procedures consistent with overall ADOT policy and direction that will maximize the effectiveness of the organization for implementing snow and ice control procedures;

- Develop recommended snow and ice control procedures, given the current resources, organizational structure, and organizational culture that will provide the safest and most efficient travel. Develop operating procedures for use by the ADOT personnel.

- Define the optimum equipment requirements necessary to implement effective snow and ice control procedures.

- Recommend state-of-the-art training programs for RWIS use and for snow and ice control operations (equipment operators and decision makers).

2.3 DATA GATHERING

2.3.1 Surveys

Approximately 300 surveys were mailed to 17 Orgs (maintenance yards) with snow and ice control responsibilities in the ADOT districts of Kingman, Flagstaff, Holbrook, Prescott, and Globe, as well as to the District Maintenance Engineers in those same districts; 76 surveys were returned. The purpose of the surveys was to gather information from as many personnel as possible in the various Orgs and Districts in Northern Arizona. Questions were asked relative to weather and road condition information availability and its use; procedures and resources used in winter maintenance; snow and ice control route information; and current training requirements and programs for personnel involved in winter maintenance. The questionnaire is shown in Appendix A.

The main purpose in distributing the questionnaires was to gather information relative to the needs of the project. The information gathered from the questionnaires was then used to develop interview guides.

2.3.2 Interviews

Detailed interview guides were developed to assist researchers in conducting interviews with ADOT maintenance personnel. The interviews were conducted in face-to-face meetings. Personnel interviewed included technicians, Org supervisors, district management staff, equipment services personnel, and Central Office highway maintenance personnel. These people were interviewed sometimes separately, sometimes all together. Although the team preferred to conduct such interviews with the groups separately, the collective sessions worked well thanks to the openness and good working relationship evident through all levels.

Interviews tended to reinforce the survey responses. However, it became apparent that the operators and supervisors don't have many procedural options from which to make operational choices.

In addition to the interviews, three meetings were held with the National Weather Service (NWS) in Bellemont to discuss the availability of weather information and weather problems in Northern Arizona. Discussions included the WSR-88D (NEXRAD) radar data and transmitter siting, the forecasting responsibilities of the various NWS forecast offices, and the division of the State into forecasting zones.

A subsequent meeting was held with the NWS in Tucson and with members of the University of Arizona meteorology staff. The purpose of these meetings was to discuss the availability of special fine-scale forecasting products being produced by the NWS in Tucson.

Four other meetings were held with the ADOT Technical Advisory Committee for the project to discuss project-related issues. These meetings were held both in Northern Arizona and Phoenix depending on the availability of the members.

2.4 DATA ANALYSIS

2.4.1 Weather Information for Snow and Ice Control

Responses to the survey questions on the type of weather information used varied greatly depending on location. Those along the I-40 corridor indicated they used the RWIS information and pointed out its local value. Those with RWIS access pointed out the value of pavement temperature and its forecast. Two Orgs with the SBWIS touted its usability and the availability of radar and satellite data. Those in locations where there is access to television indicated they relied on that medium for information, including information from The Weather Channel for those with cable TV access where the satellite and radar information is used the most. In some remote locations, radio broadcasts were monitored for weather information and ADOT patrols were very common. Someone in almost every Org said they used NWS information.

One person mentioned accessing NWS information from the Internet. Those who use weather information indicated a need for more localized information, additional RWIS sites, and "better" and more accurate forecasts. A few mentioned the need for on-vehicle pavement temperature monitoring equipment.

Currently Installed And Planned RWIS Equipment

In order to address this issue the research team defined RWIS to include all related weather and pavement condition observations and forecasts. This information must always be considered intertwined in the decision processes. Therefore, for the purpose of this investigation, RWIS included:

- Standard in-road and roadside sensors, the remote processing units (RPU), and the communications equipment required for acquisition and dissemination of data;
- The central processing unit (CPU) to which all data and information are transmitted, and from which all data and information are acquired;
- Forecasts of pavement temperature, weather, and road conditions from Value-added Meteorological Services (VAMS) or the National Weather Service (NWS);
- Other weather information from other sources such as SBWIS receivers and processors, weather data vendors such as WSI or Kavouras, and the Internet;
- Weather information obtained from the media, including the Weather Channel;
- Road thermography (thermal mapping); and
- Mobile sensors.

All personnel at one time or another typically access weather and road condition data and information, especially when the weather expected or observed will impact highway maintenance activities. However, by access by whom and how often varies greatly. The following describes the use by category described above.

- In-road and roadside sensor data are accessed by Org supervisors with laptop computers that can retrieve data from the CPU in Flagstaff. District superintendents and engineers access the same information from the CPU using office computers. Data are typically accessed when precipitation is expected to fall. Pavement temperature is usually rated the most important piece of information. Those with laptop computers don't like their monochrome displays, and have limited access to data when not in their office (or home) environment. However, most of the foremen have telephones in their vehicles and can call for weather information.
- RWIS data and information are monitored at the Flagstaff District by dispatchers when they are on duty. The dispatchers can and do relay information to district personnel. The dispatchers become the eyes and ears for weather information during snow and ice situations.
- VAMS forecasts are available to any personnel with access to the RWIS CPU. These forecasts provide 24-hour forecasts of pavement temperature, weather conditions: air temperature, wind speed and direction, dew point temperature, precipitation type and intensity, and any accumulations of snow if greater that 2" are expected. The use of these forecasts varies by individual. Many personnel indicated lack of confidence in the forecasts while others thought the forecasts were fairly accurate. The pavement temperature forecast is used more often than the weather forecasts. Managers in the Flagstaff District tend to rely on the NWS forecasts from

Bellemont. They have more faith in the local forecasts than in the RWIS provider forecasts. Now that the NWS in Bellemont has access to the RWIS information, these same people have increased faith in the NWS information in the short-term. Some managers call the NWS while others will, on occasion, stop in the NWS offices.

- Increased use is being made of ancillary data such as radar and satellite data available from the SBWIS. The SBWIS is user-friendly, presents rather timely information, and can be programmed to provide specific products routinely. Managers with access to the SBWIS rely on its imagery, but point out the lack of site-specific information. Some use is being made of data available on the Internet, but some Orgs have no access due to fiscal and physical constraints. No other access to ancillary weather data was identified. Personnel in Show Low were able to get Internet access in order to obtain weather information. One worker in Fredonia had personal access to Internet weather and provided information to the Org (the Fredonia Org has since obtained a SBWIS). Personnel in Kingman, Prescott, Holbrook and Flagstaff Districts and Orgs were provided Internet addresses to obtain weather information. Internet weather information address “bookmarks’ were set into managers’ computers in Kingman, Prescott and Holbrook Districts to facilitate access.
- Managers without the RWIS and SBWIS systems use the Weather Channel frequently to obtain information. The access to locally important information is not always as quick as needed, but the radar imagery is usually of value. The forecasts are retransmissions of NWS text forecasts and have the same inherent flaws of the standard NWS forecasts. Some local television broadcasts are monitored for weather information, but users have to wait for the standard news broadcasts to get information. No use of NOAA Weather Radio was identified. Although this system is particularly valuable for severe weather situations, this medium provides warnings, watches, advisories, forecasts and observations with only a minor investment required in hardware to procure the radios.
- One Org supervisor has an under-body infrared thermometer mounted on his pickup to monitor pavement temperature. This device has the capability to produce thermal profiles of pavement temperature, and does provide what seem to be reasonably accurate measurements of pavement temperature. No formal road thermography (thermal mapping) program has been implemented in ADOT, although there is some interest in doing so.
- Other mobile sensors are being tried by some Orgs. These include air temperature sensors as well as pavement temperature sensors. The air temperature sensors appear to be very difficult to calibrate and don’t provide accurate information. In reality, pavement temperature sensors provide more meaningful information and are now being tried. Mirror-mounted infrared sensors that measure pavement temperature have been procured for a few trucks and early indications are that operators like to have the information provided. Formal testing should be conducted on these devices to determine their accuracy and applicability.

Forecasts (VAMS and NWS) are disseminated to Org supervisors in the Flagstaff District by dispatchers. The dispatchers will also provide forecast information in response to radio inquiries. Dispatchers in Holbrook and Kingman Districts don’t have access to the RWIS system. Forecasts are sometimes posted at work locations for operators to see. Those Orgs/Districts with SBWIS weather information only have that information available in the office. Consequently operators rarely see forecasts and rely on radio communication to and from vehicles when on the job, and from television or radio in general when not at work.

The use of weather data and information in decision processes for snow and ice control varies considerably from Org to Org because of the availability of or access to information. Some examples of the use of the information are given below.

- Winslow uses pavement temperature forecasts for anti-icing decisions on Little Colorado River bridge;
- Three new RWIS sites for snow and ice control assistance are being installed in the Holbrook area and should provide extremely valuable additional information. These sites are at MP 312 on I-40, MP 291 on SR87, and MP 0 on SR377.
- Winslow also watches the Riordan RWIS forecast and monitors by road patrol the pass on SR 87 by Blue Ridge Reservoir for approaching weather. The new RWIS site going near there should be a big help. On this route there is also a weather station at the service station (gas station) at about MP 290 and the Forest Service, located at MP 300, can be contacted for telephone reports.
- Prescott District personnel indicated they make decisions to implement patrols but need better forecasts: the current forecasts cause them to be deployed too late;
- The quality of telephone lines to Winslow is bad and this sometimes inhibits access to the RWIS.
- Holbrook District would like to see more reliable weather information between Ganado and Window Rock on SR 264;
- Winslow needs additional pavement information from Flagstaff to Winslow and Winslow to Holbrook;
- Many Orgs, such as Little Antelope, Page, Prescott, Flagstaff, and Holbrook are using whatever weather information they can get in order to make decisions to spot treat trouble areas with liquid chemicals or mixtures of chemicals and cinders. Some personnel indicated a reluctance to use liquid chemicals because of past problems with initial slipperiness, so dry chemicals are used when the pavement is wet and problems are anticipated;.
- Most supervisors indicate the weather information they get is most helpful for scheduling personnel and shift determinations;
- Prescott District believes thermal mapping would help understand the nature of severe problems with road conditions during storms, especially if done on other-than interstate routes, and especially in the Mogollon Rim areas;
- Kingman personnel pay attention to the “snow line” forecast because of elevation changes from 600 to 6000 feet in their area of responsibility. They could use pavement temperature forecasts in the Kingman area, too;
- Kingman would also like to see better forecasts that deal with the end of storm conditions.

Typical comments received from ADOT personnel indicate a desire for better weather information in order to make more informed decisions. Examples of suggestions include:

- More pavement and weather sensors in trouble areas;
- More detailed site-specific forecasts. Most current forecasts are too general.
- More pavement-specific forecasts for pavement temperature and conditions;
- Provide more SBWIS access;

- Provide RWIS forecasts and data on the SBWIS;
- Provide Internet access for more weather information; and
- Conduct thermal mapping;

RWIS Site Surveys

All seven sites along I-40 were physically surveyed to determine their representativeness and the utility of their data. In general, it appears that there was careful consideration of siting characteristics and the need for representative observations from each of the sites. District managers had planned to expand the system as money became available. Comments related to each of the sites are contained in Table 1.

Table 1. RWIS Site Comments

SITE NAME	I-40 MILEPOST	SITING COMMENTS	DATA COMMENTS
Fort Rock	91.15	Standard, representative site.	Reason for the site location is not obvious.[1]
Crookton	132.25	Wide open, good representative site.	Road is elevated slightly but data should still be good.
Ash Fork	154.2	Looks like a good site.	Data should be good.
Pine Springs	158.99	In median between widely separated traveled ways, surrounded by pine trees.	Winds may not be as representative as desired due to trees; air temp should be good in the median.
Riordan	190.76	Site is high on south side.	Anemometer is about 20m above pavement, but should be representative for E,W and S winds. Air temp and RH may not be too representative due to height above roadway elevation.
Little Colorado River	256.89	Good site, wide open, very representative.	Data should be good.
Lupton	358.88	Standard RWIS siting along roadside.	Data should be representative of the site but most atmospheric sensors were missing from the tower at the time of inspection.

1. The site is close to high cuts along I-40, has good radio communications. Site was selected by the Kingman Superintendent

RWIS System Support

Early discussions with ADOT highway maintenance personnel seemed to point to a concern about the health of the RWIS along I-40. There appeared to be some disagreement concerning responsibilities to maintain the system.

Follow-on discussion indicated that the system appears to be functioning well (with the exception of the Lupton site which is undergoing extensive repair following a lightning strike two years ago) after the RWIS vendor inspected and calibrated sensors at each location. In addition, the signal technicians from Flagstaff installed replacement sensors and re-set pavement sensors where problems existed.

The general tenor of comments from personnel from Kingman to Holbrook is that the installed RWIS is a valuable tool in helping to make decisions. It just needs to be expanded to cover areas where no information is currently available.

There is a feeling among maintenance personnel that more use could be made of the weather and pavement condition forecasts if these forecasts were "better." In this context, "better" can mean any one of the desires for better information expressed above. There was some indication that because of some bad experience(s) with forecasts, there was reluctance to use forecasts again. Examples of bad experiences include forecasts of up to four inches of snow, no snow occurred, and call-outs of people were unnecessary. Also, poor forecasts or storm duration and end-of-storm conditions had precluded proper resource management and materials usage.

It is apparent that better training in the use of weather information and the installed RWIS equipment could help ADOT decision-makers make better use of the information to which they already have access. Maintenance personnel have been exposed to training in the use of weather information. However there has been little participation and attendance in the training by management. Management participation is crucial to the success of establishing new procedures and implementing new technology. Without management support, interest and participation, from District Engineers to Org supervisors, there is little buy-in at the lower levels. Consequently there is little effort to learn about or use the new tools.

Also, some form of cross-feeding of information on the use of weather information, its use in decision making, and the successes and failures of decisions would help in promoting more effective decision-making. The storm actions taken by maintenance personnel need to be documented to assess how well they are doing and for use in training sessions.

2.4.2 Snow and Ice Control Strategies and Tactics in Northern Arizona

Procedures Used For Snow and Ice Removal

Snow and ice control can be a result of active or passive processes. Most of the ADOT procedures for snow and ice removal are active and are reactions to snow and ice conditions on the roadways. Active procedures in ADOT are most generally plowing of snow accumulations and procedures to improve traction for the road users. Passive procedures include doing nothing if conditions and forecasts warrant, installing snow fencing, letting wind and/or sun clear a roadway, etc.

Plowing

Most of the snow plowing is done with truck-mounted front plows which are capable of clearing a path about eight-to-nine feet wide. Newer plow trucks equipped with front and wing plows can clear a little over a lane width. Occasionally tandem plowing with two trucks is done on the interstates when crews are removing slush or need to remove snow away from the median barrier over several lanes, but the width of most plows restricts the plowing to a little under one complete lane at a time. Once pavement is restored to full width operation, cleanup is accomplished by pushing the shoulders back and clearing other areas. Plowing typically commences after snow begins to accumulate and continues until the desired condition is reached. There are no formal specific goals for this desired condition.

Traction Improvement

In general, the ADOT practice is to improve traction with the application of cinders. Applications may contain various amounts of snow and ice control chemicals, both solid and liquid. Some Orgs use solid chemicals to prevent the stockpile from freezing and to achieve some deicing. At some locations, liquid chemicals are used to prewet the cinders in order to help bond the cinders to snow or ice on the roadway in order to create a higher friction surface. The prewetting of cinders may need to be evaluated to determine its effectiveness as a treatment. A limited amount of direct liquid chemical applications are conducted for anti-icing and spot treatment of certain features, such as bridges, hills, curves, shaded areas, and interchanges.

Passive Measures

A limited amount of activities are passive in nature. These activities include the use of snow fencing, tree removal, and elements of highway design.

Snow fences are used effectively in selected areas, such as the fences on SR 273 to the Sunrise ski area. There are other locations where snow fencing would be beneficial. As an example, operators identified the road segment from MP 218 to 235 on Interstate 40 where snowdrifts frequently exceed plowing capability.

ADOT is also taking positive action to reduce shelterbelts and shadings along roads, particularly along I-40 between Williams and Flagstaff. This reduction improves the ability of sunlight to assist in the removal of snow and ice and to prevent ice spots that result from the shade of the trees.

In some instances, snow and ice control is being considered in design features for highway construction and reconstruction. These features include, for example, highway profiles, slopes, appurtenances, and snow storage areas.

Materials Used In Deicing And Preventive (Anti-Icing) Treatment Programs

Solid chemicals, typically road salt (sodium chloride) and magnesium chloride with other property-enhancing additives, are used separately or in combination with abrasives to conduct deicing, although calcium magnesium acetate (CMA) has been used in Oak Creek Canyon. Mixtures of abrasives and chemicals range from ratios of seven to one down to zero to one (pure chemical). District snow plans provide some guidance on the use of mixes and their application rates. Applications of lower ratios (more chemicals) are restricted to priority locations and areas that do not restrict chemical usage. Existing truck spreader capacity and the length of current truck routes sometimes do not allow for the complete treatment of the road with the mixtures being used.

Liquid magnesium chloride products and CMA are being applied to trouble spots to maintain friction by preventing a bond from forming between snow and ice and the pavement. This facilitates plowing and pavement clearing. Limited trials of straight liquid applications for anti-icing operations have been tried in the Flagstaff District. Liquid magnesium chloride is also being used to prewet abrasives. The effectiveness of this practice should be evaluated due to the nature of the abrasives (cinders). Liquid magnesium chloride has also been tried as a pavement treatment, however some difficulty with initial slipperiness was reported with the use of this material. The resulting slipperiness may have resulted from the additive to the chemical and/or from dilution and freeze back. There is also some indication from other research projects that this initial slipperiness may result from pavement surface contaminants, chemical concentration levels, relative humidity, and/or the addition of any moisture rather than any specific ice control chemical.

Information Used to Influence Decisions and Procedures

Weather information from various sources is used to help with the resource allocation decisions. However, these decisions usually do not go past mobilization of the workers and equipment. Some treatment strategies depend on weather and road conditions and the information available is not always used. Some decision-making shortfalls exist relative to the use of weather information. Supervisors tend to rely heavily on observations of conditions and information from adjacent areas and Orgs rather than forecasts to make decisions.

Types and Amounts of Snow and Ice Control Equipment Available to Implement the Procedures

- *Trucks* The ADOT snow and ice truck fleet is comprised of approximately 238 units. About 34 percent of the fleet is two axle with limited materials spreading range. The average age is about 13.3 years (fall of 1997), with about 71 percent of fleet being 12 or more years old. The fleet suffers from inconsistent replacement purchasing that results in bunches of trucks reaching critical age at more or less random points in time. About 20 trucks (8 percent) have wing plows. Since that time 92 highly capable trucks have gone into service.

  - *Truck Up-time* - Even with the advanced age of the fleet, up time is remarkably good. Exclusive of preventive maintenance the trucks are only down about five percent of the time, based on data from ADOT Equipment Services. This is probably a result of cooperative efforts among Equipment Services and the Orgs. The "incentivized equipment rental rate" program that was initiated in 1996 appears to be contributing to good up time. There is a perception among some supervisors that the down time probably exceeds five percent.

  - *New Trucks* - Specifications for new plow trucks are producing truly first class trucks. The components are all heavy duty and high capacity in order to accommodate the rigors of snow plowing. This should result in better up time, and longer service life. There are many features that make the truck more comfortable and safe for the operator (as it should be for people who routinely spend 12 hours a day driving snow and ice operations).

  - *Truck Retrofit Items* - There are newer technology items that can be purchased and installed that will make the older trucks safer and more user friendly. Four retrofit items are improved windshield wipers, heated side mirrors, defrost fans, and glare-resistant paint.

Most of the older trucks have windshield wipers that are powered by "vacuum" wiper motors. In reality they are most likely compressed air systems. The disadvantage of these systems is lack of full range speed control and maintenance requirements that do not necessarily get priority attention. In a true "vacuum" system, the wipers actually slow as engine speed increases. In some of the older air systems, the lack of sufficient water on the windshield will actually slow the system due to increased friction between the wiper blades and the windshield. If the older trucks without electric wiper systems are to remain in service for any length of time, they should be retrofitted with electric wipers that have a full range of speed control from “mist” to “full.” If those trucks do not have windshield “washer” systems, they should be installed at the same time.

Some state highway agencies are using “winter wiper blades” which are totally encapsulated in a rubber compound to reduce accumulation of snow and/or ice on the articulated metal parts. These blades are available for a modest premium, perhaps as low as $2.00 per blade. Also, heated windshield wiper blades are available which reputedly prevent snow and ice buildup, but may cost over $100 per pair.

Most of the older trucks do not have heated side mirrors. In snow plowing situations, these often become covered with snow and provide no benefit. Heated side mirrors are available and should be installed on all snow and ice trucks. Before adding any electrical component, the capacity of the alternator should be checked to be sure it can handle the increased demand.

The defrost systems on many of the older trucks are not very effective during most snow and ice situations. Auxiliary dash-mounted fans can improve defrosting capability dramatically and should be installed in all snow and ice trucks. Training on cab climate control would also be helpful as some defrost problems result from poor air exchange and having the cab too warm.

In order to minimize glare from the various light sources on the truck, all surfaces (truck and plow) the operator can see should be painted flat black or flat blue.

◦ *Utilizing Smaller Trucks* - ADOT has a fair number of small dump and other trucks (< 26,000 lbs. GVWR) in the fleet. Those that are not already equipped with plows and various materials spreading equipment, as in Flagstaff District, could be equipped to do special plowing of ramps, intersections, crossovers, parking lots, etc., and special materials spreading (liquids on bridges, cold spots, intersections, etc., abrasives on grades and intersections, etc.). By virtue of being under 26,000 lbs. GVWR, these trucks do not require a CDL operator. This does not preclude the need for adequate operator training.

◦ *Red Tag Issues* - There is some diversity of opinion of what makes a truck unfit for snow and ice operations. Equipment Services has developed a list of deficiencies that are serious enough to cause a vehicle to be not road worthy. In addition, an operator can request that a vehicle be pulled from service for identified deficiencies. From the interviews, it appears the list of deficiencies is not being applied uniformly from district to district.

- *Plow Equipment* ADOT has a variety of plow equipment attached to its fleet of snow and ice trucks. The plow equipment configurations could be improved to increase efficiency and effectiveness.

Wing Plows - As indicated earlier, only a small percentage of the plow trucks are equipped with wing plows. However, most new trucks have wing plows. Wing plows allow more efficient clearing of the highway and the capability of benching and pushing back to accommodate future snowstorms. Wing plows are a very cost-effective investment. Based on Equipment Services’ close work with field personnel, the procurement policy for new plow trucks allows the receiving Org to specify wing plows as required.

◦ *Front Plows* – Inputs from operational personnel indicate that plowing speeds are sometimes greater than the speeds suggested in operational guidelines. This is due to operators' need to plow at speeds close to the prevailing traffic flow to avoid becoming a low-speed traffic hazard. Relatively high-speed commercial traffic occurs on many ADOT roads in inclement winter weather. The geometry of most of the plows is not well suited for high speed plowing. There is not enough curvature or "funneling" in the moldboard and there is not enough rake angle to start an efficient flow process, particularly in drier snows. When using reversible plows, this is a necessary trade-off in order to cast snow reasonably well in both directions. However, this results in a fair amount of blow-over in spite of the existing containment shrouds added to the top of the moldboard. Blow-over contributes to impaired driver visibility caused by the airborne snow particles in the driver's line of sight, snow accumulating on windshield wipers, backscatter of light from high-mounted plow lights and headlights, and abrasives loading on the windshields. The newer plows are significantly improved in this area.

◦ *Matching Plow Equipment to the Task* – a high-speed one-way front plows with a right wing plow is the most effective plow configuration for the majority of ADOT work. Power reversible front plows (with left and right wing plows) are appropriate for plowing the outside lanes on multi-lane highways, ramps, and interchanges. Their utility does not go much beyond that. In fact, a left-casting high-speed front plow would be more effective in the median lane situation, provided there is adequate median width, but would not be of much use anywhere else.

- *Spreading Equipment* ADOT currently uses V-box spreaders in both single and dual rear-axle dump trucks for applying abrasives and chemicals. On some of the spreaders the truck exhaust system is routed through the hopper to warm the materials. Some of the newer trucks also have saddle tanks for liquid prewetting materials. The ability to apply materials in sufficient quantities is frequently limited due to the material carrying capacity in the smaller trucks in the fleet.

The new spreading equipment that is currently being purchased is very adequate. The necessity and expense of warming the hopper with engine exhaust has been questioned. The original method of running a single tube down the center of the hopper caused material bridging in the bottom of the hopper. Next, an S-shaped tube was installed in the hoppers to provide more heat distribution, however, the exhaust heating influence in the material was very localized. The newer trucks with exhaust being infused into the sides of the hoppers and with holes in the braces for exhaust distribution have eliminated the localized heating and material bridging in the hoppers. The results of recent discussions between ADOT maintenance personnel and Equipment Services indicated the heating process would be continued. The personnel who don't want the heating system in operation can simply disconnect it.

All new spreaders contain prewetting systems using saddle tanks. Based on interviews, few operators understand the use and operations of the prewetting system. In addition, the ADOT Technical Training Institute's *Snow and Ice Control Guidebook* needs significant revision to accommodate newer system capabilities and new snow and ice control technology.

- *Loaders* Loaders are located at both Org and satellite locations for loading and reloading of materials and the mixing of abrasives and chemicals. The number of loaders is adequate to perform the basic required functions, but presupposes no equipment breakdowns. A few swing loaders or loaders available from the Central District exist but are not used due to equipment rental costs. In the past, ADOT also rented loaders when needed from outside equipment rental companies.

Most loaders are stored out-of-doors and are not protected from the elements. Some operator time is lost in starting equipment in the remote areas under harsh conditions. This can result in damage to loaders if they are used without sufficient warm up. In some cases, loaders have been left running unattended for long periods of time and occasionally until fuel runs out. This can also damage engines if engine speed is not high enough to provide proper lubrication.

Review of Districts' Snow and Ice Maintenance Plans

A review of the District snow and ice control plans shows that there is some commonality among the plans but there is obviously no standard format. It is therefore difficult in some cases to find the level of detail required for analysis of resources and procedures. Topics covered in the various District plans are shown in Table 2.

Given that some of the topics in Table 2 overlap and may be hard to identify from one plan to another, the table does show the differences in snow plans from one district to another. It appears that a standard format, perhaps suggested in a state snow and ice control plan, would provide a framework for consistency among plans. The plans also need to define their purpose and audience to be reached and be crafted accordingly.

Routine and Special Strategies for Snow and Ice Control

Some roads are being closed to permit maintenance activities under severe conditions. This occurs primarily on interstate highways and is a proactive strategy to minimize the potential for accidents and prolonged road closures.

Snow blowers are routinely employed in certain areas due to high amounts of snowfall. However, there are relatively few snow blowers in the ADOT inventory. Blowers are very expensive to have and operate due to the high rental rate from Equipment Services. Each district is equipped to move snow blowers to satisfy urgent needs.

Level of Service

Level of Service (LOS) for snow and ice control refers to operational guidelines establishing maintenance activities associations with the prevention and removal of snow and ice from the roadways. LOS may establish a prescribed end-of-storm condition, intermediate stages acceptable while obtaining that condition, or the frequency of snow and ice control maintenance operations. ADOT is currently in a process of establishing a LOS for snow and ice control that satisfies the customers' needs. This process, once refined, will aid in defining the budget, resources, and strategies that are necessary for a comprehensive snow and ice control program in Northern Arizona. The status of this process, plus measures of effectiveness to be used in evaluating how well the LOS is being provided, are described below.

The current LOS for snow and ice control in ADOT is undefined in measurable terms. This limits the ability to define resources and strategies that are necessary for a comprehensive

Table 2. District Snow Plan Contents

Topic[1]	Maintenance District Globe	Flagstaff	Holbrook	Kingman	Prescott
General (Purpose)		X		X	
Snow and Ice Control Policy	X	X	X	X[2]	X
District Map	X		X	X	X
ADT Map		X	X		
S&IC Priorities	X		X	X	X
Priority in Operations	X	X	X[3]	X	X
Operational Guidelines	X	X	X		X
Equipment Available for Snow Removal	X			X	X
Equipment/Personnel Route Assignments	X	X[4]	X	X	X
Route Maps		X			
Supervisor –Emergency call out lists				X	X
Material Management Zones				X	X
Deicing Agent Spread Rate				X	X
Snow Plowing and Sanding	X	X	X[5]	X	X
CG-90 SS Liquid Applications				X	
Weather and Road Condition Reports	X	X	X	X	X
Road Closure Details	X	X	X	X	X
Ice Alert Signing		X		X	X
Highway Closure and Inspection Procedures	X	X	X	X	X
Miscellaneous Road Closures		X	X		X
Chain, 4-Wheel Drive, or Snow Tire Control Policy	X	X	X	X	X
Accident/Incident Notification		X	X	X	X
DPS Requests for Rerouting Snow Plows	X	X	X		
Stopping for Vehicles Off the Road		X			X

[1] Actual topic title may vary between district plans
[2] Contained in above topic
[3] Although the title is similar to the above, the material is different
[4] No equipment shown for routes in Flagstaff Org
[5] Very limited discussion

Table 2. District Snow Plan Contents (continued)

Topic[1]	Globe	Flagstaff	Holbrook	Kingman	Prescott
Abandoned Vehicle Removal Requests	**X**	**X**	**X**	**X**	**X**
Emergency Response Clarifications for ADOT	**X**		**X**		
Snow Removal Notification Procedure	**X**		**X**		
Reporting an Accident			**X**		
Information on Accident for DPS			**X**		
ADOT Radios with DPS	**X**				
Radio Call List		**X**			**X**
10-Code			**X**		
Repeater Number for Base Station			**X**		**X**
Emergency Radio Dispatching Schedule		**X**	**X**	**X**[2]	
District Phone Extensions			**X**	**X**	**X**
Emergency Support Personnel Numbers		**X**	**X**	**X**	**X**
Emergency Support Numbers (other agency)		**X**	**X**	**X**	**X**
Org Snow Removal Information			**X**		
Section Maps			**X**		

1. Actual topic title may vary between district plans
2. Provides names of radio monitors

snow and ice control program. Also missing are measures of effectiveness to be used in evaluating how well the LOS is being provided, although a process is evolving.

The current ADOT LOS process is to record the LOS in terms of pavement condition at various points in time. The conditions are shown in Table 3.

In order to establish a level of service, ADOT is assessing the duration of LOS at LOS 2 and lower. Measurements of duration begin at LOS 2 and will continue until LOS 1 is reached. These measurements will establish baselines for improvement in the snow and ice control LOS by reducing the duration of LOS 3 and below. Seasonal road closures are not measured, although snow and ice control activities prior to or after a seasonal closure are measured.

Table 3. Current ADOT Levels of Service for Snow and Ice Control

Level of Service	Description
LOS 1	**Dry**
LOS 2	**Wet** (Minor snowfall or rainfall is occurring, visibility is slightly affected, and there may be isolated icy spots on the roadway)
LOS 3	**Ice** (Traffic has slowed down due to visibility and road conditions. There is ice and/or snowpack on the roadway)
LOS 4	**Chains Required** (Chains are required, visibility is severely limited, drifting is prevalent throughout section)
LOS 5	**Road Closed**

Figure 1 shows the form provided to the Districts for obtaining LOS information. The following guidance was sent to the Districts following the TAC approval for completing the form.

- A six-hour storm with one inch per hour snow accumulation was to be used as a basis for LOS analysis and subsequent resource determinations for snow and ice control.

- The time to achieve the end-of-storm LOS Goal (condition 2.0) was to be based on route priority as defined in the State Plan.

- The time to achieve that goal would be as follows:

Priority I	4 hours
Priority II	6 hours
Priority III	12 hours
Priority IV	No time specified.

- Each District was to provide the priority for each route using the form shown in Figure 1. They were to fill in each column except the one on the far right. That one would be completed by the project team.

District: ______________________ **Org:** ______________________

Route	Mileposts		AADT	Cycle Time		Min. Acceptable Pavement Condition During Storm	Desired Time to Attain LOS Goal at End of Storm
	From:	To:		Plowing Applications	Materials		

Figure 1. ADOT Level of Service Data Base Form

Issues Identified

The research team identified a number of items not specifically addressed in the Proposal or the Work Plan for this project. The issues identified with these items follow.

- *Personnel*

ADOT highway maintenance personnel who perform snow and ice control activities are highly motivated to perform their work in a professional manner. However, there are a number of demotivating factors affecting the overall efficiency. First, the wage scale for the maintenance technicians is well below that for comparable workers in local government agencies in Arizona and surrounding states with similar snow and ice control problems. Many times the technicians need to maintain multiple jobs in order to maintain subsistence-level existence. Consequently, overtime pay is considered an expected benefit of the job. That reduces the potential for proactive, efficient, and effective decision-making.

Secondly, operator, supervisor and manager training are neither formally programmed, user driven, nor continuous. Consequently, supervisors and managers receive no feedback or evaluative information on the performance ability and knowledge of their personnel. Without a formal training program, there are no goals or objectives established for training. Frequently, workshop and training sessions on new technology is not well received or adopted due to limited access to the minimum necessary resources. Any such technology training would also be better received if management were participating in the training and would then show interest in implementing new technology or ideas. There is no standardized on-the-job training (OJT) for either equipment operators or the snow and ice control procedures. This contributes to some of the equipment problems. Training program recommendations are provided in Section V.

Thirdly, there is no formal career ladder that could motivate personnel to seek advancement. The skill-certification process may alleviate this problem if it’s tied to monetary compensation.

- *Highway Design*

The research team identified issues that need to be considered for highway design, construction and reconstruction. For instance, rutting of road surfaces is occurring, especially on primary and secondary state highways. This creates unique snow and ice control problems as well as safety issues related to trapped water on the pavement. Rutting may result from insufficient highway structure or excessive wear.

Additionally, some highway delineators and safety appurtenances are being placed too close to the traveled way at some locations. Some delineator posts are also too weak to withstand the snow load from plowing action and shorter posts get covered by snow. Some guardrail is placed too close to the roadway and fills up at the base too quickly with cinders. This can prevent the runoff of water and can cause refreezing. In some locations the guardrail probably cannot be moved.

It should also be noted that when ADOT changed the cross-section of SR 89 north of Flagstaff and widened it to five lanes with flatter slopes, the drifting problems on this highway seemed to be reduced. A review of this effort might provide insight for future road design, construction, and reconstruction.

- *Resources Issues*

Equipment and staffing levels generally result in two to four hour cycle times, but in some cases, cycle times can reach six hours. These staffing levels may be adequate for spread-only operations, but are probably insufficient for clearing moderate to heavy snowfall. The staffing was developed to provide maintenance for one inch per hour snowstorms. Staffing and equipment issues, along with LOS goals, are addressed in Section V.

In addition, reducing cycle times in some areas will require the addition of satellite stockpiles and loaders to maximize the ability to apply materials.

The current staffing level also permits two operators per truck per 24 hours only if everyone shows. There may some opportunity to modify operator assignments once the LOS is specified for all areas. Currently there is also some redistribution of resources for the snow and ice control season. Extra personnel are available in the traffic maintenance Orgs. However, they are usually in the Central or District Headquarters areas. Flagstaff District has also borrowed personnel for the winter maintenance season from the Phoenix District.

2.4.3 Snow and Ice Control Resources

In order to evaluate the equipment resources available for snow and ice control, the project team gathered information from the District Snow Plans, contact with District personnel, and from ADOT records. Table 4 lists the equipment available for snow and ice control in the five districts, by Org (1997-1998).

The ADOT snow and ice control truck fleet was comprised of 238 units in the initial count. This included plow and spreader trucks, equipment for liquid applications, and loaders. This does not include equipment that can be leased from ADOT Equipment Services in Phoenix. About 20 percent of the fleet is two-axle trucks with five-yard material capacity. This limits the material spreading range to half that of the three-axle, ten-yard capacity trucks. Most newer trucks have wing plows. The equipment shown in the table does not include road graders and dozers.

Even with the advanced age of the fleet, up time is remarkably good. According to Equipment Services records, exclusive of preventive maintenance, the trucks are only down about 5 percent of the time. This means most of the equipment is typically available for snow and ice control. Interviews with operators, however, indicate that the operational availability of the equipment deteriorates with the length of a storm and the subsequent snow and ice cleanup. What begins with better than 90 percent of the equipment operational at the start of a storm, becomes about 75 percent after 24 hours. After 48 hours, mechanical problems become even more apparent due to the age of the equipment. The loss of equipment impacts the lane miles required of the remaining equipment and the work level of the operators on the road.

Table 5 lists the staffing for each of the Orgs. Orgs are typically staffed with two maintenance personnel for each snowplow truck, plus foremen and secretaries who should not plow. This results in Orgs in heavy snow areas being staffed with more FTEs than would

Table 4. Snow and Ice Control Equipment[1]

Org	2-Axle Trucks	3-Axle Trucks	Loaders	Other
HOLBROOK DISTRICT				
Holbrook	4	4	2	2 Water tanks[2], loaders
Winslow	3	5	2	
Kayenta	3	5	3	
Keams Canyon	3	2		Additional spreader[3]
Ganado	4	3	2	
Chambers	3	4	2	
KINGMAN DISTRICT				
Kingman	3	4	3	1 deicer truck
Seligman	4[4]	3	3	1 deicer truck
Needle Mountain	2	2	2	1 spreader, no plows
Wikieup	2	2	2	2 snowplows, 3 spreaders
PRESCOTT DISTRICT				
Prescott	2[5]	5	2	2500 gal deicer truck
Cordes Junction	2[4]	3	3	
Wickenburg	1	1	2	
Payson	3[4]	6	3	
GLOBE DISTRICT				
Globe	3[6]	2	2	1 water truck, anti-icing
Roosevelt		3	4	
Superior	1	2	2	1 13-yd dump truck
Indian Pine		6[7]	2	13yd dump +1 snowblast[7]
Show Low	3[6]	4	3	1 13-yd dump truck
St. Johns	2	2	3[8]	1 13-yd dump truck
Springerville	2[6]	5	3	1 Unimog
FLAGSTAFF DISTRICT				
Flagstaff	1	7	3	1 snowblast
Williams	2[4]	7	2	1 trk for liquid chemicals
Gray Mountain	1[9]	3	2	
Little Antelope	2[4]	5	4	
Page	3	2	2	
Fredonia	3[5]	2	3[10]	1 snowblast
District Pool	2		1	
Equipment Svcs		1		

[1] Equipment list comes from equipment billings, list of snow equip. from Equipment Svcs and from Superintendents

[2] Holbrook has two additional trucks 1500 gallon water tanks which can be used for applying snow and ice control chemicals; two additional loaders are in the District pool.

[3] Keams Canyon additional spreader is a v-box sand spreader for a small truck.

[4] Plus one Mack snowplow truck

[5] Plus one 1-ton truck and 1 Mack snowplow truck

[6] Plus one 1-ton with plow and spreader

[7] Plus one boot truck for anti-icing

[8] St. Johns shares a loader with Holbrook

[9] Plus two Mack snowplow trucks

[10] One loader is located in Littlefield

Table 5. Organizational Staffing[1]

HOLBROOK DISTRICT			
Org	**FTEs Allowed**	**FTEs Filled**	**Admin**[2]
Holbrook	15	11	0
Winslow	16	13	0
Kayenta	12	12	1
Keams Canyon	10	9[3]	0
Ganado	12	12	0
Chambers	12	11	0
Org. 8769	9[4]	8	3
KINGMAN DISTRICT			
Kingman	16	13	1
Seligman	14	14	1
Needle Mountain	12	10	1
Wikieup	11	11	1
PRESCOTT DISTRICT			
Prescott	16	16	1 sec'y[5]
Cordes Junction	14	12	1 sec'y
Wickenburg	10	9	1 sec'y
Payson	17	17	1 sec'y
GLOBE DISTRICT			
Globe	13	12	1
Roosevelt	11	11	1
Superior	11	11	1
Indian Pine	15[6]	12	1
Show Low	16[7]	14	1
St. Johns	12[8]	10	1
Springerville	15[8]	14	1
Org. 8369	4	3	0
FLAGSTAFF DISTRICT			
Flagstaff	17	17	1
Williams	17	18[8]	1
Gray Mountain	14	14	1
Little Antelope	17	15	1
Page	12	12	1
Fredonia	12	12	1
District Pool	5	5	0

[1] Staffing information was obtained from district administrative services or supervisory personnel.
[2] Administrative Support. Secretaries counted in FTEs.
[3] Two temporary employees.
[4] Includes two transport drivers with CDLs
[5] Secretaries not included in FTEs in the Prescott District
[6] Org with three seasonal employees
[7] Orgs with two seasonal employees
[8] Allowed 5% overfill

normally be needed to support the highway maintenance feature inventory and more personnel than needed to perform the summer work. Some Maintenance Engineers therefore hold off on filling vacant positions until late summer or early autumn. They then train the new hires for winter snow and ice control work. Depending on the winter storm burden on the Org, this may not afford enough time to fully train new people for the arduous winter tasks.

This staffing arrangement does not provide for illness or other loss of personnel during the winter and can lead to snow and ice control equipment not being utilized during winter storms. Additional workers are or can be made available. In some cases, additional personnel have been obtained from Phoenix Maintenance for the winter. Most districts have additional personnel with CDL's who could plow snow, e.g., transport drivers, and vegetation control and striping crews. These employees should be trained in snow removal and the operation of snowplows. In some cases, help can also be obtained in the Flagstaff, Holbrook, Prescott, and Globe Districts from sign and striping crews where there may be CDL-qualified workers.

The lane mile requirements for snow and ice control vary significantly depending on the climate of an area, the types of roads, the available equipment, and the location of stockpiles. Due to variations in snow plans between districts, it was not always readily apparent what equipment was assigned to a particular route. Conversations with supervisors ironed out most of the uncertainty.

From what could be gleaned from the snow plans for Orgs along I-40 and I-17, lane miles per truck route were distributed as shown in Table 6. The lane miles per truck route on I-40 ranged from an average of about 42 miles in Winslow to about 85 miles in Seligman. On I-17, the lane mile averages ranged from approximately 111 in Little Antelope to approximately 144 in Cordes Junction. Some of the Interstate routes included in the averages above also included some distance on state routes. Additionally, in reality some of the routes are longer because the operator had to travel to the route starting point. For example, if the distance to a route start were included in the calculations for Holbrook, the average would be about 56 lane miles. And, in reality, if there is snow or ice on the road, and a material application is required, the truck operator en route to a starting point will usually perform the required operation on the way to the assigned route.

Some of the lane-mile requirements for non-Interstate highways are confounded, unless analyzed carefully. For example three routes out of Payson on SR87 are 22-24 lane miles, but begin as much as 26 miles from Payson.

Some routes are just plain long. For example,

- The truck route on SR264 out of Keams Canyon is 171.6 lane miles long.
- The truck route north out of Ganado on US191 is 166.6 lane miles long.

These route assignments result in extremely long cycle times. At 40 mph driving speed, the cycle times are greater than 4 hours. These cycle times can increase further in snow and ice situations.

From the map in Figure 2, it is clear that the heavy snowfall areas are located along a swath of higher elevation stretching from north central Coconino County through Flagstaff, and then east-southeast along the Mogollon Rim to the White Mountains. Although the scale of the map

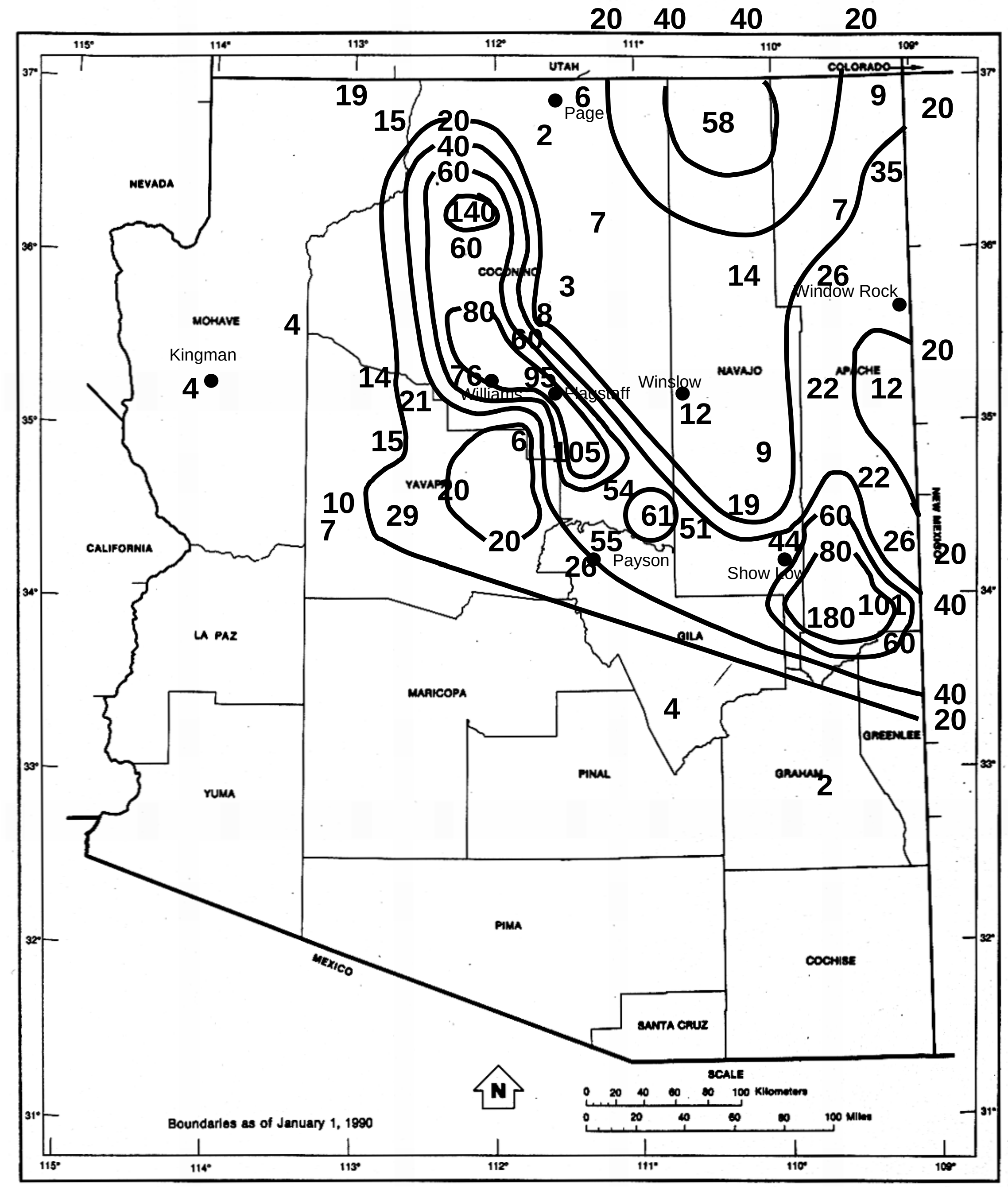

Figure 2. Average Annual Snowfall in Arizona

Note: The map was created using data obtained from the Office of the Arizona State Climatologist. The isolines are increments of 20 inches of annual snowfall, beginning with 20 inches. Detail is NOT provided in those locations where very large annual snowfall amounts are recorded, such as Jacob Lake and Hawley Lake.

doesn't permit analysis in detail, it is evident that the I-40 corridor begins receiving its heaviest snowfall from Ash Fork eastward to somewhere near Winona. There are also regions of heavier snowfall in northern Navajo County and northeastern Apache County.

In order to analyze resource allocations fully, one has to know the level(s) of service for highway segments. Until such time as a basic level of service is established by route, the staffing and equipment resources required to meet that level of service cannot be determined. An analysis of the snow plans resulted in a determination of the average lane miles per truck route on Interstate routes. These data are presented in Table 6 and discussed subsequently.

Table 6. Average Lane Miles per Truck Route on Interstate Routes[1]

Maintenance Org	Truck Route Lane Miles	Remarks
Chambers (I-40)	48	
Holbrook (I-40)	48	Includes Business 40
Winslow (I-40)	42.5	Assumes 4 3-axles on 40
Flagstaff (I-40)	47	Ranges from 36-58[2]
Williams (I-40)	66[3]	Ranges from 16 - 79
Seligman (I-40)	85.2[4]	Ranges from 70-103[5]
Kingman (I-40)	59.6	Ranges from 48-73
Little Antelope (I-17)	111	Ranges from 92-162
Cordes Junction (I-17)	144	Ranges from 104 to 184

1. Computed, where possible, from District Snow Plans
2. The Flagstaff Org has one 10-wheeler used as a "rover" on I-40 covering over 44 interstate miles, with significant winter weather usually occurring on about 25 or those miles. The truck can also take care of TIs as required.
3. Two routes of 79 and 78 lanes miles are covered by two trucks each for an effective 39.5 lane mile average.
4. Four the two dual-axle trucks on I-40.
5. Two routes out of Seligman require 37 – 44 miles of travel on I-40 prior to their truck routes of 96 and 36 lane miles, respectively, both with single-axle trucks.

The numbers show some snow and ice control routes that appear to be unusually short (lane miles) with probable short cycle times, while others have inordinately long routes with very long cycle times. Some of these long cycle times are increased by the locations of existing stockpiles. In some cases, the cycle time is further increased because smaller single axle trucks cover the routes with half the load capacity than the dual axle trucks.

When comparing the results in Table 6 with the average snowfall data, the resource allocations for the I-40 corridor appear reasonable if the only consideration is snowfall data. However, during wintry conditions, truck routes of 85 lane miles may result in over 3-hour cycle times. The routes on I-17, however, especially for Little Antelope, appear very long.

2.4.4 RWIS Maintenance Infrastructure

<u>Interviews with Signal Maintenance Personnel</u>

- No records are kept of RWIS maintenance and/or the status of the system.
- Overall system maintenance appears to be good at this point.

    - One pavement sensor has “popped out” and needs to be replaced;
    - A number of surface sensors needed to be “re-glued” and they’ve been taken care of by highway maintenance;
    - Two precipitation sensors needed to be replaced; that has been taken care of by the signal technicians.
    - One mountaintop radio repeater site was down for a while, but has been fixed.
- Historically, very little time is given to the RWIS maintenance. Attention is devoted to traffic signals and RWIS ends up on the bottom of the agenda.
- One signal technician recommended that one full-time technician devoted to the RWIS would be the proper level of maintenance to be provided by ADOT.
- Some problems go uncorrected for a long time. The Lupton site went down (due to lightning) “about 1.5 years ago”, the parts are in to fix it, it is on the agenda to fix, but awaits converting to the same configuration as the Coastal Environmental sites to be installed in the Holbrook District.
- It was reported that vendor-provided maintenance prior to 1995 kept the system going, but at a significant cost to ADOT.
- The signal tech plans to do preventive maintenance and inspection work every six months, especially checking bearings on anemometers. This does not include sensor calibration.
- If compared with vendor-provided maintenance, the current site maintenance was originally described as “marginal at best.” It now appears to be adequate with the repairs done in the last two-three months. The “in-house” maintenance can tend to be unresponsive due to concerns for the health of the traffic signals and the associated liability. It’s a real dilemma with more and more signals going in and more and more liability issues.
- The office equipment, which includes the central processing unit, software, and remote terminals, is maintained by the Information Services person at Flagstaff and appears to be in good operating condition.
- No formal maintenance training has been provided to anyone maintaining the system. The signal technicians do have a full set of maintenance manuals to work from.

Interviews with Highway Maintenance Personnel

Interviews with highway maintenance personnel shed little light on the RWIS maintenance quality. There was consternation expressed in Holbrook with respect to the lightning strike that destroyed much of the electronics at the Lupton site. The impression left with the interviewers was that they believed the original vendor should fix the system because it must have been poorly protected from lightning. The interviewees also indicated that the site would be repaired by the signal technician(s) and a second RWIS vendor who won a contract to install three new RWIS sites in that District. (In an interview with a signal technician it was revealed that the new vendor was actually under contract to upgrade the site to their configuration).

It was disclosed in one other interview that one surface sensor at the Riordan site had been overlaid with asphalt concrete and was inoperable.

In order to use RWIS effectively, proper hands-on training in a scenario-based setting is generally accepted as the best mechanism. Such performance-based training has been used elsewhere effectively in developing anti-icing programs. The RWIS sites along I-40 were installed in 1993. Prior to the 1993-1994 winter the RWIS vendor provided initial operator training, i.e., the initial introduction to the system. This included instruction on what data are available from the system, and how to use the terminals and software to access data displays and forecasts. There was no real hands-on training and no training was provided on the system software or communications. Subsequently, the RWIS vendor provided some general weather training. Also, prior to the 1997-1998, ADOT contracted with Mr. Bob Blackburn to conduct some decision-based training based on the work he'd been doing with the Nevada DOT.

From evaluating the survey responses and the interviews of personnel, it is apparent there is a varied ability to fully utilize the RWIS data and products available. Most personnel recognize the utility of the pavement temperature and the pavement temperature forecast. Some don't use the system at all because of difficulty in accessing the system remotely. When away from an office/home environment, data are only available by talking to someone with access. Some of the individuals with the laptop computers didn't like to use them because of their monochrome display.

It is also apparent that the ADOT highway maintenance people who use the information don't put much faith in the forecasts they receive. There seems to be more acceptance of the NWS forecasts because the users can "call up the forecaster" in Bellemont. They find comfort in being able to talk to the forecaster. There has been no effort to do the same with VAMS forecasters even though the provider encourages such dialogue and provides an "800" number for that purpose.

Another problem with fully utilizing the RWIS lies in the relative lack of options available to the decision makers. Although anti-icing is being tried and tested, the capability is limited to a few locations where some liquid application capability exists. With manpower and equipment constraints, when anti-icing is being conducted, a standard plowing/spreading resource is unavailable.

Where anti-icing is not conducted, options are usually whether to apply abrasives or plow, or both, although some snow and ice control chemical capability does exist. Therefore, the major decisions center on when to call out people and when to implement plowing and spreading. These decisions usually are not based on RWIS information, although one Org indicates they plan to call out people with a 50 percent chance of snow forecast. From that point on, the practice is typically to keep at the work (plowing and spreading) until the roadways are near bare pavement. There are few efforts to use the information available to assist in attaining this informal level of service, such as monitoring forecasts of pavement temperature and clearing skies (during the day) for sufficient warming to assist in clearing the roads.

Information from the RWIS Vendor

In 1995, ADOT received a bid from the vendor to provide a service contract for the RWIS. The cost of that proposal was $22,000, and included annual inspections of each site, preventive maintenance (PM) at each site, and corrective maintenance as required. In 1995 that proposal also included repair of any damage caused by lightning. ADOT deemed the service contract to be too expensive and arranged for the in-house maintenance currently being conducted by the signal technicians in Flagstaff. There was never any training on system maintenance provided by the vendor, nor was any requested.

The cost to ADOT to maintain the system with the current policy is difficult to determine because very little maintenance has been conducted. ADOT did contract with the RWIS vendor to conduct an annual check and PM at each site prior to the 1997-1998 winter. The vendor conducted an annual preventive maintenance service at the seven RWIS sites along I-40 in November 1997. The cost for this maintenance was approximately $4,500.

The RWIS vendor identified the following RWIS problems:

- Two failed subsurface probes that the vendor would replace under warranty.
- The overall condition of the surface sensors as "poor. Immediate attention should be given to specific sensors …"
- One failed and one failing precipitation sensor; and
- One additional overlayed sensor at Lupton.

The responsibility for repair and service of the RWIS was not clearly defined initially. The damaged system consisted of roadside electronics, roadside and roadway hardware (including surface and subsurface sensors), communications, central computer equipment and software, and display terminal hardware and software. Numerous pavement sensors required re-epoxying, including re-epoxying of cables in Kerf cuts. The issue was resolved when ADOT highway maintenance agreed to fix the problems with the pavement sensors and signal maintenance was able to get some of the system up and running.

2.4.5 Level of Service (LOS)

Part of the information needed to address operational procedures resides in the LOS to be provided by highway maintenance personnel. Since this project focuses on procedures for winter maintenance operations, the LOS for snow and ice control from the Dye Management Group maintenance management system report was to be used.

Unfortunately, the information from that report was insufficient to conduct a meaningful analysis. The Dye process involved the use of photographs that showed five levels of service ranging from bare pavement (LOS 1) to closed roads (LOS 5) [1]. The surveys and interviews resulted in a desired LOS goal of 1.5 compared with a perceived current LOS of 2.1. In other words, people expected close to bare pavement. However, there was no indication of when this goal was expected to be achieved, e.g., how long after a storm? There was also no indication of a minimum acceptable LOS during a storm. Finally, there was no indication of what LOS is applicable to the various highway type classifications or descriptions. Certainly near bare pavement is not expected nor is it achievable everywhere.

Additional information was requested from each of the five Districts with snow and ice control responsibilities in northern Arizona. The project team developed an average winter storm scenario and presented that and other assumptions to the project's Technical Advisory Committee (TAC). As a result of that TAC meeting, each District was asked to complete a LOS form so that the team could assess resource needs with respect to the desired LOS for given road segments.

The team, with TAC approval, used an average storm scenario of one inch of snow per hour for six hours. The Districts were also presented a suggested set of end-of-storm goals based on roadway priority from the District Snow Plans. These goals and requests for other information were sent to the Districts for their response. The resulting data helped define LOS goals for snowplow routes in the five Northern Arizona Districts. The goals for the storm scenario are presented in Table 7.

Table 7. Level of Service Goals

Priority	Highway Description	Level of Service Goal
1	Interstate and other controlled access highways and freeways	Substantially free of loose snow, ice, and pack two hours after end of storm
2	Moderate volume U.S. numbered routes and state routes	Substantially free of loose snow, ice, and pack six hours after end of storm
3	Low volume state routes	Substantially free of loose snow, ice, and pack twelve hours after end of storm
4	Very low volume state routes	Plow and treat only after storm; patrol as required
5	Seasonal roads	Patrol as required

In order to meet the primary objective of this research, the research team had to look at the following areas:

- The use of weather information for snow and ice control
- Snow and ice control strategies and tactics;
- Decision making processes;
- Resources available for winter maintenance;
- RWIS siting and equipment maintenance; and
- LOS issues.

The team analyzed the various interactions between these areas and developed a set of recommendations that would provide ADOT with the capability to improve its snow and ice control procedures and processes in order to provide an improved level of service.

3. RWIS IN NORTHERN ARIZONA

3.1 RWIS HARDWARE

RWIS hardware consists of two major components: the roadside monitoring equipment, hereafter referred to as RWIS sites; and equipment, both hardware and software required to acquire other weather information, e.g., observations and forecasts of weather and pavement conditions, and ancillary weather products (radar and satellite imagery). The primary focus of this section will be the RWIS sites.

In 1993 ADOT installed seven RWIS sites along I-40. These sites are listed in Table 8 and are shown in Figure 3. In 1998, ADOT installed five additional RWIS sites, three in the Holbrook District in northern Arizona and two in the Safford District for monitoring blowing dust conditions. The Holbrook sites are listed in Table 9 and are shown in Figure 4.

The procurement specification for the new RWIS equipment required that the system be compliant with the Environmental Sensor Station (ESS) National Transportation Communications for ITS Protocol (NTCIP). The only vendor who indicated their equipment was NTCIP ESS compliant was Coastal Environmental.

One result of the second RWIS site procurement was the acquisition of equipment that was not compatible with the existing hardware and software. The older RWIS is a proprietary system based on a closed architecture. This system, originally designed for airport installations, had not yet evolved to an open system where multiple sources of information could be intermixed in a statewide highway environment.

Table 8. First Seven RWIS Sites Along I-40 in Northern Arizona

District	Name	Milepost
Kingman	Fort Rock	91.15
Kingman	Crookton	132.25
Flagstaff	Ash Fork Hill	154.2
Flagstaff	Pine Springs	158.99
Flagstaff	Riordan	190.76
Holbrook	Little Colorado River	256.89
Holbrook	Lupton	358.88

Table 9. RWIS Sites Added in 1998 in Northern Arizona

Name	Highway	Milepost
Clints Well	SR 87	291
Heber	SR 377	0
Painted Desert	I-40	312

Figure 3. Location of First Seven RWIS Sites along I-40 (Red Dots) per Table 8

Note: Locations are only approximate due to the base map and software used.

Figure 4. Location of First Seven RWIS Sites along I-40 (Red Dots) Plus Three New Sites Added in 1997-1998 (Blue Dots) per Table 9.

Note: Locations are only approximate due to the base map and software used.

Table 10. Road Weather Information System Sites (ITS Plan)

PRIORITY	DISTRICT	DESCRIPTION	STATUS
1	Flagstaff	I-17 @ MP 307	
2	Flagstaff	I-17 @ MP 314	
3	Flagstaff	I-40 @ MP 206	
4	Holbrook	I-40 @ MO 312	**Done**
5	Holbrook	SR87 @ MP 291	**Done**
6	Holbrook	SR 377 @ SR277	**Done**
7	Safford	I-10 @ MP 365	**Done**
8	Safford	I-10 @ MP 387	**Done**
9	Flagstaff	I 40 @ MP ___	
10	Holbrook	SR77 S. Holbrook	
11	Holbrook	SR264 @ Ganado	
12	Holbrook	SR264 @ Keams Canyon	
13	Holbrook	US160 @ Tuba City	
14	Holbrook	US64 @ Teec Nos Pos	
15	Flagstaff	SR89 N. Flagstaff	
16	Flagstaff	SR64 N. Williams	
17	Flagstaff	I-17 S. Flagstaff	
18	Flagstaff	I-17 @ Stoneman Lake	
19	Kingman	SR66 @ Peach Springs	
20	Globe	US60 @ Springerville	
21	Globe	SR77 @ Show Low	
22	Globe	US180 @ St. Johns	
23	Globe	SR77 S. of Holbrook	
24	Globe	SR260 @ Pinedale	
25	Globe	SR260 @ Heber	
26	Prescott	SR89 S. Ash Fork	
27	Prescott	SR89 N. Prescott	
28	Holbrook	I-40 @ Sanders	
29	Holbrook	I-40 @ New Mexico Line	
30	Holbrook	I-40 West of Sanders	
31	Holbrook	I-40 W. of Holbrook	
32	Holbrook	I-40 E. of Winslow	
33	Holbrook	I-40 W. of Winslow	
34	Holbrook	SR87 S. of Winslow	
35	Kingman	I-40 S SR89	
36	Kingman	I-40 E. of Kingman	
37	Kingman	US93 N. of Kingman	
38	Safford	I-10 West of Bowie	
39	Safford	I-10 @ New Mexico Line	
40	Tucson	I-10 N. of Tucson	
41	Safford	I-10 E. of Tucson	
42	Safford	I-10 @ I-19	
43	Safford	I-19 Btwn Nogales and Tucson	
44	Yuma	SR95 @ Parker	
45	Holbrook	SR77	

Table 10. Road Weather Information System Sites (ITS Plan) (continued)

46	Holbrook	SR264 @ Window Rock	
47	Holbrook	SR264 W. of Oraibi	
48	Holbrook	SR264 E. of Tuba City	
49	Holbrook	US160 E. of Kayenta	
50	Holbrook	US160 @ US191	
51	Safford	SR80 (20mi. Spacing)	
52	Safford	SR80 (20mi. Spacing)	
53	Safford	SR80 (20mi. Spacing)	
54	Safford	I-10 Btwn Wilcox & S. Simon	
55	Safford	SR181 Chir. Nat'l Mon.	
56	Safford	US191	
57	Safford	SR266 E. of Bonita	
58	Safford	US70 @ Duncan	
59	Safford	SR78 S. Morenci	
60	Safford	USFS Road	
61	Kingman	I-40 @ US93	
62	Kingman	I-40 @ MP 110	
63	Kingman	SR66 @ MP 117	
64	Kingman	SR68 @ MP 12	
65	Tucson	I-8 (40mi. Spacing)	
66	Tucson	I-8 (40mi. Spacing)	
67	Tucson	SR77 N. of Tucson	
68	Tucson	SR386 (Bottom)	
69	Tucson	SR386 (Top)	

As a result of the system incompatibility, two sets of central computers are required to access data from the sites. User software to access the data is also different. Therefore, the process for decision makers to acquire data is very cumbersome and in many cases, precludes the use of potentially valuable information.

Figure 5 shows the original 1997 ITS statewide plan for RWIS sites. As developed by ADOT's Transportation Technology Group, the site locations from the ITS plan are listed in Table 10. The following criteria were used in the identification of proposed RWIS sites:

- Elevations over 4000'
- Locations where predictive information would be beneficial
- Locations, that by history, districts deem advantageous;
- Key point where initial icing occurs
- Non I-40 locations, to track storms.

Inputs were requested from the five Districts regarding their need and recommendations for new RWIS sites. These sites are shown in Figure 6. Their locations are specified in Table 11. Changes have been made to the ITS Plan (Table 10) by some of the Districts. These changes are shown in boldface type. For example, there are two sites in the Holbrook District that have locations shown in the "New List" column with boldface type. These sites have been moved from the previous ITS locations. There are also six sites shown with "2008" in the same column. The specific locations were not identified since these locations are not programmed until FY 2008.

Sites that have been recommended by the Districts that are in addition to the ITS plan are shown in italics. Also, any additional information beyond that contained in the ITS Plan is also shown in italics.

Some sites from the original ITS plan have been dropped. Those ITS sites from Table 11 that are not included in the recommendations have "NO" shown in the column labeled "New List." These sites are also shown in Figure 7 with an X over the sites.

3.2 OTHER CONSIDERATIONS

Thermal mapping, the development of temperature profiles of roadways (road thermography) under various conditions, can be an important tool in the development of an RWIS plan. One of the best uses is to identify locations for RWIS sites. Thermal mapping can also be used to identify selected sites that are representative of other sites and therefore one or another site could be eliminated. Thermal mapping typically pays for itself in siting analysis alone, not including benefits accrued from more precise forecasting with thermal mapping information available to forecasters. The thermal mapping allows for forecasts of pavement temperature where there are no pavement sensors in place.

Adequate communications are necessary for the successful implementation of RWIS. If data cannot be acquired routinely, data may not be available when most needed. The current communication system for the existing RWIS is unreliable. Any upgrade of the existing RWIS and any addition to the current RWIS needs to consider developing reliable communications.

3.3 BENEFIT-COST OF RWIS

There are both direct and indirect costs associated with snow and ice control and RWIS usage. The direct costs for snow and ice control are the resources required (equipment), materials used (chemicals and abrasives), and labor. Indirect costs (or savings) for snow and ice control include increased mobility for travelers and throughput for commerce, reduced accident rates, decreased insurance premiums, reductions in costs to industry due to tardiness or inability to get to work, reductions in fuel consumption, and cleaner air with the reduced fuel consumption and increased mobility.

The costs of RWIS need to consider the costs for the hardware for the sites and associated data collection and processing capabilities, communication for acquiring and disseminating RWIS data and information, the purchase of site-specific tailored forecasts, and the maintenance of the system. If thermal mapping is included, that cost needs to also be considered.

Most studies in this country have been directed toward comparing direct costs of snow and ice control with the costs of RWIS. There have been varied results, but the SHRP RWIS project indicated benefit cost ratios of up to 5 to 1 for RWIS use [2]. This means for every dollar spent for RWIS, five dollars are saved in direct snow and ice control maintenance costs. Another study from Minnesota looked at implementing a statewide RWIS that would be comprised (originally) of over 200 sites. Looking at life cycle costs, which included communications, maintenance, training, and the additional personnel to monitor and conduct those functions, Minnesota calculated the entire system would be paid back in savings in six years.

Figure 5. Locations of Planned RWIS Sites Added from the 1997 ITS Plan (Green Dots)

Table 11. Road Weather Information System Consolidated Site Listing for Northern Arizona

ITS PRI.	ITS NO.	DISTRICT	ITS DESCRIPTION NEW LIST DESCRIPTION	NEW LIST
1	--	Flagstaff	I-17 @ MP 307 *(Barrier Wall)*	***MP 313***
2	--	Flagstaff	I-17 @ MP 314 *(Rocky Park)*	***MP 315.58***
3	--	Flagstaff	I-40 @ MP 206 *(Winona)*	***MP 212***
4	--	Holbrook	I-40 @ MO 312	**NO - Done**
5	--	Holbrook	SR87 @ MP 291	**NO - Done**
6	--	Holbrook	SR 377 @ SR277	**NO - Done**
9	--	Flagstaff	I 40 @ MP *Bellemont*	MP 185
--	--	Holbrook	*I-40 @ MP 270*	*MP 270*
10	29	Holbrook	SR77 S. Holbrook	MP 371
11	39	Holbrook	SR264 @ Ganado	MP 463?
12	40	Holbrook	SR264 @ Keams Canyon	MP 367
		Holbrook	US160 @ Jct SR564	*MP 374±*
13	43	Holbrook	US160 @ Tuba City	**NO**
14	46	Holbrook	US64 @ Teec Nos Pos	MP 450+/-
15	47	Flagstaff	SR89 N. Flagstaff *(Summit)*	MP 431.3
16	48	Flagstaff	SR64 N. Williams *(Tusayan)*	MP 233
17	49	Flagstaff	I-17 S. Flagstaff *(Kelly Canyon)*	MP 330.5
--	--	Flagstaff	US89 @ Rossman Hill	MP 536
--	--	Flagstaff	US89A @ Jacob Lake	MP 579.4
--	--	Flagstaff	*US160 @ Cow Springs*	*MP 354*
18	50	Flagstaff	I-17 @ Stoneman Lake	MP 306.3
19	52	Kingman	SR66 @ Peach Springs	MP 108
20	23	Globe	US60 @ Springerville	**NO**
--	--	Globe	SR273 @ Sunrise	*MP 377.6*
21	24	Globe	SR77 @ Show Low	**NO**
22	25	Globe	US180 @ St. Johns	**NO**
23	26	Globe	SR77 S. of Holbrook	**NO**
24	27	Globe	SR260 @ Pinedale	**NO**
25	28	Globe	SR260 @ Heber	MP304.2
--	--	Globe	SR191@Hannagan Meadow	MP 225.0
26	56	Prescott	SR89 S. Ash Fork	**NO**
27	57	Prescott	SR89 N. Prescott	**NO**
--	--	Prescott	SR87 @ Hefner Cut	*MP 281.9*
--	--	Prescott	*SR 260 @ Gordon Canyon*	*MP 286.9*
--	--	Prescott	*I-17 @ Copper Canyon*	*MP 280.6*
--	--	Prescott	*SR69 @ Bullwhacker Hill*	*MP 275.2*
--	--	Prescott	*SR80 @ Top of Pines*	*MP 306.5*
--	--	Prescott	*SR89A @ Mingus Mountain*	*MP 336.7*
28	30	Holbrook	I-40 @ Box Canyon	MP 345.25
29	31	Holbrook	I-40 @ New Mexico Line	US 191-345
30	32	Holbrook	I-40 West of Sanders	MP 331
31	33	Holbrook	I-40 W. of Holbrook	MP 294
32	34	Holbrook	I-40 E. of Winslow	US 191-448
33	35	Holbrook	I-40 W. of Winslow	MP 230
34	36	Holbrook	SR87 S. of Winslow	MP 330

Table 11. Road Weather Information System Consolidated Site Listing for Northern Arizona (continued)

--	--	Flagstaff	*SR64 @ Reservation Boundary*	*MP 278*
--	--	Flagstaff	*SR98 @ Kaibito*	*MP 331*
--	--	Flagstaff	*SR15 @ Virgin River Canyon*	*MP 14.0*
--	--	Flagstaff	*SR15 @ Black Rock*	*MP 27.0*
--	--	Flagstaff	*I-40 @ Monte Carlo*	*MP 149*
--	--	Flagstaff	*SR 89 @ Cedar Ridge*	*MP 505*
--	--	Flagstaff	*SR 89 @ Big Cut*	*MP 528*
--	--	Flagstaff	*SR 89A @ Midgley*	*MP 376.0*
--	--	Flagstaff	*SR 89A @ Rim Camp*	*MP 390.0*
--	--	Flagstaff	*SR 98 @ Summit*	*MP 344.0*
--	--	Flagstaff	*SR 180 @ Kendrick Park*	*MP 236*
35	51	Kingman	I-40 S SR89	MP 354
36	54	Kingman	I-40 E. of Kingman	MP 66
37	55	Kingman	US93 N. of Kingman	MP 48
45	37	Holbrook	SR77	2008
46	38	Holbrook	SR264 @ Window Rock	2008
47	41	Holbrook	SR264 W. of Oraibi	2008
48	42	Holbrook	SR264 E. of Tuba City	2008
49	44	Holbrook	US160 E. of Kayenta	2008
50	45	Holbrook	US160 @ US191	2008
61	53	Kingman	I-40 @ US93	**NO**
62	58	Kingman	I-40 @ MP 110	MP 110
63	59	Kingman	SR66 @ MP 117	MP 117
64	60	Kingman	SR68 @ MP 12	MP 12
--	--	Kingman	I-40 @ MP 82	*MP 82*

Figure 6. Locations of Planned RWIS Sites from the ITS Plan (Green Dots) with Added Input from the Five Northern Arizona Districts (Violet Dots).

Figure 7. Locations of Planned RWIS Sites from the ITS Plan (Green Dots) with Added Input from the Five Northern Arizona Districts (Violet Dots), Old ITS Sites Crossed Out.

In nearly all cases, the reduction in snow and ice control costs are related to labor (reduced overtime) and reductions in materials usage, particularly chemicals. The latter saving is typically related to anti-icing or pretreatment where the amount of chemicals can be reduced by as much as 50% compared to deicing. Amounts of abrasives can be reduced by 75%. These savings are related to the quality of the weather and pavement condition forecasts and the ability of the decision makers to make correct decisions based on the RWIS information. For a strategy such as plowing with friction enhancement (abrasives), the savings might be considerably less and the benefit-cost ratio lower.

Some states find even greater savings using RWIS for other maintenance decision needs, such as vegetation control, painting and striping, and pavement maintenance and repair. The information is also useful for construction decisions, too. The benefit-cost ratio could increase significantly if direct costs (savings) from these functions is considered.

Indirect costs need to be another consideration. A major study in Europe showed a benefit-cost ratio of 5 to 1 for indirect costs. These indirect costs were identified above. Studies in this country and in Canada have also showed significant reductions in accidents (costs) using deicing chemicals appropriately and through anti-icing.

If ADOT adopts a chemical priority policy in areas where appropriate and possible, the potential for lowering both indirect and direct costs for snow and ice control will likely be greater.

As indicated above, thermal mapping costs may also need to be included but results from thermal mapping projects have indicated that, by finding one redundant RWIS site that can be replaced the staff can typically pay for the cost of thermal mapping.

3.4 RECOMMENDED RWIS FOR NORTHERN ARIZONA

ADOT has developed a well-thought out RWIS site location plan that when fully implemented will provide adequate and appropriate information to its snow and ice control managers. ADOT should continue to pursue acquisition of RWIS hardware for those sites described in Table 12 and shown in Figure 7. The Table does not include sites with Xs in Figure 7. The key to successful implementation will require the involvement of the ADOT Snow and Ice Control Manager and the District RWIS Coordinators.

ADOT should develop an RWIS specification for equipment designed to meet the agency needs. This specification can then be included as a line item in maintenance or construction contracts, a specification for ADOT RWIS acquisition, or as a stand-alone RWIS acquisition tool for use by local contractors if ADOT chooses to acquire hardware using this method.

In addition to management oversight, successful implementation will require appropriate training of ADOT personnel, from first line decision-makers to Org and District supervisors and managers. Such training should not just include how to turn on equipment, acquire data, and describe what types of data are available; the training should be scenario-based performance based and preferably interactive using either computer-based or web-based training. The training program that is recommended by the research team is described in Chapter V.

Table 12. Recommended Road Weather Information System Sites for Northern Arizona

ITS PRI.	ITS NO.	DISTRICT	SITE DESCRIPTION	LOCATION
1	--	Flagstaff	I-17 @ MP 307 (Barrier Wall)	MP 313
2	--	Flagstaff	I-17 @ MP 314 (Rocky Park)	MP 315.58
3	--	Flagstaff	I-40 @ MP 206 (Winona)	MP 212
9	--	Flagstaff	I 40 @ Bellemont	MP 185
--	--	Holbrook	I-40 @ MP 270	MP 270
10	29	Holbrook	SR77 S. Holbrook	MP 371
11	39	Holbrook	SR264 @ Ganado	MP 463?
12	40	Holbrook	SR264 @ Keams Canyon	MP 367
		Holbrook	US160 @ Jct SR564	MP 374±
14	46	Holbrook	US64 @ Teec Nos Pos	MP 450+/-
15	47	Flagstaff	SR89 N. Flagstaff (Summit)	MP 431.3
16	48	Flagstaff	SR64 N. Williams (Tusayan)	MP 233
17	49	Flagstaff	I-17 S. Flagstaff (Kelly Canyon)	MP 330.5
--	--	Flagstaff	US89 @ Rossman Hill	MP 536
--	--	Flagstaff	US89A @ Jacob Lake	MP 579.4
--	--	Flagstaff	US160 @ Cow Springs	MP 354
18	50	Flagstaff	I-17 @ Stoneman Lake	MP 306.3
19	52	Kingman	SR66 @ Peach Springs	MP 108
--	--	Globe	SR273 @ Sunrise	MP 377.6
25	28	Globe	SR260 @ Heber	MP304.2
--	--	Globe	SR191@Hannagan Meadow	MP 225.0
--	--	Prescott	SR87 @ Hefner Cut	MP 281.9
--	--	Prescott	SR 260 @ Gordon Canyon	MP 286.9
--	--	Prescott	I-17 @ Copper Canyon	MP 280.6
--	--	Prescott	SR69 @ Bullwhacker Hill	MP 275.2
--	--	Prescott	SR89 @ Top of Pines	MP 306.5
--	--	Prescott	SR89A @ Mingus Mountain	MP 336.7
28	30	Holbrook	I-40 @ Box Canyon	MP 345.25
29	31	Holbrook	US 191 @ (Nr) Witch Wells	MP 345
30	32	Holbrook	I-40 West of Sanders	MP 331
31	33	Holbrook	I-40 W. of Holbrook	MP 294
32	34	Holbrook	US 191 @ (Nr) Many Farms	MP 448
33	35	Holbrook	I-40 W. of Winslow	MP 230
34	36	Holbrook	SR87 S. of Winslow	MP 330
--	--	Flagstaff	SR64 @ Reservation Boundary	MP 278
--	--	Flagstaff	SR98 @ Kaibito	MP 331
--	--	Flagstaff	SR15 @ Virgin River Canyon	MP 14.0
--	--	Flagstaff	SR15 @ Black Rock	MP 27.0
--	--	Flagstaff	I-40 @ Monte Carlo	MP 149
--	--	Flagstaff	SR 89 @ Cedar Ridge	MP 505
--	--	Flagstaff	SR 89 @ Big Cut	MP 528
--	--	Flagstaff	SR 89A @ Midgley	MP 376.0

Table 12. Recommended Road Weather Information System Sites for Northern Arizona (continued)

--	--	Flagstaff	SR 89A @ Rim Camp	MP 390.0
--	--	Flagstaff	SR 98 @ Summit	MP 344.0
--	--	Flagstaff	SR 180 @ Kendrick Park	MP 236
35	51	Kingman	I-40 S SR89	MP 354
36	54	Kingman	I-40 E. of Kingman	MP 66
37	55	Kingman	US93 N. of Kingman	MP 48
45	37	Holbrook	SR77	2008
46	38	Holbrook	SR264 @ Window Rock	2008
47	41	Holbrook	SR264 W. of Oraibi	2008
48	42	Holbrook	SR264 E. of Tuba City	2008
49	44	Holbrook	US160 E. of Kayenta	2008
50	45	Holbrook	US160 @ US191	2008
62	58	Kingman	I-40 @ MP 110	MP 110
63	59	Kingman	SR66 @ MP 117	MP 117
64	60	Kingman	SR68 @ MP 12	MP 12
--	--	Kingman	I-40 @ MP 82	MP 82

ADOT needs to upgrade its original seven RWIS sites along I-40 in order to make them state-of-the-art and compatible for the free-flow exchange of data. The new RWIS in northern Arizona also needs to be upgraded. Having two Central Processing Units (CPUs) at Flagstaff is not only cumbersome but limits access to important data. A single ADOT server should be the goal for current and future data acquisition from RWIS sites. Data should be accessible from the central server by managers and supervisors via Internet, the ADOT Intranet or dial-up telephone access. This upgrade specification should be identical to any specification developed by ADOT for new RWIS sites.

ADOT needs to consider alternate means of RWIS communications. Due to the extremely remote areas of Arizona, where radio or cellular telephone communications are currently limited, consideration needs to be given to using local telephone access to Internet Service Providers or to using Low Earth Orbiting Satellite (LEOS) communication in order to acquire data from remote RWIS sites. A communications analysis needs to be a part of formal site surveys that are conducted for each new site. A similar analysis should be conducted for existing sites with communication problems. Communication costs need to be considered an important aspect of the acquisition of new sites and should be included in life cycle cost analysis for each site.

Due to the nature of the technology, and after the problems experienced with in-house RWIS hardware maintenance, any RWIS acquisition should include service contracts beyond the warranty phase of a purchase. The service contract should include annual (at a minimum) preventive maintenance as well as provisions for on-site maintenance within an appropriate time period from notification of equipment problems.

In order to fully maximize the ADOT RWIS plan, a few additional RWIS sites are recommended.

Prescott District

1. Locate one or two additional sites on SR 260 at top and bottom of the hill east of Christopher Creek. This could be one site with pavement sensors near the top and the bottom of the hill. Consider moving the Gordon Canyon site west to this location.

2. Select one problematic bridge in the transition zone on each of SR 87, SR 89, and I-17. The installation should have pavement sensors on the bridge decks and approaches to the bridges as well as a suite of atmospheric sensors. Data from these sites would be used for frost prediction and treatment. Thermal mapping could indicate one or two locations that would suffice.

Globe District

Select one problematic bridge in the transition zone on US 60. Install, at a minimum, pavement sensors on the bridge deck and approach(es) to the bridge. Data from this site would be used for frost prediction and bridge deck snow and ice control treatments. The District should also review the sites identified on the original ITS Plan that are not included in Table 12 (see Figure 7) to determine if indeed one or more of these sites should be revived.

Flagstaff District

The District should consider moving the site identified at Bellemont to Parks (MP 178) or at the ADOT Rest Area (approximately MP 180) in order to provide better information for forecasters monitoring upslope meteorological conditions west of the divide. If there is a specific additional need near Bellemont, for instance monitoring wind and pavement conditions for blowing snow and icing, then perhaps an additional site near Bellemont needs to be considered. An additional consideration could be the installation of a lower-cost system at either location to monitor atmospheric conditions and a fully compatible RWIS with pavement sensors at the other.

The District shows two sites on I-17 (Barrier Wall and Rocky Park) that are to be located approximately 2.5 miles apart. A formal site survey should determine if these sites can be combined into one using remote-reporting pavement sensors for pavement conditions and if the meteorological information from one location is applicable to the other. Thermal mapping could also assist in this analysis.

The District should also add two sensor suites on SR 89 at Oak Creek Canyon north of Cave Spring. This could be one RPU site with pavement sensors near top and bottom of hill if the system installed can remotely monitor pavement sensors.

All Districts

In addition to the above additional site recommendations, and as recommended in earlier Working Papers, ADOT should conduct thermal mapping along:

- I-40 from Kingman to the NM state line;
- I-17 from Camp Verde to Flagstaff;
- SR 87 from Payson to Clints Well;

- SR 89 from Prescott to Ash Fork or SR89A on the Oak Creek Canyon Hill;
- SR 260 from Payson Ranch to Heber; and
- US 60 from Show Low to Springerville/Eagar to determine best locations for RWIS. It is likely there is redundancy in sites currently on the list, especially along I-40.

The possible redundancy arises from sites having similar meteorological and pavement temperature characteristics. The cost of any thermal mapping will be amortized quickly by not installing one or two sites. Thermal mapping will provide important information for pavement condition forecasters for frost or ice formation and snow accumulation. There can be operational benefit from thermal mapping for decision makers who can review thermal profiles to determine areas of concern or non-interest.

Prescott and Globe Districts each indicate a need for an RWIS along SR 260 near Heber: Prescott at MP 286.9 and Globe at MR 304.2. The Districts should analyze their needs, given that Holbrook has installed a site at Heber on SR 377, MP 0.2, to determine if the Heber site will satisfy their needs. Indications from vegetation at this location are that the moisture level is not representative of the area just to the West. Thermal mapping could assist in this analysis.

ADOT District maintenance and construction need to coordinate plans. Maintenance should overlay the RWIS plan onto construction plans. Where construction programs coincide with planned RWIS siting, the District should include a requirement in the plan for the installation of an RWIS. The Federal Highway Administration (FHWA) has indicated that RWIS is eligible for the same cost sharing that is used for FHWA-funded construction. For example, if the project is a “90-10” cost sharing project, then the RWIS installation is eligible for 90% funding by the FHWA. This provides additional rationale for ADOT to develop a standard RWIS specification. There should also be consideration for replacement of pavement sensors when resurfacing pavement.

Each ADOT District should coordinate its RWIS plan with the counties and municipalities in its area of responsibility. It is likely that one or more of the agencies would be interested in participating with ADOT through a partnering arrangement. Site locations can possibly be moved slightly to provide information for county roads or city streets. These agencies can also reap the benefits of better decision information. And through a partnering arrangement, costs can frequently be shared and the cost to ADOT could be reduced.

Partnering arrangements can usually prorate the costs in a particular area. For instance, an agency may participate in the installation of a site, e.g., paying 20% of the cost of that site, in order to access data from that site and perhaps obtain forecasts for that site. Then that agency could also pay 20% of the costs to maintain that site, 20% of the cost of the communications, and 20% of the cost of the forecasts (if the same forecast is used). These partnering arrangements typically work out to be win-win arrangements. ADOT personnel just need to find the right “hot buttons” to push. The ADOT LTAP program has provided many of these agencies with some insight into RWIS technology and its benefits.

ADOT maintenance should coordinate the RWIS plan with the ADOT Aeronautics Section. Frequently the aeronautics people have their own plan to install or upgrade weather equipment at state-owned, operated, or monitored airports. Many times these airport weather sites could be used by highway personnel and vice versa. There are plans for an Automated Surface Observing System (ASOS) IV. ASOS IV is similar to the current ASOS III but has pavement sensors added for runway (and could be for collocated highway) monitoring. An ASOS IV system has been tested. If fielded, there is opportunity for and additional justification for an integrated statewide system, one with costs shared by the aviation and surface transportation sectors.

In a similar vein, ADOT should coordinate the final plan with the National Weather Service (NWS) office in Bellemont. It is assumed that data from all planned RWIS sites would be accessible to the NWS. There is a possibility that some federal funds from the Department of Commerce through the NWS might be available to establish additional weather monitoring sites in the remote areas of Arizona. Additional data for the NWS are important for forecast preparation, forecast verification, and radar data ground truth. As in the case of other highway agencies, ADOT instrumentation from planned sites, or sites with some slight adjustments of planned ADOT siting, could satisfy NWS needs. There may also be some opportunity to have the NWS share in the communications costs from certain sites.

It is not without precedent for the private sector to partner with a government agency. One such arrangement had a (very) large corporation paying for forecasts provided to a state DOT. The corporation recognized the benefit to them and their employees to get a better level of service for snow and ice control. The trucking industry might be a willing partner.

There may also be partnering opportunities with other entities such as the Bureau of Indian Affairs, Native American nations, Bureau of Land Management, National Forest Service, National Park Service, ski areas, etc. All of these agencies have some need for weather information.

Other RWIS-related recommendations are described in Section V under Weather Information for Snow and Ice Control.

4. SNOW AND ICE CONTROL STRATEGIES AND TACTICS

4.1 SNOW AND ICE CONTROL STRATEGIES

The following describes a generic set of snow and ice control strategies and tactics that can be accomplished by any of the ADOT Districts. In some cases, additional resources are required in order to implement fully these procedures. These resources are identified in Section V.

There are four basic strategies used in snow and ice control:

- Anti-icing
- Deicing
- Mechanical removal of snow and ice together with friction enhancement
- Mechanical removal alone.

The anti-icing strategy is designed to prevent the bonding of snow or ice to a roadway surface by use of timely applications of snow and ice control chemicals. This strategy can keep pavement bare in cases where frost or black ice might otherwise form. It can also increase the efficiency of mechanical snow or ice removal because of lack of bonding to the pavement. It can also make passive snow and ice control (e.g., do nothing more) work where surface and air temperatures are expected to rise above freezing and accumulations of snow or ice will melt.

Deicing is the use of chemicals to assist in the removal of snow or ice that is already bonded to pavement. Because of the higher chemical demand (energy) required to break the bond of ice to pavement, deicing typically requires the use of four to five times more amounts of snow and ice control chemical than does anti-icing.

Mechanical removal of snow and ice together with friction enhancement requires that abrasives (cinders, sand, etc.) be applied to snow or ice already bonded to pavement. The snow or ice can already be partially removed by plowing or scraping. Abrasives alone cannot be effective for either anti-icing or deicing.

Mechanical removal alone refers to the physical removal of snow or ice accumulations by plowing, scraping, brooming, blowing, etc. It involves no chemical or abrasive applications.

4.1.1 Goals

The goal of anti-icing is to maintain a high level of service or attain a level of service more quickly through the applications of chemicals to prevent snow and ice bonding. As such, an anti-icing strategy is well suited for highway routes with a high snow and ice control priority, provided the appropriate resources are available for maintenance forces. Anti-icing can be used for frost or black ice prevention. It can also be used in advance of a weather event where snow or thin ice is expected and the application of the chemicals produces a wet surface where falling precipitation either melts or can be removed efficiently because it has not bonded to the surface. Anti-icing can involve the use of one or many applications of chemicals during a storm in amounts less than that required for deicing operations, depending on the pavement and weather conditions.

The goal of deicing is to assist in the removal of accumulations of snow or ice where there is bonding to the pavement. Deicing of a snow accumulation can produce a mealy substance that is relatively easily removed from the pavement. It can also facilitate ice removal when applications follow scraping. Deicing can involve one or many applications during and after a storm depending on the pavement and weather conditions.

The goal of mechanical removal of snow or ice with friction enhancement is to provide a level of mobility by removing accumulated snow and ice and improving the friction available for road users. This usually requires applications of abrasives following the physical removal passes and frequently requires multiple treatments depending on the nature of the event and pavement conditions.

The goal of a snow and ice control strategy that involves mechanical removal alone is to physically remove significant accumulations of snow and ice without the use of snow and ice control chemicals or abrasives.

4.1.2 Conditions for Implementing Strategies

Anti-icing utilizing pretreatment usually involves the application of a liquid chemical or prewetted solid chemical (limit prewetted solids to lower speed and volume highways) in anticipation of events that would cause snow or ice to bond to and accumulate on a surface. This strategy can be used for the occurrence of frost or black ice on bridge decks or roadways. It can also be used in advance of a weather event. Current state of the practice and recent research findings suggest that when using liquid chemicals to prevent frost or black ice, the chemicals should be applied sufficiently far in advance of the expected or probable occurrence that the liquid water evaporates and leaves a chemical residue on the surface. This means no later than midday for expected occurrences at night. For precipitation events, liquid chemicals may be applied within a couple of hours of when precipitation is expected to occur and should NOT be applied if the onset of the precipitation event is expected to be rain. Rain will dilute the application and make it ineffective. Prewetted solids or straight solids can be applied at the time of precipitation. In all cases, the existing and forecast pavement temperature should be in a range suitable for the chemical being used.

Solid and prewet solid chemicals may also be used to support anti-icing by pretreating and treating very early in a storm. This pretreating with solid or prewet solid chemicals should be limited to low-speed and low-volume highways.

Deicing typically involves the application of solid or prewet solid chemicals on accumulations of snow or ice that are generally bonded to the pavement in order to break the bond. Chemicals should be applied under conditions where the chemicals will work and when the post treatment temperatures are not expected to lower sufficiently to cause refreezing of melted snow or ice snow and diluted chemical solution. Once the bond of snow or ice is broken, the snow or ice may be removed mechanically or displaced by traffic.

Mechanical removal alone is used with warm pavement temperatures where snow or ice is not likely to bond to the pavement and in very cold temperatures where chemicals will cause snow or ice to adhere to the pavement. It may also be used to keep low priority roads passable and as part of safety restoration operations, e.g., shoulder plowing, sight distance improvement, and clearing around safety appurtenances.

4.2 TACTICS

The particular tactics used in support of the strategies for snow and ice control are related to the equipment and materials available and the conditions at a particular location.

The tactics used in anti-icing require the application of liquid, solid, and prewet solid snow and ice control chemicals. Liquids have been distributed using tanks in pickup trucks, saddle tanks on plow trucks, and a tanker truck (see FHWA Manual of Practice for Effective Anti-icing [3]). ADOT personnel anecdotally indicate success in improving the ability to remove snow and prevent the bonding of snow and ice with liquids. Solid and prewet solid chemicals are distributed with conventional materials spreaders. Some ADOT spreaders have prewetting capability.

Deicing tactics usually include the application of solid or a prewet solid chemical to snow or ice that is usually bonded to the pavement. Various kinds of spreaders are used to make applications. Solid chemicals can be prewetted to enhance the melting capability of the chemical and to help adhere the chemicals to snow or ice.

Mechanical removal of snow or ice followed by friction enhancement involves plowing of loose snow or ice followed by the application of abrasives on critical areas or general applications. These materials will not significantly melt or disbond snow or ice unless chemicals are mixed with the abrasives in either a high ratio mixture (50-50) or are applied in high quantities. Abrasives can also be prewetted with liquid chemicals in order to enhance their ability to stick to snow or ice.

Mechanical removal alone involves plowing or otherwise removing loose snow or ice from highway areas without being followed by the application of chemicals or abrasives. Tactics include the use of various kinds of front-mounted truck plows and wing plows.

Some mechanical removal of packed snow or ice is accomplished with motor graders and underbody plows that have down-pressure capability. Other attachments for motor graders fracture the snow pack or ice and make it easily removable with bladed equipment. The final layers of ice will have to be loosened chemically or by solar warming of the pavement.

In some areas with significant snow accumulations, snow blowers are used to remove the deep snow. In some cases, front-end loaders can also be used in areas where plows or motor graders cannot operate.

4.3 RECOMMENDED PROCEDURES FOR SNOW AND ICE CONTROL IN NORTHERN ARIZONA

Currently. ADOT snow and ice control typically involves the mechanical removal of snow and ice (plowing) and friction enhancement (cinders). This strategy frequently does not allow the restoration of road surfaces to an acceptable pavement condition within an acceptable period of time. It can also allow the pavement surface to deteriorate to unacceptable (Table 7) levels of service.

In order to attain an acceptable LOS, ADOT needs to adopt anti-icing and deicing snow and ice control strategies appropriate for conditions like those given in Table 7. In particular, a chemical priority policy, i.e., using chemicals when they are likely to produce the desired result, is needed to ensure that the LOS goals can be attained. It is recognized that the application of chemicals for snow and ice control can meet with resistance in certain areas and with certain customers or interested parties.

It is also recognized that weather and road conditions can vary greatly over northern Arizona and into the transition zone. The various strategies and tactics are resource dependent and the implementation of them needs to consider the level of service goals for the snow and ice control routes.

In all cases, the implementation of strategies and their associated tactics should be based on the considerations of site conditions, the local climate, and traffic. Table 13 describes various factors that need to be taken into consideration when selecting strategies and tactics. This table is based on research in the National Cooperative Highway Research Program (NCHRP) Project 6-13, Guidelines for Snow and Ice Control Materials and Methods. The results of that research will provide more definitive guidelines for certain strategies and tactics.

4.3.1 Recommended Strategies

Where level of service goals and site conditions allow, ADOT should implement anti-icing as a standard strategy, recognizing that the actual implementation is a case-by-case operation dependent upon the current and expected road and weather conditions.

Table 13. Factors to Consider for Snow and Ice Control Strategies and Tactics

Table 13A. Climate Considerations

Frequency of Snow and Ice Events • Low • Moderate • High
Severity of Winter Temperatures • Mild • Moderate • Servere
Urban Influence • Small • Medium • Large
Water Influence • Minor • River • Lake • Other (steam plants, cooling towers, hot springs, etc.)
Elevation/Large Scale Topography • Plain • Rolling • Sloped (e.g., Mogollon Rim) • Mountainous

Table 13B. Traffic Condition Factors

Traffic Volume • Low • Moderate • High
Commercial Vehicle Mix • Low • Moderate • High
Vehicle Speeds • Low • Moderate • High

Table 13C. Site Condition Factors

Area Type • Urban • Suburban • Rural
Highway Segment Features • Hills • Curves • Grades • Intersections • Bridges • Sags • Ramps • Cross Slopes • Weaving Areas • Narrowings • Pavement Surface Types • Tangents
Solar Influence • Slope and Solar Aspect (e.g., uphill N-S or E-W) • Forest/Vegetation • Structures • Cuts
Wind Influence • Forest/Vegetation • Cuts • Exposed Stretches • Wind Channels

In addition to anti-icing, in areas where level of service requirements suggest that because of current resource limitations the goals are unattainable, ADOT should implement a deicing strategy. Deicing can improve the efficiency and effectiveness of snow and ice removal in those areas and help to maintain or attain a higher level of service.

Table 14. Recommended Application Rates for Solid and Liquid Sodium Chloride (Road Salt)

Probable Pavement Temperature at Treatment and Before Next Treatment	Ice Control Chemical Dilution Potential	Ice-Pavement Bond Characteristics Before Treatment	Application Rate			
			Solid (Note 5)		Liquid (Note 6)	
			Pounds Per Lane Mile	Kilograms Per Lane Kilometer	Gallons Per Lane Mile	Liters Per Lane Kilometer
Greater than 32°F (0°C)	Low	Bonded/Packed	50 - 100	41 - 28	NR	NR
		Unbonded	Note 7	Note 7	Note 7	Note 7
	Medium	Bonded/Packed	100 - 200	28 - 55	NR	NR
		Unbonded	Note 8	Note 8	Note 8	Note 8
	High	Bonded/Packed	200 - 300	55 - 83	NR	NR
		Unbonded	50 - 100	14 - 28	22-44	52-104
23°F to 32°F (-5°C to 0°C)	Low	Bonded/Packed	100 - 200	28 - 55	NR	NR
		Unbonded	50 150	14 - 42	22-66	52-155
	Medium	Bonded/Packed	200 - 300	55 - 83	NR	NR
		Unbonded	150 - 200	42 - 55	66-88	155-207
	High	Bonded/Packed	300 - 400	83 - 100	NR	NR
		Unbonded	200 - 300	55 - 83	88-134	207-319
12°F to 22°F (-11°C to -5.5°C)	Low	Bonded/Packed	250 - 400	70 - 110	NR	NR
		Unbonded	100 - 250	28 - 70	NR	NR
	Medium	Bonded/Packed	350 - 450	98 - 125	NR	NR
		Unbonded	250 - 400	70 - 110	NR	NR
	High	Bonded/Packed	400 - 500	110 - 140	NR	NR
		Unbonded	350 - 450	98 - 125	NR	NR
Below 12°F (-11°C)	A. If unbonded, try mechanical removal without chemical. B. If bonded, apply chemical @ 450 to 500 pounds per lane mile. Plow when slushy and retreat when necessary. C. Apply abrasives when necessary.				NR	NR

Notes:

1. These are starting points. Local experience should refine these recommendations.
2. Pre-wetting chemicals should allow application rates to be reduced.
3. Application rates for chemicals other than sodium chloride will have to be adjusted.
4. Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible.
5. Values include the equivalent dry chemical weight in the prewetting solutions.
6. Values are shown for 23% contentration solution
7. If unbonded, try mechanical removal without applying chemicals. If pretreating, use 25-75 lb/ln-mi of solid or prewet solid chemical or 11-33 gal/ln-mi of liquid chemical.
8. If unbonded, try mechanical removal without applying chemicals. If pretreating, use 38-88 lb/ln-mi of solid or prewet solid chemical or 17-39 gal/ln-mi of liquid chemical.
9. NR = NOT RECOMMENDED

The implementation of anti-icing and deicing strategies should be based on tactics using reasonable amounts of chemicals based on current and expected conditions. Table 14 provides suggested applications rates of liquid and solid road salt.

The concentration of chemicals applied can change over time, i.e., become diluted, with the interaction of the chemicals, precipitation and accumulated snow or ice. Table 15 provides relative potentials of dilution of chemicals under various weather conditions. Care should be taken in applications of chemicals when the dilution potential is medium or high. For instance, the application of liquid chemicals on bonded or packed snow or ice is not recommended. However, very thin pack ice (<1/16 in [1.6 mm]) may be treated with liquids if post-treatment dilution potential is low. When the dilution potential is medium or high, application should be made more frequently. If the cycle times don't allow for an increase in frequency, applications should be either at greater rates, or the strategy should change to mechanical removal if refreeze is expected.

Table 15. Ice Control Chemical Dilution Potential

<table>
<tr><td colspan="5">Table 15A. Ice control Chemical Dilution Potential for Snow Events</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Rate of Precipitation</td></tr>
<tr><td>Light</td><td>Moderate</td><td>Heavy</td></tr>
<tr><td rowspan="3">Moisture Content of Snow</td><td>Powder</td><td>Low</td><td>Low</td><td>Medium</td></tr>
<tr><td>Ordinary</td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td>Wet/Heavy</td><td>Medium</td><td>High</td><td>High</td></tr>
<tr><td colspan="5">Table 15B. Ice Control Chemical Dilution Potential for Various Precipitation Events</td></tr>
<tr><td colspan="2" rowspan="2">Form of Precipitation</td><td colspan="3">Rate of Precipitation</td></tr>
<tr><td>Light</td><td>Moderate</td><td>Heavy</td></tr>
<tr><td colspan="2">Rain</td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td colspan="2">Freezing Rain</td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td colspan="2">Sleet</td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td colspan="5">Table 15C. Ice Control Chemical Dilution Potential for Ice Deposition Events</td></tr>
<tr><td colspan="2" rowspan="2">Form of Precipitation</td><td colspan="3">Rate of Precipitation</td></tr>
<tr><td>Light</td><td>Moderate</td><td>Heavy</td></tr>
<tr><td colspan="2">Frost or Black Ice</td><td>Low</td><td>Medium*</td><td>High*</td></tr>
</table>

* These rates are not likely.

4.3.2 Snow and Ice Control in the Transition Zones of Arizona

Transition zones in Arizona are simply locations that generally experience fewer snow and ice events than higher elevations and more than experienced by lower elevations. The key factor is average air temperature that decreases with increasing elevation, all other factors being equal.

Most snow and ice conditions that occur in the higher elevations also occur within the transition zone. These include:

- Snow of all types, intensities and duration
- Freezing rain
- Preferential icing of bridges and pavement sections

The difficulty here is in predicting where and what type of event is likely to occur. The rain/snow line and pavement temperature gradients are very difficult to predict. Strategically placed RWIS and other sensing systems and customized weather forecast products can help improve prediction accuracy.

4.3.3 Treatment Options for the Transition Zone

The treatment options and the decision making required are the same as for all other snow and ice areas in the rest of the state. The only difference is in the frequency and distribution of the various types of snow and ice events.

Preferential icing or black ice is more likely to occur in the transition zone because it is more often associated with nighttime air temperatures in the range of 32°F (0°C). Other snow and ice areas have sustained periods of lower temperatures that do not generate preferential icing as readily. Preferential icing is particularly hazardous because it is unexpected and virtually undetectable to drivers – especially those that live in the lower and warmer areas of the state.

Localized icing conditions occur when the pavement (or bridge deck) temperature is at or below 32°F (0°C) AND below the dew point temperature. It is common for bridge deck surfaces to develop frost (preferential icing conditions) when the adjacent highway surfaces do not. This typically happens in the fall and spring when these temperature conditions are satisfied, the sky is free of cloud cover, and the wind speed is calm (0 to 3 mph). The early morning hours, just before sunrise, are ideal times for bridge deck icing/frosting to occur. The prediction of these icing conditions is particularly difficult, especially for rural areas with elevation changes and varied roadside vegetation coverage.

The recommended treatment strategy for this condition is pre-treating with a liquid ice control chemical 6 to 66 hours before the potential event. Liquid ice control chemicals are also effective in treating black ice that has already occurred if the pavement temperature is above 23°F (-5°C). The availability and type of assets will ultimately determine how black ice is treated.

Some highway agencies have resorted to pretreating bridge decks with a liquid chemical when conditions are favorable for localized icing conditions to occur. These treatments are made either on a routine basis, either once or twice a week, or when forecasts indicate conditions are favorable. Field experience shows that a 27% concentration solution of magnesium chloride applied at 25 gal/ln-mi or a 23% concentration solution of sodium chloride applied at 11-28 gal/ln-mi have been successful in preventing frosting conditions for up to one week on low-volume roads and 3-4 days on higher volume freeways. These liquids need to be applied in the early afternoon to enable the water in the solutions to evaporate before dark, leaving only the chemical residue on the pavement surface. Such pretreatment applications should not be made if precipitation is expected to occur. Reapplication of the liquid chemical should be made after precipitation occurs that would dilute or wash away the residual chemical.

There have been relatively rare situations where low concentrations of residual calcium chloride and magnesium chloride on pavement or bridge surfaces have become damp and then frozen to form ice or have just become slippery from mixing with other surface contaminants. Attention to spread pattern control and the timing of applications is advised when using these chemicals.

Table 16 contains recommended strategies and tactics for northern Arizona based on road priority. The actual implementation will of necessity be related to available resources. Funding for additional resources will be required in order to implement these strategies and tactics in all areas.

Table 16. Recommended Strategies and Tactics for Northern Arizona

Table 16A. Strategies and Tactics for Interstate and High Volume Urban Arterials		
STRATEGY	**WHERE APPROPRIATE**	**TACTICS**
Anti-icing (pretreatment)	All areas[1]	Liquids or Prewet solids[2,3,4]
Anti-icing (pretreatment for frost prevention)	Bridges with a history of frost formation problems[5]	Liquids[4]
Anti-icing operations during a winter weather event	All areas	Liquids, solids or prewet solids[3]; Plowing
Deicing	Entire system	Solids or prewet solids; Plowing
Mechanical Removal w/Friction Enhancement	Entire system when conditions are not favorable for anti-icing or deicing	Plowing, scraping; Cinders
Mechanical Removal Alone	Entire system for large accumulations and post storm operations	Plowing, scraping, blowing

Table 16B. Strategies and Tactics for Moderate Volume Urban US and State Routes		
Anti-icing (pretreatment)	All areas[6]	Liquids or prewet solids[7,8,9]
Anti-icing (pretreatment for frost prevention)	Bridges with a history of frost formation problems[10]	Liquids[3]
Anti-icing operations during a winter weather event	All areas	Liquids, solids or prewet solids[2]; Plowing
Deicing	Entire system	Solids or prewet solids; Plowings
Mechanical Removal w/Friction Enhancement	Entire system when conditions are not favorable for anti-icing or deicing operations	Plowing, scraping; cinders
Mechanical Removal Alone	Any roads or other features that require snow removal.	Plowing, scraping, loading

[1] If resources are limited, at a minimum hills, curves, ramps; bridges; and segments with history of problems should be pre-treated.
[2] Tactics used here are dependent on traffic conditions, pavement temperature and winter weather event type. See the FHWA Manual of Practice for Anti-icing. Prewet solids are not effective in high speed or high volume traffic conditions.
[3] Don't use liquids with moderate to high dilution potential and/or event water content.
[4] For best results, apply liquids midday to allow liquid water to evaporate.
[5] Liquids can be applied twice weekly during the frost season or when forecasts indicate frost is likely.
[6] If resources are limited, at a minimum hills, curves, intersections; bridges; and segments with history of problems should be pre-treated.
[7] Tactics used here are dependent on traffic conditions, pavement temperature and winter weather event type. See the FHWA Manual of Practice for Anti-icing. Prewet solids are not effective in high speed or high volume traffic conditions.
[8] Don't use liquids with moderate to high dilution potential and/or event water content.
[9] For best results, apply liquids midday to allow liquid water to evaporate.
[10] Liquids can be applied twice weekly during the frost season or when forecasts indicate frost is likely.

Table 16C. Strategies and Tactics for Low Volume Rural US and State Routes		
Anti-icing	Hills, curves, intersections, bridges with history of problems[1]	Liquids or prewet solids[2,3,4]
Anti-icing (pretreatment for frost prevention)	Bridges with a history of frost formation problems[5]	Liquids[2]
Anti-icing operations during a winter weather event	Hills, curves, intersections, bridges with history of problems[4]	Liquids, solids or prewet solids[5,1,2]; Plowing
Deicing	Segments of routes with history of problems[6]	Solids or prewet solids; Plowing
Mechanical Removal w/Friction Enhancement	Entire system when conditions require snow removal and surface friction	Plowing; Cinders
Mechanical Removal Alone	Any roads or other features that require snow removal	Plowing, Scraping, Blowing

[1] If resources permit, anti-icing should be used on as many other road segments as is possible.
[2] Tactics used here are dependent on traffic conditions, pavement temperature and winter weather event type. See the FHWA Manual of Practice for Anti-icing. Prewet solids are not effective in high speed or high volume traffic conditions.
[3] Don't use liquids with moderate to high dilution potential and/or event water content.
[4] For best results, apply liquids midday to allow liquid water to evaporate.
[5] Liquids can be applied twice weekly during the frost season or when forecasts indicate frost is likely.
[6] If resources permit, deicing should be used on as many road segments as is possible within the considerations for environmental management areas.

5. ADDITIONAL RECOMMENDATIONS AND CONCLUSIONS

5.1 WEATHER INFORMATION FOR SNOW AND ICE CONTROL

The access to and use of short-term weather information by ADOT highway maintenance personnel can be improved. Better access to weather information, combined with appropriate training for decision makers, can improve the effectiveness and efficiency of snow and ice control operations. In addition to better access, the acquisition and use of more accurate and user-specific forecasts should also assist in improving operations. Although currently RWIS sites are installed in northern Arizona along I-40 and at two other locations in the Holbrook District, forecasts can and should be acquired from a forecasting service for all locations involved in snow and ice control. This should be stated in a functional specification for forecasting services. NWS forecasts and those obtained from media sources are neither timely nor site-specific enough for effective decision making.

One project task required recommendations for new or expanded RWIS sites in northern Arizona, and any other weather information systems that may be required. Recommended RWIS siting was provided in Section III. Given the expansive definition of RWIS that includes forecasting, the recommendations that follow include additions and upgrades to the information systems and their use.

In order to improve the acquisition and use of weather information and forecasts, a number of procedures are recommended for ADOT. These recommendations are presented in the form of guidelines. Actual implementation decisions will in some cases require funding. In addition, implementation of many of the recommendations will require upper maintenance management support.

The procedures and guidelines are divided into three groups of recommendations: equipment needed to implement recommendations; operating procedures for ADOT personnel to use in acquiring, and disseminating forecasts; and data analysis procedures for using forecasts and documenting forecast performance.

5.1.1 Weather Information Recommendations

The following recommendations are related to equipment and software procurements or upgrades that will improve access and use of weather and road condition forecasts.

1. Procure from Integrated Financial Solutions remote access software for downloading weather information from the SBWIS to PCs or laptops. This will allow access to weather information away from the office. This can be a stand-alone package for one PC/laptop computer where there is a SBWIS. Also, data can be entered into the ADOT Intranet using a network package at one node, or more than one node for redundancy, and then using node packages at each PC or laptop. One-time costs are approximately $695 for the network copy; $200 for each node (user on the net); or $395 for stand-alone software for use with a PC to access data from an existing SBWIS unit. The latter would allow remote access to the SBWIS unit that now has to be in a fixed location. There is still a monthly access fee per node from the SBWIS but the cost will be about $53 per node compared with SBWIS monthly lease costs of about $76 per unit. Integrated Financial Solutions can be contacted at (800) 729-5037.

2. Participate with the University of Utah's Cooperative Institute for Regional Prediction in its development of a mesoscale weather information acquisition capability that would include access to RWIS and weather data in Arizona and surrounding areas. The University of Utah serves as a focal point with assistance and cooperation from agencies in surrounding states that "own" the weather infrastructure, and with the NWS. This weather information should be accessible on the ADOT Intranet via the Internet.

Figure 8 is a representation of a web site for the Utah Mesonet. The Utah web site is on the Internet at **http://www.met.utah.edu/jhorel/html/mesonet/**. Items shown Figure 8 in boldface type are "hotlinks" to other web pages where mesonet data are available in different formats. The Utah DOT (UDOT) link is password protected because Utah has decided not to release to the publicly RWIS data. ADOT will need to decide what, if any, road measurements could be included in its release of data to the Utah Mesonet.

The web site was developed in conjunction with the Utah DOT and, the National Oceanic and Atmospheric Administration including the National Weather Service.

The following description of the Utah Mesonet is extracted from the web site in order to describe its purpose and capabilities. Some Arizona weather data are already displayed and are accessible via the Mesonet.

> **"Overview**
>
> "The Utah Mesonet is a cooperative project between researchers at the University of Utah and forecasters at the Salt Lake City National Weather Service Office. The goal of this project is to provide access to current weather observations in Utah and nearby states. Support for this project is being provided by the National Weather Service.
>
> "The Utah Mesonet relies upon weather observing networks that are managed by federal, state, and local agencies and private firms. Additional stations have been installed at key locations such as near the Great Salt Lake and at venue sites for the 2002 Winter Olympics in the Wasatch Mountains. Weather observations of temperature, relative humidity, wind speed and direction, precipitation, and other weather parameters are available at several hundred locations.
>
> "The Utah Mesonet is used operationally by the National Weather Service to monitor weather conditions around the region in order to protect lives and property. The Mesonet is also used extensively by researchers to understand severe weather events such as winter snow storms and damaging winds. The Utah Mesonet is available to the educational community for use in the classroom. Students in grades K-12 can observe weather conditions near their school or around the region.
>
> **"Access to Weather and Climate Information**
>
> "We've developed several different ways to access weather information in the Intermountain West. Weather information can be visualized in many different ways and different users have different needs. Here's a brief overview of the purpose for each of the available interfaces:

UTAH
MESONET

Public Interface
Current Weather Conditions
Around the Intermountain West

Research Interface
Detailed Weather and Climate
Information around the Region

NWS Interface
Developed by the National
Weather Service

UDOT Interface
Weather Information for Road
Managers

2002 Olympics Interface
Weather Conditions at Olympic
Venues our

Information and Links
Mesonet Overview and Links to
Data Providers

Outreach
Educational Activities and
Lesson Plans

Mesonet Operations
Status Information and Quality
Control

Figure 8. Recreation of the Utah Mesonet Web Site for Weather Information Access

- Public Interface. Designed for quick and flexible access to current weather conditions. Stations are grouped by counties to direct users to weather information. Users are able to view weather conditions locally or on a large scale via the Weather Map option.
- Research Interface. Complete access to all of the weather and climate products developed as part of the Utah Mesonet, including: graphical overlays of surface temperature and wind on detailed terrain maps; spatial maps of surface temperature, dew point temperature, and sea level pressure; 3-dimensional analyses of the current weather; daily summaries of weather conditions around the region; and access to past weather information.
- National Weather Service (NWS) Interface. This Interface is maintained by the forecasters at the Salt Lake City National Weather Service Office. It is intended to provide fast access to the spatial distribution of weather conditions based on graphical overlays of surface temperature and wind on detailed terrain maps. In addition, changes in weather conditions are monitored in text format at stations selected by the user.
- Utah Department of Transportation (UDOT) Interface. Developed for local road managers who need to have flexible access to weather and road conditions.

It is password protected as a result of limitations on the redistribution of radar imagery and pavement conditions.

- 2002 Olympics Interface. Developed in cooperation with the Salt Lake City Organizing Committee in order to plan weather support for the 2002 Winter Games. Weather and climate information near venues is accessible.

"Usage Restrictions

"Data contained in the Utah Mesonet arise from cooperative arrangements with many different agencies and commercial firms. The data are intended to be used by personnel in governmental agencies to protect lives and property and by the public for general information. The data may also be used for research and educational purposes. Any other uses of the data from one or more stations must receive written approval from the agencies that installed the weather sensors. Contact the NOAA Cooperative Institute for Regional Prediction to receive information on how to obtain written approval.

"Due to the nature of data transmission across the Internet and other communication factors, the information found in the Utah Mesonet may not always be current. No warranties are expressed or implied regarding the accuracy, completeness, or reliability of the information contained in the Utah Mesonet. Data users are cautioned to consider the provisional nature of the data before using it for decision making."

3. In coordination with the National Weather Service in Bellemont, AZ, procure additional weather stations to fill in meteorological gaps. This could improve NWS forecasts and provide both the NWS and ADOT with valuable weather information where there currently is none. Whenever possible, coordinate this same effort with the RWIS Plan that was presented in Section III.

4. Procure up-to-date portable computers for Org decision makers in order for them to access weather and other information resources. Portable computers purchased to acquire data from the original RWIS procurement and currently used by foremen along the I-40 corridor are old and lack graphics capabilities. They should be replaced.

5. Provide all snow and ice control decision makers with access to the Internet for acquiring weather information and forecasts.

6. Provide Org decision makers who have laptop computers with portable telephones that have appropriate jacks for using laptop computers in vehicles or away from the office to access the ADOT Intranet, SBWIS, the ADOT RWIS and forecast products, and Internet weather. Figure 9 shows ATT Wireless Coverage in the western US, including Arizona. Most of northeast Arizona and the I-40 and I-17 corridors are covered. Gaps exist on I-40 east of Kingman and on I-17 well south of Flagstaff.

7. Provide all personnel who have or will have Internet access Internet browser software that is Java-compatible. This will permit users to see and use the latest advances in visualizing weather information, such as regional radar loops.

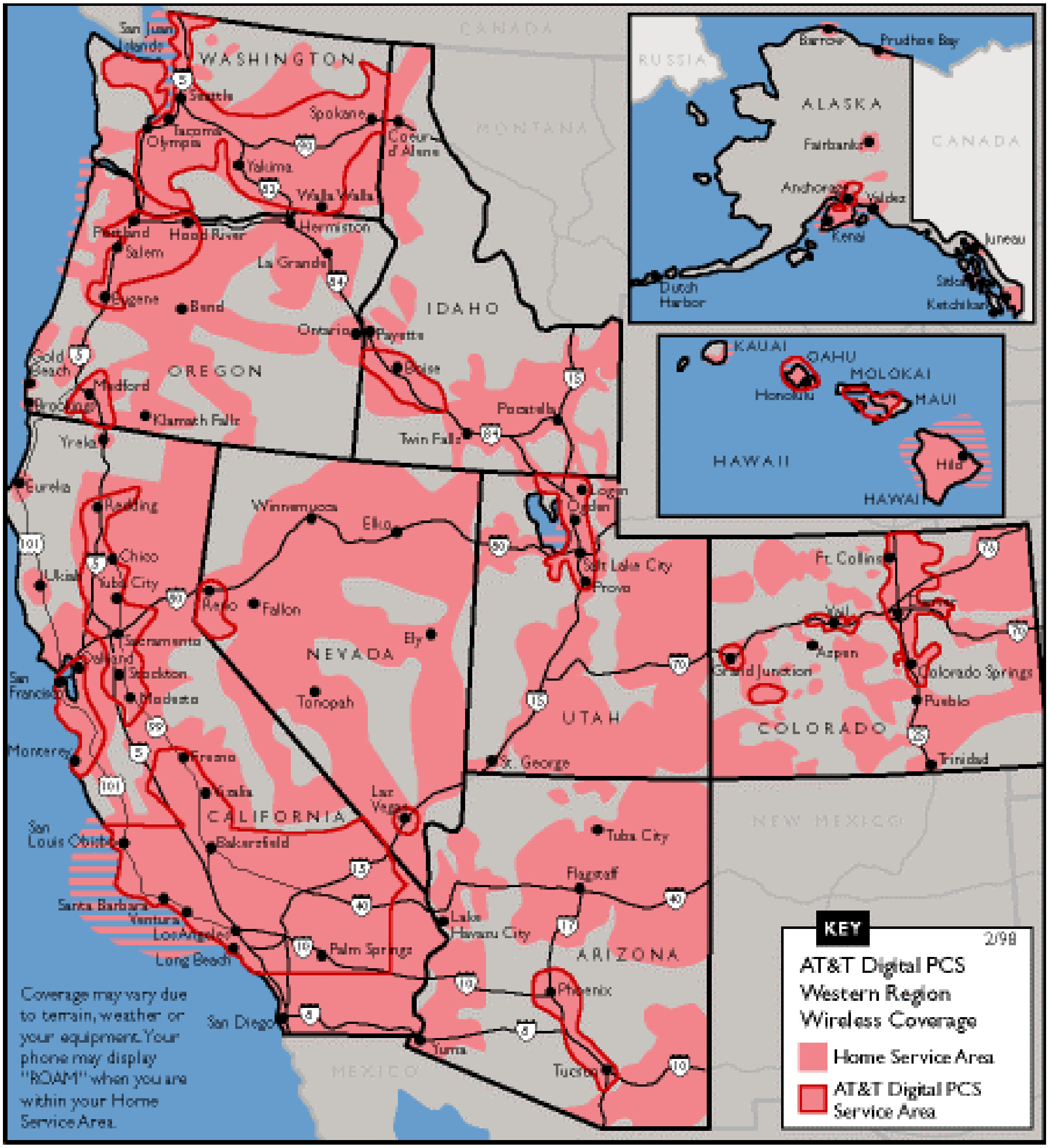

Figure 9. ATT Wireless Coverage in the Western US.

8. Contract with the University of Arizona, for the development of mesoscale forecast products that will enhance the forecasting of winter weather along the transition zone, the Mogollon Rim, and the high country in Arizona. Products developed by the University should be made available on the Internet for use by whoever provides the forecasting support to ADOT. A minimum set of useful products should include high resolution forecasts of surface temperatures, dew point temperatures, snow level, precipitation amounts, and a cross section of these parameters from west to east through the transition zone and the Mogollon Rim.

9. Conduct thermal mapping on state roads to help provide better information for pavement temperature forecasting, especially in areas where no RWIS data exist. Thermal mapping data can help improve pavement temperature forecasting for snow accumulation, freezing rain events, and frost. A minimum set of roadways for thermal mapping should include, but not necessarily be limited to:

- I-17 from Camp Verde to Flagstaff;
- I-40 from Kingman to the New Mexico border (Ash Fork to Winslow at a minimum);
- Either SR89 from Prescott to Ash Fork or SR89A to the top of the hill at Oak Creek Canyon;
- SR 87 from the Payson area to Clints Well;
- SR 260 from Payson to Heber; and
- US 60 from Show Low to Springerville/Eagar.

10. Begin a library of weather- and snow-and-ice-control-related materials at each Org. Include books at the introductory level. A minimum set of books should include:

- *SKYWATCH – The Western Weather Guide*, authored by Richard A. Keen, and published in 1987 by Fulcrum Inc. of Golden, CO. Each Org in the Flagstaff District at one time had a copy.
- *The Snow Fighters Handbook* from the Salt Institute.
- The AASHTO *Guide for Snow and Ice Control*.
- The FHWA *Manual of Practice for Anti-Icing*.
- *Basics of Snow and Ice Control* from the American Public Works Association.
- District Snow Plan.
- *Handbook on the Use of Chemicals in Arizona* from ADOT.

11. Develop a guide to the availability of weather information in Arizona.

12. If the in-place RWIS sites are not working properly, the capability to provide good forecasts is diminished. Add sufficient personnel to the signal technician section in Flagstaff to be able to respond to RWIS outages or problems within 24 hours. If adding personnel is not an option, then issue a Request for Proposals (RFP) to obtain contract maintenance for its RWIS equipment. The RFP should include minimum standards for maintaining system performance and penalty clauses for not doing so.

13. If the AASHTO winter Maintenance Policy Coordinating Committee votes to develop a computer-based training program for snow and ice control, contribute to the pooled fund study.

In addition to the above recommendations for weather information, the research team developed a set of procedures for ADOT to implement in order to utilize weather information more effectively in their snow and ice control operations. The procedures are shown in Appendix B.

5.2 RESOURCES FOR SNOW AND ICE CONTOL

The level of service capability is primarily the result of the cycle time (plowing and materials spreading) that can consistently be maintained. Mainly this is a function of fleet size and associated personnel resources. Other important factors include: the capability of the plowing and materials spreading equipment (plowing width, spreader capacity and spreader type), available treatment options, facility/loading point locations and the nature of the snow and ice events. The current ADOT snow and ice fleet size, character, and associated support resource are simply ***not adequate*** to provide the level of service desired.

5.2.1 ADOT Snow and Ice Control Truck Fleet Size

An analysis of existing truck fleet capability in terms of cycle time was performed. This was based on the responses of ADOT personnel to the ADOT LOS data base form in Figure 1 and information found in the District snow and ice control plans. The responses to the LOS form provided data on route location, route boundaries, length, route priority level as defined in the State Plan, current cycle time for the route, and current and desired times to reach a desired road condition of 2.0 ("Occasional areas of snow accumulation with small patches of ice or slush, no traction aids required; generally safe") after the end of a typical storm. Cycle time, as used in this report, is the time it takes to complete a snow and ice treatment – including time for deadheading, reloading and attending to necessary human body requirements.

Tables 17A – 17E contain priority and cycle time data taken directly from the LOS Data Base Forms (Figure 1) returned from the five districts. Lane miles were calculated by subtracting LOS questionnaire milepost limits, multiplying by the number of highway lanes and adding five percent for intersections, turning lanes, widening, etc. The number of trucks for each route was determined from the questionnaire and the District snow and ice control plans. The average cycle time, the average lane-miles per truck, and the average production rate per truck are given by route priority level for each District in Tables 17A–17E. The weighted average production rate per truck is also given for each District. Here, production rate is defined as the number of lane-miles that a snow and ice control truck treats during a cycle, divided by cycle time.

Table 17A. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Flagstaff District

	Priority 1				
	A	**B**	**C**	**D**	**E**
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	50	1.5	52	1	1.5
	50	1.1	36	1	1.1
	50	2.0	180	4	8.0
	51	6.0	156	3	18.0
	52	8.0	154	2	16.0
	53	4.7	164	3	14.1
	53	1.5	32	1	1.5
	54	5.0	124	2	10.0
	54	1.5	6	1	1.5
	55	5.0	78	2	10.0
	55	3.0	66	2	6.0
Sum		39.3	1048	22	87.7
Avg.		3.6			
	Average Lane Miles/ Truck				**48**
Average Production Rate	Sum C/Sum E =		11.9	ln-mi/hr/truck	

	Priority 2				
	A	**B**	**C**	**D**	**E**
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	50	2.8	70	1	2.8
	51	6.5	104	2	13.0
	52	4.8	94	2	9.6
	52	3.7	36	1	3.7
	53	2.3	56	2	4.6
	54	6.0	112	1	6.0
Sum		26.1	472	9	39.7
Avg.		4.4			
	Average Lane Miles/ Truck				**52**
Average Production Rate	Sum C/Sum E =		11.9	ln-mi/hr/truck	

	Priority 3				
	A	**B**	**C**	**D**	**E**
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	50	12.0	36	1	12.0
	51	5.3	30	1	5.3
	51	6.0	78	1	6.0
	52	3.3	58	1	3.3
	54	6.0	104	1	6.0
	55	2.0	26	1	2.0
Sum		34.6	332	6	34.6
Avg.		5.8			
	Average Lane Miles/ Truck				**55**
Average Production Rate	Sum C/Sum E =		9.6	ln-mi/hr/truck	

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 11.6 \text{ ln-mi/hr/truck}$$

Table 17B. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Prescott District

	Priority 1					Priority 2					Priority 3				
	A	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	51	4.6	184	1	4.6	51	1.5	30	1	1.5	51	1.6	31	1	1.6
	51	2.1	84	1	2.1	51	2.1	41	1	2.1	53	1.0	19	1	1.0
	51	1.1	22	1	1.1	53	1.5	30	1	1.5	50	1.4	28	1	1.4
	51	0.7	14	1	0.7	53	1.3	22	1	1.3					
	53	3.4	80	1	3.4	53	1.3	25	1	1.3					
	53	2.5	50	1	2.5	53	1.2	24	1	1.2					
	53	1.0	20	1	1.0	50	1.5	30	1	1.5					
	53	1.6	32	1	1.6	50	1.2	23	1	1.2					
	50	1.5	30	1	1.5	50	2.8	56	1	2.8					
						52	2.5	51	1	2.5					
Sum		18.5	516	9	18.5		16.9	332	10	16.9		4.0	78	3	4.0
Avg.		2.1					1.7					1.3			
	Average Lane Miles/ Truck				**57**	**Average Lane Miles/ Truck**				**33**	**Average Lane Miles/ Truck**				**26**
Average Production Rate	Sum C/Sum E =		27.9	ln-mi/hr/truck		Sum C/Sum E =		19.6	ln-mi/hr/truck		Sum C/Sum E =		19.5	ln-mi/hr/truck	

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 23.0 \text{ ln-mi/hr/truck}$$

Table 17C. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Globe District

	Priority 1					Priority 2					Priority 3				
	A	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	50	1.5	12	1	1.5	50	1.0	18	1	1.0	52	8.0	108	1	8.0
	52	4.0	45	1	4.0	50	2.0	43	2	4.0	55	5.0	67	1	5.0
	53	0.5	20	1	0.5	50	1.0	14	1	1.0	55	5.0	45	1	5.0
	53	0.5	22	1	0.5	53	2.0	20	1	2.0					
	54	4.0	75	1	4.0	54	3.0	127	3	9.0					
	54	4.0	39	1	4.0	56	2.0	67	1	2.0					
	56	3.0	98	2	6.0	56	2.0	40	1	2.0					
	57	2.5	53	1	2.5	56	0.5	9	1	0.5					
	57	1.0	32	1	1.0	55	2.5	61	1	2.5					
	57	1.5	51	1	1.5	55	2.5	58	1	2.5					
	57	2.5	43	1	2.5	55	1.5	14	1	1.5					
Sum		25.0	490	12	28.0		20	471	14	28.0		18.0	220	3	18.0
Avg.		2.3					1.8					6.0			
	Average Lane Miles/ Truck				**41**	**Average Lane Miles/ Truck**				**34**	**Average Lane Miles/ Truck**				**73**
Average Production Rate	Sum C/Sum E =		17.5	ln-mi/hr/truck		Sum C/Sum E =		16.8	ln-mi/hr/truck		Sum C/Sum E =		12.2	ln-mi/hr/truck	

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 16.6 \text{ ln-mi/hr/truck}$$

Table 17D. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Holbrook District

	Priority 1					Priority 2					Priority 3				
	A	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	50	4.5	166	3	13.5	50	4.0	27	1	4.0	50	4.0	68	1	4.0
	50	5.0	110	2	10.0	52	9.0	241	4	36.0					
	50	2.5	28	1	2.5	53	4.0	118	2	8.0					
	51	3.0	160	3	9.0	54	3.0	44	1	3.0					
	51	1.7	21	1	1.7	54	1.5	26	1	1.5					
	52	6.5	56	1	6.5	54	1.5	30	1	1.5					
	54	3.0	62	1	3.0	55	4.0	28	1	4.0					
	54	2.5	70	2	5.0										
	55	8.0	188	4	32.0										
Sum		36.7	861	18	83.2		27	514	11	58.0		4.0	68	1	4.0
Avg.		4.1					3.9					4.0			
	Average Lane Miles/ Truck				**48**	**Average Lane Miles/ Truck**				**47**	**Average Lane Miles/ Truck**				**68**
Average Production Rate	Sum C/Sum E =		10.3	ln-mi/hr/truck		Sum C/Sum E =		8.9	ln-mi/hr/truck		Sum C/Sum E =		17.0	ln-mi/hr/truck	

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 10.0 \text{ ln-mi/hr/truck}$$

Table 17E. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Kingman District

	Priority 1					Priority 2					Priority 3				
	A Org	**B** Cycle Time, Hours	**C** Lane Miles	**D** No. of Trucks	**E** B x D	**A** Org	**B** Cycle Time, Hours	**C** Lane Miles	**D** No. of Trucks	**E** B x D	**A** Org	**B** Cycle Time, Hours	**C** Lane Miles	**D** No. of Trucks	**E** B x D
	50	3.0	113	2	6.0	50	6.0	133	1	6.0					
	50	3.0	16	1	3.0	53	2.0	44	1	2.0					
	50	3.0	58	1	3.0										
	50	3.0	38	1	3.0										
	51	3.0	296	4	12.0										
	51	4.0	36	1	4.0										
	53	2.0	64	1	2.0										
	53	2.0	36	1	2.0										
Sum		23.0	657	12	35.0		8	177	2	8.0					
Avg.		2.9					4.0								
	Average Lane Miles/ Truck				**55**	**Average Lane Miles/ Truck**				**89**	**Average Lane Miles/ Truck**				
Average Production Rate	Sum C/Sum E =		18.8	ln-mi/hr/truck		Sum C/Sum E =		22.1	ln-mi/hr/truck		Sum C/Sum E =			ln-mi/hr/truck	

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 19.3 \text{ ln-mi/hr/truck}$$

Table 18 is a summary of existing cycle time capability and average lane miles per truck taken from Tables 17A – 17E.

Table 18. ADOT Snow and Ice Control Cycle Time Analysis

	Average Cycle Time (Hours)			Average Lane Mile*/ Truck		
District	**Priority 1**	**Priority 2**	**Priority 3**	**Priority 1**	**Priority 2**	**Priority 3**
Flagstaff	3.6	4.4	5.8	48	52	55
Globe	2.3	1.8	6.0	41	34	73
Prescott	2.1	1.7	1.3	57	33	26
Holbrook	4.1	3.9	4.0	48	48	68
Kingman	2.9	4.0	--	47	89	--
* computed from mile marker data, number of travel lanes and a five percent add-on for intersections, turning lanes, widenings, etc.						

ADOT has selected a pavement condition of 2.0 (as defined earlier) as an after-storm level of service goal. The target time after storm to achieve this goal varies with the priority classification of individual road segments. Priority 1 is four hours; Priority 2 is six hours, and Priority 3 is 12 hours. The research team believes that average operational cycle time capability of 2, 4, and 6 hours, respectively, will allow the level of service goals to be met most of the time. This will allow at least one treatment and some time for chemicals and/or the sun to work after the end of each storm. These cycle times will also allow a reasonable within-storm LOS, most of the time.

In order to achieve this capability, ADOT will have to acquire more snow and ice trucks and associated personnel, and reconfigure existing routes to balance cycle times with highway priorities where possible. One approach to determine truck fleet size for snow and ice control is through use of truck production rate capability.

From Tables 17A – 17E there appears to be little relationship among production rate and route priority. This is to be expected as production rate is more based on logistics and individual route characteristics than anything else. Also, production rate varies considerably within and among the districts. The use of a statewide average production rate tends to reduce the impact of these variations on individual Districts. This was identified as the best representation of ADOT truck production rate capability.

The existing average statewide production rate of 15 lane miles per hour, per truck was calculated from the data in Tables 17A – 17E using the formula: average statewide production rate = sum of (District weighted average production rate times number of District trucks) divided by the total number of trucks in the five Districts.

Using the average statewide production rate, and target cycle times described above, the minimum snow and ice truck requirements were calculated for the five ADOT districts in Northern Arizona. These results appears in Tables 19A – 19E. Table 20 is a summary of data found in Tables 19A – 19E and describes the minimum additional snow and ice truck requirements for the five Districts. If complete truck reassignment is possible, an additional 30 trucks for the 5 districts will be required. This assumes that all excess (negative [-] minimum number of additional trucks) on lower priority routes can be reassigned to higher priority routes. If no reassignment is possible, an additional 50 trucks will be required. The actual number of trucks required will need to be determined after a route-by-route analysis of what is, and what is not possible in terms of reassignment.

Table 19A. Minimum Snow and Ice Truck Requirements, Flagstaff District

		Priority 1	Priority 2	Priority 3	Total
A)	Lane Miles	1048	472	332	1852
B)	Production Rate, Lane Mile/Hour	15	15	15	
C)	Target Cycle Time, Hours	2	4	6	
D)	Lane Miles/Cycle (BxC)	30	60	90	
E)	Minimum Number of Trucks Required (A/D)	35	8	4	47
F)	Number of Existing Trucks	22	9	6	37
G)	Minimum Number of Additional Trucks (E-F)	13	-1	-2	10

Table 19B. Minimum Snow and Ice Truck Requirements, Prescott District

		Priority 1	Priority 2	Priority 3	Total
A)	Lane Miles	861	514	68	1443
B)	Production Rate, Lane Mile/Hour	15	15	15	
C)	Target Cycle Time, Hours	2	4	6	
D)	Lane Miles/Cycle (BxC)	30	60	90	
E)	Minimum Number of Trucks Required (A/D)	29	9	1	39
F)	Number of Existing Trucks	18	11	1	30
G)	Minimum Number of Additional Trucks (E-F)	11	-2	0	9

Table 19C. Minimum Snow and Ice Truck Requirements, Globe District

		Priority 1	Priority 2	Priority 3	Total
A)	Lane Miles	490	471	220	1181
B)	Production Rate, Lane Mile/Hour	15	15	15	
C)	Target Cycle Time, Hours	2	4	6	
D)	Lane Miles/Cycle (BxC)	30	60	90	
E)	Minimum Number of Trucks Required (A/D)	16	8	2	26
F)	Number of Existing Trucks	12	14	3	29
G)	Minimum Number of Additional Trucks (E-F)	4	-6	-1	-3

Table 19D. Minimum Snow and Ice Truck Requirements, Holbrook District

		Priority 1	Priority 2	Priority 3	Total
A)	Lane Miles	861	514	518	1893
B)	Production Rate, Lane Mile/Hour	15	15	15	
C)	Target Cycle Time, Hours	2	4	6	
D)	Lane Miles/Cycle (BxC)	30	60	90	
E)	Minimum Number of Trucks Required (A/D)	29	9	6	44
F)	Number of Existing Trucks	18	11	12	41
G)	Minimum Number of Additional Trucks (E-F)	11	-2	-6	3

Table 19E. Minimum Snow and Ice Truck Requirements, Kingman District

		Priority 1	Priority 2	Priority 3	Total
A)	Lane Miles	657	177		834
B)	Production Rate, Lane Mile/Hour	15	15	15	
C)	Target Cycle Time, Hours	2	4	6	
D)	Lane Miles/Cycle (BxC)	30	60	90	
E)	Minimum Number of Trucks Required (A/D)	22	3		25
F)	Number of Existing Trucks	12	2		14
G)	Minimum Number of Additional Trucks (E-F)	10	1		11

Table 20. Estimates for Additional Snow and Ice Trucks

District	Route Priority			Total
	1	2	3	
Flagstaff	+13	-1	-2	+10
Globe	+4	-6	-1	-3
Prescott	+11	-2	0	+9
Holbrook	+11	-2	-6	+3
Kingman	+10	+1	--	+11
Total	+49	-10	-9	+30

This analysis does not address the issue of spare trucks. With up-time in the range of 90%, access to about 10% spare trucks should be provided. Keeping some auction-bound trucks in reserve or having sufficient downtime replacements that are not charged to ADOT can accomplish this.

The acquisition of 30-50 additional snow and ice trucks will take time. The recommended first step in the process for ADOT is to conduct a route (beat)-by-route analysis to realign existing resources to be compatible with highway priority and cycle time. It is recognized that the incidental treatment of lower priority roads coincident with higher priority roads is necessary in some circumstances. The proximity of routes (beats) to garage and stockpile facilities may also impact some potential realignments.

Opportunities for cooperation and efficiency with adjoining Districts and Orgs should also be explored at this time. Other efficiencies to reduce cycle time should also be explored at this time. These include stockpile siting and cooperative arrangements with other governmental entities and possibly the private sector.

5.2.2 ADOT Snow and Ice Truck Fleet Character

In 1997, when this study was undertaken, the average truck age was 13.3 years with about 71 percent being 12 years or older. About 34 percent of that fleet were two-axle 5 to 8-yard capacity trucks with limited capacity for plowing and spreading. Since that time ADOT, equipment services has acquired 92 state-of-the-art snow and ice trucks and placed them into service. This is a remarkable achievement that was accomplished through favorable rate third party financing and good bid prices on the equipment. This needs to aggressively continue until the less capable trucks are retired and the average fleet age is decreased to the range of six years. Once that goal is achieved, purchasing/replacement should be done in a way to provide a uniform distribution of age class trucks.

5.2.3 Loading Equipment

As ADOT places more snow and ice trucks into service, more loading equipment may be required. This will depend on stockpile locations and the number of trucks being loaded at particular sites. These are unknown at this point and will depend on how successful ADOT is with cooperative and partnering efforts. A recommended loader distribution would be one large (two yards plus) loader for loading points serving up to five trucks. Locations serving more than five trucks should have two large loaders. Back-up capability should be provided in the form of district spares and smaller other purpose loaders.

5.2.4 Snow and Ice Control Chemicals

In order for ADOT to successfully attain its level-of-service goals, it needs to adopt a chemical priority policy for the use of chemicals in snow and ice control where possible. This policy would apply to both anti-icing and deicing strategies. This will require additional cost for chemicals and reduced cost for cinders.

Current research and the majority opinion of snow and ice professionals indicate that a chemical priority policy is less costly (materials) than the abrasives priority policy currently being used by most of ADOT. After start-up costs there should be no additional cost for chemicals and there will probably be an over all savings in the total cost of snow and ice control operations.

The following discussion describes the resources necessary for ADOT to make the transition to a chemical priority snow and ice control system.

Liquid Chemical Storage Tanks

Most of the 27 Orgs in northern Arizona will need additional liquid chemical storage capacity to implement anti-icing and support liquid applications and prewetting of solid chemicals. Typical tanks cost about $2000 plus any incidental site work.

Solid Chemical Storage Capacity

Only about 25 percent of the ADOT loading points in northern Arizona have adequate solid chemical storage capability. The remaining locations need a covered storage facility with appropriate drainage control[1]. Typical cost for a 3000-ton facility ranges from $300,000 to $400,000 depending on site work.

Liquid Chemical Distribution Systems

ADOT will have to transition into liquid chemical distribution. A phased approach is recommended.

Phase One will involve acquiring capability in each Org for anti-icing (pretreating) bridges and other problem areas. This can be accomplished by equipping existing small dump trucks (26,500 lbs GVWR±). This can be done for about $12,000 per unit depending on specification. This cost per unit can be reduced considerably by installing small 300-gallon tanks with a simple spray bar system on the back end of a heavy-duty pickup truck, or by simply using readily available water trucks. These units do not need sophisticated control systems, but do need to be calibrated so that the appropriate liquid application is used during the pretreatment operation. Two capable units per Org are recommended for a starting point.

Phase Two will include acquiring the capacity to treat significant stretches of the priority 1 highway system. This may be accomplished by having slip-in tanks that interchange with the hopper/spreaders on the existing 12-yd. truck. Other options include purchasing tanker trailers to be pulled by existing truck tractors (horses) and larger tanks that can be mounted on low bed trailers and attached to the tractors. Tank systems for low bed trailers cost in the range of 20 thousand dollars. Large slip-in units cost in the range of 16 to 25 thousand dollars.

Tanker trailer costs are highly variable depending on the acquisition method. For instance, the Iowa DOT was successful in acquiring used tankers designed to haul food products. The tankers were modified by Sprayer Specialties (Ag Chemical Dealer) in Grimes, IA. They also acquired five tankers from the military at a very reasonable cost. However, these tankers needed to be repainted to cover the camouflage paint. Acquiring surplus tanker trucks can save considerable funds compared to acquiring new equipment. The Iowa tank trailers have cost between 10 and 15 thousand dollars to become fully operational. Tanker equipment currently in use for other functions, e.g., vegetation control, may also be available and can be used if properly cleaned prior to the winter maintenance season.

[1] Refer to the AASHTO Guide for Snow and Ice Control [4] for detailed information on chemical storage requirements.

5.2.5 Additional Personnel Costs

Once additional equipment is acquired, it will be necessary to acquire additional staff to operate it. ADOT is currently utilizing internal transfers, temporary reassignment in work location, temporary hiring, and personnel from other state agencies. Aggressive use of these options is currently yielding barely enough people to operate existing equipment. The root problem here is pay scale. A minimum wage increase of 50 percent will begin to make ADOT competitive with the private sector (and other governmental agencies) for qualified equipment operators.

Implementing the change in policy will require at least 60 additional equipment operators (maintenance technicians) to staff additional equipment.

5.2.6 The Cost of Implementation

The costs identified above are summarized in Table 21. The costs shown are estimated initial costs and an annualized cost basis.

Table 21. Implementation Costs for a Chemical Priority Snow and Ice Control Policy

Cost Item	Number	Initial Cost ($)	Annualized Cost ($)
Snow & Ice trucks	30	4,320,00[1]	986,400[2]
Storage tanks	27	317,500	31,750
Storage buildings	19	6,650,000	232,750[3]
Phase 1 Liquid Distribution	54	648,000	46,656
Phase 2 Liquid Distribution	27	540,000	56,700
Personnel	60	1,684,800[6]	1,684,800
Total	—	14,160,300	3,039,056
Ice Control Chemicals			
Liquid (gals)	2,942,000	1,765,200[4]	1,765,200[4]
Solid (tons)	44,000	1,760,000[5]	1,760,000[5]

[1] purchase only by Equipment Services
[2] total rental cost to ADOT at current rates
[3] 30 year life cycle with 5% annual operating cost
[4] 10 gal/ton pre-wet plus 25% treatment of Priority 1 routes (1 application each for 12 storms @ $0.60/gal)
[5].5 t/ln-mi for Priority 1, .38 t/ln-mi for Priority 2, and .25 t/ln-mi for Priority 3 (12 storms per year @ $40/ton)
[6] $9 per hour plus 50% fringes, full time

5.2.7 Financing Options & Recommendations

Equipment to be managed by Equipment Services may have to be purchased using third party leasing in order to spread the cost out. In addition, ADOT may be able to lease some equipment on a seasonal basis. However, in order to have a sustainable operation, Equipment Services will need periodic supplemental funding to iron out the effects of erratic purchasing. This may be from legislative appropriations directly applied or passed through ADOT. Raising current equipment rental rates is another option that requires approval. This will work as long as ADOT is provided with funds to cover cost increases.

Other non-material cost items can be purchased directly or through financing. ADOT should pursue cost sharing opportunities with local government on storage structures and storage tanks if co-use mechanisms can be implemented.

5.3 TRAINING

ADOT needs to establish a formally programmed, user driven, and continuous technical training program for snow and ice control. The training goals and objectives should be established. By establishing such a program, consistent practices and procedures can be implemented effectively and efficiently. The result should be an improvement in the quality and quantity of work performed. The use of ADOT's *Snow and Ice Control Guidebook*, dated September 11, 1995 in any training program is not recommended until the document is revised to correct numerous misunderstandings and to incorporate new technology.

All snow and ice control training should fall under the guidance of and be monitored by the ADOT Technical Training Coordinator. Implementation of this technical training should be the responsibility of the Regional Training Officers. Each Org Supervisor should appoint a Snow and Ice Control Trainer (Org Trainer) – a focal point for ensuring that training is consistent, is implemented effectively, and is documented appropriately.

It is further recommended that the Technical Training Coordinator develop a Training Information Management System. A viable system should be accessible on-line by the Regional Training Officers and the Snow and Ice Control Trainers within the Org in order to update and review records. The Org Trainers can review the status or each individual and schedule appropriate initial, recurring, or perhaps remedial training (which could be OJT). The system would further document those individuals with special skills who can be used as resources for conducting or assisting with training.

It is clear the skill-based certification program under development by ADOT will be a start toward proper measurement and documentation of performance. The form and function of this program can be used as a basis for developing the Training Information Management System.

The research team provided ADOT with a detailed list of topics to be covered in training for operators, supervisors, and managers respectively. To effectively conduct the training, it is recommended that ADOT develop training modules. For instance, snow and ice control training modules should be developed for:

- plowing and spreading techniques;
- operational decision making;
- strategies and tactics;
- communications;
- equipment operations and personal safety;
- equipment inspection and operator maintenance (by type); and
- pre- and post-season snow and ice control activities.

Different modules may need to be developed depending on the audience. For instance operators and supervisors may need different safety training; supervisors and managers may need different decision making training. However, all managers responsible for snow and ice control operations need some form of exposure to equipment operations. At a minimum this will include accompanying operators during actual snow and ice control operations and attending a sampling of Org training programs.

The Technical Training Coordinator should tie any performance requirements identified in these modules to the skill-based certification program. In addition, the snow and ice control training should be one of the items in the skill-based certification program in order to provide merit pay for skilled snow and ice control personnel.

5.3.1 On-the-Job Training (OJT)

The OJT program needs to be formalized. It should be consistent across the agency and should be based on ADOT operational policies and procedures. The following is a recommended minimum set of OJT topics:

- CDL Acquisition
- ADOT Safety Policies
- Equipment Operation
- Snow and Ice Control Equipment Operation
- Operator Equipment Maintenance Requirements and Procedures
- Snow and Ice Control Operational Procedures
- Route Familiarization Demonstration
- Radio Operations and Procedures
- Personnel Procedures

The research team also provided to ADOT a checklist for supervisors to use in order to document the proficiency in each of these topic areas.

5.3.2 Initial and Recurring Training

All operators and supervisors should be provided the same training, whether it be initial or refresher training. This will ensure that all personnel are knowledgeable of current policies and guidelines, procedures, and safety requirements. Training should be hands-on when appropriate in order to be assessed properly. Training for decision making should also be performance based.

Training needs to be conducted sufficiently in advance of the winter season to allow for proper evaluation. Remedial training can then be scheduled in time for winter operations.

5.3.3 Training for Temporary and Reassigned Personnel

ADOT should establish a minimum set of training requirements for temporary or reassigned personnel. These minimum training requirements should include safety and ADOT policies, guidelines, and procedures for snow and ice control. This training should also be provided to environmental and other personnel assigned for snow and ice control chemical applications.

Each Org trainer should verify Commercial Driver License possession when appropriate for the intended use of the personnel. Those without CDL should be scheduled for functions not requiring a CDL, such as chemical applications with small trucks.

Org Trainers should use the appropriate sections of the checklist for OJT in Appendix D to document the training provided these employees.

5.3.4 Training Modules

A team of agency staff and hired consultants should develop training modules or tailor existing training programs in order to prepare Org trainers to conduct Org training programs. This would involve key experienced winter maintenance personnel to provide their expertise in building the training program.

Sufficiently in advance of each winter season, a "train the trainer" session needs to be conducted to ensure the Org trainers are aware of changes in policies and procedures. All Org trainers would also be provided briefings or insight into new technologies being evaluated or implemented.

5.3.5 Other Training

Workshops and Conferences

Key people such as Org trainers should attend a selected set of these forums. The Org trainers would pass on the knowledge gained to other Org trainers and Org personnel. In addition to the Org trainers, certain individuals could also be selected to attend, based on rewards for their performance.

A suggested subset of conferences to consider includes:

- The APWA Western Snow Conference, typically in Colorado early each Autumn;
- The APWA North American Snow Conference;
- The University of Wisconsin continuing education program for snow and ice control operations;
- Regional road weather seminars; and
- LTAP training programs.

New Technology

Again, the Org trainers are key to passing information to Org personnel. All personnel should be made aware of new technology that has become available, whether snow and ice control equipment or material related. The success of implementing new technology will be directly related to the understanding of the users and operators. Management participation is also crucial to the success of establishing new procedures and implementing new technology.

Org trainers should assess whether classroom or OJT is the appropriate medium for conducting the training. The trainers should conduct or have a subject-matter expert conduct the training. The trainers should then ensure and document that all personnel have received the training.

Special Topics

As people become aware of new procedures, environmental issues, etc., at a minimum, information should be shared with Org personnel, and training conducted when required. It is important to not only provide the training, but document it as well.

Weather Education

Some form of "informal training" or education on weather is recommended. This can be in a classroom environment or by individual learning. There are sites on the Internet designed to provide weather education. The following is a sample of Internet sites that have learning modules.

- The University of Illinois has a site at

  http://w2010.atmos.uiuc.edu/(GH)/guides/mtr/home.rxml

This site provides learning modules at the high school or introductory college level.

- The Weather Channel provides a list of learning resources. Its resource site is

  http://www.weather.com/education/

- The National Center for Atmospheric Research, in cooperation with Universities and the National Weather Service has advanced weather learning modules. These can be found at

  http://www.comet.ucar.edu/

These sites and others can be browsed during breaks, off-duty hours, or even during time set aside for specific learning.

In addition, there are books at the introductory level that should be considered for an Org library. One such book deals relatively well with mountain weather in the west. It is entitled "*SKYWATCH – The Western Weather Guide,"* authored by Richard A. Keen, and published in 1987 by Fulcrum Inc. of Golden, CO.

Commercial weather service providers as well as the local National Weather Service personnel can also provide seminars on weather. The Weather Channel also produces videos that can be useful for weather education. A little knowledge of weather can go a long way in helping to interpret weather data and weather forecast products.

In general, the more training that personnel receive, the more attuned they will be to their job. Such training and education also helps to build self-esteem and should make for a more capable and cooperative workforce.

5.4 OTHER CONSIDERATIONS

One final consideration, which was not included in earlier recommendations, could affect level of service and resource requirements. ADOT should consider conducting a route optimization study of its snow and ice control routes within each District. Certain assumptions need to be made in order to make the study worthwhile.

First, additional materials storage sites are needed to reduce dead-head time. It is assumed ADOT could acquire additional land or could share land with other agencies to create new storage facilities.

Second, ADOT should consider establishing additional facilities for snow and ice control equipment. This may be more difficult than acquiring materials storage sites, but a study could indicate that significant increased efficiency is possible with perhaps a combined materials and equipment storage facility.

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3. Ketchum, Stephen A, L. D. Minsk, R. R. Blackburn, E. J. Fleege, *Manual of Practice for an Effective Anti-icing Program*, Federal Highway Administration FHWA-RD-95-202, Washington, DC, June 1995.

4. *Guide for Snow and Ice Control*, American Association of State Highway and Transportation Officials, Washington, DC, 1999.

APPENDIX A. QUESTIONNAIRE SENT TO ADOT PERSONNEL

USE OF RWIS BY ADOT PERSONNEL

PEOPLE TO CONTACT:

District Mtce Engineers, Kingman, Holbrook;
Marc Lozano, Flagstaff;
Maintenance Superintendents, Kingman, Holbrook, Flagstaff;
Maintenance Supervisors, in following orgs:
Kingman, Seligman;
Williams, Kingman
Winslow, Holbrook, Chambers.

Good morning (or …) I'm _________________ working on an ADOT research contract to evaluate snow and ice control pollicies and procedures. As part of our analysis, we're hoping to gather some information on the road weather information system use and operational availability in ADOT. It's my understanding that you use the RWIS in snow and ice control decisions. Is this true?

Yes _______ No _______. If no, whom should I contact in your ORG?

1. Do you keep any records on the availability of your RWIS system to determine its operational health?
____

____

____

2. Who maintains your RWIS sensors and equipment?

____

____

____

3. What is your perception of the maintenance of the RWIS?

   Sensors? ____

   Communications? ____

   Computers? ____

   Software? ____

4. What problems exist with the system that go uncorrected? _____________________________

____

5. Describe any experience with vendor-provided maintenance on the RWIS hardware and software.

____

____

____

6. How does the current maintenance compare with vendor-provided maintenance?

____

____

7. How do you get RWIS information? ______________________________________

____

____

8. What kind of information do you get from your RWIS? ________________________

____

____

9. Have you had any training on how to use RWIS data? Yes ______ No ______

If yes, please describe the training. ____

____

____

10. Do you make different decisions with the RWIS information than you would without it?

Yes ______ No ______. If yes, how are they different? ___________________________

____

____

11. In your opinion, would additional training or recurring training be helpful to you to use RWIS more effectively?

Yes ______ No ______. If yes, what would you like to see? _________________________

____

____

12. Do you archive any RWIS information? Yes ______ No ______. If yes. In what form?

____

____

____

13. Is there anything you'd like to see different with the ADOT RWIS?

____

____

____

Thank you for answering the questions and for your help. We look forward to seeing you during the course of this project.

APPENDIX B. PROCEDURES FOR ACQUIRING AND USING WEATHER INFORMATION

The following procedures are designed to help ADOT acquire, understand, disseminate, and use weather forecasts for snow and ice control decision making. The procedures are divided by organizational level for implementation. In general, if a procedure should be applicable to all Districts having snow and ice control responsibilities, then the responsibility for the procedure is assigned to ADOT.

ADOT Responsibilities/Deputy State Engineer or State Engineer

1. Appoint a full-time Weather Information Manager or Snow and Ice Control Manager. Weather-related responsibilities would include:

- Developing the weather information training program;
- Operation, maintenance of, and planning for the statewide RWIS;
- Obtaining weather information;
- Acquiring forecasting services;
- Exchanging lessons learned between districts; and
- Coordinating weather-related research activities.

2. Develop a formal RWIS and weather information training program. Hold annual weather training sessions for maintenance and operations personnel as close as possible to October 1. Highlight resources available for self-education.

3. Issue a Request for Proposals or a Request for Professional Services to obtain forecasting services. Include in the Request a requirement for meetings between ADOT and the weather forecast provider prior to, during, and after the winter season to discus forecast performance and utility. A sample RFP is shown in Attachment B - 1.

4. Issue the Request for Proposals for RWIS equipment maintenance.

5. Monitor RWIS equipment status in the ADOT Maintenance Management System (MMS). Ensure all missing data or communications problems are prominently displayed on all graphical user interfaces for RWIS information presentation.

6. Gather weather forecast quality assurance information from District Coordinators. Analyze these data for weather forecast contract compliance.

7. Conduct post-storm-related analyses and discussions for multi-District weather events. Crossfeed findings to District Coordinators.

ADOT District Responsibilities

1. Appoint a Weather Information Coordinator or Snow and Ice Control Coordinator in each District. The Coordinator shall (see *Data Analysis Procedures* in the following section):

- Conduct forecast quality assurance analyses, based on weather forecasts, weather and pavement condition logs, and weather event summaries.
- Provide quality assurance information and post storm analyses to the ADOT Weather Information Manager or Snow and Ice Control Manager within a week following each winter weather event.
- Crossfeed important lessons learned to other District Coordinators.
- Communicate lessons learned to Org Foremen/Supervisors.
- Monitor the conditions of the RWIS and quality of the data. Report discrepancies into the ADOT MMS.

2. Ensure that District personnel attend ADOT weather training sessions. Attendees should include the District Engineer, District Maintenance Engineer, District Maintenance Superintendent, each Org Foreman/Supervisor, and Weather Information or Snow and Ice Control Coordinator, at a minimum.

District Dispatcher or Other Designated Person

1. Upon receipt of forecasts, review forecast for significant weather (snow, sleet, freezing rain, frost, possible severe weather [thunderstorms, hail, high winds]). If not sure of the forecast meaning or intent, contact the weather service provider immediately and discuss the forecast.

2. Disseminate forecasts to District Orgs as specified in the District Snow Plan.

3. Provide forecast to designated District individual(s), e.g., maintenance superintendent, maintenance engineer, District engineer, as specified in the District Snow Plan. Provide any additional comments from the forecast provider.

4. Contact Org Foreman/Supervisor to verify forecast receipt if significant weather is forecast or if required in the District Snow Plan. Provide any additional comments from the forecast provider.

5. Disseminate forecast to other Districts, as required by the District Snow Plan. Provide any additional comments from the forecast provider.

Org Foreman/Supervisor

1. Review forecast for significant weather. Use the Weather Event Decision Assistance checklist form (Figure B1) as an aid in determining responses and decisions related to the weather event(s). It can be thought of as a checklist to record with appropriate data (or even check marks) the information that was taken into account. The form should be completed for each route and for major changes in elevation, e.g., Ash Fork to Williams. The form should include:

Precipitation type, expected intensity and amount

Expected weather event start time
Forecast pavement temperatures
Forecast bridge deck temperatures
Forecast dew point temperature
Expected weather event duration
Strategies and tactics to be used

2. Contact the weather service provider if you are uncertain about any of the significant weather thresholds that require action.

3. Determine maintenance strategies and tactics appropriate for expected weather. Determine resources required (equipment, personnel, materials).

4. Implement appropriate procedures found in the District Snow Plan.

5. Brief equipment operators on the forecast. Post the forecast for viewing by all personnel.

6. If conditions differ from those forecast, contact the weather service provider if they don't call first.

7. Complete the Weather Event Summary (Figure B2) at the end of the weather event.

8. If surveying the roads during a storm or winter weather event, complete the Weather and Pavement Condition Log (Figure B3).

Org Equipment Operators (DO NOT COMPROMISE SAFETY TO COMPLETE FORMS)

1. Perform functions directed by the Org supervisor and as required in the District Snow Plan.

2. Call in to dispatcher or record road conditions on the Weather and Pavement Condition Log (Figure B3) for every pass/cycle over a route for every weather event.

3. Record materials used and application rates on the Operator Log (Figure B4) for every pass/cycle over a route for every weather event.

3. Notify Org supervisor when conditions differ significantly from forecast conditions.

Data Analysis Procedures

Data analysis is required in order to assess the performance of the weather forecast service and the use of weather information by maintenance personnel. Ultimately, data analysis is required to perform evaluations of snow and ice control treatment effectiveness. Performance hinges on the use of RWIS data, especially weather and pavement temperature forecasts, and their accuracy.

Equipment Operators

1. Complete the Weather and Pavement Condition Log (Figure B3) for every pass/cycle over a route each winter weather event.

2. Complete the Operator Log (Figure B4) for every pass/cycle over a route each winter weather event

3. Provide the Logs to the Org Foreman/Supervisor following each shift.

Org Foremen/Supervisors

Each Org Foreman or Supervisor is a key element in reporting necessary information back to the respective District Maintenance Superintendent and the Weather Information or Snow and Ice control Coordinator for each winter weather event.

1. Record pertinent information as described in the *Operating Procedures* section. This includes the Weather Event Decision Assistance Chart (Figure B1) and the Weather Event Summary (Figure B2).

2. Review the Weather and Pavement Condition Logs (Figure B3) and Operator Logs (Figure B4) following each shift. Forward copies to the District Maintenance Superintendent following each shift.

Type of Data	Forecast	Decision Type					
		Personnel	Equipment	Materials	Strategy	Tactic	Public Info
Probability of Precipitation							
Probability of Frost							
Weather Event Start (Date/Time)							
Weather Event End (Date/Time)							
Pavement Temperature							
Bridge Deck Temperature							
Air Temperature							
Dew Point Temperature							
Wind Direction and Speed							
Wind Chill							
Precipitation Type							
Precipitation Intensity							
Precipitation Amount							

Figure B1 – Weather Event Decision Assistance Chart

WINTER WEATHER EVENT SUMMARY

ORG: ______________________ Site Location: ______________________________

Date Event Began: _______/______/_______ 24-Hour Time: ______________

Forecast Time of Weather Event Start: 24-Hour Time: ______________

Date Maintenance Began: _______/______/_______ 24-Hour Time: ______________

Date Event Ended: _______/______/_______ 24-Hour Time: ______________

Forecast Time of Weather Event End: 24-Hour Time: ______________

Date Maintenance Ended*: _______/______/_______ 24-Hour Time: ______________

Brief Description of the Event

Prepared by: _______________________ Date: ______________

* Does not include post storm cleanup activities

Figure B2 – Weather Event Summary

Weather and Pavement Condition Log

ORG: ______________

ROUTE: ______________ OBSERVER: ______________ DATE: ______________

			WEATHER CONDITIONS							PAVEMENT CONDITION											
	ROUTE INFORMATION			Precipitation Rate: L = Light, M = Moderate H = Heavy Moisture of Snow 1 = Powder, 2 = Ordinary 3 = Wet/Heavy							BARE			SNOW-COVERED				ICE-COVERED			
TIME	MILE POST START	MILE POST END	AIR TEMPERATURE	RAIN	FREEZING RAIN	SLEET	SNOW	BLOWING SNOW	NONE	PAVEMENT TEMP	DRY	DAMP	WET	SLUSH	LOOSE SNOW	PACKED SNOW	PERCENT COVERAGE	FROST	BLACK ICE	GLAZE ICE	PERCENT COVERAGE

Figure B3 – Weather and Pavement Condition Log

TRUCK/OPERATOR ACTIVITY LOG

ROUTE NUMBER: ___________

TRUCK ID: _______________ SPREADER: ____

DATE: ___________________

DATE OF LAST CALIBRATION: _________________________ OPERATOR(S): _______________________

PAGE ________ OF ________

START TIME	ROUTE MILE POSTS		METHOD OF TREATMENT check all that apply			PASS NO.	LANE(S) BEING TREATED check all that apply		MATERIAL AND APPLICATION RATE DATA (for chemical and abrasives treatments)		COMMENTS
	start	end	plowing	chemical	cinders		driving	passing	material(s) applied	application rate(s)	

Figure B4 – Operator Log

2. Keep a record of the forecast performance. Use the simple decision matrix, as shown in Figure B5, to keep track of forecast accuracy. Record one check mark in a box for each forecast.

3. Complete an After-Action Report for each weather event. Record what went wrong or what went right. Complete the Report with the assistance and input from Equipment Operators. Critical elements in the After-Action Report include:

- forecast performance;
- materials used and their results
- strategies and tactics used and their results;
- time to attain the appropriate level of service;
- documentation of good performance;
- recommendations to improve performance.
-

		OBSERVED	
		Snow	**No Snow**
FORECAST	**Snow**		
	No Snow		

Figure B5. Decision Matrix for Recording Forecast Performance

4. Forward a copy of the After-Action Report, Weather Event Summary, Weather and Pavement Condition Logs, and Operator Logs to the District Maintenance Superintendent.

5. Following each weather event, discuss the forecasts and their timing with the District Weather Coordinator or Snow and Ice Control Coordinator for discussion with the District Maintenance Superintendent. It is equally important for forecasters to know when they hit forecasts correctly as it is to know when they miss forecasts. It also helps for the forecasters to understand the needs of the maintenance personnel and the consequences of "bust" forecasts.

District Weather or Snow and Ice Control Coordinator

1. Review the After-Action Reports, Weather Event Summaries, and Weather and Pavement Condition Logs and Operator Logs from each Org. Look for patterns of good or poor

performance for either forecasts or maintenance. Document exceptional (good or bad) as lessons learned for crossfeed to Orgs and to other Districts.

2. Prepare decision matrices for each type of weather event. The one shown in Figure B5 is for snow events. Use another similar log for frost or freezing rain, or for all types of winter weather events, including frost events.

> Good forecast performance will have a significantly greater share of check marks in the upper left and lower right boxes. For instance, for 75% correct forecasts, 75% of the checks will occur in these two boxes. However, it is equally important to keep track of the other two boxes.
>
> Forecast errors can be due to over forecasting or pessimism in the forecasts. This causes forecasts of events that do not occur. These forecasts tend to cost money in terms of wasting resources (usually people). These would be the marks in the upper right corner. Marks in the lower left corner are particularly troublesome because they can result in non-action when action was really needed.
>
> Ideally the forecasters should strive to have zero occurrences in the lower left and should strive to minimize those in the upper right. In so doing, the forecast accuracy will increase and be more meaningful to ADOT decision makers.

3. Record the forecast pavement temperatures for each RWIS site along with the actual pavement temperature for weather events, including frost. Note the discrepancies in qualitative and quantitative terms. For instance, note a tendency for temperatures to be forecast too low or too high; also note the numerical errors in the forecast temperatures.

4. Share and discuss these running forecast performance assessments with the forecast providers, including the National Weather Service. Dialogue between the users (maintenance) and the forecasters is crucial to both improvement in forecast performance and in the perception of forecast performance.

5. Provide status reports and assessments as required to the District Maintenance Superintendent or the District Maintenance Engineer.

District Maintenance Superintendent

1. Using Weather and Pavement Condition Logs, document the Levels of Service (LOS) attained at various times during a storm. Use the LOS definitions from the Dye Maintenance Management System report. Note where improvements can and should be made.

2. Provide performance feedback to Org foremen/supervisors based on LOS analysis and documentation of weather and pavement conditions combined with strategies and tactics.

3. Involve the District Maintenance Engineer or District Engineer when conditions warrant management involvement, for example:

- resource (personnel, equipment and materials) problems, limitations or requirements;
- problems attaining the appropriate LOS;

- unresolved RWIS equipment problems;
- weather and pavement condition forecast problems; or
- any snow and ice control issue that requires his/her assistance or guidance.

4. Schedule maintenance training as appropriate to share lessons learned and improve maintenance as required.

District Maintenance Engineer

1. Keep abreast of each winter weather event. Discuss all facets or each event with the District Maintenance Superintendent.

2. Provide guidance to the District Maintenance Superintendent on strategies and tactics as appropriate.

3. Report to the District Engineer as required.

APPENDIX B – 1. Draft of a Functional Requirements Document for Forecasting Services

SAMPLE AGREEMENT FOR METEOROLOGICAL SERVICES

(Preceded and followed by ADOT boiler plate)

Functional Requirements for Meteorological Services

Consultant Responsibility

The consultant shall have a qualified meteorologist on duty 24 hours each day this contract is in effect. A qualified meteorologist is one that has as a minimum a Bachelor's degree in meteorology from an accredited college or university with at least two years experience forecasting weather in the mountainous west or southwestern United States. It is desired that the consultant shall have familiarity with forecast sites.

Department Responsibility

The Department shall administer this contract through the Maintenance Division in accordance with the Scope of Work described in this Agreement. The Department shall provide the consultant with names and phone numbers of personnel to be notified of conditions outlined below.

Duration of Contract

This contract will be in effect starting the ____ Day of ___________ 1998 and ending on the _____ day of _______ 1999.

Scope of Work

A. The consultant will provide:

1. A daily routine weather forecast for ________ specific sites in Arizona produced twice a day and transmitted prior to ___ p.m. Mountain Standard Time (MST) and ____ a.m. MST daily.

a. RWIS location site specific forecasts will be prepared prior to _____ p.m. MST daily for the following locations:

ADOT Organization	Site Name	Site Location
Kingman District	Fort Rock	I-40, mp 91.15
	Crookton	I-40, mp 132.25
Flagstaff District	Ash Fork	I-40, mp 154.2
	Pine Springs	I-40, mp 158.99
	Riordan	I-40, mp 190.76
Holbrook	Little Colorado River	I-40, mp 256.89
	Petrified Forest	I-40, mo 312.0
	Lupton	I-40, mp 358.88
	Clints Well	SR87, mp 291.4
	Heber	SR377, mp 0.2

b. [*It is suggested that*] Other detailed, site specific forecasts shall be provided for [*actual sites to be determined by ADOT*]

Mingus Mountain area	SR 89A
Oak Creek Canyon	SR 89A
Kohls Ranch(?)	SR 260
Ganado	SR 264
White Mtn. Rec Area	SR 260
[*Others*]	________

c. The ____ p.m. forecast shall be composed of two parts:

- a site specific forecast of weather parameters at designated times over a 24 hour period; and
- a general forecaster's discussion for each of the 5 Northern Arizona ADOT Districts: Kingman, Flagstaff, Holbrook, Prescott, and Globe (Show Low) containing extended forecast information (24-48 hours) and general comments including county detail on critical aspects for the forecast.

(1) The 24 hours section of the forecast shall contain these components displayed at the specific time intervals:

PARAMETERS	**INTERVAL**
Pavement temperature[1]	20 min
Bridge deck temperature[1]	20 min
Precipitation type and intensity	20 min
Wind direction and speed	3 hr
Air Temperature	3 hr
Dew point temperature	3 hr
Wind chill	3 hr
Probability of precipitation	3 hr

(2) The forecaster's discussion shall contain the following:

(a) Forecaster's general remarks about conditions in the first 24 hours for the region to include maximum and minimum air temperature, precipitation type and amount, and wind direction and speed.
(b) The maximum and minimum air temperature in the second 24-hour period.
(c) Precipitation expected during the second 24 hour period
(d) Beginning time of any storm in the 24 hour period detailed by county
(e) Total expected snowfall or ice accumulation during the storm detailed by county.
(f) Profile of surface temperatures, as produced by the NWS MM5 Model by U of Arizona and the Tucson NWS office, expected at approximately 1400 GMT (0700 MST) for the following cross sections:

<u>(1)</u> along I-40 from Fort Rock to I-17
<u>(2)</u> along I-40 from I-17 to Lupton
<u>(3)</u> along I-17 from Cordes Junction to I-40

[1] RWIS sites only

(4) along a line from Payson to Heber

(g) Probability of frost formation on bridges located on highways in the transition zone, by county
(h) Wind direction and speed following a storm.
(i) Sky conditions following the storm; and
(j) Probability and time black ice may occur.
(k) Rationale for any significant disparity between NWS and consultant forecasts during the forecast period.

(3) The Friday ___ p.m. forecast or forecast just prior to a holiday shall include extended forecast information for the duration of the weekend or holiday period to include the probabilities for precipitation by county and the frost formation on transition zone bridges.

d. The ____ a.m. forecast shall contain the same components as the ____ p.m. forecast with the exception that the _____ a.m. forecast shall be limited to those events expected within the next 24 hours, with special emphasis on bridge frost formation.

2. Forecast update notification: when weather conditions are expected to occur that meet the conditions defined below the consultant shall notify the department immediately. The consultant shall telephone the (*dispatcher at the Flagstaff District Headquarters?) or District Maintenance Engineer in the affected district or designated representative* [*to be specified by ADOT according to Snow Plans*]. The updated forecasts will also be transmitted to the RWIS CPUs in Flagstaff.

Conditions that warrant notification:

a. The snowfall forecast changes by two inches or more;
b. Precipitation is expected to change from rain to snow or snow to ice;
c. The start or end of a storm has changed by two hours or more'
d. Frost is or is not expected to occur on bridges in the transition zone when frost was not or was forecasted.
e. ________________[*Other*]_________________

3. Forecast accuracy:

a. Pavement temperature: Forecasts of pavement temperature shall be within ± 2°F 80 percent of the time.
b. Precipitation: Forecasts for the occurrence or non-occurrence of 2" of snow (not on pavement) or more shall be accurate 80 percent of the time.
c. ________________[*Other*]_________________
d. Failure by consultant to achieve an average accuracy within five percent of the accuracy requirements for the above sites will result in a five percent monthly fee penalty.
e. Exceeding the accuracy requirements by five percent on average for the above sites will result in a five percent monthly bonus.

4. The consultant shall notify ITD of all NWS-issued weather and flood warnings and winter storm advisories that affect the agencies identified in A.1.c., above. The consultant shall telephone the (*dispatcher at the Flagstaff District Headquarters?)*

or District Maintenance Engineer in the affected district or designated representative [*to be specified by ADOT according to Snow Plans*}.

5. The consultant shall transmit the daily site-specific forecasts and any updates for each site-specific forecast to the RWIS central processing unit located at Flagstaff. Extended forecasts will be transmitted by telephone facsimile to the maintenance district headquarters.

6. The consultant shall provide a no-charge telephone number Department personnel to use to gain access to the forecaster. Consultant will maintain a log of telephone calls received from Department personnel.

7. [*Consider delivery of forecasts via the SBWIS.*]

B. Any climatological data or graphics

Access to records

Ownership and Release of Information

Indemnification

Assignability

Consideration and Payment

Total contract amount, payment schedule, and compensation for consulting (e.g., expert testimony requested by the Department).