Evaluation of Utah Department of Transportation's Weather Operations/RWIS Program: Phase I

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16. Abstract

The UDOT Weather Operations/ RWIS program is unique among state departments of transportation nationally, as it assists the DOT operations, maintenance, and construction functions by providing detailed, often customized, area-specific weather forecasts. Staff meteorologists are stationed in the Traffic Operations Center (TOC), providing easily accessible weather information and quality control of weather forecasts. A national survey confirmed the benefits of such customized forecasts, including more accurate forecasts; timely forecasts and access to a forecaster; advanced warning of storm conditions; better response time and improved planning and scheduling of staff; and better use of chemical products.

By examining the labor and materials cost for winter maintenance in the 04-05 season for 77 UDOT sheds, an artificial neural network model was trained and tested to establish the shed winter maintenance cost as a function of UDOT weather service usage, evaluation of UDOT weather service, level-of-maintenance, seasonal vehicle-miles traveled, anti-icing level, and winter severity index. The model estimated the value and additional saving potential of the UDOT weather service to be 11-25 percent and 4-10 percent of the UDOT labor and materials cost for winter maintenance, respectively. It was also estimated that the risk of using the worst weather service providers to be 58-131 percent of the UDOT labor and materials cost for winter maintenance.

Further evaluation of other benefits of UDOT weather service are not included in this phase, such as better traveler information, accident reduction, value added to UDOT training and risk management, and benefits to programs outside UDOT.

The research findings are expected to provide planners cost-benefit information to consider integrating weather service into their TOC or Transportation Management Center (TMC), and to provide maintenance engineers useful information about the value of customized weather service.

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GLOSSARY OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
ANN	Artificial Neural Network
ATR	Automatic Traffic Recorder
CARS	Condition Acquisition and Reporting System
CASA	Collaborative Adaptive Sensing of the Atmosphere
DOT	Department of Transportation
FHWA	Federal Highway Administration
GIS	Geographic Information System
ITS	Intelligent Transportation Systems
LMC	Labor and Materials Cost
LOM	Level of Maintenance
LOS	Level of Service
MDSS	Maintenance Decision Support System
MMQA	Maintenance Management Quality Assurance
NWS	National Weather Service
RWIS	Road Weather Information System
SMSE	Sum of Mean Squared Error
TMC	Transportation Management Center
TOC	Traffic Operations Center
UDOT	Utah Department of Transportation
VMT	Vehicle-Miles of Travel
WSI	Winter Severity Index

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EXECUTIVE SUMMARY

The UDOT Weather Operations/ RWIS program is unique among state departments of transportation (DOTs) nationally, as it assists the DOT operations, maintenance, and construction functions by providing detailed, often customized, area-specific weather forecasts. Staff meteorologists are stationed in the Traffic Operations Center (TOC), providing easily accessible weather information and quality control of weather forecasts. A national survey confirmed the benefits of such customized forecasts, including more accurate forecasts; timely forecasts and access to a forecaster; advanced warning of storm conditions; better response time and improved planning and scheduling of staff; and better use of chemical products.

By examining the labor and materials cost for winter maintenance in the 04-05 season for 77 UDOT sheds, an artificial neural network model was trained and tested to establish the shed winter maintenance cost as a function of UDOT weather service usage, evaluation of UDOT weather service, level-of-maintenance, seasonal vehicle-miles traveled, anti-icing level, and winter severity index. The model estimated the value and additional saving potential of the UDOT weather service to be 11-25 percent and 4-10 percent of the UDOT labor and materials cost for winter maintenance, respectively. It was also estimated that the risk of using the worst weather service providers to be 58-131 percent of the UDOT labor and materials cost for winter maintenance.

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1. INTRODUCTION

"As a general rule the most successful man in life is the man who has the best information." – Benjamin Disraeli (1804-1881)

1.1. UDOT Weather Operations/RWIS Program

The response of the transportation community to the weather challenges has evolved over time, as forecasting tools have become more accurate, reliable and precise. UDOT has taken a notable step forward through the creation of its Weather Operations/RWIS Program. The UDOT Weather Operations Program became operational for the 2002 Winter Olympics. In preparation for the Olympics, a 30-year weather history of Utah was researched, and the reasons to prepare for adverse weather conditions during the Olympics were identified as follows (Horel et al, 2002).

- "Significant weather events have affected all past winter Olympics."
- "Adverse weather (e.g., heavy snowfall, strong winds, low visibility due to fog or snow, or avalanches) may delay or postpone events associated with the 2002 Winter Games."
- "Snow and ice-covered streets and highways… could impede road access to the venues by athletes and spectators while limited visibility and high winds could hamper aviation operations over mountain passes."
- "The Olympic weather support system must meet the diverse requirements of the 2002 Winter Games in the context of the winter weather often experienced in northern Utah."

The need to document weather events prior to and during the Olympics resulted in an increase in weather sensors and weather stations installed at key locations throughout Utah. During the Olympics, a Hazardous Winter Weather Potential was produced for the primary transportation corridors twice each day, which included the weather forecast as well as wind, temperature, and precipitation predictions. This report was also produced for the avalanche zones along US Route 189. The information from these reports along with forecasts from NorthWest Weathernet Inc. assisted UDOT with their winter road maintenance (Horel et al., 2002).

Nationally unique, the UDOT Weather Operations/ RWIS Program assists the DOT operations, maintenance, and construction functions by providing detailed, often customized, area-specific weather forecasts. Established under the UDOT Traffic Management Division, the program has two main components. First, the Weather Operations component features four staff meteorologists stationed in the Traffic Operations Center (TOC), providing year-round weather support for winter maintenance, road construction and rehabilitation projects, TOC operations, the Highway Avalanche Safety Program, planning, risk management, training, and incident management. With the staffed meteorologists, quality control of weather forecasts is ensured. Weather briefings are conducted in the TOC on a daily basis, involving TOC personnel, area supervisors, and maintenance foremen. In addition, the program provides tailored crew-specific forecasts in a text format for all 82 maintenance sheds (Patterson, 2005).

Another component of the program is the intelligent transportation systems (ITS) component, which manages 48 road weather information system (RWIS) stations and expert systems such as bridge spray systems, high wind alerts, and fog warnings (Patterson, 2005).

As shown in Figure 1-1, the program provides various services to numerous customers within UDOT. It provides the Office of Central Maintenance with year-round, long-term weather forecasts that are mainly used for planning in terms of materials (storage & purchasing), staffing, and equipment. It provides construction engineers and contractors with weather forecasts for new construction and renovation projects, which are mainly used to plan for staffing, materials, and equipment. The program provides pre-storm, during-storm, and post-storm weather forecasts to the maintenance engineers, area supervisors and local sheds. In addition to snow and ice control, such forecasts are also useful for the operations/projects of road rehabilitation, weed abatement, and avalanche safety.

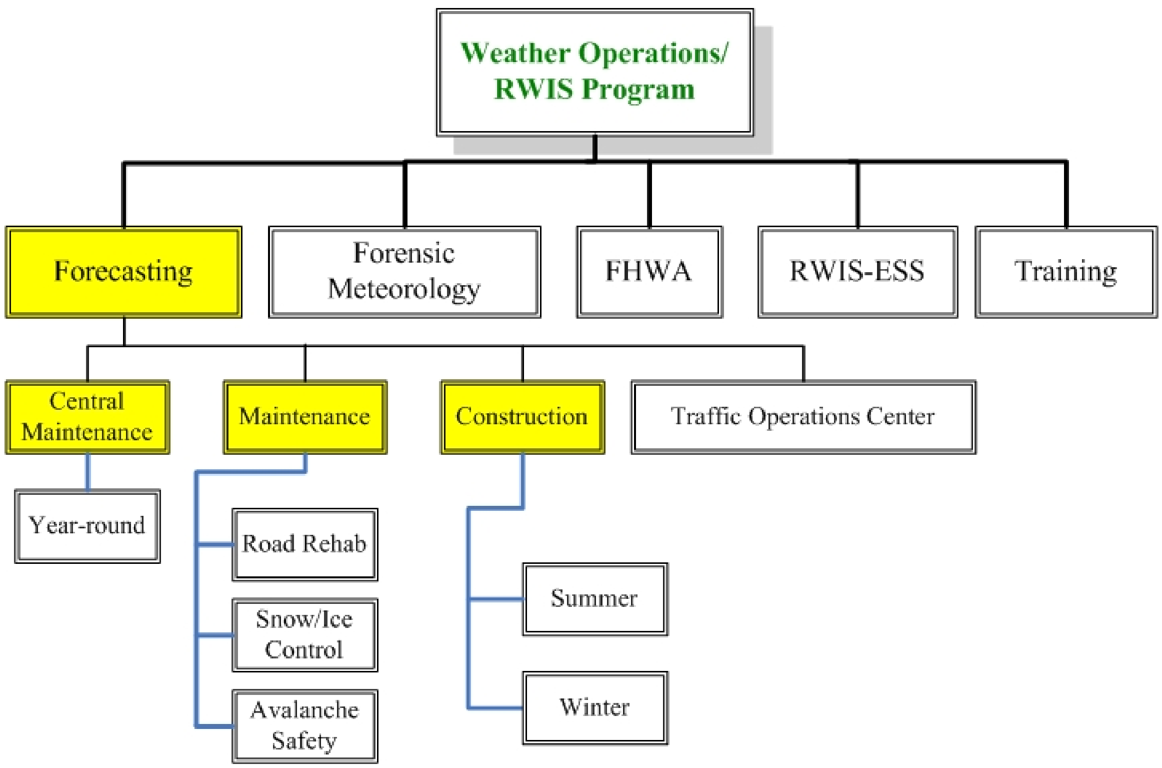


Figure 1-1: Organizational Chart of UDOT Weather Operations/RWIS Program's Services

The TOC also receives weather service from the program, which is expected to result in better information for TOC staffing and planning, better traveler information (through 511/ CommuterLink/ Variable Message Signs), as well as improved operations of the Advanced Traffic Management System (ATMS), Incident Management Teams (IMTs), Signal Group, and Department of Public Safety.

As a result of the program, road and weather information with improved quality and accessibility is available for UDOT personnel and other stakeholders. This is expected to have a positive impact on UDOT's goals and objectives, in terms of overall safety, mobility, efficiency, productivity, environmental conservation, and customer satisfaction. With the right weather information, maintenance managers can plan ahead of time and respond proactively to weather events, construction managers can avoid labor costs or project delays due to inaccurate weather forecasts, and traffic managers can respond to weather events more effectively. In addition to safer and smoother highway operations and traffic flow, improved weather forecasting capabilities reduce operational expenses by deploying resources more efficiently across the different levels and units of UDOT.

The program is continuing to evolve to meet customer needs. Some of these added features include phone conferences to key personnel prior to storm events; increased reliance on telephone consultation with decreased emphasis on text forecasts; 24/7 meteorological staffing support out of the TOC; assisting TOC personnel in scripting weather-related messages for variable message signs, highway advisory radio and 511; and advising signal systems operational engineers on when to initiate corridor-specific snow signal timing plans.

Evaluating the effectiveness and benefits of the UDOT Weather Operations/RWIS Program is critical for UDOT to be able to answer the question as to whether the program was a good investment. If the program is proven to be cost-effective, UDOT may consider how to maximize its benefits and whether or not to expand its scope. In addition, the program may serve as a model for other states, especially those in the Intermountain West that experience rapid population increases (Horel et al, 2002). Information characterizing and quantifying the benefits of the adoption and deployment of such a program would allow other DOTs to support decisions in determining whether it should commit to customized weather service and, if so, at what rate it might budget and schedule deployment.

The research team took a phased approach to the evaluation of the UDOT Weather Operations/RWIS Program. This phase I evaluation focused on the forecasting services provided by the program to the Office of Central Maintenance, regional maintenance engineers and local maintenance sheds, and construction engineers and contractors, as highlighted in Figure 1-1 in yellow. This research is innovative in that it aims to evaluate the program-level benefits through micro-level analyses, while most existing evaluation efforts aim to evaluate the project-level benefits of a specific system such as 511.

The evaluation of the services provided by the program to the TOC, and the activities involving the offices of Forensic Meteorology, Federal Highway Administration (FHWA), RWIS-ESS, and Training are not included in this phase.

1.2. Winter Maintenance Challenges and the Role of Weather Information

In the northern United States and Canada, snow and ice control operations are essential to ensure the safety, mobility and productivity of winter highways, where the driving conditions are often worsened by the inclement weather. The U.S. spends $2.3 billion annually to keep roads clear of snow and ice (FHWA, 2005); in Canada, more than $1 billion is spent annually on winter maintenance including road salts (Transportation Association of Canada, 2002).

Depending on the road weather scenarios, resources available and local rules of practice, DOTs use a combination of tools for winter road maintenance and engage in activities that include anti-icing, deicing, sanding and snowplowing. As the detrimental environmental impacts of abrasives are generally greater than those of chemicals (Staples et al., 2004), DOTs have begun to minimize the use of abrasives. The increased use of chemicals, however, has raised growing concerns over their effects on motor vehicles, the transportation infrastructure, and the environment (FHWA, 2002; Mussato et al., 2003; Buckler and Granato, 1999).

In recent years, transportation agencies across North America have been shifting from reactive strategies to proactive strategies for snow and ice control, such as anti-icing. Compared with traditional methods for snow and ice control (e.g., deicing and sanding), anti-icing leads to decreased applications of chemicals and abrasives, decreased maintenance costs, improved level of service, and lower accident rates (O'Keefe and Shi, 2006). Reliable weather forecasts are key to a successful anti-icing program, as the pavement surface temperature dictates the timing for anti-icing applications and the appropriate application rate.

Maintenance agencies are continually challenged to provide the desired level of service (LOS) and improve safety and mobility in a cost-effective manner while minimizing corrosion and other adverse effects to the environment. To this end, it is desirable to use the most recent advancements in the application of anti-icing and deicing materials, winter maintenance equipment and vehicle-based sensor technologies, and road weather information as well as other decision support systems. Such best practices are expected to improve the effectiveness and efficiency of winter highway operations, to optimize material usage and to reduce associated annual spending and corrosion and environmental impacts.

One key component in helping to meet these goals is obtaining and using accurate weather information. The benefits of accurate weather information are clearly evident when contrasted with some of the costs of inaccurate weather information, such as excessive use of chemicals and materials, failure to respond in a timely matter to a storm event (resulting in greater crash risk and user delay), unplanned use of overtime staffing, and others. Improvements in weather information can help in all stages of winter storm response, including pre-, during and post-storm.

Weather information can be divided into two temporal categories: observations, which reflect current conditions; and forecasts, which predict future conditions (Boselly et al., 1993). While understanding current conditions can be valuable, predictive forecasts can be used to develop an appropriate response to the weather. Forecasts may be subdivided into decision scales: micro (less than 1 hour); meso (1-6 hours); synoptic (6 hrs-week) and climatic (weeks and beyond) (FHWA, 1998). These scales correspond to the different ways that a forecast may affect future activities. A micro-scale analysis may be useful in deciding an application rate, while a synoptic-scale would be helpful for staffing and resource planning.

The UDOT Weather Operations/RWIS Program provides pre-storm, during-storm, and post-storm weather forecasts to the maintenance engineers, area supervisors and local sheds. The type of information in each forecast, and the benefits to maintenance, are shown in Table 1-1. In addition to snow and ice control, such forecasts are also useful for the operations/projects of road rehabilitation, weed abatement, and avalanche safety.

Table 1-1: Information Provided by the Program to Local Maintenance Sheds

Timing	Type of Information	Application
Pre-Storm	▪ Timing/onset of the weather event ▪ Rain vs. snow ▪ Temperature trends	▪ Key for anti-icing operations, which aim to prevent the bonding of ice to the roadway by spreading chemicals prior to or in the early stage of a winter weather event, allowing easier removal by mechanical means.
During-Storm	▪ Intensity and duration of the weather event ▪ Temperature trends	▪ Key for snow and ice removal operations. Based on the forecast, various tools could be used to remove snow and ice from roadways or to improve traction, including de-icing, snowplowing, and sanding.
Post-Storm	▪ Exit timing of the weather event ▪ Blowing snow ▪ Temperature trends	▪ Key for snow and ice cleanup operations

Mostly through e-mail, the program creates and distributes weather forecasts in a text format (as shown in Figure 1-2) twice a day and as weather conditions worsen. The morning forecast is for the next 36 hours, and the evening forecast is for the next 24 hours. In addition, area supervisors or shed foremen can call the program office to receive "nowcasts", and on average the program receives 25 calls daily (with a maximum of 75 calls). The meteorologists will also call area supervisors or shed foremen if new information about the weather event indicates that an earlier forecast was inaccurate.

```
UDOT Traffic Operations Center, Weather Desk
REGION 1

Date:  01/18/05
Time:  1200
Meteorologist:  Merrill




Region 1 Discussion:
Forecast still on track and beginning to sound like a broken record. Building inversion
conditions will continue to increase fog/smog in the Cache and Bear Lake Valley areas with
building hazy/patchy fog conditions along the I-15/84 corridors west of the Wasatch Crest.
High clouds will continue to ripple through with off chance for a few wet flurries this
evening Logan Summit, but no road concerns anticipated due to this. Extended looks dry
long-term, and expect no new storm systems through the weekend.

1)      1431 Snowville/Park Valley
.TUE NIGHT .. Dry with a few high clouds. Patchy fog. Low lower 20s.
.WED .. Mixed high overcast and continued dry. Highs in the upper 30s.
```

Figure 1-2: Typical UDOT Weather Forecast in a Text Format

The UDOT Program provides weather forecasts that are much more detailed than traditional weather services. A traditional weather forecast might be in the following format:

- Tonight…Mostly cloudy with a 20 percent chance of light snow. Breezy. Lows near 8 above. North winds 15 to 25 MPH. (Osborne, 2002)

In comparison, the UDOT weather forecast would be more localized and area-specific; for instance (courtesy of UDOT):

- "Quick ¾″ to 1″ snow over the next 1 hour."
- "Alerted for road concerns developing by 1400, sloppy onset. Up to 1-2″ road snow for the commute tonight."
- "Snow band stalling again over your routes areas. Big thing will be dropping temps W-E late afternoon Park Valley, I-15 areas around 1800. General tapering trend west desert areas after temp drop, snow I-15 corridor through 0000."

It is expected that such weather service will continually help UDOT maintenance personnel better utilize their resources (materials, staffing, and equipment) in snow and ice control and provide a desired LOS. For instance, as a proactive strategy, successful use of anti-icing chemicals requires application immediately prior to formation of snowpack, taking into account the onset, type, intensity and duration of winter storms, and thus entails accurate weather forecasts. The benefits from appropriate anti-icing include: improved LOS, cost savings, better maintenance response, improved environmental quality, and other indirect benefits (Boselly, 2001). When applied correctly, anti-icing can reduce the required plowing and decrease the quantity of chemicals required (U.S. EPA, 1999). In many conditions, anti-icing eliminates the need for abrasives, because it eliminates the cause of slipperiness (Williams, 2001). The benefits of anti-icing were demonstrated in a comparison between two maintenance divisions in Montana between the years 1997 and 2000. One division used anti-icing operations to a greater degree and achieved a higher LOS with a 37 percent cost savings per lane-mile (Goodwin, 2003).

1.3. Information Offered by This Report

This report preliminarily examines the business case of the UDOT Weather Operations/RWIS Program, and assesses its effectiveness and benefits particularly to the UDOT maintenance and construction functions. The evaluation aims to answer the following fundamental questions:

- Is the information provided by the program accurate, reliable, and easy to use? Is the program delivering the products it is supposed to? Are the customers satisfied with the service provided by the program?

- Is the information provided by the program changing users' behavior, and if so, how?

- Is the information provided to UDOT personnel valuable in their operations, beyond what is available from other weather information providers?

- What are the benefits of the UDOT weather service to winter maintenance personnel?

1.4. Report Organization

The organization of this report is as follows. Chapter 2 reviews the need of weather information for surface transportation, existing efforts for improved weather forecasting and information integration, and the state-of-the-practice of using customized weather forecasts for winter maintenance in North America. Chapter 3 presents the methodology used to evaluate the benefits of the UDOT Weather Operations Program. Chapter 4 details the analysis of benefits of the UDOT weather service to winter maintenance personnel. Chapter 5 details the overall performance of the UDOT weather service as ranked by customers. Chapter 6 provides conclusions and recommendations.

2. REVIEW OF NATIONAL STATE-OF-THE-PRACTICE

The research team reviewed the use of weather information in surface transportation through a literature review and an on-line survey of transportation agencies. The purpose of this review was to help define how UDOT's Weather Operations Program is similar to or different from other efforts, and to help identify potential benefits of the program.

2.1. Literature Review

A literature review was performed using both computerized searches as well as manual searches to identify the need for weather information for surface transportation and existing efforts to improve weather forecasting and information integration. The literature review also aimed to determine the following: how other maintenance agencies utilize weather information; if other maintenance agencies contract with a customized weather service provider or have staffed meteorologists; and how utilizing customized weather service information benefits maintenance agencies. The literature review targeted publications and documents from FHWA, transportation agencies, scientific journals and reliable websites. Researchers used the following sources in the computerized search:

- Transportation Research Information Service (http://trisonline.bts.gov/sundev/search.cfm)
- Transportation Research Board (http://www.trb.org)
- FHWA (http://www.fhwa.dot.gov/)
- State Departments of Transportation (DOTs)
- Google Scholar (http://www.scholar.google.com)
- Montana State University Library (http://www.lib.montana.edu/)

The rest of this section summarizes the findings of the literature review.

2.1.1. Weather Information Needs for Surface Transportation

Surface transportation in the U.S. is constantly threatened by the capricious character of weather, as weather "acts through visibility impairments, precipitation, high winds, temperature extremes, vehicle maneuverability, pavement friction, and roadway infrastructure" (OFCM, 2003). Adverse weather increases the likelihood of traffic accidents, which may result in injuries and fatalities. In 2001, there were more than 1.4 million weather-related crashes, resulting in 615,000 injuries and more than 6,900 fatalities (FHWA, 2004). The estimated economic cost from weather-related crashes in the U.S. alone amounts to nearly $42 billion annually (OFCM, 2003). In addition, adverse weather causes traffic delays, estimated at nearly one billion person-hours per year (FHWA, 2004), which degrade the productivity, reliability and user experience of the surface transportation system.

Improving the quality and accessibility of road and weather information may benefit a wide spectrum of weather data users, including: state and municipal departments of transportation (DOTs), public weather "forecasting" agencies, public weather "consumer" agencies, private weather information providers, electronic and print media, road users, in-vehicle navigation system providers, the general public, mass transit, and rail (Murphy, 2005).

For the State of Utah, a RWIS traveler information evaluation completed in 2000 indicates that drivers prefer road condition information when the conditions alter driving performance (e.g., accumulating snow, ice, high wind for truckers, road closures). In addition, conditions by specific location and corridor are preferred over a more general description of area weather (Martin et al., 2000).

For transportation agencies operating and maintaining roadways, railroads and waterways, their operational environment is harnessed to the uncertainty of weather forecasting. Because of their responsibilities, their personnel need to travel in all weather conditions, and knowledge of current, forecasted, and historical road and weather conditions assists in the completion of the agencies' missions. Furthermore, they can use road and weather information to make the surface transportation system safer for the traveling public and to inform travelers of potentially dangerous conditions.

Adverse weather is unavoidable, but it is possible to mitigate the threats it poses on the surface transportation system, through timely, accurate, reliable, and user-friendly road and weather information that supports surface transportation. In addition to ensuring the safety, mobility, efficiency and productivity of the transportation system, weather information for surface transportation will play an increasingly important role in emergency preparedness at all levels of federal, state, and local planning and response (OFCM, 2003).

While there is an abundance of information from weather stations operated by various agencies, challenges for transportation agency users remain. First, such information is often not available in a timely fashion. Second, such information may not be reliable in terms of data quality and availability. Third, such information is usually too general to derive the trend of road temperature in a specific area or on a specific route. Finally, such information is not easily accessible in a user-friendly manner. Therefore, assessing the road and weather conditions in the region is usually a time-consuming and inefficient task, as most of the available weather data are not designed for the purpose of supporting surface transportation.

Partly attributable to the paradigm shift from reactive to pro-active winter maintenance strategies and tactics, state and local maintenance professionals across North America are beginning to realize the importance of high-resolution, customized, area-specific weather forecasts for surface transportation (Block et al, 2003; Pisano, 2001; Davies et al, 1998).

While progress has been made to provide maintenance agencies with weather information, the information is often insufficient for operations (Block et al, 2003; Williamson and Estis, 2005; Pisano et al, 2005; Davies et al, 1998). This is in part because many crews rely on the National Weather Service (NWS) or private services that re-package data from NWS. NWS forecasts are often too vague for maintenance personnel in terms of timing, storm intensity and location (Davies et al, 1998). In 2003, FORETELL, a multi-state program focused on integrating ITS and intelligent weather systems (IWS) to provide weather information for surface transportation, performed a market analysis. From this analysis, the deficiencies with current weather information were highlighted, including:

- Lack of information and geographic coverage;
- Insufficient timeliness;
- Inaccuracies that result in lack of confidence in making decisions;
- Lack of necessary detail,
- Difficulties in acquiring information, and
- High cost of acquiring information (Skarpness et al, 2003).

Benefits of using detailed forecasts for winter maintenance include the reduction of unnecessary worker call-outs, reduction in unnecessary use of snow and ice control materials, better planning in advance of a storm, and increased use of anti-icing practices. It is also possible that the winter maintenance activities could be performed at lower costs while increasing the level of safety for travelers (Davies et al, 1998).

2.1.2. Improved Weather Forecasting and Better Information Integration

Weather information may be gathered from a variety of sources. One trend among transportation agencies is to use sources that provide information more customized toward the roadway environment. This includes development of forecasts at a smaller geographic scale, in addition to focusing on weather at the road surface, where reduced pavement friction can adversely affect motorist safety and travel time. The Strategic Highway Research Program (SHRP) conducted research regarding the potential benefits of improved weather information (Boselly et al., 1993; Boselly and Ernst, 1993) in the early 1990s. This research provided a comprehensive examination of RWIS at a time when RWIS implementation in the United States was not widespread. It also analyzed the potential cost-effectiveness of adopting improved weather information (including RWIS and tailored forecasting services), with a simulation model based on data from three U.S. cities.

Currently, there are several efforts across the United States focused on providing weather information for surface transportation, particularly in the fields of improved weather forecasting and better information integration. While these efforts have advanced how weather information is accessed and used for management of the highway system, the UDOT Weather Operations/ RWIS Program is nonetheless unique, with staff meteorologists stationed in the TOC providing detailed, often customized, area-specific weather forecasts.

RWIS

Many transportation agencies have adopted RWIS as an important weather information tool. RWIS includes the hardware, software, and communications interfaces necessary to collect and transfer field observations from a remote site to a display device at the user's location. RWIS collects data from an environmental sensor station (ESS), which includes a suite of atmospheric, pavement/sub-surface, and water level sensors (Manfredi et al., 2005). They differ from conventional weather stations in that they are always deployed in the immediate highway environment, they often measure conditions on the roadway itself; and they are generally deployed where roadway weather conditions tend to be worst. Pavement sensors may be very useful in helping to forecast the likelihood and timing of icing events; however, due to their cost, not all RWIS will use these sensors.

ESS installation may be characterized as either regional or local. Regional sites focus on defining initial conditions to support road weather prediction models, providing ground truth measurements for evaluating forecast accuracy, and improving the ability to anticipate weather changes. They are generally sited to be representative of conditions in the area, and thus are recommended for placement in areas of uniform roadway conditions in flat, open terrain. Local sites require sensors to be placed to measure whatever conditions are of most interest for road weather at specific points, such as icy pavement, low visibility, and high winds (Manfredi et al., 2005).

RWIS provide detailed weather information, but only for specific points along the roadway; information on conditions between these points must be generated from other sources and/or interpolated. Moreover, there are significant costs associated with RWIS networks, not only for initial installation activities, but on-going maintenance, calibration, communications and power.

Clarus Initiative

In 2004, the National Research Council published a visionary document entitled "Where the Weather Meets the Road: A Research Agenda for Improving Road Weather Services" (National Academies, 2004). The report identified the need for a nationwide resource to better utilize surface transportation weather observations that would ultimately provide a more concise picture of current conditions on the surface transportation system and to energize efforts to improve forecasting for the roadway environment. This led to the birth of the *Clarus* (which means "clear" in Latin) Initiative funded by FHWA from 2004 to 2009, the goal of which is to "develop and demonstrate an integrated surface transportation weather observation data management system, and to establish a partnership to create a nationwide surface transportation weather observing and forecasting system" (Pisano et al, 2005). Such a "system of systems" would "collect, quality control, archive, and disseminate surface transportation weather observations" (Pisano et al., 2005). It is envisioned to improve surface transportation weather forecasting with enhanced data density, quality and integration. A Clarus demonstration is currently planned for the winter of 2006-07, with more development activity occurring in subsequent years (Clarus Initiative, 2006). UDOT is actively supporting the Clarus Initiative and has been selected as one of states in its Proof of Concept study.

MDSS

In 2000, FHWA engaged a pool of maintenance practitioners from several state DOTs and researchers from several national laboratories with expertise in weather forecasting and winter road engineering to develop a prototype winter Maintenance Decision Support System (MDSS). MDSS aims to provide current road and weather data and forecasts and real-time treatment recommendations specific to winter road maintenance routes (e.g., treatment locations, types, times, and rates), tailored for winter road maintenance decision makers. With the right information, winter maintenance managers can respond proactively by managing the infrastructure and deploying resources in real time.

FHWA's functional prototype MDSS capitalized on existing road and weather data sources and state-of-the-art weather forecasting models and data fusion techniques. By integrating measured and forecasted road and weather data with proven rules of practice, MDSS provides winter maintenance personnel with diagnostic and prognostic maps of road conditions by maintenance route and a decision support tool with treatment recommendations along with anticipated consequences of action or inaction. The functional prototype has been tested through field demonstrations in central Iowa in 2002-03 and 2003-04 (CTRE, 2003; NCAR, 2004), and on Colorado's E-470 in 2004-05 (NCAR, 2005).

In 2002, a pooled fund study, led by South Dakota and now including Colorado, Indiana, Iowa, Kansas, Minnesota, New Hampshire, North Dakota and Wyoming, emerged as a natural offshoot of the Federal initiative. The study sought to establish an operational MDSS that meets or exceeds the federal vision of an MDSS (Hart and Osborne, 2003) and contracted with Meridian Environmental Technology to develop the operational prototype. Phase 1 of the study resulted in the development of an architecture, based on evaluating FHWA's functional prototype MDSS and extensive outreach to DOT personnel to understand the requirements of the operational MDSS. The resulting architecture differed from the FHWA functional prototype in that it used "a forecasting technique that integrates computer-based processing and the expertise of professional meteorologists," and it does not rely on FHWA Rules of Practice but instead "views each weather-induced situation as unique and the appropriate response is based upon the physics and chemistry of the processes occurring on the pavement surface" (Hart and Osborne, 2003). Phase 2 worked toward development of an operational MDSS. There were concurrent efforts including fundamental research used for developing and enhancing modules (e.g. chemical concentration/freezing point computation) and software programming and development. A Limited Deployment Tactical Integration (LDTI) was unveiled in spring 2004. Training workshops resulted in identification and implementation of improvements to the graphical user interface. Phase 2 recommended demonstration and evaluation of an operational test in the 2004-05 winter (Hart et al., 2004). Through subsequent project phases, testing has expanded to 200 test sections in the winter of 2005-06, with a plan for 600-800 test sections during the winter of 2006-07 (Huft, 2006). The purpose of this testing is similar to that conducted on the federal prototype: verifying the reliability of weather and road condition predictions, and assessing the usability of the interface and treatment recommendations. Guidance has also been prepared to assist states in procuring MDSS-compliant technology. An evaluation project led by the Western Transportation Institute is under way to assess the benefits and costs associated with implementation of MDSS by a state transportation agency. Another MDSS system, developed by DTN/Meteorlogix, is being tested by other states.

In its ultimate vision, MDSS provides forecast functionality that overlaps some of what the UDOT Weather Operations/RWIS Program currently provides. However, earlier demonstrations have shown that MDSS forecasting modules need to be adjusted to better reflect local conditions. Such adjustments are based on human experience that is already integrated within the UDOT program. MDSS seeks to go beyond this by providing treatment recommendations, which currently are not provided by the UDOT meteorologists. However, UDOT meteorologists can provide customized, user-specific information that goes beyond specific scenarios in winter maintenance.

UDOT is not a member of the pooled-fund study, nor is it actively supporting the DTN/Meteorlogix effort. However, UDOT is involved in an Aurora research study to integrate UDOT's weather forecasts into the Pooled Fund MDSS modules.

Aurora

The Aurora program is an international, collaborative group that focuses on research, evaluation and deployment of RWIS with a goal "to improve the efficiency of highway maintenance operations and distribute effective real-time information to travelers" (Belter et al, 2005). Participating transportation agencies provide funding that is pooled together to support a variety of collaborative research projects.

One of Aurora's projects involved synthesizing the use of road weather forecasts internationally. It was determined that the majority of the transportation agencies surveyed, including the Ontario Ministry of Transportation (Canada); the German Federal Ministry of Transport, Building, and Housing; the Danish Road Directorate; the Norwegian Public Roads Administration; the Lancashire County Council (United Kingdom); and the Swedish National Road Administration; had a direct agreement with their meteorological agency to receive forecast information. Other transportation agencies, including the Finnish National Road Administration, Transit New Zealand and the Hokkaido Development Bureau in Japan, did not have a direct agreement with their meteorological agency but contracted with a private weather service provider instead (Newsome, 2001).

Aurora is continually supporting research topics that range from MDSS, meso-scale modeling for detailed and short term weather forecasts, standards and architecture for RWIS, dissemination of data, equipment evaluations, to road condition monitoring (Belter et al, 2005). UDOT is a member of the Aurora Group.

CASA

Collaborative Adaptive Sensing of the Atmosphere (CASA) is a group that aims to improve surface weather information by forecasting weather conditions in the lower atmosphere. Research within CASA focuses on improving storm forecasts by providing a dense network of low-powered radars. These low-powered radars have the ability to adjust their target automatically and should help improve the forecasting of surface weather information by sensing changing weather patterns in the lower atmosphere (Brotzge and Droegemeier, 2006). The first test-bed demonstrating CASA's technology is currently operational (McLaughlin and Phillips, 2006).

FORETELL

FORETELL is a multi-state advanced road and weather condition prediction system developed by Castle Rock Consultants that integrates satellite, radar and surface observations with RWIS data, using state-of-the-art NOAA/NWS weather models and decision support displays (http://www.crc-corp.com/projects/archive/Foretell.htm). For instance, the FORETELL application can display the current or predicted precipitation for the area of interest, at a six-mile grid resolution. FORETELL uses NWS data sources, airport sensors, road sensors and mobile platforms. National weather prediction is supplemented by regional weather models covering New England and the Upper Mississippi Valley at greater resolution. Manual road reports are added to the system using the sister system, Condition Acquisition and Reporting System (CARS). CARS is a road reporting system that creates a multi-state database of highway events and acts as the hub of state-wide and regional traveler information systems, bringing multiple agencies together and creating state-wide virtual transportation management centers (TMCs) (http://www.crc-corp.com/projects/Cars.htm).

The service provided by FORETELL includes a 24-hour forecast updated four times per day as well as hourly updates known as "nowcasts", and pavement condition predictions (Pisano, 2001). FORETELL also uses pager, e-mail, radio and 511 telephone systems to distribute weather and road conditions on demand. It is expected that the information provided by FORETELL will benefit maintenance agencies in the following ways:

- Know when to call for additional trucks/drivers,
- Plan for split shifts for long storms,
- Pre-treat roads with anti-icing materials,
- More effective management of staff and materials, and
- Save money by reducing overtime and material usage (Pisano, 2001).

rWeather

rWeather is a web-based system that was created and is maintained by the Washington State Department of Transportation (WSDOT) and the University of Washington to collect real-time and predictive statewide road and weather information and disseminate it to WSDOT maintenance and other decision makers, as well as to the public. In February 2004, the rWeather website became part of WSDOT's Statewide Traveler Information site (http://www.wsdot.wa.gov/traffic/weather).

rWeather integrates weather data from nearly 400 weather stations throughout the state and offers the data at a single location in a graphic format. The MM5 forecast model used for rWeather is generated by the Northwest Regional Weather Consortium and the University of Washington.

A study was conducted to evaluate the impacts of rWeather on WSDOT winter road maintenance activities, in which questionnaires were distributed to area superintendents, supervisors, and lead technicians. A total of 129 questionnaires were returned and analyzed. 79 percent of respondents were aware of the rWeather website, and of those, 78 percent had used it. Nine of the ten features on the rWeather website were rated useful by more than half of the respondents. The most valuable features recognized by maintenance personnel users included: NWS warnings, satellite and radar images, and the statewide weather map. On the other hand, less than half of the respondents indicated that the rWeather pavement temperatures feature was useful. Approximately 70 percent of respondents wanted more investment in training related to interpreting weather data, and 50 percent of respondents wanted additional training to improve anti-icing strategies. The study recommended that comparisons be made between forecast and actual pavement temperatures and atmospheric weather conditions, and the findings be shared with maintenance personnel (http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ByLink/BOTM-April2006).

WeatherShare

Similar to rWeather, WeatherShare is a web-based system that features the integration of regional weather and road data and forecasts from multiple sources and agencies. WeatherShare does not offer interactive or customized weather forecasts. WeatherShare was funded by the California Department of Transportation (Caltrans) and created by the Western Transportation Institute, as a component of the Redding Incident Management Enhancement (RIME) program, which consists of a group of technology initiatives designed to improve public safety in the Redding area.

Phase I of WeatherShare focused on 11 counties in Caltrans District 2 as well as 9 counties in the adjacent Caltrans districts. The goal was to streamline currently available weather and road data from Caltrans RWIS sites, NWS sites, and other sources available in the region into one single source easily accessible by incident responders and potentially the traveling public. The system allows users to view a compilation of all available road weather information from various sources in the region, increasing the efficiency of situation assessments for a variety of purposes, including incident management, highway maintenance, emergency medical services, traveler information, and, possibly, homeland security applications. Variation of the user interface depends on the user's needs and specifications (Shi et al., 2006).

Phase II is under way to expand the Phase I product, a proof-of-concept system (www.weathershare.org), to cover the entire state and to enhance its functionality and user interface. In addition, the research team will assist Caltrans in analyzing the business case while developing partnerships and plans for long-term maintenance and management of the system. The team will evaluate system use and functionality over multiple seasons and across a wide audience of prospective users with results incorporated in the business case analysis. In conjunction with evaluation, WTI will conduct an on-going needs and requirements analysis and, where appropriate, conduct development and outreach to address identified needs and requirements.

WeatherView

WeatherView is a web-based system maintained by the Iowa State Department of Transportation to collect real-time and predictive statewide road and weather information and disseminate it to DOT maintenance and other decision makers, as well as to the public (http://www.dotweatherview.com/). The information is from a variety of sources:

- RWIS sensors located in and along Iowa's Interstate and primary roads
- AWOS (Automated Weather Observing System) sensors as part of the Iowa Aviation Weather System, located at 35 airports across the state
- Regional forecasts: excerpts from a winter forecast received by the Iowa DOT from a private contractor
- Bridge frost forecasts: from a private contractor by the Iowa DOT to make decisions on managing bridge frost

Private-Sector Meteorological Services

Maintenance agencies often contract with independent weather service providers to receive detailed forecasts. For instance, Meridian Environmental Technology is one weather service provider that supplies maintenance agencies with detailed forecast information. Meridian has increased the efficiency of forecast generation and dissemination, which allows meteorologists more time to analyze weather patterns, producing forecasts with higher accuracy (Block et al, 2003).

It has been reported that advances in meteorology, telecommunications and computational programs "have created a situation in which forecasters have more to offer transportation operators and users than ever before" (Davies et al, 1998). The weather support system that was developed as part of the effort to prepare Salt Lake City and Utah for the 2002 Winter Olympics is a great example of such new advancements at work. This system assisted UDOT with the maintenance of winter roadways, preventing delays to venues by both athletes and spectators. NorthWest Weathernet Inc. was the primary provider of road and pavement condition forecasts for UDOT during the Olympics, and since the Olympics, this provider has continued providing weather forecasts to UDOT (Horel et al, 2002).

2.2. Survey of Use of Customized Weather Forecasts for Winter Maintenance

The use of weather programs and customized, area-specific forecasts across North America was evaluated both through the literature review as well as an online survey posted on the Snow and Ice List Serve (http://www.sicop.net/snow_and_ice_list-serve.htm). This survey was also sent to members of the Pacific Northwest Snowfighters Association (http://www.wsdot.wa.gov/partners/pns/). Questions for this survey were developed with the knowledge of the UDOT program and the information gained through the literature review. The survey on the list serve was brief, focusing on if agencies used forecasting; if agencies used customized, area-specific forecasts and from what source; benefits from using weather forecasting; and satisfaction with forecasting services. Incomplete entries were followed up by e-mail. The questionnaire is included as Appendix A.

Many transportation agencies utilize and rely on weather information for maintenance tasks. Maintenance professionals throughout North America were contacted and asked to fill out a survey through the Snow and Ice List Serve. A total of 31 individuals from 19 U.S. states and 4 Canadian provinces responded to the survey, of which 81 percent were from the U.S. while the remaining 19 percent were Canadian. Professionals included directors (16 percent), maintenance managers (33 percent), engineers (32 percent), superintendents (13 percent), area supervisors (3 percent), and technologists (3 percent) from U.S. and Canadian city agencies as well as U.S. State DOTs and Canadian Provincial/Regional agencies. The geographic distribution of respondents is shown in Figure 2-1.

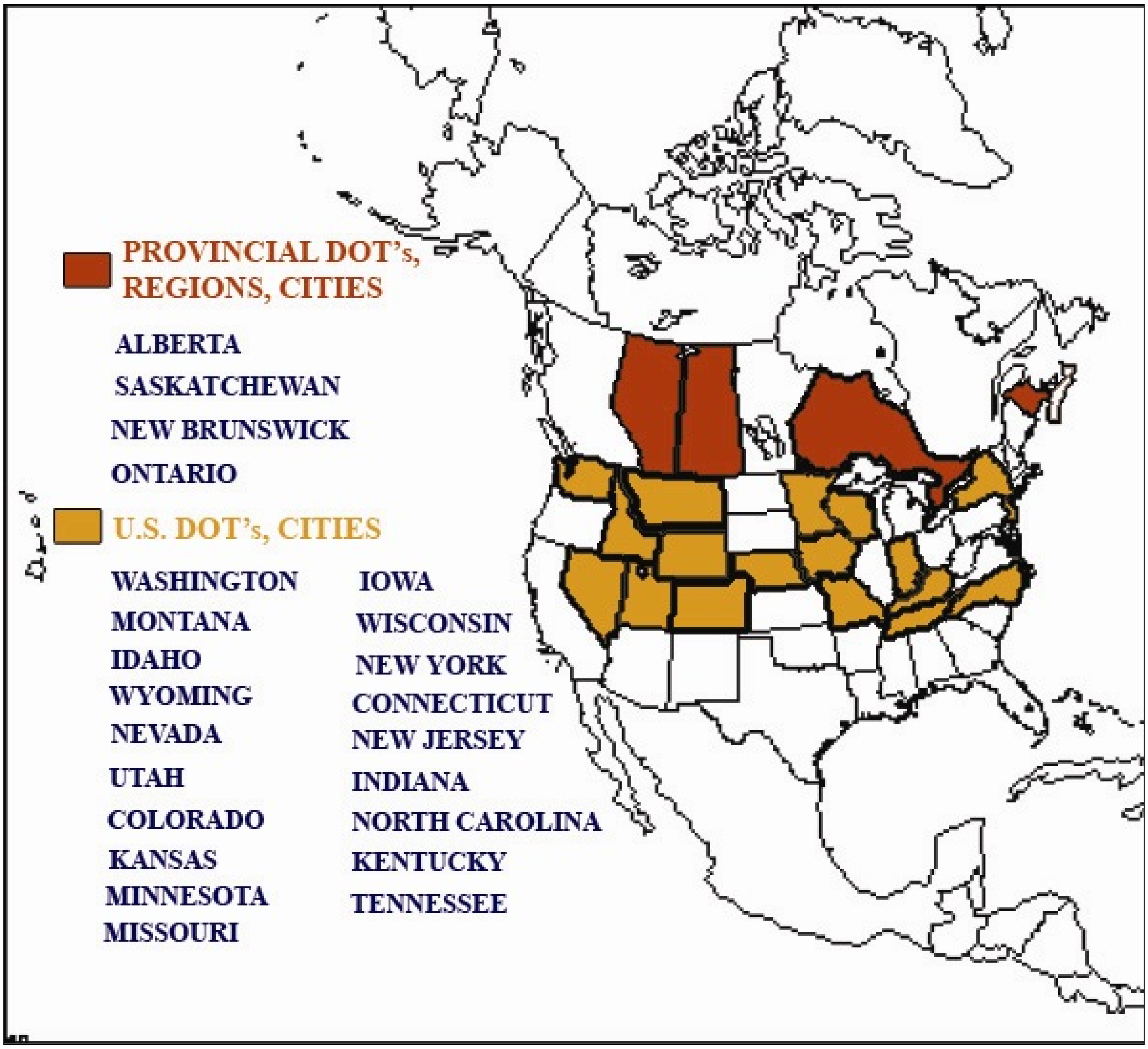


Figure 2-1: States and Provinces Participated in the Snow and Ice List Serve Survey

All respondents indicated that they used weather forecasts to assist them in winter road maintenance activities, and that they paid for customized weather forecasts as well. The most common weather service providers were NorthWest Weathernet, Meridian, Meteorlogix, World Weatherwatch and Accuweather (see Figure 2-2). An interesting finding was that most agencies, 52 percent, are relatively new subscribers to this type of weather service (see Figure 2-3). Some respondents also considered their RWIS service provider as a customized, area-specific forecast provider, which may not be accurate.

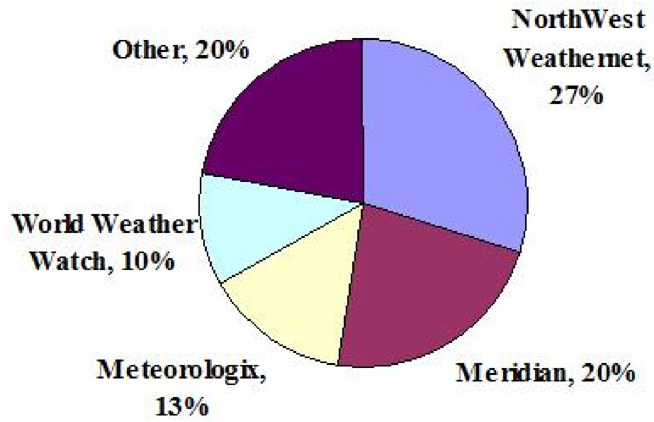


Figure 2-2: Survey Results: Most Common Weather Service Providers

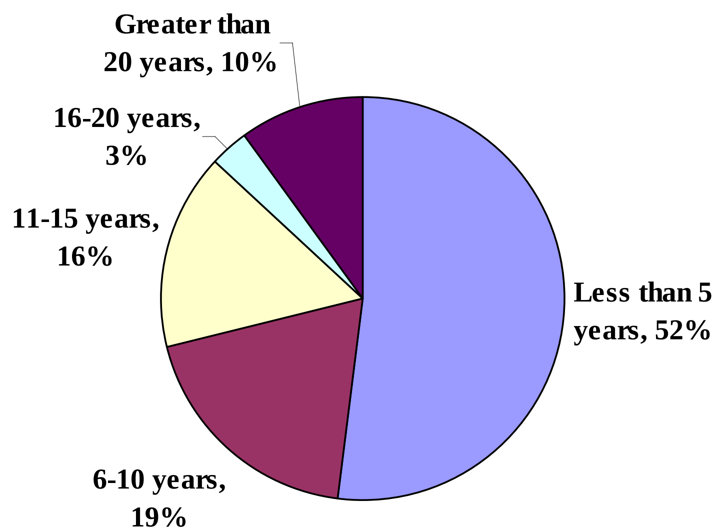


Figure 2-3: Survey Results: Number of Years using Customized Weather Information

The most common benefits of using a customized, area-specific forecast, as recognized by the surveyed maintenance professionals, include:

- More accurate forecasts (due to the knowledge of microclimates);
- Timely forecasts and access to a forecaster;
- Advanced warning of storm conditions that allows for better response time and improved planning and scheduling of staff; and
- Knowledge of pavement temperatures and the timing, type, and amount expected for the precipitation, allowing for better use of chemical products

Some respondents stated that using customized, area-specific forecasts was cost-effective.

Overall, the surveyed maintenance professionals were satisfied with their forecast provider and the service they received (see Figure 2-4). Respondents satisfied with their weather service provider stated that the forecasts were reliable and easily accessible. They also reported that the provider was willing to work with them to resolve any problems. Respondents who reported their service as "adequate" were those who did not fully believe maintenance agencies needed to receive customized forecasts, and also believed that, in the near future, the National Weather Service or a similar provider would suffice. Only 13 percent of the respondents were not satisfied with their service, and the main reason was the poor accuracy of the forecast.

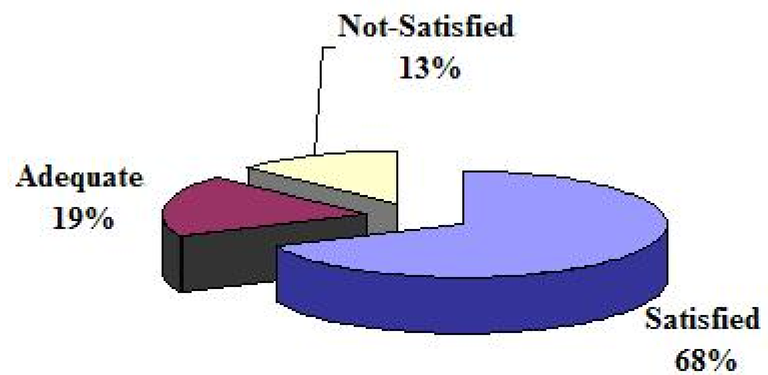


Figure 2-4: Survey Results: Satisfaction of Customized Weather Forecasting Services

3. METHODOLOGY

A basic understanding of the history, current practice, and stakeholders of the UDOT Weather Operations/RWIS Program was obtained through a site visit to the TOC and the Central Maintenance office. During the visit, the research team also interviewed users such as maintenance engineers, area supervisors, shed foremen, construction engineers, avalanche forecasters, and incident responders. This information, supplemented by the findings of the literature review and transportation survey, aided in the development of the project approach.

The project approach included surveying UDOT maintenance and construction personnel and analyzing data on labor and materials cost for winter maintenance along with other related data for the maintenance sheds in order to evaluate both the intangible and tangible benefits of the UDOT weather service to winter maintenance.

3.1. UDOT Personnel Interviews

A survey of UDOT personnel in maintenance and construction was developed and conducted in the first few months of the project. Questions were developed based on the understanding gained from the site visit to UDOT and initial interviews, and included the following:

- Use of weather forecasting: how weather information is utilized, from what source, and whether it is cost-effective
- Awareness of the UDOT Weather Operations/RWIS Program
- Experience with using UDOT weather service, including satisfaction, efficiency, recommended improvements, and how the program may have altered their practices

For service users in winter maintenance, all the UDOT maintenance engineers, area supervisors, and station supervisors were contacted. For service users in construction, all the UDOT resident engineers and a few contractors were contacted. The questionnaires are included as Appendix B. The survey responses were followed up with phone interviews.

3.2. Investigated Factors for Benefit Analysis

To quantify the benefits of UDOT weather service to winter maintenance activities, labor and materials cost (in U.S. dollars) at the maintenance shed level was considered to be a key indicator. The assumption is that the maintenance sheds that have more confidence in the UDOT weather service and use it more frequently might save money through better planning and proactive operations.

In order to compare the different sheds at the same baseline, it is assumed that shed-level labor and materials cost (*LMC*) is a function of several factors described as follows.

$$LMC = f(USE, EVLN, ANTI, LOM, VMT_a, WSI) \tag{2-1}$$

where LMC = the shed-level labor and materials cost for winter maintenance annually

USE = overall usage of the UDOT service in winter season by the shed
$EVLN$ = overall evaluation of the UDOT service by the shed
$ANTI$ = the level of anti-icing practice (0 if no anti-icing; 0.5 if to start anti-icing program soon; 1 if already anti-icing)
LOM = the level-of-maintenance of the winter roadways the shed manages
VMT_a = the vehicle-miles traveled on the winter roadways the shed manages
WSI = winter severity index for the area managed by the shed

USE is a factor that aggregates both the number of calls to UDOT meteorologists by the shed (data obtained from meteorologists) and the user-reported usage during the winter and when winter storms are likely (data obtained from the UDOT survey). Based on observations and statistical data analysis, *USE* is defined as follows.

$$USE = \log_{10}(CALL + 1) + WU + WSU \tag{2-2}$$

where $CALL$ = the number of calls to UDOT meteorologists by the shed annually
WU = the frequency reported using the UDOT weather service during the winter (1 if weekly, 2 if daily, 3 if twice daily, 4 if more than twice daily)
WSU = the frequency reported using the UDOT weather service when winter storms are likely (1 if weekly, 2 if daily, 3 if twice daily, 4 if more than twice daily)

EVLN is a factor that aggregates the ranking of UDOT weather service and the user satisfaction with the overall service, reliability and usability (data obtained from the UDOT survey). *EVLN* is defined as follows.

$$EVLN = \frac{SERVICE + RELIABILITY + USABILITY}{RANK} \tag{2-3}$$

where *SERVICE*, *RELIABILITY*, and *USABILITY* indicate the user satisfaction with the overall service, reliability and usability with respect to other forecasting services (on a 1-5 scale, with 1 being less satisfied and 5 being more satisfied)
$RANK$ = 1, if the UDOT weather service was used as the primary source; 2, if otherwise.

For each shed, *LOM* is the weighted average level-of-maintenance of the winter roadways that the shed manages. For each route, the level-of-maintenance data (see their definitions in Table 3-1) were recorded by snowplow operators based on road observation at one hour into the winter weather event. The data were stored in the UDOT Maintenance Management Quality Assurance (MMQA) system as a performance measure of winter maintenance.

Table 3-1: Definitions of Level-of-Maintenance Code in the UDOT MMQA System

Condition 1: Bare pavement conditions.	
Condition 2: Snow build-up encountered occasionally. Patches of black ice, slush or packed snow.	
Condition 3: Snow build-up encountered regularly. Black ice or packed snow with only wheel track bare.	
Condition 4: Compact snow build-up encountered regularly.	
Condition 5: Road closed. Not seasonal road. Temporary closure of route due to significant amounts of snow - unpassable.	

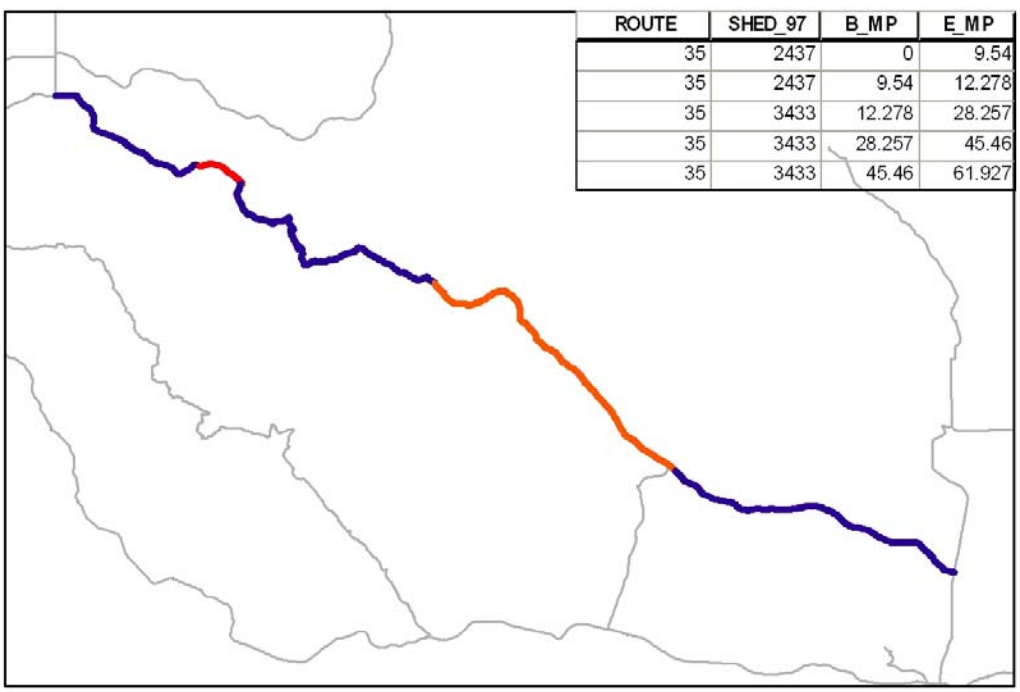
For each shed, *LOM* was calculated based on the following equation:

$$LOM = \frac{\sum_{i=1}^{4} iLOM_i + LOM_5}{\sum_{i=1}^{5} LOM_i} \tag{2-4}$$

where LOM_i = The number of reports for level-of-maintenance condition i for the 2004-05 winter season.

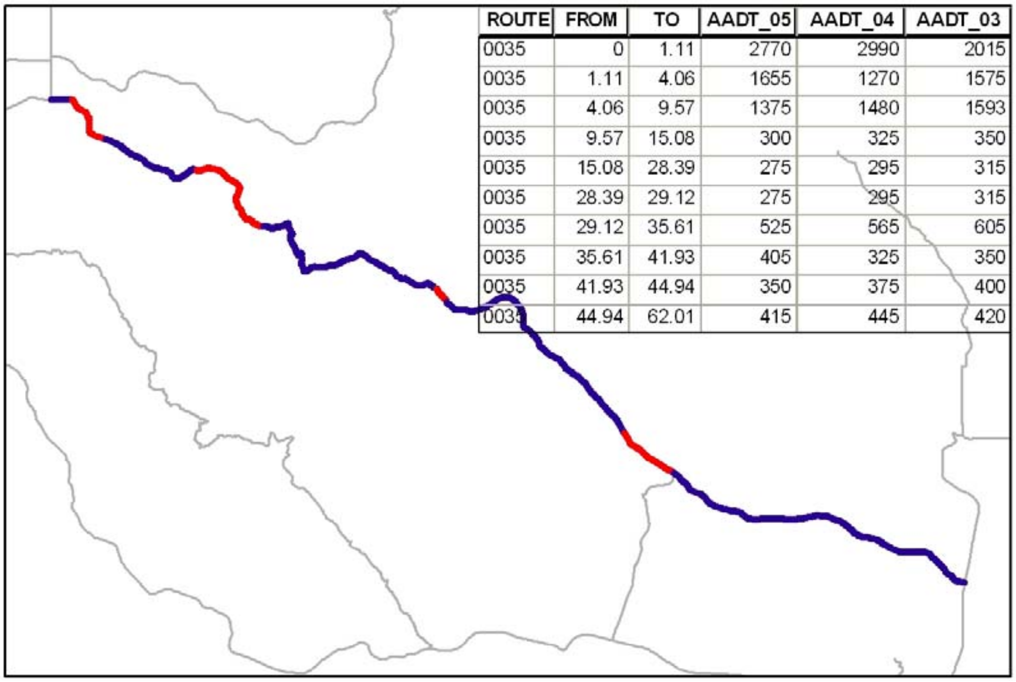
VMT_a is the vehicle-miles traveled on the winter roadways that the shed manages. For the 2004-05 winter season, the following procedures were used to calculate the VMT_a value for each shed.

1) First, the geographic information system (GIS) shape files of maintenance shed boundary and road traffic volume data were obtained from UDOT. The shed boundary shape file includes information about shed number, route number, and route segments in milepost (B_MP, E_MP variables), and an example is shown in Figure 3-1. The traffic volume shape file includes information about route number, route segments in milepost (FROM and TO variables), annual average daily traffic (AADT) volume data for the years 2003, 2004, and 2005, and an example is shown in Figure 3-2.



ROUTE	SHED_97	B_MP	E_MP
35	2437	0	9.54
35	2437	9.54	12.278
35	3433	12.278	28.257
35	3433	28.257	45.46
35	3433	45.46	61.927

Figure 3-1: Boundary of Route 35 for UDOT Sheds 2437 and 3433



ROUTE	FROM	TO	AADT_05	AADT_04	AADT_03
0035	0	1.11	2770	2990	2015
0035	1.11	4.06	1655	1270	1575
0035	4.06	9.57	1375	1480	1593
0035	9.57	15.08	300	325	350
0035	15.08	28.39	275	295	315
0035	28.39	29.12	275	295	315
0035	29.12	35.61	525	565	605
0035	35.61	41.93	405	325	350
0035	41.93	44.94	350	375	400
0035	44.94	62.01	415	445	420

Figure 3-2: AADT Data for Route 35

By joining and matching the route number and route segments in the shed boundary data and the traffic volume data, traffic volume for all the routes in each shed were calculated, and an examples is shown in Table 3-2. The VMT for each shed[1] was calculated based on the following equation:

$$VMT = \sum_{i} AADT_i \times MILE_i \tag{2-5}$$

where $AADT_i$ = annual average daily traffic volume for i^{th} route managed by the shed
$MILE_i$ = length of highway segment for the i^{th} route managed by the shed.

[1] For some sheds, the traffic volume data were missing (route 999 in shed 4434 with a length of 7.33 miles, route 308 in shed 4324 with length of 2.14 miles, and route 295 in shed 3425 with length of 0.65 miles) but the missing data are not expected to significantly change the value of calculated VMT. For some sheds, the shed boundary data were missing and the *VMT*s were not calculated for these sheds (sheds 1445 and 1448). In addition, for the same route, the route number used in shed boundary may be different from the route number in traffic volume. Therefore, a manual checking and correcting process using ArcGIS was applied before joining and matching shed boundary data and the traffic volume data.

Table 3-2: AADT Data for Route 35 of Shed 2437 and 3433

Route	Shed_97	B_MP	E_MP	AADT_05	AADT_04	AADT_03
35	2437	0	1.11	2,770	2,990	2,015
35	2437	1.11	4.06	1,655	1,270	1,575
35	2437	4.06	9.54	1,375	1,480	1,593
35	2437	9.54	9.57	1,375	1,480	1,593
35	2437	9.57	12.278	300	325	350
35	3433	12.278	15.08	300	325	350
35	3433	15.08	28.257	275	295	315
35	3433	28.257	28.39	275	295	315
35	3433	28.39	29.12	275	295	315
35	3433	29.12	35.61	525	565	605
35	3433	35.61	41.93	405	325	350
35	3433	41.93	44.94	350	375	400
35	3433	44.94	45.46	415	445	420
35	3433	45.46	61.927	415	445	420

The UDOT map of automatic traffic recorder (ATR) locations was compared with the UDOT maintenance shed location map, in order to identify the ATR(s) with the shortest roadway distance to each shed. For each shed, their adjacent ATR(s) had monthly traffic data indicating seasonal trends in daily traffic volumes across the state. The monthly average daily traffic volumes were divided by the AADT to determine monthly adjustment factors. For each shed[2], two seasonal traffic adjustment factors were calculated in order to derive the winter VMT value from the annual average value. Monthly adjustment factors for Nov.-Dec. 2004 (or the next most recent data available for these two months) were used to calculate the seasonal traffic adjustment factor *F1*. Monthly adjustment factors for Jan.-March 2005 (or the next most recent data available for these three months) were used to calculate the seasonal traffic adjustment factor *F2*. Table 3-3 shows the seasonal traffic adjustment factors for some sheds.

2 The research team only calculated the seasonal traffic adjustment factors for the 78 maintenance sheds for which winter maintenance cost data were available.

Table 3-3: Seasonal Traffic Adjustment Factors for Selected Sheds

Shed Name	ATRs #	November	December	January	February	March	Nov-Dec 2004 Adjustment Factor, F1	Jan-March 2005 Adjustment Factor, F2
Clinton	348	92.92%	92.97%	93.04%	94.59%	98.83%	92.95%	95.49%
Ogden	329	97.09%	98.38%	92.37%	100.71%	101.54%	97.74%	98.21%
Brigham City	613	94.48%	93.08%	81.78%	89.38%	98.50%	93.78%	89.89%
Clearfield	316	98.73%	96.74%	89.13%	94.90%	100.00%	97.74%	94.68%
Huntsville	320	77.80%	83.32%	89.18%	91.31%	88.80%	80.56%	89.76%
Morgan	307	88.93%	86.10%	81.67%	81.54%	85.80%	87.52%	83.00%
Centerville	315	97.12%	98.39%	88.20%	93.79%	100.28%	97.76%	94.09%
Snowville	430	90.89%	88.15%	74.38%	80.00%	86.52%	89.52%	80.30%
Bothwell	614	93.32%	88.24%	73.68%	79.92%	95.26%	90.78%	82.95%
Riverside	310	94.90%	89.17%	74.05%	82.09%	95.33%	92.04%	83.82%
Wellsville	363	94.84%	93.81%	83.48%	91.29%	97.86%	94.33%	90.88%
Logan	511	101.66%	95.64%	91.66%	100.04%	101.07%	98.65%	97.59%
Laketown	362	57.54%	57.05%	52.28%	55.21%	57.68%	57.30%	55.06%
Logan Summit	304/362	53.15%	51.82%	47.19%	49.17%	51.66%	52.48%	49.34%

The VMT_a for each shed was calculated based on the following equation:

$$VMT_a = \frac{2F1 \times VMT_{2004} + 3F2 \times VMT_{2005}}{5} \qquad (2\text{-}6)$$

In determining the use and benefits of the UDOT weather service, it was important to establish a method to compare maintenance sheds with exposure to varying winter weather conditions. Therefore, a winter severity index (*WSI*) was used and the following procedures were used to calculate the WSI value for each shed in the 2004-05 winter season.

1) First, the historical, daily weather summary data were collected from nearly 400 weather stations across the state through Mesowest (http://www.met.utah.edu/mesowest/), for the winter season beginning October 31, 2004 and ending March 30, 2005 (150 days). Data gathered from the weather stations included minimum and maximum daily temperature, 24-hour accumulated precipitation, and minimum and maximum relative humidity. Additionally, the latitude, longitude and elevation data were recorded for each weather station.

2) Second, quality control procedures were employed and weather stations without precipitation data or with fewer than 100 days of precipitation data were removed. A total of 252 weather stations were used for calculating the WSI. Figure 3-3 illustrates the distribution of weather stations with respect to UDOT's maintenance sheds.

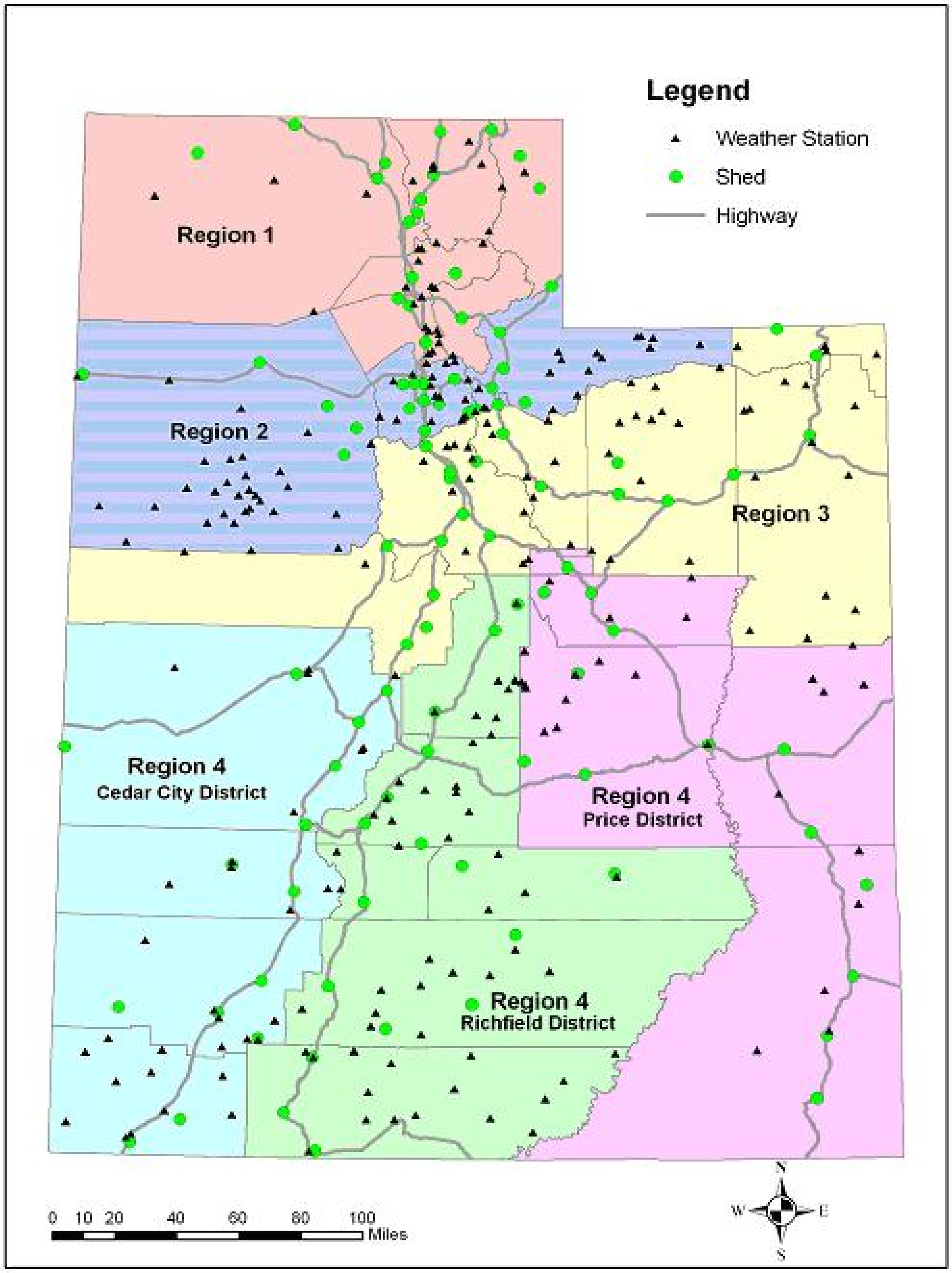


Figure 3-3: Locations of Weather Stations and UDOT Maintenance Sheds

3) Third, the Strategic Highway Research Program winter severity index (Boselly et al., 1993) was utilized to calculate the *WSI*s. As indicated below, the index was calculated based on the mean daily snowfall values as well as minimum and maximum temperatures averaged over the season.

$$WSI = a\sqrt{t_{seasonindex}} + b\ln\left(\frac{S_{daily}}{10}+1\right) + c\sqrt{\left(\frac{d_{freeze2}}{T_{range2}+10}\right)} + d \qquad (2\text{-}7)$$

where $t_{seasonindex}$ = average value of $t_{dayindex}$ over season ($0 \le t_{seasonindex} \le 1$)

$t_{dayindex}$ = 0, if minimum air temperature (T_{min}) is above 32°F (0°C)
1, if maximum air temperature (T_{max}) > 32°F (0°C) while $T_{min} \le$ 32°F (0°C)
2, if $T_{max} \le$ 32°F (0°C)

S_{daily} = Mean daily values of snowfall (millimeters)

$d_{freeze2}$ = t_{freeze} averaged over all days in study period

t_{freeze} = 0, if average daily temperature ($T_{avg} = [T_{min} + T_{max}]\div 2$) > 32°F (0°C)
1, if $T_{avg} \le$ 32°F (0°C)

T_{range2} = Difference between maximum and minimum daily air temperatures averaged over study period

The coefficients *a*, *b*, *c* and *d* are determined by particular weights and critical values of the parameters in each term that are indicative of typical weather conditions in a given geographic area. This index was previously used by UDOT in a study developing a winter maintenance metric (Decker et al, 2001). That study used values of *a* = -25.59, *b* = -11.50, *c* = -99.50, and *d* = 50.00, which were maintained for this study.

In order to use the WSI equation listed above, a few assumptions had to be made. The amount of precipitation in a 24-hour period is the water content of the precipitation (regular rainfall, snow, sleet, freezing rain, or freezing drizzle). According to graphs shown in Figure 3-4 (Fuchs et al., 2000), the threshold air temperature, T_{thr}, that determines the phase of the precipitation (T> T_{thr}: rain, T≤ T_{thr}: solid precipitation, i.e., snow or ice), has an approximately linear relationship with the relative humidity as follows.

$$T_{thr} = 12 \times (1 - RH) \qquad (2\text{-}8)$$

where T_{thr} = threshold temperature (ºC)
RH = relative humidity

In the event of snowfall, it was assumed (based on convention) that ten inches of snow is equivalent to one inch of liquid water. It should be noted that this ratio tends to under-forecast snow events (Cox et al., 2005). Both of these assumptions were used to convert the amount of precipitation recorded by the weather stations during a 24-hour period into the mean daily snowfall values (S_{daily}).

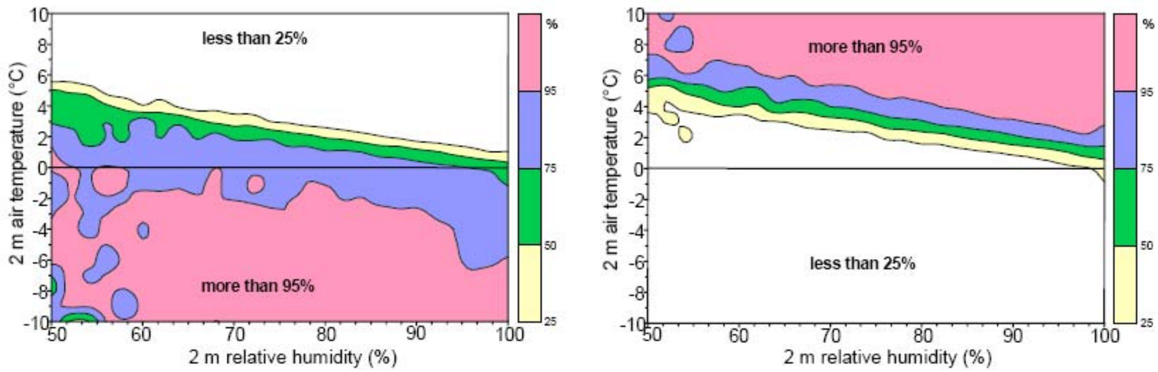


Figure 3-4: Phase Change Graphs of Precipitation Events

Fourth, once the *WSI* values for all 252 weather station locations were calculated, it was assumed that *WSI* would vary continuously across the state, as a function of latitude, longitude and elevation. It is recognized that this simplifies the diversity in weather conditions that may be experienced within a given shed area, but the simplification was necessary to interpolate *WSI* values at the shed locations. The interpolation was conducted by multi-variable linear regression as follows.

$$WSI = 326.083 - 3.14465 Lat + 1.45588 Long - 0.00553 Elev \quad (2\text{-}9)$$

where *WSI* = weather severity index value
Lat = latitude of station location (°N)
Long = longitude of station location (°W)
Elev = elevation of station (feet above sea level)

A relatively high R-square of 0.68 and the small *p*-values (<0.01) indicate that this model was reasonable. In addition, it is observed that the WSI value decreases with the increase of elevation and latitude and with the decrease of longitude. This coincides with the knowledge that winter tends to get colder in high-elevation, northern and/or western areas.

Another tool the research team used to validate the *WSI* values was the Google Earth™ mapping (as shown in Figure 3-5), which indirectly confirmed that the *WSI* model was reasonable.

Figure 3-5: A Google Earth™ Snapshot of Weather Severity Indices for Two Different UDOT Maintenance Sheds

Finally, the elevation data for all the UDOT maintenance sheds were calculated using the Utah 10-meter digital elevation model. Then, *WSI* values for all UDOT maintenance sheds were calculated using the shed latitude, longitude and elevation along with the established linear regression model. Figure 3-6 illustrates the distribution of UDOT maintenance sheds and their winter severity indices.

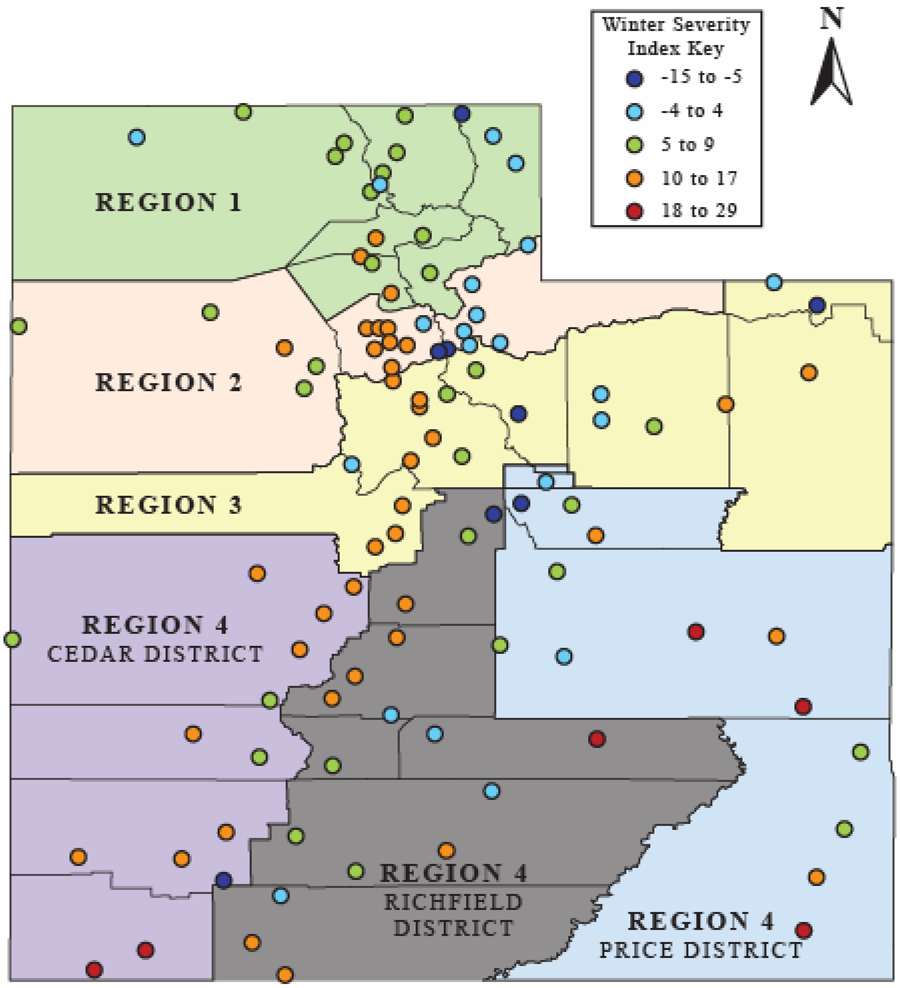


Figure 3-6: Weather Severity Index Map of UDOT Maintenance Sheds

3.3. Evaluating Benefits of UDOT Weather Service to Winter Maintenance

3.3.1. Modeling through Multi-variable Linear Regression

As discussed in Section 2.4, the research team assumed the shed labor and materials cost for the 2004-05 winter season (*LMC*) as a function of six investigated factors, including: the overall usage of UDOT weather service (*USE*), the overall evaluation of the UDOT weather service (*EVLN*), the level-of-maintenance of the winter roadways that the shed manages (*LOM*), the vehicle-miles traveled on the winter roadways that the shed manages (VMT_a), the level of anti-icing practice (*ANTI*), and the winter severity index for the area (*WSI*). A multi-variable linear regression was conducted to see whether a strong linear correlation existed between LMC and these variables and, if so, how the linear regression model can be used to quantify the benefits of UDOT weather service to winter maintenance (in the form of cost savings).

3.3.2. Modeling through Artificial Neural Network

Artificial neural networks (ANNs) are powerful tools to model the non-linear cause-and-effect relationships inherent in complex processes (Shi et al., 2003), as they provide non-parametric, data-driven, self-adaptive approaches to information processing. ANNs have been successfully used to model, predict, control and optimize non-linear systems, and are gaining favor in applications as diverse as forecasting, signal processing, pattern recognition and classification, process control, and decision-support. This may be attributed to their distinguishing features and to the advantages that they hold over traditional, model-based methods. First, ANNs are robust and can produce generalizations from experience even if the data are incomplete or noisy. Second, ANNs can learn from examples and capture subtle functional relationships among case data. Prior assumptions about the underlying relationships in a particular problem, which in the real world are usually implicit or complicated, need not be made. Third, ANNs provide universal approximation functions flexible in modeling linear and nonlinear relationships. The ANN paradigm adopted in this study was the multiplayer feed-forward neural network, of which a typical architecture is shown in Figure 3-7.

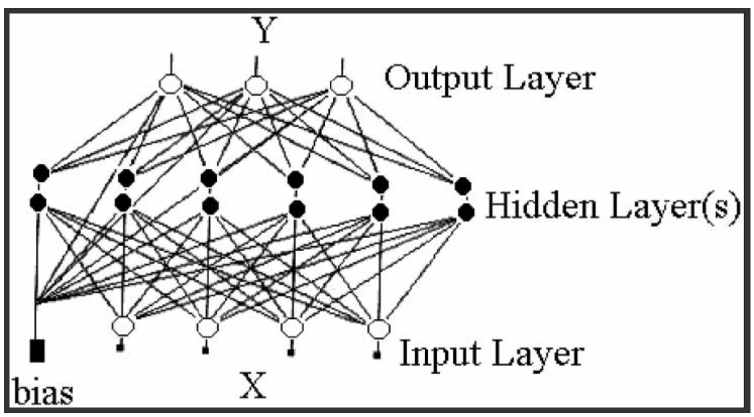


Figure 3-7: Typical Multiplayer Feed-forward Neural Network Architecture

The nodes in the input and output layers consist of independent variables and response variable(s), respectively. One or two hidden layers are included to model the dependency based on the complexity of relationship(s). For a feed-forward network, signals are propagated from the input layer through the hidden layer(s) to the output layer, and each node in a layer is connected in the forward direction to every node in the next layer. Every node simulates the function of an artificial neuron. The inputs are linearly summated utilizing connection weights and bias terms and then transformed via a non-linear transfer function.

For the training of the networks, an error back-propagation (BP) algorithm was adopted. All the connection weights and bias terms for nodes in different layers are initially randomized and then iteratively adjusted based on certain learning rules. For each given sample, the inputs are forwarded through the network until they reach the output layer producing output values, which are then compared with the target values. Errors are computed for the output nodes and propagated back to the connections stemming from the input layer. The weights are systematically modified to reduce the error at the nodes, first in the output layer and then in the hidden layer(s). The changes in weights involve a learning rate and a momentum factor and are usually in proportion to the negative derivative of the error term. It may take thousands of rounds, repeating the feed-forward and error back-propagation, before the predicted output gets very close to the target value. The learning process is continued with multiple samples until the prediction error across all samples in the training data is minimized to a reasonable range or stabilized (convergence).

$$f(x) = \left(1 + e^{-x}\right)^{-1} \tag{2-10}$$

$$NX_i = \frac{(x_i - x_{\min} + 0.1)}{(X_{\max} - X_{\min} + 0.1)} \tag{2-11}$$

In this study, a modified BP algorithm was employed for the ANN training, in which a sigmoid function in Equation 2-10 was used as the nonlinear transfer function and the sum of the mean squared error (SMSE) in the output layer as the convergence criteria. The training of the networks was performed in batch mode.

All the data for input and output were normalized based on Equation 2-11, where X_i and NX_i are the i^{th} value of factor X before and after the normalization, and X_{min} and X_{max} are the minimum and maximum value of factor X, respectively. The program was written in C language.

As shown in Table 3-4, data from 50 UDOT maintenance sheds were used for the modeling, as they both responded to the UDOT personnel survey and had traffic data available. From the data set, one sample was randomly selected as the test data (highlighted in yellow in Table 3-4) and the remaining 49 samples were used as the ANN training data. The test data were used to monitor the performance of the model during training. The training process involved selecting the appropriate number of hidden layer nodes (only one hidden layer was used) and determining the appropriate limit of allowable training error (based on observations and perceived accuracy of the modeling data).

Then, a set of validation data were used to measure the performance of the trained model (see Table 3-5). The trained model was used to predict the dependency of *LMC* on the winter traffic volume managed (VMT_a) and the winter severity (*WSI*), respectively, with the other five factors at the median level of the 50 sheds in the modeling data set. The pattern of these two dependencies was used to determine whether the ANN model was properly trained.

Table 3-4: Data Set Used to Train and Test the ANN Model

USE	*EVLN*	*LOM*	Lg(*VMT* a)	*ANTI*	*WSI*	*LMC*	Modeled$	Error
4.826	4.500	2.508	6.267	0.0	9.66	$115,434.0	$124,171.5	7.6%
5.320	4.167	2.424	6.065	1.0	7.50	$123,249.0	$134,289.1	9.0%
5.031	4.333	1.952	6.358	1.0	8.35	$144,762.0	$130,788.1	-9.7%
3.699	2.250	2.481	5.188	1.0	5.70	$235,458.0	$234,768.2	-0.3%
4.822	4.000	2.185	4.417	0.5	6.13	$134,676.0	$136,584.6	1.4%
5.851	4.333	2.571	6.238	1.0	11.13	$67,035.0	$70,362.7	5.0%
3.954	4.667	2.389	5.495	1.0	7.22	$166,270.0	$176,630.2	6.2%
3.822	5.000	2.259	5.599	1.0	6.41	$150,388.0	$158,135.0	5.2%
5.263	4.667	2.183	5.586	0.0	8.61	$67,603.0	$94,955.9	40.5%
4.704	4.333	2.199	5.669	0.0	7.13	$143,681.0	$103,002.9	-28.3%
4.826	3.167	2.000	6.099	0.0	11.48	$214,039.0	$216,455.4	1.1%
4.381	3.667	2.351	6.238	1.0	11.70	$204,601.0	$184,761.2	-9.7%
6.190	4.667	1.722	6.474	1.0	11.32	$220,123.0	$230,483.9	4.7%
5.712	3.833	1.800	6.212	1.0	11.56	$134,623.0	$139,939.8	3.9%
5.720	4.333	1.859	6.110	1.0	10.04	$187,957.0	$156,770.2	-16.6%
4.863	4.500	1.321	6.393	1.0	11.49	$183,632.0	$183,510.2	-0.1%
5.716	4.333	2.562	6.062	1.0	-5.79	$702,506.0	$682,872.3	-2.8%
4.982	4.333	1.994	5.973	0.0	-0.75	$408,886.0	$408,811.7	0.0%
3.699	3.333	2.462	5.450	0.0	2.51	$175,828.0	$208,576.2	18.6%
5.190	4.333	2.118	5.256	1.0	0.29	$278,701.0	$275,280.7	-1.2%
2.301	4.000	2.204	4.840	0.0	-0.49	$118,219.0	$121,219.6	2.5%
2.801	3.667	2.787	5.938	0.0	10.09	$227,740.0	$228,844.0	0.5%
4.755	4.833	2.583	6.330	1.0	10.27	$202,045.0	$206,709.8	2.3%
3.301	4.667	2.641	5.759	0.0	9.96	$110,992.0	$119,691.7	7.8%
3.000	3.667	2.371	5.409	0.0	7.97	$139,028.0	$113,456.3	-18.4%
3.301	4.333	2.528	5.911	0.5	9.89	$172,920.0	$159,449.1	-7.8%
3.477	4.000	1.938	6.250	1.0	11.80	$80,192.0	$104,889.5	30.8%
4.477	4.000	1.926	5.444	1.0	3.14	$278,241.0	$288,867.2	3.8%
3.000	3.667	2.246	4.280	0.0	1.31	$139,683.0	$140,508.8	0.6%
3.500	4.833	2.361	5.429	0.0	11.32	$88,697.0	$104,774.4	18.1%
2.500	2.333	2.111	5.813	0.0	26.14	$23,211.0	$23,945.3	3.2%
5.076	4.667	1.920	5.623	0.0	9.73	$297,920.0	$300,333.1	0.8%
3.903	3.667	2.488	5.621	0.0	9.01	$204,213.0	$166,242.7	-18.6%
1.801	3.333	2.330	4.861	0.0	13.02	$74,248.0	$56,042.9	-24.5%
3.699	4.333	2.103	5.500	0.0	7.61	$290,996.0	$285,551.4	-1.9%
3.477	1.833	2.652	5.523	0.5	12.37	$35,013.0	$33,635.0	-3.9%
2.500	4.333	2.162	5.402	1.0	10.10	$115,388.0	$114,924.4	-0.4%
2.801	2.333	2.566	4.126	0.0	-11.35	$142,977.0	$139,066.7	-2.7%
3.000	4.333	3.145	4.875	0.0	9.73	$203,446.0	$203,708.4	0.1%
2.000	2.000	3.600	4.867	0.0	6.79	$173,994.0	$172,107.5	-1.1%
3.500	3.167	2.500	4.571	0.0	9.19	$59,284.0	$50,982.7	-14.0%
2.000	2.000	2.403	5.683	1.0	11.92	$242,281.0	$241,064.1	-0.5%
1.301	1.500	2.361	4.866	0.0	16.18	$54,323.0	$60,406.6	11.2%
4.000	4.667	2.642	5.230	1.0	8.48	$153,864.0	$149,411.2	-2.9%
1.000	3.667	2.500	5.284	0.0	22.97	$33,048.0	$45,095.7	36.5%
2.000	4.667	2.064	5.438	1.0	15.36	$35,318.0	$38,995.8	10.4%
2.778	4.667	2.341	5.309	1.0	20.50	$55,685.0	$59,733.6	7.3%
3.301	1.667	2.853	5.390	0.0	8.87	$213,935.0	$219,214.7	2.5%
2.301	3.500	3.014	5.367	0.0	0.16	$495,415.0	$491,991.2	-0.7%
2.801	3.667	2.324	5.365	0.0	4.68	$109,153.0	$118,625.4	8.7%

Table 3-5: Data Set Used to Validate the ANN Model

USE	*EVLN*	*LOM*	Lg(*VMT* a)	*ANTI*	*WSI*
3.70	4.08	2.356	4.126	0.00	9.42
3.70	4.08	2.356	4.243	0.00	9.42
3.70	4.08	2.356	4.361	0.00	9.42
3.70	4.08	2.356	4.478	0.00	9.42
3.70	4.08	2.356	4.595	0.00	9.42
3.70	4.08	2.356	4.713	0.00	9.42
3.70	4.08	2.356	4.830	0.00	9.42
3.70	4.08	2.356	4.948	0.00	9.42
3.70	4.08	2.356	5.065	0.00	9.42
3.70	4.08	2.356	5.182	0.00	9.42
3.70	4.08	2.356	5.300	0.00	9.42
3.70	4.08	2.356	5.417	0.00	9.42
3.70	4.08	2.356	5.534	0.00	9.42
3.70	4.08	2.356	5.652	0.00	9.42
3.70	4.08	2.356	5.769	0.00	9.42
3.70	4.08	2.356	5.887	0.00	9.42
3.70	4.08	2.356	6.004	0.00	9.42
3.70	4.08	2.356	6.121	0.00	9.42
3.70	4.08	2.356	6.239	0.00	9.42
3.70	4.08	2.356	6.356	0.00	9.42
3.70	4.08	2.356	6.474	0.00	9.42
3.70	4.08	2.356	5.512	0.00	-11.35
3.70	4.08	2.356	5.512	0.00	-9.47
3.70	4.08	2.356	5.512	0.00	-7.60
3.70	4.08	2.356	5.512	0.00	-5.72
3.70	4.08	2.356	5.512	0.00	-3.85
3.70	4.08	2.356	5.512	0.00	-1.97
3.70	4.08	2.356	5.512	0.00	-0.10
3.70	4.08	2.356	5.512	0.00	1.78
3.70	4.08	2.356	5.512	0.00	3.65
3.70	4.08	2.356	5.512	0.00	5.52
3.70	4.08	2.356	5.512	0.00	7.40
3.70	4.08	2.356	5.512	0.00	9.27
3.70	4.08	2.356	5.512	0.00	11.15
3.70	4.08	2.356	5.512	0.00	13.02
3.70	4.08	2.356	5.512	0.00	14.90
3.70	4.08	2.356	5.512	0.00	16.77
3.70	4.08	2.356	5.512	0.00	18.64
3.70	4.08	2.356	5.512	0.00	20.52
3.70	4.08	2.356	5.512	0.00	22.39
3.70	4.08	2.356	5.512	0.00	24.27
3.70	4.08	2.356	5.512	0.00	26.14

ANN was used as a data mining approach to abstract the useful information from existing happenstance data; in other words, to deduce reliable data from noisy data. Once the empirical ANN model was validated, it was used to predict the output of unknown samples within the ranges of the modeling data. The model was used to predict the *LMC* value of 77 UDOT sheds under three different scenarios; i.e., all the sheds used non-UDOT weather service providers on a daily basis as the only source for weather information, used poorer quality weather service providers than they currently use on a weekly basis, or used the UDOT weather service as the primary source to a maximum level. As such, the ANN model was used quantify the benefits of UDOT weather service to winter maintenance (in the form of cost savings).

4. BENEFITS OF UDOT WEATHER SERVICE TO WINTER MAINTENANCE

4.1. Process Flow Charts

As expected, the UDOT weather service changed how the UDOT maintenance personnel (as well as some construction engineers) perform their daily operations by altering the way current weather information and weather forecasts were gathered. As shown in Figure 4-1, Figure 4-2, and Figure 4-3 respectively, the research team established flow charts to understand how the UDOT weather service affects winter maintenance processes and to illustrate its detailed activities and interactions with the pre-storm, during-storm, and post-storm planning.

The stakeholder interviews indicated that the UDOT weather service had added value to UDOT operations in the following ways:

- Improved the planning of annual budget for winter maintenance
- Decreased the cost of winter maintenance by reducing labor hours (staff overtime), unnecessary callouts, and materials required
- Increased the level-of-service for road users by providing better roads with fewer road closures, fewer delays, and less accidents
- Decreased the incident response time
- Decreased the cost of construction projects by better planning based on storm predictions

4.2. Modeling through Multi-variable Linear Regression

As discussed in Section 3.3.1, a multi-variable linear regression was conducted to see whether a strong linear correlation exists between the shed labor and materials cost for the 2004-05 winter season (*LMC*) and the six investigated factors. The LINEST function in Microsoft Excel™ was used to calculate the statistics to fit the data of 50 UDOT maintenance sheds (as shown in Table 3-4) to a straight line by using the least squares method; the resulting R-square value of 0.4833 indicated a poor fit. This may be attributable to potential interactions between the investigated factors, nonlinear relationships involved, and the noise inherent in the modeling data.

The *LMC* value for each shed predicted by the regression model was compared with the actual labor and materials cost (see Figure 4-4), and the relative error ranged from -246.9% to +306.9%, which further indicated that the regression model was unsuitable for predicting the output of known or unknown samples within the ranges of the modeling data. Therefore, a better method was needed to model the correlation between the shed winter maintenance cost and the six investigated factors before it was possible to quantify the benefits of UDOT weather service to winter maintenance (in the form of cost savings).

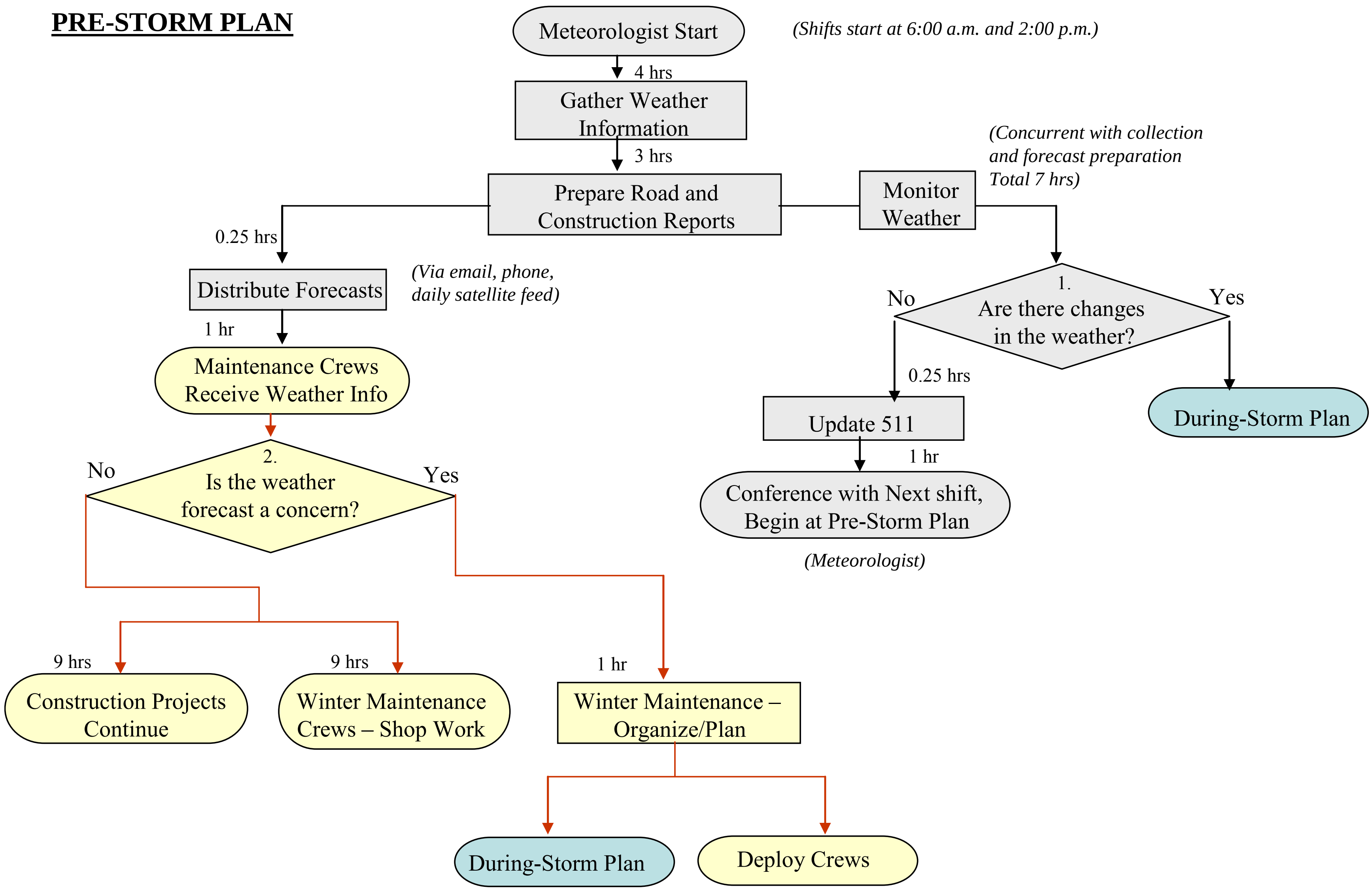


Figure 4-1: The Role of UDOT Weather Service in Pre-Storm Planning

DURING-STORM PLAN

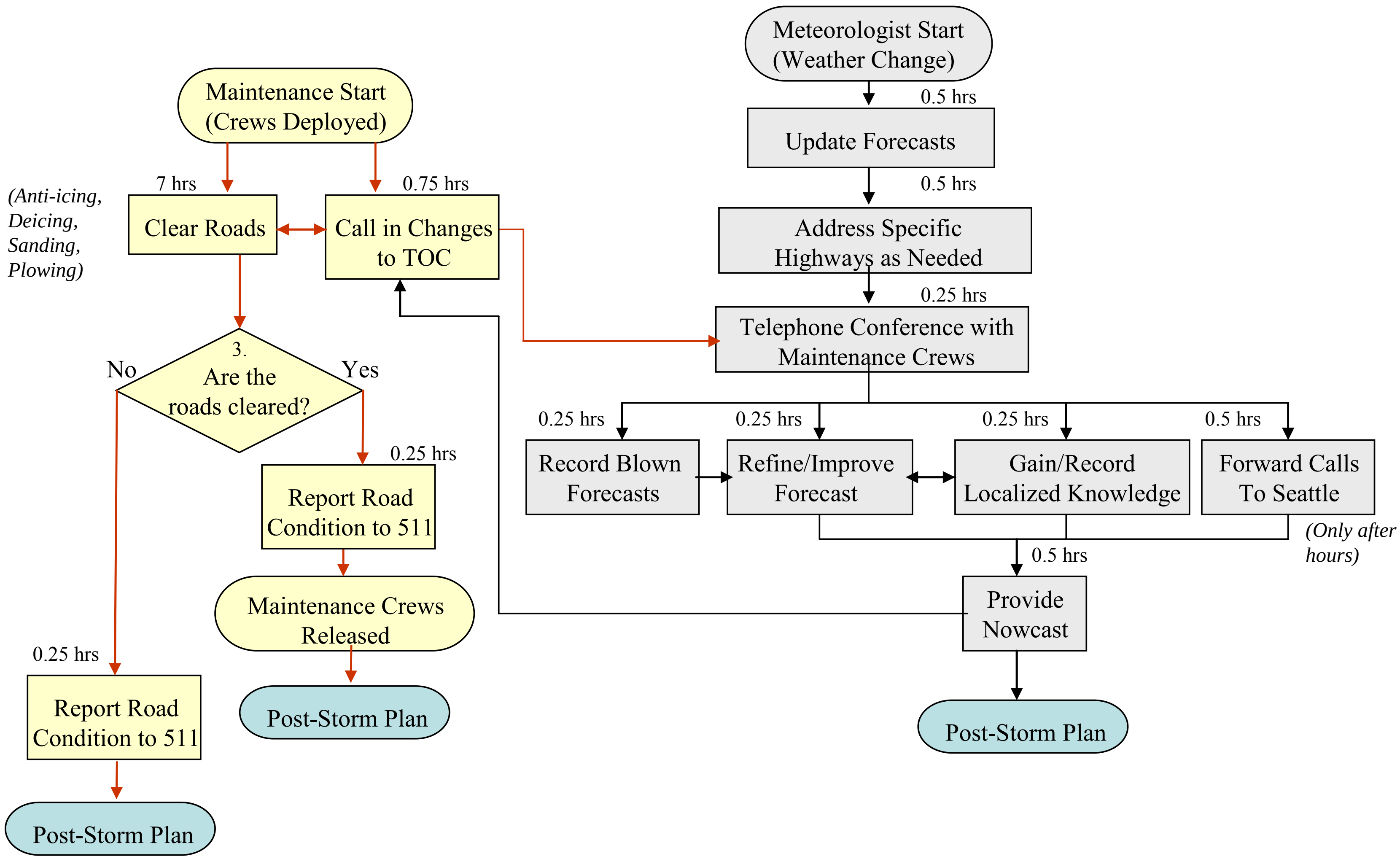


Figure 4-2: The Role of UDOT Weather Service in During-Storm Planning

POST-STORM PLAN

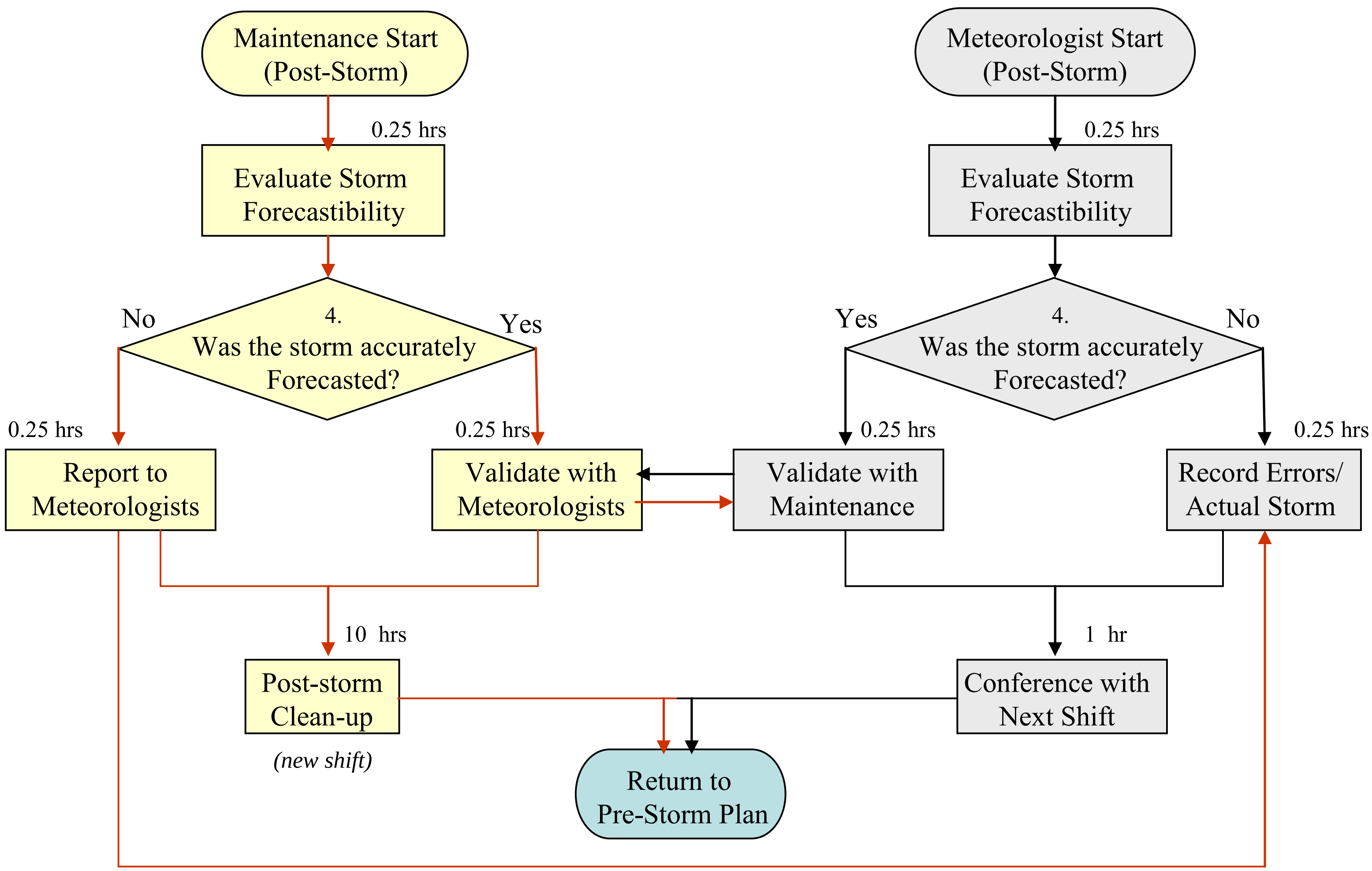


Figure 4-3: The Role of UDOT Weather Service in Post-Storm Planning

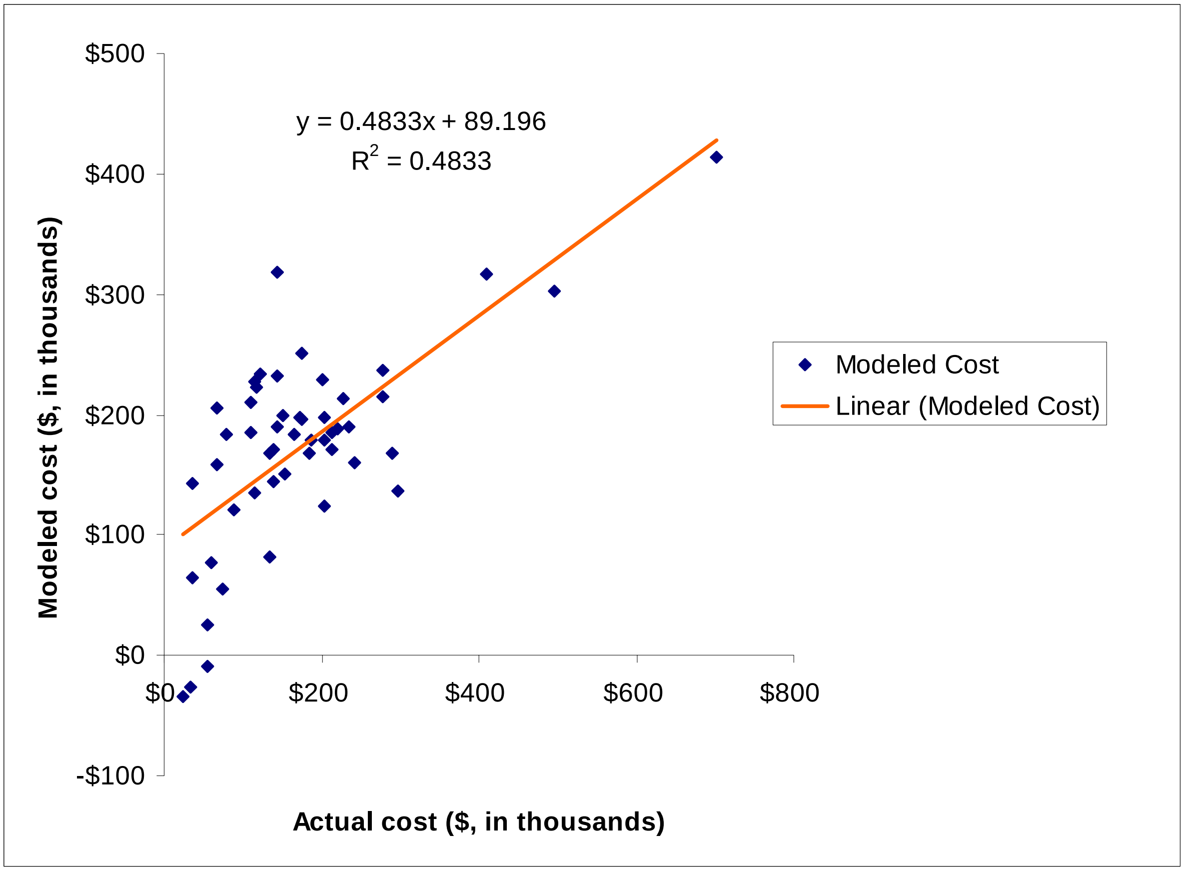


Figure 4-4: Labor and Materials Cost Modeled by Multi-variable Linear Regression versus Actual Cost

4.3. Modeling through Artificial Neural Network

As discussed in Section 3.3.2, artificial neural networks (ANNs) were trained, tested, and validated to correlate the shed labor and materials cost for the 2004-05 winter season (*LMC*) with the six investigated factors.

The training of ANNs was conducted using the 49 training samples in Table 3-4. As a result, a mathematic model with topological structure of 6-5-1 was selected, which was trained to allow for a reasonable error (SMSE of 0.021). With the trained model and the testing sample in Table 3-4, a reasonable testing error (SMSE of 0.048) was achieved. The *LMC* value for each shed predicted by the ANN model was compared with the actual labor and materials cost (see Figure 4-5), and the relative error ranged from -28.3% to +40.5%, the standard deviation of which (σ) was 12.8%. From the learning results, it appears that the established ANN model has relatively good "memory" and the trained matrices of interconnected weights and bias reflect the hidden functional relationship very well. It was noted that the relative error for the collective winter maintenance cost of all 50 sheds was only -0.2%. Coupled with the validation results mentioned above, it was concluded that the ANN model was reasonably suitable for predicting the output of unknown samples within the ranges of the modeling data and could be used to quantify the benefits of UDOT weather service to winter maintenance (in the form of cost savings). It was also assumed that the inherent error in the ANN model was no more than 3σ, i.e., 38.4%.

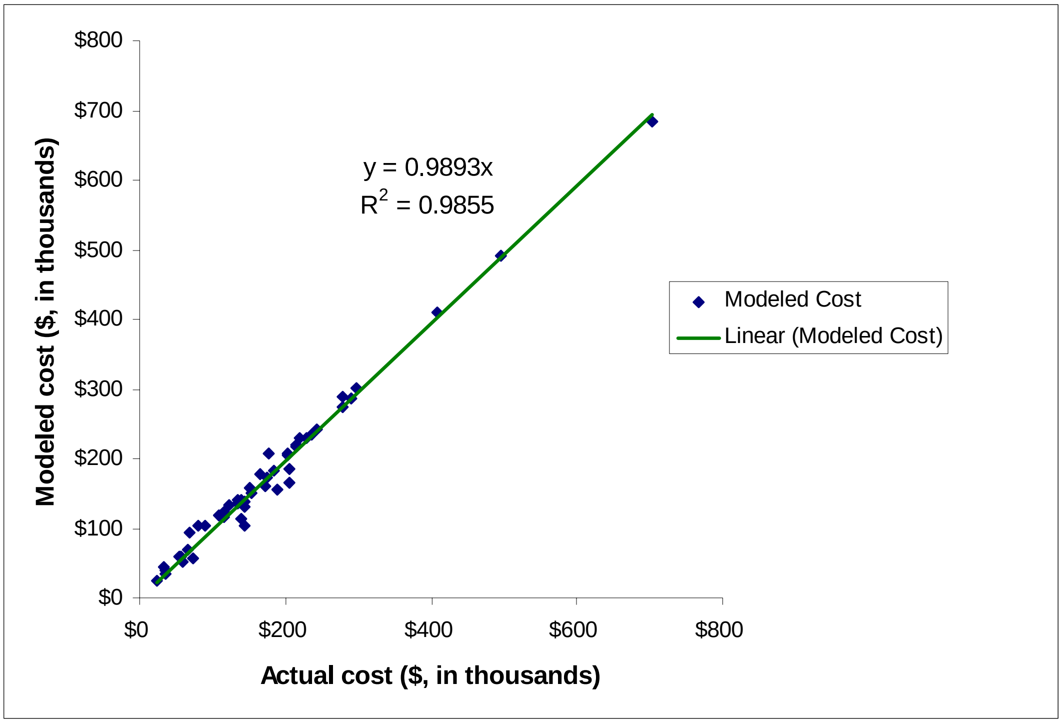


Figure 4-5: Labor and Materials Cost Modeled by ANN versus Actual Cost

The trained model was further validated with the data set shown in Table 3-5, by predicting the dependency of *LMC* on the winter traffic volume managed (VMT_a)[3] and the winter severity (*WSI*)[4], respectively, with the other five factors at the median level of the 50 sheds in the modeling data set. Figure 4-6 shows that there is a linear relationship between the forecasted winter maintenance cost and the winter traffic volume managed by the shed, and it is consistent with the common knowledge that the management of more traffic volume leads to increased winter maintenance cost. Figure 4-7 shows that there is an exponential relationship between the forecasted winter maintenance cost and the modified shed winter severity index, and it is consistent with the common knowledge that a warmer winter season (higher *WSI* value) experienced by the shed leads to decreased winter maintenance cost. These results indirectly validated that the ANN model was properly trained.

[3] Overall Usage =3.70, Overall Evaluation = 4.08, LOM weighted average = 2.356, Anti-icing level = 0, Winter severity index = 9.42

[4] Overall Usage =3.70, Overall Evaluation = 4.08, LOM weighted average = 2.356, Lg(VMTa)=5.512, Anti-icing level = 0

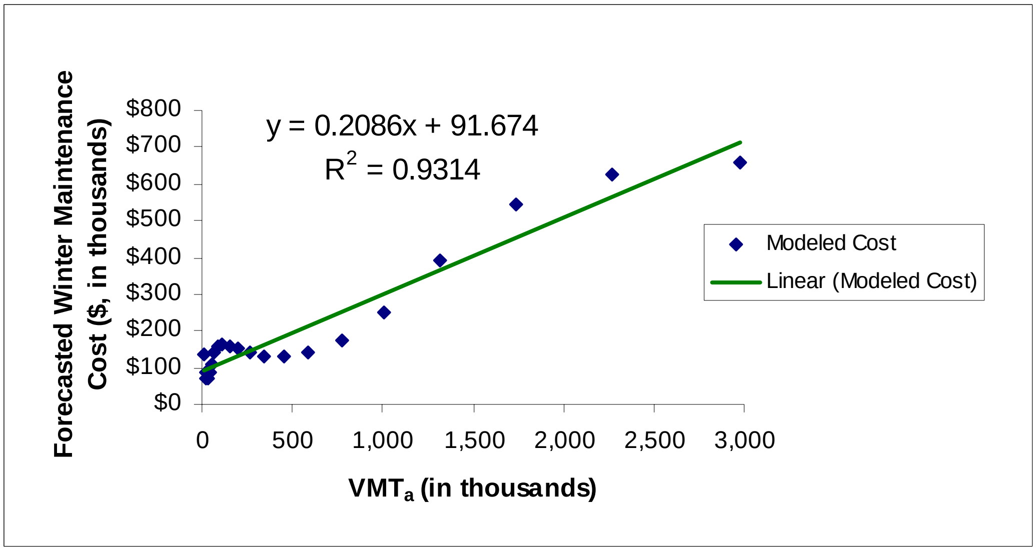


Figure 4-6: Forecasted Winter Maintenance Cost as a Function of Winter Traffic Volume

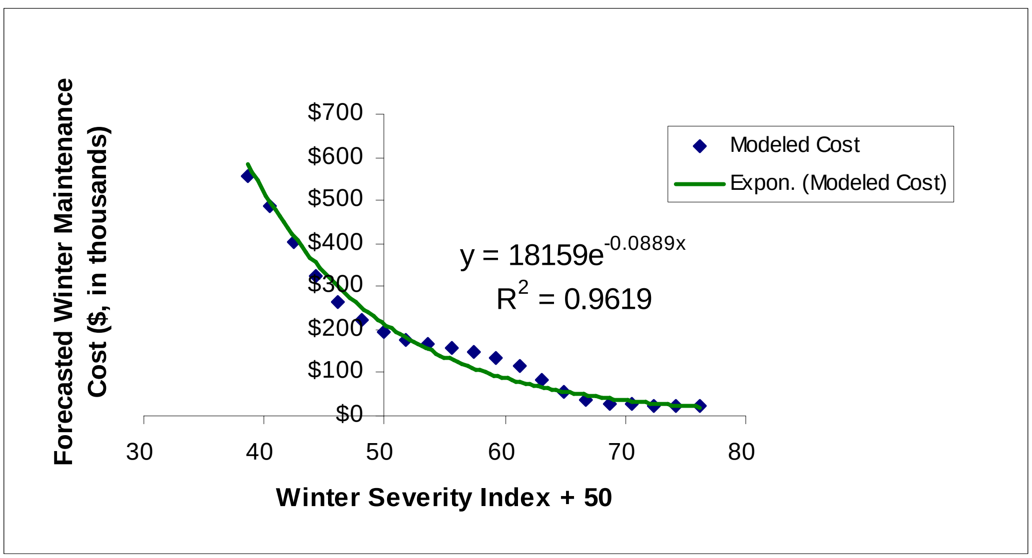


Figure 4-7: Forecasted Winter Maintenance Cost as a Function of Winter Severity

4.4. Value of UDOT Weather Operations

The established ANN model was used to predict the shed winter maintenance cost under various conditions in order to estimate the benefits of UDOT weather service to winter maintenance (in the form of cost savings). For the estimation, the following methods were used to handle missing data:

1) It was assumed the *LOM* value for sheds 2434, 3435, 4321, 4332, 4422, and 4521 was 2.361, which was the average value of all other sheds.

2) It was assumed the anti-icing level was 0.44 for the 23 sheds that did not respond to the question, which was the average value of all responding sheds.

3) It was assumed the VMT_a values for shed 1445 and shed 1448 were 878,424 and 827,958, respectively, which was their winter maintenance cost divided by the average winter maintenance cost per VMT_a for all other sheds.

4) Only 77 UDOT maintenance sheds were considered, as there was not sufficient information available for the rest of sheds.

4.4.1. Compared to Non-UDOT Providers

Assuming all 77 UDOT maintenance sheds had used other weather service providers on a daily basis as the only source (i.e., overall usage = 2, overall evaluation = 3) and the level of maintenance, winter traffic volume, anti-icing level, and winter severity were the same, the ANN model estimated that altogether the 77 sheds would have spent \$2,244,000 more on winter maintenance for the 2004-05 winter season. Due to the inherent error in the model (3σ=38.4%), the value of the existing UDOT weather service for winter maintenance is estimated to be \$1,382,000 to \$3,106,000, which corresponds to 11-25% of the UDOT labor and materials cost for winter maintenance in the 2004-05 winter season (\$12,517,000).

4.4.2. Compared to Poorest Quality of Weather Information

Assuming all 77 UDOT maintenance sheds had used weather service of poorer quality than other providers on a weekly basis as the only source_(i.e., overall usage = 1, overall evaluation = 1) and the level of maintenance, winter traffic volume, anti-icing level, and winter severity were the same, the ANN model estimates that altogether the 77 sheds would have spent \$11,864,000 more on winter maintenance for the 2004-05 winter season. Due to the inherent error in the model (3σ=38.4%), the risk of using the poorest quality weather service providers for winter maintenance is estimated to be \$7,306,000 to \$16,422,000, which corresponds to 58-131% of the UDOT labor and materials cost for winter maintenance in the 2004-05 winter season (\$12,517,000).

4.4.3. Compared to Potential Value

Assuming all 77 UDOT maintenance sheds had used the UDOT weather service as the primary source to a maximum level (i.e., overall usage = 6.19[5], overall evaluation = 5[6]) and the level of maintenance, winter traffic volume, anti-icing level, and winter severity were the same, the ANN model estimates that altogether the 77 sheds could have spent \$883,000 less on winter maintenance for the 2004-05 winter season. Due to the inherent error in the model (3σ=38.4%), the potential savings of the UDOT weather service for winter maintenance is estimated to be \$544,000 to \$1,222,000, which corresponds to 4-10% of the UDOT labor and materials cost for winter maintenance in the 2004-05 winter season (\$12,517,000).

[5] This corresponds to the scenario where the usage of UDOT weather service during winter season and when winter storm is approaching are both more than twice daily, and the number of calls to UDOT weather program is 165, the record high of all sheds.

[6] This corresponds to the scenario where the UDOT weather service is used as the primary source of weather information and its service, reliability and usability are all ranked better than other providers.

5. QUALITATIVE EVALUATION BY UDOT CUSTOMERS

To evaluate the institutional performance of the UDOT Weather Operations/RWIS Program and to determine the value added by the program to UDOT customers, the user satisfaction with and impact of the UDOT weather service were assessed through surveys. The survey responses from UDOT maintenance engineers, area supervisors, and station supervisors as well as UDOT resident engineers provided a qualitative estimate of the overall program performance. The details are described as follows.

5.1. Maintenance Personnel

Eighty UDOT maintenance employees were contacted and asked questions regarding the use of weather forecasting services and specifically the use of the weather information provided by UDOT. To clarify the context of survey responses from the UDOT maintenance personnel, Table 5-1 lists the tasks included for each specific position.

Table 5-1: Winter Response Responsibilities for UDOT Maintenance Personnel

Position	Responsibilities
Maintenance Engineer	• Plan for resources (equipment, staff, and materials) prior to the winter season • May move resources between areas to help fight winter storms
Area Supervisor	• Before Storm: survey stations for readiness • During Storm: decide whether or not to share resources • After Storm: analyze application rate and application frequency, examine whether or not the practice used was appropriate and cost-effective
Station Supervisor	• Deal with daily tasks such as preparing for a storm, managing crews during a storm, or cleaning up after a storm. • Change plans as needed throughout the storm • Constantly communicating with forecasters during weather events • May send employees home to rest based on weather forecast

All but one of the 80 respondents reported using weather forecasts; the other respondent relies on the experience of the station supervisor. Also, all 80 were aware of the UDOT program.

Respondents were asked how often they use weather forecasting information to aid them in staffing, planning or road treatment decisions; the average was 4.24, 4.15, and 3.57 out of 5, respectively. It should be noted that the average values listed above were more reflective of the opinions of the station supervisors as there were more station supervisors to interview. There were regional variations observed in these ratings, as shown in Figure 5-1. All regions use weather information fairly frequently to support staffing and strategic planning. Respondents in

Regions 1 and 2 use weather information for roadway treatment decisions more frequently than respondents from the other two regions.

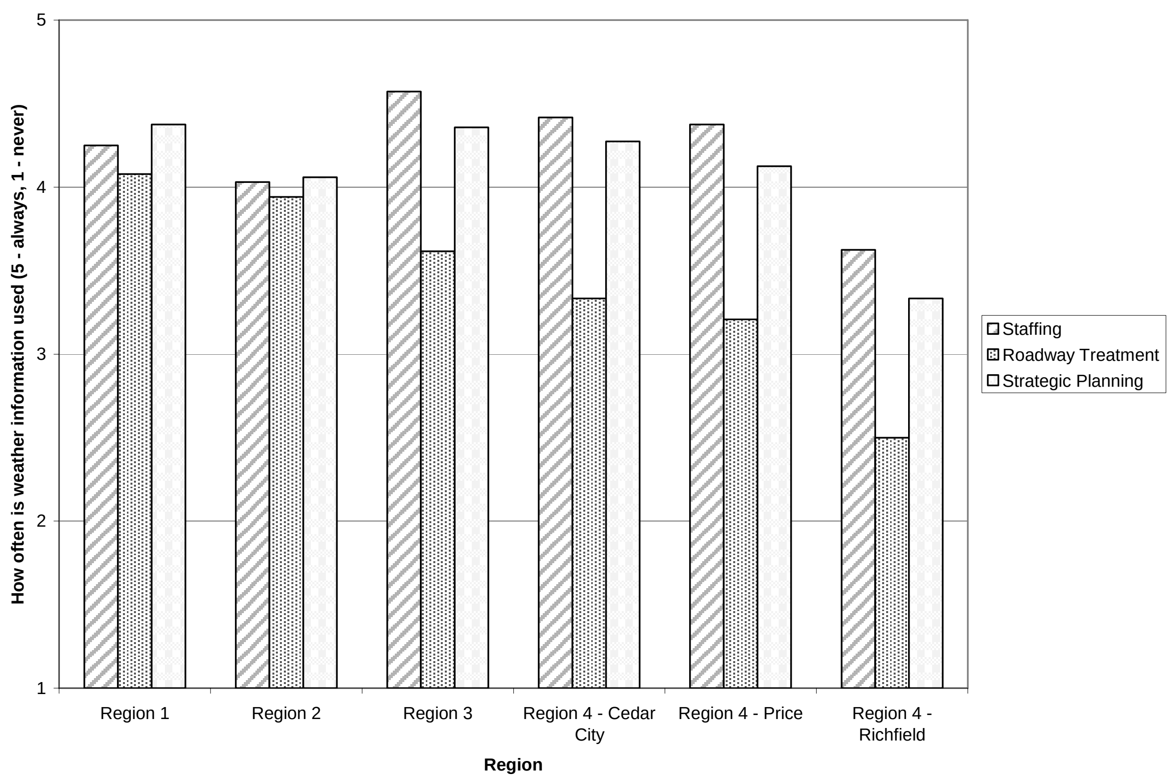


Figure 5-1: How Often Weather Information is Used, by UDOT Region

Many of the respondents said that using weather forecasts did impact their maintenance costs. However, none would comment on how much their costs were affected.

The respondents were asked to indicate their sources of weather information, and to rank these sources in terms of usefulness. All respondents included UDOT's program in their rankings. Generally, the UDOT program was ranked as the number one source. Other sources used by maintenance employees were NWS/NOAA, television broadcasts, RWIS, traffic cameras, weather stations located at the maintenance shed, Accuweather, radar, airports, ski reports, avalanche reports, Meteorologix, satellite, and Utah Highway Patrol.

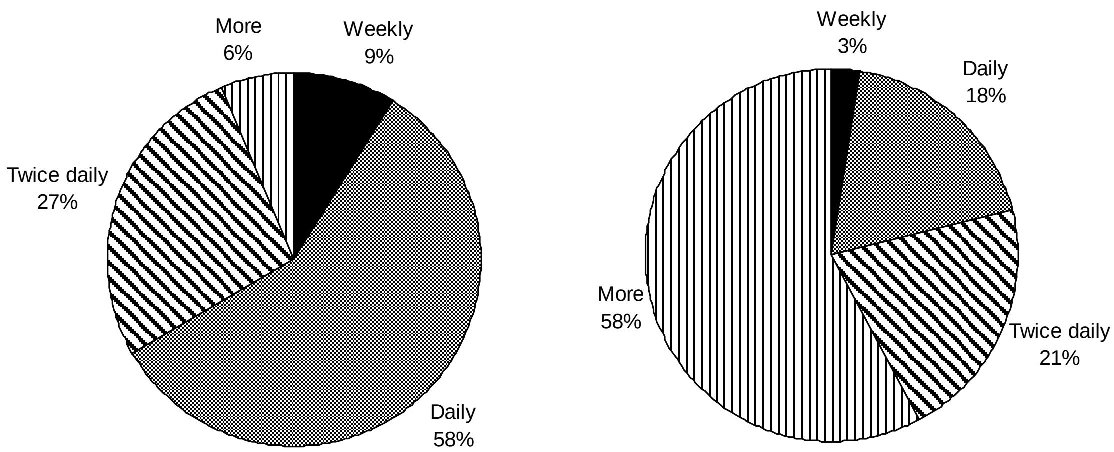
Respondents were also asked to comment on the methods in which they receive the UDOT weather forecasts and the efficiency of these methods. As shown in Table 5-2, the most common way of receiving information was through email (90 percent of respondents), with telephone contact with a staff meteorologist (42 percent) ranking second. All but three of the respondents used one of these two methods; these respondents, along with 11 other respondents, used Web-based forecasts. Overall, respondents felt the program was efficient in relaying weather forecast information.

Table 5-2: Use of UDOT Weather Operations Program Services

	Count	Pct.
E-mail forecasts	71	89.9
Call meteorologist	33	41.8
Web-based	14	17.7
Visit to the TOC	1	1.3
Other	10	12.7
	N =	79
	* =	1

Note: Respondents were allowed to check more than one response for this question

During the winter season, station supervisors become the most active users of the UDOT weather service. The interview process yielded a 70 percent response rate from station supervisors (54 out of 77 individuals). Among them, most respondents (91 percent) use the UDOT weather service at least once per day during the winter season. As a storm approaches and encapsulates the area, an even higher number of them (97 percent) used the service at least once per day and more than half of them (58 percent) use the service more than twice per day (see Figure 5-2).

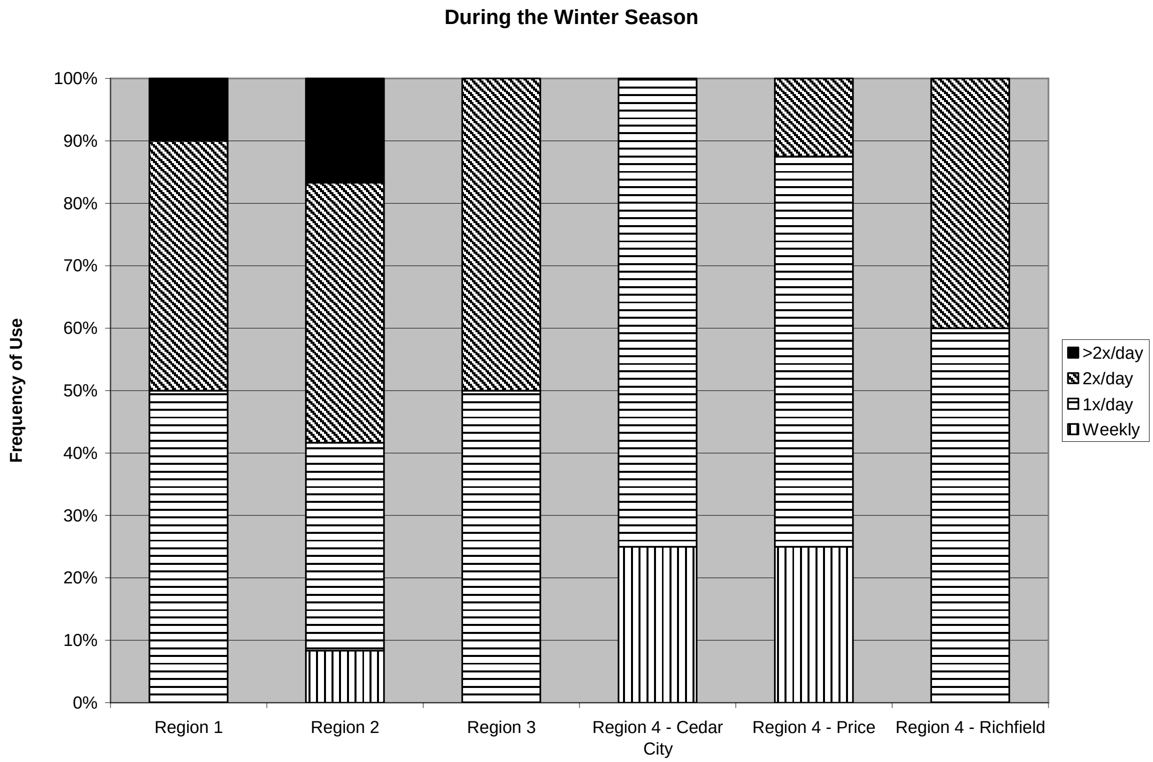


Overall During the Winter

When a Storm is Approaching

Figure 5-2: Frequency of Using the UDOT Weather Service

There were notable differences between the UDOT regions in terms of the frequency of using the UDOT weather service, as shown in Figure 5-3. For instance, the percentages of Region 1 and Region 2 station supervisors who use the UDOT weather service more than twice per day for the overall winter season are 10 percent and 17 percent, respectively. When a winter storm is expected, these percentages increase to 80 percent and 100 percent, respectively. No station supervisors from Regions 3 or 4 reported using the UDOT weather service more than twice per day for the overall winter season. When a winter storm is expected, these percentages increase to 40 percent and 33 percent for Regions 3 and 4, respectively.



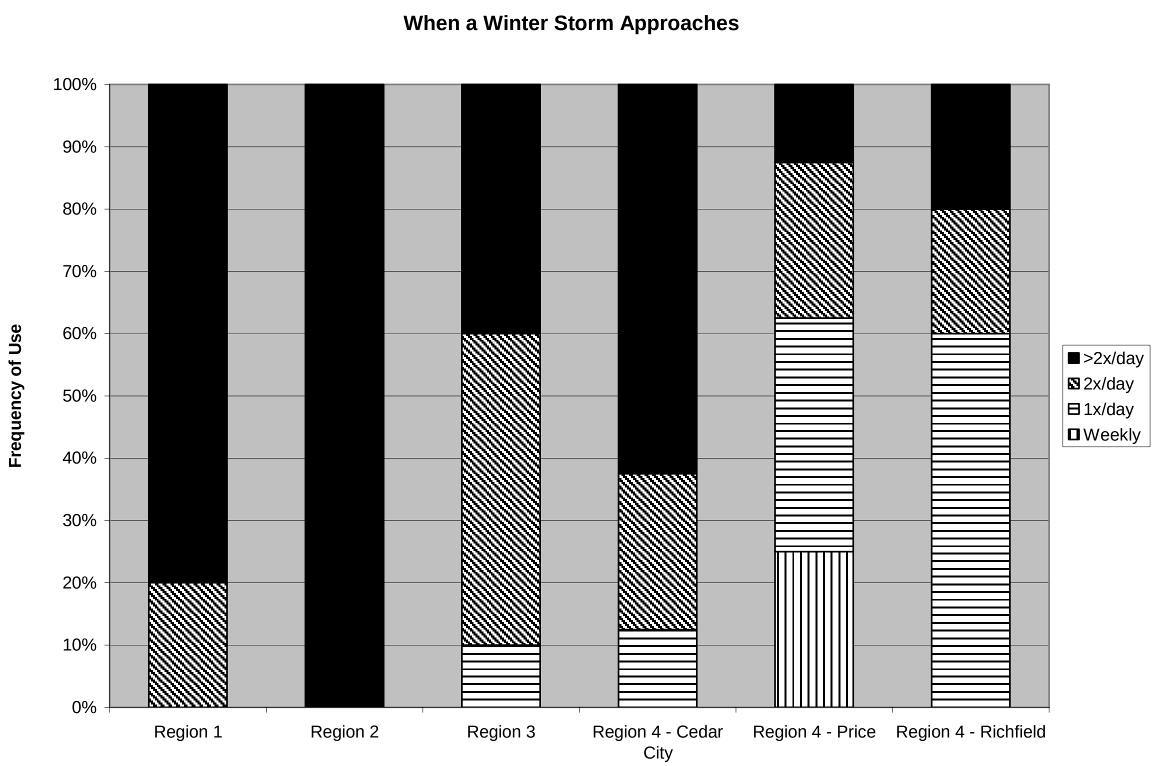


Figure 5-3: Regional Differences in Using the UDOT Weather Service

There are a couple of explanations why station supervisors in Regions 3 and 4 might use the program less than their counterparts in Regions 1 and 2. It may be that these districts experience less adverse winter weather than the rest of the state. Weather severity index values for Utah, shown in Figure 3-6, indicate greater winter severity in Regions 1 and 2 than in Regions 3 and 4. It may also be that Regions 3 and 4 use anti-icing practices less frequently, which leads to less reliance on weather forecasts for winter maintenance. This is consistent with the survey responses which showed that respondents from Regions 3 and 4 are less likely to use weather information to influence roadway treatment decisions.

Respondents were asked what time frame of forecast was most useful to them. As shown in Table 5-3, approximately 60 percent of respondents liked receiving forecast information for a time frame of 12-24 hours. While some respondents liked receiving forecasts for a shorter time frame, a larger percentage of respondents wanted forecasts that extended past three days.

Table 5-3: Preferred Forecast Time Frames

	Count	Pct.
0-6 hour	6	7.7
6-12 hour	2	2.6
12-24 hour	47	60.3
24-36 hour	12	15.4
3-5 day	17	21.8
6 month	-	-
Other	4	5.1
	N =	78
	* =	2

Note: Respondents were allowed to select multiple time frames

Other aspects of user satisfaction examined included the overall service, reliability and usability of the UDOT weather forecasts, as perceived by the UDOT customers with respect to other weather service providers. Respondents were asked to rank the UDOT weather forecasts for each of these three aspects on a scale of 1 to 5 (1 being less satisfied and 5 being more satisfied, and thus 3 being equal to other providers). The service factor was used to gauge the relevance and timeliness of weather forecasts and the availability of a forecaster. The reliability factor was used to gauge the accessibility and accuracy of weather forecasts. And the usability factor was used to gauge the user-friendliness of weather forecasts to UDOT users.

Overall, the vast majority of UDOT station supervisors (90 percent) recognized that the UDOT Weather Operations/RWIS Program provided better service than other weather service providers (rated 3 or higher). Most respondents also indicated that the UDOT weather forecasts were more usable (85 percent) and more reliable (76 percent) than other weather service providers.

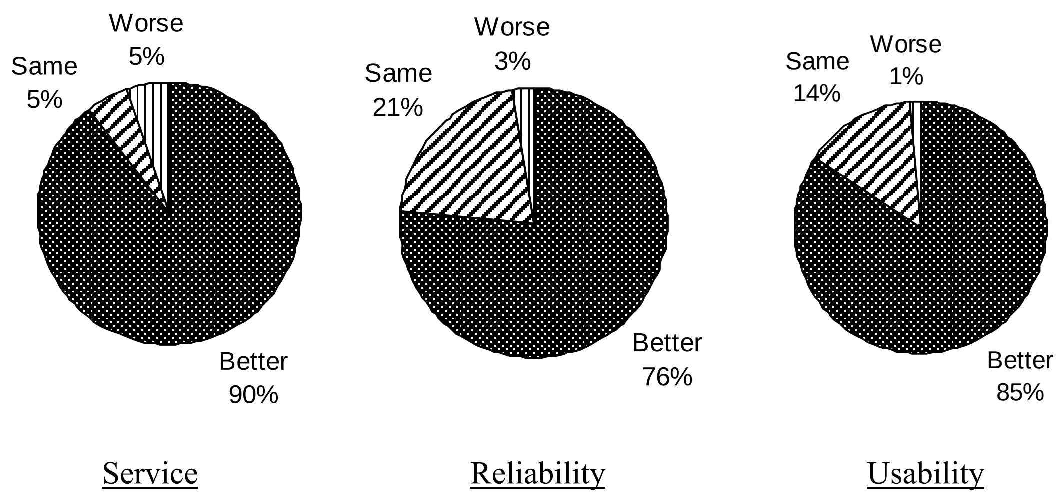


Figure 5-4: User Satisfaction

There were notable differences between the UDOT Regions in terms of the perceived service, usability and reliability of the UDOT weather service, as shown in Figure 5-5. Overall, regions that frequently experience adverse winter weather conditions (Regions 1, 2, and 3) reported higher satisfaction levels in terms of usability, service and reliability of the UDOT weather forecasts.

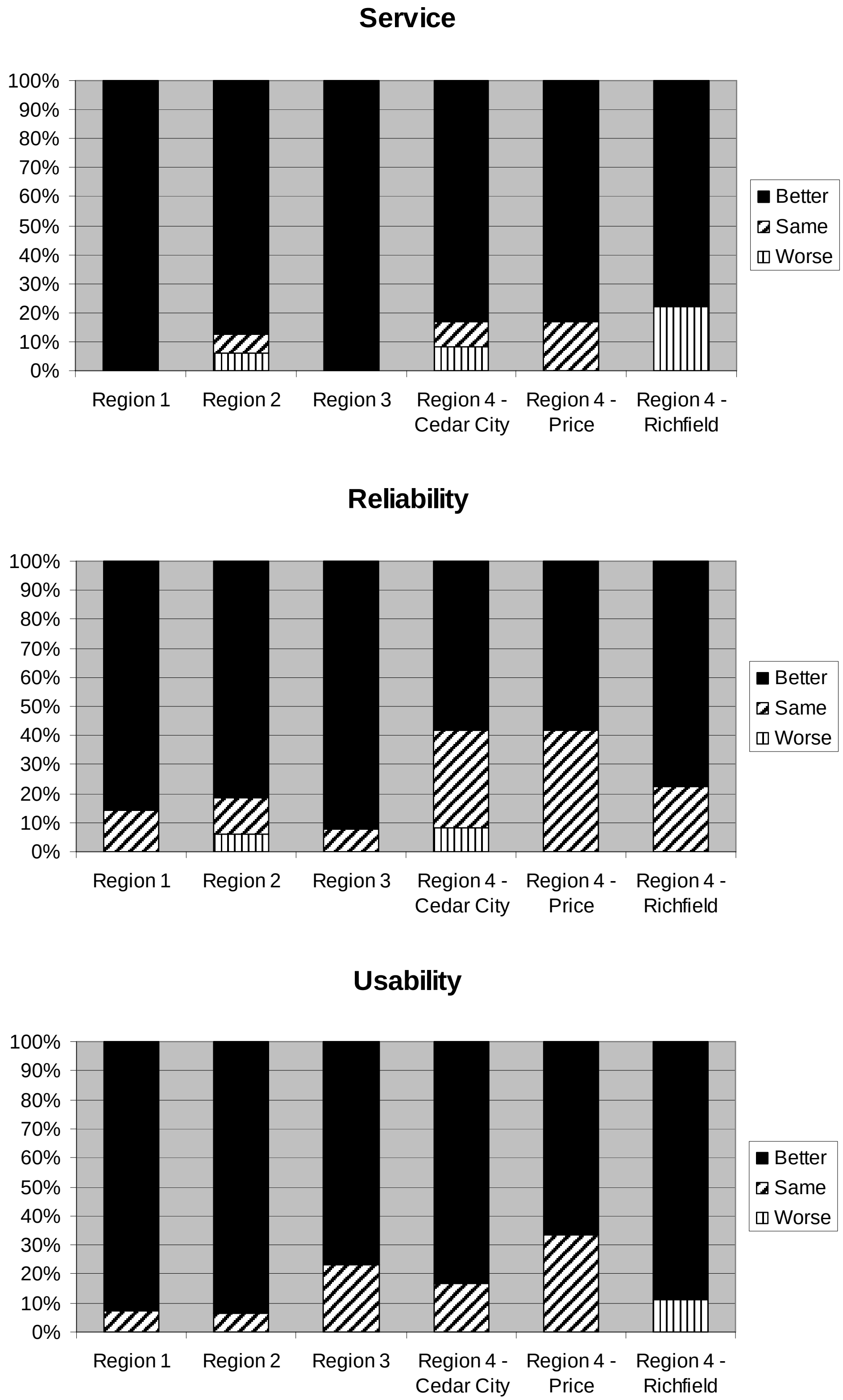


Figure 5-5: Regional Differences in User Satisfaction with UDOT Weather Forecasts

Nearly 80 percent of the respondents reported changing their approach to winter maintenance with the aid of weather forecasts. This was true for planning and crew management. Most respondents felt with more accurate forecasts, they were able to be more prepared than before. Thirteen respondents said they were moving forward with anti-icing although they had not started at the time of the interview. However, about 35 percent of respondents indicated that they had changed their approach to already include anti-icing techniques, and many reported that using the weather forecasts helped to make implementation of anti-icing more widespread and more successful. There were a few respondents who said their areas would likely not be good candidates for anti-icing given the colder temperatures. However, these individuals reported using the forecasts for planning and material usage. They also mentioned the potential of anti-icing for the "right" storms, or storms with higher temperatures and conditions suitable to anti-icing techniques.

The maintenance employees were also asked whether or not they had referred others to the UDOT program. Ten said they would recommend it, but had not done so yet. Nearly 40 said they had recommended it to other UDOT maintenance employees especially crew members. Additionally, they had recommended it to friends, family, the traveling public, ski areas, avalanche crews, other states, county and city workers, and the highway patrol. One contact reported being on a committee that presents this information to others.

Finally, respondents were asked to give feedback on the program and suggest changes. The following is a list of the suggestions offered by maintenance personnel:

- Increase communications, specifically personal communications between the meteorologist and maintenance employees
- Have longer forecasting timeframes and have more in-depth examination of trends
- Increase the RWIS system and incorporate this more into the daily forecast
- Improve forecasts, specifically the accuracy of the timing of an event
- Forecast more often and send automatic e-mails with updates
- Extend the service through May
- Give feedback on accuracy of predicted storm data versus actual storm data
- Decrease the size of the zones or areas for localized forecasts
- Become more familiar with all areas
- Increase the number of cameras
- Increase the staff at the TOC office so that maintenance personnel do not have to call NorthWest Weathernet's Seattle office

Overall, satisfaction of the program was high amongst maintenance employees with many stating that the program was great and that it had already evolved so much. Many maintenance employees felt that the program was changing before they even knew what suggestions to make. One individual felt that the maintenance side was failing to report back to the forecasters with information regarding storms.

5.2. Construction Personnel

All 13 construction resident engineers were interviewed, and all were aware of the UDOT Weather Operations/RWIS Program. Ten respondents reported using weather forecasts for managing their construction projects, and among them, nine used the UDOT program to obtain weather forecasts. Other weather forecast providers mentioned were NWS/NOAA, local TV stations, weather.com, Doppler radars, and MSN. Additionally, one individual reported using past weather history to manage and plan construction projects.

Eight of the respondents acknowledged that using weather forecasts affects their construction costs. Six of these individuals reported a decrease in costs. Specifically, it was mentioned that staffing and material costs may be affected by weather. It was mentioned by one resident engineer that it affects the contractor's costs more than UDOT.

When asked what forecast timeframe was best for them, the resident engineers generally felt an extended forecast was more beneficial. Only two resident engineers found the 0-6 hour forecast useful, whereas five found the 24-36 hour forecast useful and seven used 3-5 day forecasts. It was mentioned that a seven-day to two-week forecast would be useful.

The majority of contacts receive UDOT weather information through e-mail (ten respondents) and one respondent reported calling the office. The ten respondents who receive this information felt that the UDOT program was efficient in relaying this information.

On average, resident engineers ranked service, reliability and usability of the UDOT Program 4 out of 5, 3.94 out of 5, and 4.43 out of 5, respectively. This confirms their preference of the UDOT weather service to other weather service providers. There was no notable difference between Resident Engineers in different regions.

Three of the resident engineers reported changing their approach of managing construction projects using the UDOT weather forecasts. Specifically, they mentioned watching the weather more closely to schedule projects better, planning for expected weather especially for year-round projects, and being able to gear up on manpower to complete projects or completing other tasks in the office when the weather is poor. One individual made the comment that it did not change project management, but was a useful tool aiding project management.

One of the final questions asked of resident engineers was if they referred anyone else to the UDOT program. Three of the resident engineers did refer contractors to the program and one even required their contractors to sign up for the service. It was also asked what these contractors thought of the program. Most resident engineers felt that the contractors liked it and used the information provided, but also reported that some contractors were more positive than others.

The one suggestion offered to improve the UDOT weather service was to provide longer-term, more accurate forecasts. Additionally, some of the resident engineers felt that this information would be better used if it was sent to the contractors directly. Specifically, one resident engineer brought up the point that engineers cannot control when a contractor schedules work and can only make recommendations. By sending the UDOT weather forecasts to the contractors, it may promote better planning by the contractors and also allow resident engineers to hold the contractors more responsible for their work.

6. CONCLUSIONS AND RECOMMENDATIONS

This research report summarizes the findings of an evaluation of UDOT's Weather Operations and RWIS Program. As noted earlier, this evaluation focused on the Weather Operations function of the program, and included the benefits for only certain groups of users (specifically, Central Maintenance, Field Maintenance and Construction).

6.1. Conclusions

In the introduction of this report, the research team identified six questions it sought to answer about UDOT's Weather Operations/RWIS Program. The conclusions are organized around these questions.

Is the information provided by the program accurate, reliable, and easy to use?

UDOT maintenance personnel who were interviewed for this research project indicated high levels of satisfaction with the reliability and usability of the Weather Operations program's products. Seventy-six percent of respondents said that UDOT's forecasts are more reliable than other weather information services, and 85 percent said that they were more usable. The program also received high reliability and usability ratings from construction engineers.

Is the program delivering the products it is supposed to?

There was unanimous awareness of the program among respondents to the two surveys. The Weather Operations program produces forecasts twice per day on a 12-to-24 hour time frame along with longer-term outlooks, as well as providing on-call telephone consultations. The majority of maintenance personnel respondents indicated that the shorter time frame was what they preferred, while the longer-term time frame currently provided was very helpful for construction engineers. In addition, when asked how they currently receive information from the program, 90 percent of respondents indicated relying on the e-mail forecasts, while 42 percent will call staff meteorologists. Some respondents used the Internet-based forecasts. When asked how they would prefer to receive their forecast information, the vast majority of respondents indicated that they would use one or more of those three methods. Therefore, the program seems to be succeeding in delivering the right time frame of forecasts in a way that is accessible to users.

Are the customers satisfied with the service provided by the program?

Ninety percent of maintenance personnel respondents indicated that the UDOT Weather Operations program provided a better level of service than other weather information services that they might use. All maintenance and construction respondents indicated that the program is efficient in delivering forecast information to its customers.

Is the information provided by the program changing users' behavior, and if so, how?

Nearly 80 percent of the maintenance personnel respondents reported changing their approach to winter maintenance with the aid of these weather forecasts. Respondents indicated increasing their usage of the forecasts when a winter storm is approaching. Improved forecast accuracy supports anti-icing practice, which is being increasingly used in Utah, as well as general preparedness. In addition, three of the resident engineers reported changing their approach of managing construction projects using the UDOT weather forecasts to improve scheduling of projects.

Is the information provided to UDOT personnel valuable in their operations, beyond what is available from other weather information providers?

As noted earlier, UDOT's forecasts provide a level of specificity for highways that is not available from other forecasting services, such as televised weather forecasts. Combining this with the positive responses noted earlier, the UDOT program offers value to maintenance personnel beyond what is provided through other weather services. Several construction engineers also commented that improved weather information can help reduce construction costs.

What are the benefits of the UDOT weather service to winter maintenance personnel?

An artificial neural network (ANN) model was employed to estimate the shed labor and materials costs for winter maintenance as a function of its overall usage of UDOT weather service, its evaluation of the UDOT weather service, the level-of-maintenance of the winter roadways that the shed manages, winter traffic volume that the shed manages, its level of anti-icing practice, and the winter severity index for the area. Marginal costs were estimated for three different weather information scenarios:

- Using other weather information sources, but not using UDOT's program
- Using the least effective weather service providers
- Using UDOT's weather program to its current capabilities

Because of model uncertainty, ranges of cost effects were estimated. These ranges are shown in Figure 6-1. The figure shows a couple of important points. First, UDOT has realized significant cost savings (estimated at \$5.9 to \$13.3 million per year by comparing the leftmost column with the third column from the left) by its use of weather forecasts to pursue anti-icing strategies. Second, UDOT's Weather Operations Program has helped to reduce labor and materials costs beyond what has been attained through the use of other weather forecast information services. Labor and materials cost savings of \$1.4 to \$3.1 million per year are realized through the use of UDOT's Weather Operations Program (by comparing the second and third columns). Third, there is potential for greater cost savings up to \$0.5 to \$1.2 million per year in the future based on increased usage of the Weather Operations Program (by comparing the third and fourth columns).

On average, the UDOT's Weather Operations Program is estimated to save the UDOT maintenance sheds \$2.2 million per year for snow and ice control activities, which leads to a

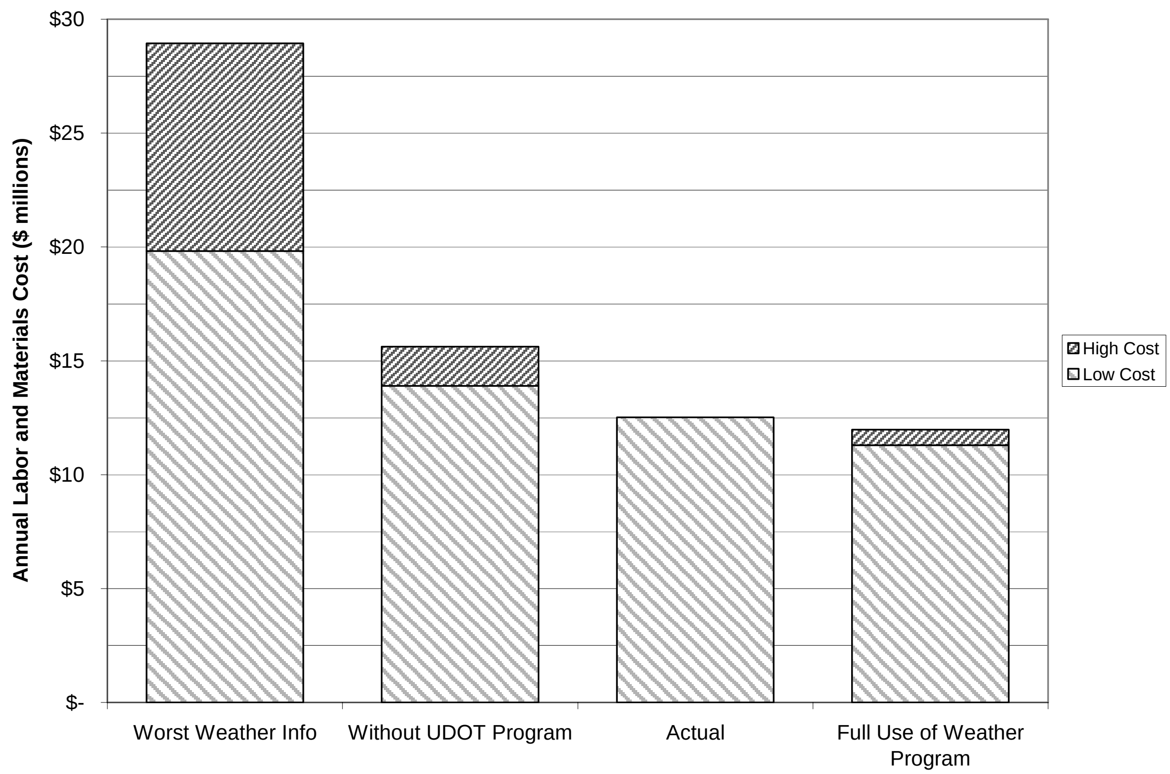


Figure 6-1: Estimates of Labor and Materials Cost based on Level of Usage of UDOT Weather Operations Program

benefit-cost ratio of 10 (as the annual budget for the program is $200,000). This ratio is conservative as it does not count the program's added value to UDOT user groups other than winter maintenance personnel.

Please note that the equipment cost was not included in the Phase I evaluation, as constrained by the data availability and limited budget. Since UDOT maintenance sheds charged an hourly fee for the usage of snow and ice control equipment, it is reasonable to assume that the improved weather information offered by the UDOT Weather Operations Program to winter maintenance personnel had reduced the equipment cost in a similar manner to how labor and materials costs were reduced.

6.2. Recommended Next Steps

This research has concluded that UDOT's Weather Operations Program provides a net benefit to the state solely from a winter maintenance perspective. There are limitations to these findings. As this research did not include the costs of the RWIS program, its findings are not based on the full scope of the UDOT Weather Operations/RWIS program. Moreover, neither does this evaluation cover the full extent of the range of benefits resulting from this program. It could be that a benefit-cost analysis over the entire UDOT Weather Operations/RWIS program might yield different findings than those presented in this report.

The following further research is recommended to help UDOT optimize its weather services program to better meet customer needs.

- How much is the cost savings in winter maintenance equipment, due to the UDOT Weather Operations program? With the equipment usage data at the maintenance shed level, the research team will use an approach similar to the one in Phase I to derive the magnitude of such cost savings. That would make the cost-benefit analysis more complete.

- What is the benefit-cost of UDOT's RWIS program? UDOT's RWIS and Weather Operations programs work together in a fashion that makes it difficult to clearly delineate the benefits and costs of one component compared to the other. However, it would be valuable to assess the value of RWIS specifically. Are RWIS data used as a substitute for customized forecasts, a supplement for them, and/or a tool to help improve forecasts? Does RWIS data reach a broader range of users than the Weather Operations Program? Understanding these specific features would be valuable in developing a philosophy to guide future RWIS investment.

- What are the indirect effects of improved maintenance practice resulting from enhanced weather forecasts? Successful anti-icing will restore the level of service more quickly than reactive winter maintenance. This should result in reduced delay for commuters as well as freight movement and reductions in crash frequency (and reductions in crash-related delay). While these relationships are intuitively understood, they have not been explored sufficiently to quantify the benefits for UDOT's ultimate customers. These benefits may indeed outweigh the direct benefits to UDOT as an infrastructure owner and operator, and may provide important information to guide not only investments in weather information, but also in winter maintenance in general.

- What are other benefits to UDOT of its Weather Operations Program? This research focused on certain groups of users, including Central Maintenance, Field Maintenance and Construction. Additional outreach to other internal users, such as the TOC, could provide a more complete picture of how the program has benefited the agency.

APPENDIX A: SNOW AND ICE LIST SERVE SURVEY

Name: ________________________

Job Title:________________________

Organization:______________________

E-mail:__________________________

1. Do you utilize weather forecasts to aid you in winter road maintenance activities? ______
   a. If yes, from where?____
   b. If no, how do you plan for weather events and treat conditions?______________
   ____

If you answered YES to #1, please answer the following:

2. Do you pay for customized weather forecasts?____________(if no, please proceed to #6)
   a. If yes, what service and how long have you subscribed?__________________
3. What benefits, if any, have you experienced from customized forecasts? Please explain.
   ____
4. Have you experienced cost savings associated with customized forecasts?____________
   ____
5. Are you satisfied with your customized weather service, why or why not? ___________
   ____

If you answered NO to #2, please answer the following:

6. What are your reasons for choosing not to pay for a customized weather forecasting service? ____
   ____

Thank you for your participation.

APPENDIX B: UDOT PERSONNEL SURVEYS

Name:__________________
Title:__________________
Region:_________________
Area:__________________
Shed:__________________

To preliminarily evaluate the institutional performance of the UDOT Weather Operations (user acceptance/perception)

WINTER MAINTENANCE

**Most concerned with timing of weather events, when is it going to happen, how long, what is it going to do to the road…less concerned with amount of precipitation
**Efficient/cost effective/accurate

- ❑ ***Engineers***
  May move employees between areas to help treat storms
  Plan for supplies, equipment, employees pre-winter
  Longer forecast may be most useful

- ❑ ***Area Supervisor***
  Before Storm: Survey stations for readiness
  During Storm: Decide whether to share resources
  After Storm: Analyze application rate/application frequency, question practice

- ❑ ***Station Supervisor***
  Change plans as needed throughout the storm
  Constantly talking with forecasters during weather events
  Shorter forecasts may be most useful
  May send employees home to rest upon weather forecast

Questions for Telephone Interviews with Winter Maintenance Personnel

1. Do you use weather forecasts for your maintenance operations? (If no, skip to question 5)
   ❑ Yes ❑ No
   If yes, how? (Rank: 1 as never, 5 as always)

Staffing	1	2	3	4	5
Roadway treatment	1	2	3	4	5
Strategic planning	1	2	3	4	5
Other______________	1	2	3	4	5

2. Does weather forecasting affect your road maintenance costs?
   ❑ Yes ❑ No
   If yes, what percentage?________ (Increase/Decrease)
   Staffing_____ Materials______ Equipment______ Other______

3. Where do you obtain weather information? Please rank your sources starting with 1 as the most useful.
   - NWS/NOAA
   - UDOT Weather Operations
   - TV Weather
   - Other______________

4. Are you aware of UDOT's weather operations program? (If no, skip to question 14)
   ❑ Yes ❑ No

5. What services do you use from UDOT's weather operations program? (If none, proceed to question 14)
   ❑ Email forecasts ❑ Call meteorologist ❑ Web-based
   ❑ Visit to the TOC ❑ Other________________

6. How often do you use these services provided by UDOT?
   ❑ During winter: weekly___ daily___ twice daily___ more___
   ❑ Winter *only* when storms are likely:
   weekly___ daily___ twice daily___ more____
   ❑ During summer (for maintenance):
   weekly___ daily___ twice daily___ more___

7. What is the most useful UDOT forecast timeframe for you?
   ❑ 0-6 hour ❑ 6-12 hour ❑ 12-24 hour ❑ 24-36 hour ❑ 3-5 day
   ❑ 6 month ❑ Other_______________

8. What is the best method of relaying UDOT forecast information to you?
   ❑ Email ❑ Phone ❑ Radio ❑ Other_____________

9. Do you feel UDOT is efficient in relaying forecast information?
   ❑ Yes ❑ No
   If no, how would you change this process?

10. On a scale of 1 to 5 with 1 being less satisfied and 5 being more satisfied, how satisfied are you with the service UDOT's weather operations program provides with respect to other forecasting services?
    1 2 3 4 5
    On the same scale, how reliable would you say these weather forecasts are with respect to other sources?
    1 2 3 4 5
    On the same scale, how usable would you say these forecasts are with respect to other sources?
    1 2 3 4 5

11. Do you recommend these services to anyone?
    ❑ Yes ❑ No

If yes, who?
- ❑ Area supervisors ❑ Station supervisors ❑ Contractors
- ❑ Other______________

12. Has UDOT's weather operations changed your approach to winter maintenance?
❑ Yes ❑ No
If yes, how?
___Implementation of anti-icing
___More widespread use of anti-icing
___More successful anti-icing program
___Other

13. What suggestions do you have to improve the UDOT weather operations program?

14. (a) If both question 1 and 5 are no:
What are your reasons for not using weather forecasts to assist you in your maintenance decisions?

What would make you more likely to use weather forecasting?

Now that you are aware a program exists within UDOT, do you think you will make use of their services?

(b) If question 1 is no, but they have heard of the UDOT program, but do not use it:
What are your reasons for not using weather forecasts to assist you in your maintenance decisions (UDOT or other)?

What would make you more likely to use weather forecasting (UDOT or other)?

(c) If question 1 is yes, but have not heard of the UDOT program:
Now that you are aware a program exists within UDOT, do you think you will make use of their services?

(d) If question 1 is yes, and they have heard of the UDOT program, but do not use it:
What are your reasons for not using UDOT's weather forecasts to assist you in your maintenance decisions?

What would make you more likely to use the UDOT weather forecasting service?

Name:__________________
Title:___________________
Region:_________________
Area:___________________
Shed:___________________

CONSTRUCTION

**Efficient/cost effective/accurate
**Most concerned with project deadlines/weather delays, calendar day vs. working day

❑ ***Resident Engineers***

Oversee construction contracts
Ensure project completion
Relay information to contractors
Long forecasts useful for overall planning
Shorter forecasts useful for timing of individual project tasks (concrete decks…)

Questions for Telephone Interviews with Construction Personnel

1. Do you use weather forecasts for your construction projects? (If no, go to question 5)
   ❑ Yes ❑ No
   If yes, from what sources? Please rank sources with one as the most useful.
   NWS/NOAA
   UDOT Weather Operations
   TV Weather
   Other______________

2. Does weather forecasting affect your road construction costs?
   ❑ Yes ❑ No
   If yes, what percentage?________ (Increase/Decrease)
   Staffing_____ Materials_____ Equipment______ Other______

3. Are you aware of UDOT's weather operations program? (If no, go to question 11.)
   ❑ Yes ❑ No
   If yes, when did you become aware of it?____________
   Do you use the weather forecasts from UDOT?_______ (If no, go to question 11)

4. What is the most useful UDOT forecast timeframe for you?
   ❑ 0-6 hour ❑ 6-12 hour ❑ 12-24 hour ❑ 24-36 hour ❑ 3-5 day
   ❑ 6 month ❑ Other________________

5. What is the best method of relaying UDOT forecast information to you?
   ❑ Email ❑ Phone ❑ Radio ❑ Other______________

6. Do you feel UDOT is efficient in relaying forecast information?
   ❑ Yes ❑ No
   If no, how would you change this process?

7. On a scale of 1 to 5 with 1 being less satisfied and 5 being more satisfied, how satisfied are you with the service UDOT's weather operations program provides with respect to other weather forecasting services?
   1 2 3 4 5
   On the same scale, how reliable would you say these weather forecasts are with respect to other forecasting sources?
   1 2 3 4 5
   On the same scale, how usable would you say these forecasts are with respect to other forecasting sources?
   1 2 3 4 5

8. Has UDOT's weather operations program changed your approach to managing construction projects?
   ❑ Yes ❑ No
   If yes, how?

9. Do you inform contractors about the weather operations program? (If no, go to question 11)
   ❑ Yes ❑ No

10. What feedback have you received from contractors regarding UDOT's weather operations program and its products and services?

11. What suggestions do you have to improve the UDOT weather operations program?

12. (a) If both question 1 and 3 are no:
    What are your reasons for not using weather forecasts to assist you in managing your construction projects?

    What would make you more likely to use weather forecasting?

    Now that you are aware a program exists within UDOT, do you think you will make use of their services?

    (b) If question 1 is no, but they have heard of the UDOT program, but do not use it:

What are your reasons for not using weather forecasts to assist you in managing your construction projects (UDOT or other)?

What would make you more likely to use weather forecasting (UDOT or other)?

(c) If question 1 is yes, but have not heard of the UDOT program:
Now that you are aware a program exists within UDOT, do you think you will make use of their services?

(d) If question 1 is yes, and they have heard of the UDOT program, but do not use it:
What are your reasons for not using UDOT's weather forecasts to assist you in managing your construction projects?

What would make you more likely to use the UDOT weather forecasting service?

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