Road Weather Information Systems (RWIS) Life-Cycle Cost Analysis

http://aurora-program.org

Aurora Project 2018-01

Final Report
May 2020
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Aurora is an international program of collaborative research, development, and deployment in the field of road and weather information systems (RWIS), serving the interests and needs of public agencies. The Aurora vision is to deploy RWIS to integrate state-of-the-art road and weather forecasting technologies with coordinated, multi-agency weather monitoring infrastructures. It is hoped this will facilitate advanced road condition and weather monitoring and forecasting capabilities for efficient highway maintenance and real-time information to travelers.

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This report provides methods and general guidelines to assist public agencies with determining RWIS site life-cycle costs. Public agencies can follow the information provided herein to gather necessary data and perform the analysis to help quantify the costs and benefits associated with RWISs. The methodologies presented in this report provide a framework for calculating life-cycle costs and net present worth, which helps agencies make more informed decisions in repairs and replacement of RWIS sites. It also helps assess and compare alternatives and associated cost implications. |

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ROAD WEATHER INFORMATION SYSTEM LIFE-CYCLE COST ANALYSIS

Final Report
May 2020

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Daryl Taavola
AECOM

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EXECUTIVE SUMMARY

A road weather information system (RWIS) is a combination of advanced technologies that collects, transmits, processes, and disseminates road weather and condition information. RWIS stations collect road weather data, which include atmospheric, pavement, and/or water level data. Once the data have been collected, central RWIS hardware and software are used to process observations from the sensors to develop nowcasts or forecasts and display or disseminate road weather information in a format that can be easily interpreted by maintenance and traffic operations personnel as well as the public. The information collected by the system can provide improvements in the effectiveness of road maintenance operations and help motorists make more informed decisions for their travel.

Agencies that deploy and use RWIS applications would likely be interested in knowing the costs associated with the ongoing use of these systems. To help state departments of transportation (DOTs) make more informed decisions with regard to budget planning for the various costs associated with the use of RWIS, the Aurora Pooled Fund Program initiated the RWIS Life-Cycle Cost Analysis (LCCA) research project. LCCA is a data-driven tool that provides a detailed account of the total costs of a project over its expected life. LCCA has been proven to create short-term and long-term savings for transportation agencies by helping decision-makers identify the most beneficial and cost-effective projects and alternatives.

The objectives of this research were to develop guidelines to:

- Help quantify the costs and benefits associated with RWIS sites
- Better assess costs arising from RWIS assets over the life cycle
- Provide a framework for calculating net present worth (NPW)
- Assess alternatives and associated cost implications
- Determine long-term RWIS life-cycle costs and the optimal point to replace RWIS equipment
- Support decisions on repair versus replacement based on projected expenses
- Assist in planning and fund the replacement or repair of RWIS infrastructure

To accomplish the objectives, a comprehensive literature review was conducted to identify documents from previous projects that are relevant to RWIS life-cycle costs and to provide a summary of the current practices for determining the cost and potential savings of RWIS stations. Key RWIS elements to be considered for evaluation as part of the cost analysis were identified and categorized as either capital or operations and maintenance elements, with consideration for entire RWIS stations as well as individual components. Those elements are defined as follows:

- **Capital costs:** Costs associated with equipment installation and capital improvements, such as hardware and software
- **Operations and maintenance costs:** Items with future cost implications, such as ongoing operations, maintenance, rehabilitation, communications, and replacement costs
Two surveys were conducted to gather RWIS product information: one for RWIS manufacturers/vendors and another for public agencies. The surveys were designed to obtain estimates of RWIS equipment costs and design service life from RWIS manufacturers/vendors and state DOT agencies. Information on actual service life, applicable warranties, and recommendations regarding preventive maintenance (including frequency, which may impact life expectancy) were also collected, among other information.

To develop guidelines on performing an LCCA, quantification of costs and benefits associated with RWIS is essential. Data for quantifying RWIS-associated costs and benefits were gathered through the surveys, a literature review, and transportation agencies’ experience. A review of the data collected was conducted to determine the applicability of this data with respect to the LCCA. Information and guidelines available from existing life-cycle benefit/cost models and other LCCA tools were also reviewed to aid in performing the analysis.

The use of RWIS requires capital, installation, operations, and maintenance costs. However, there are benefits to the RWIS that may be recognized through a reduction in unnecessary winter road maintenance operations (labor, equipment, and material), a potential reduction in weather-related crashes, and mobility improvements in travel costs and emission reduction.

This report provides methods and general guidelines to assist public agencies with determining RWIS site life-cycle costs. Public agencies can follow the information provided herein to gather necessary data and perform the analysis to help quantify the costs and benefits associated with RWISs. The methodologies presented in this report provide a framework for calculating life-cycle costs and NPW, which helps agencies make more informed decisions in repairs and replacement of RWIS sites. It also helps assess and compare alternatives and associated cost implications.

The steps for performing an LCCA for RWIS sites present the principles of life-cycle cost analysis and serve as a guide to perform the analysis. These steps for performing a life-cycle cost analysis for an RWIS site are summarized as follows:

1. **Determine RWIS deployment strategy**: Determine the components and other details of an RWIS site, including types of sensors, infrastructure (e.g., tower, pole, and foundation), communications, and power source. The location of the RWIS should be considered as it may have an impact on installation costs.
2. **Collect data**: Collect costs and life span information at an individual component level or entire RWIS site level. Data at an individual component level is preferred. Data presented herein or collected from other agencies can also be used to fill data gaps. Capital, installation, maintenance, and operational costs should be collected.
3. **Estimate RWIS benefits and savings**: The benefits and savings of RWIS are realized through winter maintenance savings, crash reduction/collision cost savings, and mobility improvements. Methods to estimate the benefits and savings in these areas are described herein. Other models to estimate the benefits and savings, particularly in crash reduction and mobility improvements, also can be used.
4. **Estimate expected life-cycle cost and NPW**: Net present worth is an important indicator to
support RWIS implementation decisions. NPW is determined using the costs and benefits associated with RWIS over its life cycle.

The report also presents a simulated case study demonstrating the use of the methodology described in the report for an LCCA. Using a hypothetical example, the report demonstrates the methods for estimating the costs as well as potential benefits associated with deploying an RWIS site. It illustrates the value of using a comprehensive assessment by taking into account the capital, operations, and maintenance costs and the estimated benefits over the useful life span of an RWIS to support investment strategies and decisions.

Finally, the report offers a set of conclusions that outlines guiding principles for consideration in performing LCCA and life-cycle planning for RWIS. The conclusions and guiding principles note that technology-oriented RWIS may have different characteristics than conventional transportation assets such as pavement or bridges. Applying conventional LCCA and life-cycle planning practices to RWIS may not always be appropriate. As such, it is vital to establish a practical life-cycle planning framework and LCCA methodology for RWIS that considers stochastic treatments of the unique characteristics of technology-oriented RWIS.
CHAPTER 1. INTRODUCTION

Throughout the US, there are many states that experience recurring patterns of inclement weather events, particularly during winter months. The occurrence of these weather events can in turn have a detrimental impact on the safety and mobility of motorists. Generally, road collision rates increase dramatically during inclement weather conditions due to the degradation of visibility and traction on the roadway.

One approach to improving the decision-making process for roadway maintenance personnel is to use real-time information (i.e., for monitoring current road conditions) and forecasts (i.e., for predicting near-future road conditions) provided by innovative technologies such as road weather information systems (RWISs). An RWIS can be defined as a combination of advanced technologies that collects, transmits, processes, and disseminates road weather and condition information to help maintenance personnel make timely and proactive maintenance-related decisions. The system collects data using environmental sensor stations (ESSs) and provides real-time road weather and surface conditions information.

RWIS stations are used to collect road weather data, which includes atmospheric, pavement, and/or water level data. Once the data have been collected by the ESS, central RWIS hardware and software are used to process observations from the sensors to develop nowcasts or forecasts and display or disseminate road weather information in a format that can be easily interpreted by maintenance and traffic operations personnel as well as the public. The information collected by the system can provide improvements in the effectiveness of road maintenance operations and help motorists make more informed decisions for their travel.

1.1. Background

Agencies that deploy and use RWIS applications would likely be interested in knowing the costs associated with the ongoing use of these systems. To help state departments of transportation (DOTs) make more informed decisions with regard to budget planning for the various costs associated with the use of RWISs, the Aurora Pooled Fund Program initiated the RWIS Life-Cycle Cost Analysis (LCCA) research project. The objectives of this research were to develop guidelines to do the following:

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To accomplish the objectives, a comprehensive literature review was conducted to identify documents from previous projects that are relevant to RWIS life-cycle costs, and to provide a summary of the current practices for determining the cost and potential savings of RWIS stations. A list of key RWIS elements to be considered for evaluation as part of the cost analysis were identified and categorized as either capital or operations and maintenance (O&M) elements, with consideration for entire RWIS stations as well as individual components. Two surveys were conducted to gather RWIS product information: one for RWIS manufacturers/vendors and another for public agencies. Information gathered from the literature review and the manufacturer and public agency surveys was used to develop guidelines for determining RWIS life-cycle costs for entire RWIS stations and individual RWIS elements.

1.2. Report Organization

This report is organized into the following seven chapters and two appendices:

- Chapter 1 outlines the general problem examined by the project and provides background information on RWISs and their various applications.
- Chapter 2 presents the information gathered during a comprehensive literature review of the life-cycle costs associated with the operation, maintenance, and replacement of RWIS equipment.
- Chapter 3 presents the RWIS components identified as elements to be considered during the analysis of overall life-cycle costs for individual RWIS equipment and entire stations.
- Chapter 4 describes the methodology used for collecting data from key stakeholders. It includes the development of two online surveys asking RWIS manufacturers and state DOTs to provide information about their RWIS products, costs, and maintenance information.
- Chapter 5 develops methodologies and offers guidelines to perform a life-cycle cost analysis for an RWIS.
- Chapter 6 presents a simulated case study of performing a life-cycle cost analysis using the methodologies developed in Chapter 5.
- Chapter 7 provides key findings and conclusions of this project and serves as a reference guide to help public agencies make more informed investment decisions regarding various elements of their RWIS systems.
- Appendix A summarizes the survey responses from RWIS manufacturers.
- Appendix B summarizes the survey responses from the state DOTs.
CHAPTER 2. LITERATURE REVIEW

This chapter presents a literature review that outlines several studies related to RWIS life-cycle costs. The goal of the literature review is to summarize the current practices for determining the cost of and potential savings from RWIS stations. Additionally, this literature review helped to develop the optimal methodology for building a tool to help transportation agencies budget for the ongoing costs of installing and maintaining RWIS sites.

McKeever et al. (1998) set a standard methodology for calculating the cost and savings associated with RWIS. Other studies have cited the results from the McKeever et al. (1998) study and built upon it, such as developing methods to determine the optimal density and location of RWIS stations. Though life-cycle methods previously have been developed, there is a need to update the methodology with current costs and reevaluate.

2.1. Life-Cycle Cost-Benefit Model for Road Weather Information Systems

McKeever et al. (1998) defines the life-cycle cost-benefit associated with deploying RWIS technology. Along with the methodology for the life cycle, a case study was presented using an RWIS installed on I-20 near Abilene, Texas. McKeever et al. (1998) was a development from Haas et al. (1997).

Many datasets were utilized for McKeever et al.’s analysis. Table 1 presents some of the input data considered when building the decision-support tool.
As shown in Table 1, many data inputs were obtained and used in the model outline. Inclement weather crash data are needed as well as budget information for the acquisition, installation, operation, and maintenance costs associated with an RWIS station. The analysis considered direct cost, direct savings, indirect savings, and potential social savings. The variables used in the analysis are presented in Table 2.
Table 2. RWIS cost-benefit variables

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<td>Accident cost</td>
</tr>
</tbody>
</table>

Sources: Haas et al. 1997 and McKeever et al. 1998

Some of the values set for these variables are presented in Table 3. The values set for each of these variables are based on 1997 data and specific to the location of the case study.

Table 3. Cost and savings calculated for Abilene, Texas

<table>
<thead>
<tr>
<th>Variables</th>
<th>Average</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>RWIS systems capital cost</td>
<td>$42,010</td>
<td>per site</td>
</tr>
<tr>
<td>RPU and CPU capital cost</td>
<td>$10,446</td>
<td>per site</td>
</tr>
<tr>
<td>Life span</td>
<td>25</td>
<td>year</td>
</tr>
<tr>
<td>Interest rate</td>
<td>5</td>
<td>%</td>
</tr>
<tr>
<td>Upgrade for RPU and CPU</td>
<td>$10,446</td>
<td>per 5 years</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>$3,000</td>
<td>per year per unit</td>
</tr>
<tr>
<td>Phone charges</td>
<td>$360</td>
<td>per year per unit</td>
</tr>
<tr>
<td>Meteorological services</td>
<td>$2,100</td>
<td>per year per unit</td>
</tr>
<tr>
<td>Winter maintenance savings</td>
<td>$12,720</td>
<td>per year</td>
</tr>
<tr>
<td>Accident savings</td>
<td>$48,100</td>
<td>per year</td>
</tr>
</tbody>
</table>

Sources: Haas et al. 1997 and McKeever et al. 1998

When determining the 50-year life cycle, the NPW of the RWIS in this location was found to be $923,000. Other benefits noted in the study were reduced risk of liability, better planning for road work, and lower travel times, which reduces pollution cost.
2.2. Road Weather Management Benefit Cost Analysis Compendium

The Federal Highway Administration (FHWA) built a compendium to assist transportation agencies with reviewing benefit-cost analyses conducted throughout the US regarding road weather management (RWM), which would include RWIS stations (Lawrence et al. 2017). A custom spreadsheet was developed to assist with cost-benefit estimations. The compendium includes the fundamentals of benefit-cost analysis, the tool developed, and case studies. Multiple case studies were reviewed, and these case study subjects included the following:

- Surveillance, monitoring, and prediction – this includes RWIS deployment studies conducted in Idaho, Michigan, and Utah
- Information dissemination
- Decision support, control, and treatment
- Weather response or treatment

The fundamentals of the cost-benefit analysis included a section on the discount factor and reviewed the elements that should be considered in the analysis. Table 4 presents the cost elements to include, as presented in the compendium.

**Table 4. Cost and benefit elements**

<table>
<thead>
<tr>
<th>Agency benefits/costs</th>
<th>User benefits/costs associated w/ transportation system management &amp; operations &amp; road weather management projects</th>
<th>Externality (non-user impacts, if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Design and engineering</td>
<td>• Travel time and delay</td>
<td>• Emissions</td>
</tr>
<tr>
<td>• Land acquisition</td>
<td>• Reliability</td>
<td>• Noise</td>
</tr>
<tr>
<td>• Construction</td>
<td>• Crashes</td>
<td>• Other societal impacts</td>
</tr>
<tr>
<td>• Reconstruction/Rehabilitation</td>
<td>• Vehicle operating costs</td>
<td></td>
</tr>
<tr>
<td>• Preservation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Routine maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Mitigation (e.g., noise barriers)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Lawrence et al. 2017

Lawrence et al. (2017) presents the various ways to determine the benefit-to-cost ratio and also the values used, as well as an overview of benefit-cost analysis tools that have been developed. Table 5 presents the reported tools from a variety of studies.
### Table 5. Summary of existing benefit cost analysis tools and methods for RWM

<table>
<thead>
<tr>
<th>Tool/Method</th>
<th>Developer</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCA.net</td>
<td>FHWA</td>
<td><a href="http://www.fhwa.dot.gov/infrastructure/asstmgmt/bcanet.cfm">http://www.fhwa.dot.gov/infrastructure/asstmgmt/bcanet.cfm</a></td>
</tr>
<tr>
<td>CAL-BC</td>
<td>Caltrans</td>
<td><a href="http://www.dot.ca.gov/hq/tpp/offices/eb/LCBC_Analysis_Model.html">http://www.dot.ca.gov/hq/tpp/offices/eb/LCBC_Analysis_Model.html</a></td>
</tr>
<tr>
<td>COMMUTER Model</td>
<td>U.S. Environmental Protection Agency</td>
<td>N/A</td>
</tr>
<tr>
<td>Evaluation Model for Freeway Intelligent Transportation Systems (ITS) Scoping (EMFITS)</td>
<td>New York State DOT</td>
<td>N/A</td>
</tr>
<tr>
<td>The Florida ITS Evaluation (FITSEval) Tool</td>
<td>Florida DOT</td>
<td>N/A</td>
</tr>
<tr>
<td>ITS Deployment Analysis System (IDAS)</td>
<td>FHWA</td>
<td>N/A</td>
</tr>
<tr>
<td>Multimodal Benefit-Cost Analysis (MBCA)</td>
<td>TREDIS Software</td>
<td><a href="http://www.tredis.com/mbca">http://www.tredis.com/mbca</a></td>
</tr>
<tr>
<td>Screening Tool for ITS (SCRITS)</td>
<td>FHWA</td>
<td>N/A</td>
</tr>
<tr>
<td>Surface Transportation Efficiency Analysis Model (STEAM)</td>
<td>FHWA</td>
<td>N/A</td>
</tr>
<tr>
<td>Tool for Operations Benefit/Cost (TOPS-BC)</td>
<td>FHWA</td>
<td><a href="http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm">http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm</a></td>
</tr>
<tr>
<td>Trip Reduction Impacts of Mobility Management Strategies (TRIMMS)</td>
<td>Center for Urban Transportation Research at the University of South Florida</td>
<td><a href="http://www.nctr.usf.edu/abstracts/abs77805.htm">http://www.nctr.usf.edu/abstracts/abs77805.htm</a></td>
</tr>
</tbody>
</table>

Source: Lawrence et al. 2017

Additionally, current safety impact defaults were presented in Lawrence et al. (2017) to assist with values for crash rates, volume/capacity ratios, and impact assumptions for various types of systems.

The three case studies summarized in Lawrence et al. (2017) are discussed in the following sections.
2.2.1. Michigan DOT

The Michigan DOT reviewed regional pre-deployment of RWIS stations in rural regions. ESSs and maintenance decision support systems (MDSSs) were deployed in four regions. To measure the benefits, the travel time, safety, and operational cost were reviewed (Krechmer et al. 2010). The Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS) model was used for the analysis. Default accident rates, vehicle fuel efficiency, and emissions rate were used in the calculation. The study was conducted for two years (2000–2002). Annualized capital costs, operational costs, and maintenance costs were included. The rural RWIS deployment found a 2.8–7.0 cost-benefit ratio depending on the region. The cost data were used for these ratios as follows:

- North region – 50 stations with a capital cost of $4.02 million and annual O&M cost of $460,000
- Bay region – 15 stations with a capital cost of $2.06 million and annual O&M cost of $256,000
- Superior region – 34 stations with a capital cost of $3.463 million and annual O&M cost of $358,000
- Grand region – No data on number of stations, but capital cost was $2.272 million and annual O&M cost of $233,500

Table 6 presents the overall cost breakdown.

### Table 6. Benefit-cost analysis results from a Michigan DOT study

<table>
<thead>
<tr>
<th>Benefits and costs</th>
<th>North</th>
<th>Bay</th>
<th>Grand</th>
<th>Superior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time savings</td>
<td>$354,000</td>
<td>$2,289,700</td>
<td>$1,036,000</td>
<td>$573,000</td>
</tr>
<tr>
<td>Crash reduction</td>
<td>$1,519,000</td>
<td>$968,000</td>
<td>$1,269,000</td>
<td>$1,630,000</td>
</tr>
<tr>
<td>Operating costs</td>
<td>$565,000</td>
<td>$94,000</td>
<td>$115,000</td>
<td>$203,000</td>
</tr>
<tr>
<td>Total annual benefits</td>
<td>$2,438,000</td>
<td>$3,351,700</td>
<td>$2,420,000</td>
<td>$2,406,000</td>
</tr>
<tr>
<td>Annualized cost</td>
<td>$870,000</td>
<td>$482,000</td>
<td>$471,000</td>
<td>$713,000</td>
</tr>
<tr>
<td>Net benefits</td>
<td>$1,568,000</td>
<td>$2,289,700</td>
<td>$1,949,000</td>
<td>$1,693,000</td>
</tr>
<tr>
<td>Benefit-cost ratio</td>
<td>2.8</td>
<td>7.0</td>
<td>5.1</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Source: Lawrence et al. 2017, Krechmer et al. 2010

Overall, Krechmer et al. (2017) found that there was a winter maintenance cost decrease with an increase in weather information.

2.2.2. Utah DOT

The Utah DOT created a weather operations and RWIS program. Within this program, Utah reviewed its RWIS sites, regional traffic operations center (TOC), incident management and freeway service patrols, anti-icing system, communications, advanced traffic management
systems, and other various applications. The overall goal for this program was to determine the benefits and cost associated with outputs from the weather operations program.

The Utah DOT utilized an artificial neural network (ANN) model for winter maintenance costs (Strong and Shi 2008). The model calculated the labor and materials cost for each maintenance/material facility and was based on 2004–2005 winter maintenance cost data. Based on all the factors reviewed in the winter operation and RWIS program, the Utah DOT found a savings of more than $2.2 million, which results in a 11:1 benefit-cost ratio (Strong and Shi 2008).

2.2.3. Idaho Transportation Department (ITD)

Idaho has invested $15 million in expanding and renovating its RWIS network statewide. Nearly every site has pavement temperature, layer type and thickness, and coefficient of friction data. The goal of Koeberlein et al. (2014) was to compare the benefits and cost of the Idaho system when compared to others using the TOPS-BC tool (see the previous Table 5 for details on this tool). Using the TOPS-BC tool, a baseline model was run with no RWIS sites, then an implementation of 9 sites in 2011–2012 was modeled, and then a model was separately run for the 2012–2013 season when 24 RWIS stations were deployed. Crash reduction, travel time reduction, safety factors, energy benefits, O&M cost, capital cost, and life span variables were used in this model. The 2011–2012 season found a 34:1 benefit cost ratio, while the 2012–2013 season found a 19:1 ratio (Koeberlein et al. 2014).

2.3. RWIS Network Planning: Optimal Density and Location

Kwon and Fu (2016) looked at various approaches for optimal density and locations for RWIS stations. The report reviewed three alternative methods as follows:

1. A surrogate measure-based approach that reviews traffic, weather, and maintenance benefits
2. A cost-benefit method, which is presented in this section
3. A spatial inference method, which required less data and utilized kriging analysis for the optimal solution

The report outlined the limitations of each approach and provided survey answers that were collected during the project as well. These data may be useful when reviewing the life-cycle cost of RWIS. Kwon et al. (2016a) further presented the cost-benefit approach, and Kwon et al. (2016b) presented the alternative three approaches based on the Kwon and Fu (2016) research.

Overall, Kwon and Fu (2016) and Kwon et al. (2016a) are the optimal resources for RWIS optimization for location and cost-benefits.

The goal of Kwon and Fu (2016) was to develop a method for determining the optimal number of RWIS stations an area should have to get the most value. Additionally, once the optimal number of RWIS stations is established, a method for finding the best placements for these new
stations is offered. Kwon and Fu (2016) presented the methodology for this analysis and used northern Minnesota as a case study.

The overall methodology is presented in a flowchart shown in Figure 1.
Figure 1. Methodology for analysis
Step one presented in Figure 1 shows the dataset utilized in Kwon et al. (2015). Step two is the cost component of the analysis, which utilized the methods developed in Haas et al. (1997). Step three allows users to see the optimal density and location for RWIS based on cost.

Figure 2 presents the results from northern Minnesota.

![Net present value for a 25-year life cycle RWIS](image)

**Figure 2. Net present value for a 25-year life cycle RWIS (a) benefits and cost (b) and projected net benefits**

As presented in Figure 2a, users should review the RWIS cost compared to the total benefits and find the point where there is the highest difference. In the case of northern Minnesota, this was at 45 RWIS stations. Note that this optimal number includes the current installed RWIS network. Figure 2b shows the projected net present value (NPV) of the benefits.
To determine the optimal location for these RWIS sites, a grid was placed over the project area and current RWIS sites. Then, the areas with the greatest maintenance benefits (reduction in maintenance cost) and collision benefits (reduction in crashes) were mapped and compared. Figure 3 presents the mapping conducted in Kwon et al. (2015).

Figure 3. Optimal location for RWIS sites with (a) highest maintenance benefits, (b) highest crash benefit, and (c) combining both

This location process may allow agencies to evaluate their current RWIS network and see where the best placement may be if the optimal number is greater than their current RWIS network.

The methodology for determining RWIS density and location is ideal for agencies; however, the cost data was pulled from Haas et al. (1997). Therefore, to get better values for the life-cycle cost, the values for each variable should be updated and set for northern Minnesota.
2.4. U.S. DOT ITS Benefits, Costs, and Lessons Learned Database

In addition to reviewing individual studies, the U.S. DOT ITS database was reviewed. This database allows users to view state transportation agencies’ experiences with specific ITS equipment. These experiences include their costs, benefits, and lessons learned when implementing specific ITS equipment. Table 7 presents the RWIS cost data pulled from the site.

Table 7. Sample RWIS data from U.S. DOT ITS Database

<table>
<thead>
<tr>
<th>Location</th>
<th>Summary</th>
<th>Cost data</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington State DOT</td>
<td>RWIS stations, CCTV cameras, and VMS on 1-5 were deployed.</td>
<td>RWIS and CCTV cameras (capital and installation cost) $165,000 in 2003. O&amp;M cost is approximately $1,200.</td>
<td>June 2009</td>
</tr>
<tr>
<td>Ohio DOT</td>
<td>Added 86 new RWIS stations, therefore managing a total of 158 stations.</td>
<td>RWIS on the highways total cost of deployment $2.2 million. RWIS deployed at county offices $1.3 million. Training cost $15,000 and warranty/service agreement was $185,000. Communication cost $49.95 per site per month for the main phone; a second phone is installed and cost $12.95 per site per month.</td>
<td>Dec. 2003</td>
</tr>
<tr>
<td>Michigan DOT</td>
<td>Completed architecture and pre-deployment plans for five of the seven regions.</td>
<td>Capital cost for the North region $4.02 million with an O&amp;M annual cost of $460,000. Capital cost for the Bay region $2.06 million with an O&amp;M annual cost of $256,000. Capital cost for Grand region $2.27 million with an O&amp;M annual cost of $233,500. Capital cost for Superior region $3.46 million with an annual O&amp;M cost of $358,000.</td>
<td>Jan. 2010</td>
</tr>
<tr>
<td>Washington State DOT</td>
<td>Spokane region implementation at several sites.</td>
<td>Weather station and installation cost at Sherman Pass $170,006 and $83,403 for the Laurier RWIS site.</td>
<td>Jan. 2004</td>
</tr>
<tr>
<td>Kansas City, Missouri</td>
<td>Six RWIS devices were installed. Note that the installation costs were reduced due to the power and cabinet installation were part of a route expansion project.</td>
<td>Capital cost for six RWIS devices $55,000. O&amp;M cost per unit per year is $3,800.</td>
<td>Mar. 2010</td>
</tr>
</tbody>
</table>

Source: https://www.itskrs.its.dot.gov/its/itsbcllwebpage.nsf/KRHomePage

These data points show cost data from multiple public agencies around the nation. These agencies may be ideal candidates to connect with in the data gathering effort for this current project.
2.5. Additional RWIS Studies

Many state agencies have developed RWIS implementation plan reports. One implementation report was created by New York State DOT in 2014 (Chien et al. 2014). The report presents the current RWIS sites, the current weather data available, and potential new RWIS sites in New York. Additionally, Chien et al. (2014) presents the benefit-cost (B/C) ratio results from other sources and found the B/C ratio ranged from 2:1 and 10:1.

The Washington State DOT reviewed the potential benefits of the integration of RWIS (Bradshaw Boon and Cluett 2002). The report includes cost-efficient snow and ice maintenance strategies and ways to increase safety and mobility. The north central region expected a 10% savings in direct snow and ice control costs, which would result in a 1.4 B/C ratio. The Washington State DOT projects a $2.5 million savings for 10 years with the expansion of their RWIS program (Bradshaw Boon and Cluett 2002).

Singh et al. (2016) built upon Kwon et al. (2015) by focusing on the methodology for determining the optimal location for RWIS sites. The main difference in Singh et al.’s (2016) analysis was they reviewed weather-related crashes more closely to determine if the crash was truly caused by the change in weather. Their model includes two main components for planning, spatial coverage, and reliability of the system if one RWIS sensor fails. Singh et al. (2016) also presented a case study of the RWIS deployment in the Texas DOT’s Austin district.

2.6. Other Equipment Life-Cycle Studies

Brom et al. (2016) reviewed the life cycle of energy equipment. In the study, the researchers reviewed two product life-cycle management models. The cost variables that were considered, when applying these models to gas turbines at a power plant, were installations, investment/capital cost, operation cost, planned maintenance, unplanned maintenance, disposal, opportunity cost (downtime losses), and the price of electrical energy. The models’ results were shown not to be precise due to the changes in the market, but the methodology of the models was appropriate (Brom et al. 2016).

Bengtsson and Kurdve (2016) looked at the life-cycle costs for machining equipment while accounting for dynamic maintenance costs. The study looked at a large automotive driveline system manufacturing site. The energy, fluid, and maintenance costs were dynamic variables, and other variables were linear. Four stages were developed with regard to the cost: project cost, acquisition costs, life support cost, and life operations cost. Three options were reviewed: replacing the existing machines with a new one, reconditioning the existing machine, and running the existing machine and risking downtime. No specific equations were presented for this model. The study used historical data and literature reviews to get values for these variables to determine the best option. The NPVs for all three options were presented in graphic form, and it appears that purchasing a new machine is the most cost-effective option (Bengtsson and Kurdve 2016).
The Ohio DOT (ODOT) has conducted multiple winter maintenance projects that include a cost analysis (Schneider et al. 2014, 2015). Schneider et al. (2014) reviewed a tow-behind trailer that contains a plow and salting system that is able to swing out and treat another lane of roadway. Schneider et al. (2015) reviewed several different types of plow blades and compared them by performance and cost. The cost analysis for both studies utilized Monte Carlo simulations, which allow each variable to be a distribution and then a simulation will randomly select from within the distribution. The result is an average and range of the simulation, which is a more realistic value since it accounts for the variation within each variable.
CHAPTER 3. RWIS ELEMENTS

The project team identified key RWIS components to be considered as part of the RWIS LCCA. The RWIS elements were identified based on the information gathered during the literature review and discussion with the Aurora committee for this project.

ESS sites have been deployed as a method to capture, manage, and utilize road weather data. Traditional ESS sites were designed to provide RWISs with pavement conditions and associated weather conditions that affect the pavement conditions. Traditional RWIS platforms, ESS sites, and field processors have evolved and now may integrate sensors that have the capacity to monitor any of the following environmental parameters:

- Meteorological and pavement conditions
- Stream flow, stream depth, and localized flood depths in flood prone or flash flood areas
- Traffic conditions and traffic flow using remote monitoring devices
- Snow depth and blowing snow
- Visibility
- Environmental pollutants and toxic materials
- Solar and terrestrial radiation
- Soil temperature and soil moisture

However, most deployed ESS sites still focus on pavement and meteorological conditions.

A modern RWIS may include the following:

- A network of ESSs to collect road weather, traffic-related, environmental data, and potentially camera images
- Instrumented vehicles to collect road weather data and maintenance treatment activities
- Weather support services designed to address highway-specific requirements
- Decision-support systems designed to transform the various sources of road weather data into operational guidance to aid operational decisions
- Road weather data coordination and distribution system for both internal use and traveler information outlets

Presented in Table 8 is a listing of key RWIS components that were considered in this research.
Table 8. Key RWIS elements

<table>
<thead>
<tr>
<th>RWIS elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPU</td>
</tr>
<tr>
<td>CPU</td>
</tr>
<tr>
<td>Telecommunications equipment to transmit data (modem)</td>
</tr>
<tr>
<td>Tower support structure</td>
</tr>
<tr>
<td>Enclosure - cabinet</td>
</tr>
<tr>
<td>Internet Protocol (IP) surveillance system (closed-circuit television [CCTV]) - optional</td>
</tr>
<tr>
<td>Software for CPU</td>
</tr>
<tr>
<td>Software for end user computer</td>
</tr>
<tr>
<td><strong>Sensors</strong></td>
</tr>
<tr>
<td>Pavement condition sensor</td>
</tr>
<tr>
<td>Surface temperature sensor</td>
</tr>
<tr>
<td>Subsurface sensor</td>
</tr>
<tr>
<td>Air temperature/Relative humidity sensor</td>
</tr>
<tr>
<td>Wind direction and speed sensor</td>
</tr>
<tr>
<td>Precipitation sensor</td>
</tr>
<tr>
<td>Barometric pressure sensor</td>
</tr>
<tr>
<td>Visibility sensor</td>
</tr>
<tr>
<td>Presence of precipitation sensor</td>
</tr>
<tr>
<td>Water level sensor</td>
</tr>
<tr>
<td>Solar radiation kit</td>
</tr>
<tr>
<td>Traffic sensor (e.g., microwave vehicle detection system [MVDS])</td>
</tr>
</tbody>
</table>
CHAPTER 4. DATA COLLECTION

Based on the RWIS elements identified in Chapter 3, the project team conducted online surveys to obtain estimates of RWIS equipment costs and design service life from RWIS manufacturers/vendors and state DOT agencies. Information on the expected service life, applicable warranties, and recommendations regarding preventive maintenance (including frequency, which may impact life expectancy) were also collected through the surveys, among other information.

4.1. Manufacturer Survey

A survey was developed and distributed to various RWIS manufacturers in September 2019 to gather information on their products, including costs, design service life, applicable warranties, and recommendations regarding preventive maintenance as related to their RWIS systems. The survey was made available to responders in an online format and sent out to the manufacturers via email, which included a link to access the survey.

4.1.1. Manufacturer Survey Background Information

A total of three manufacturers responded to the survey. Table 9 presents the three manufacturers that responded to the survey, as well as contact information for each respondent.

Table 9. RWIS manufacturer responded to survey

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Name</th>
<th>Title</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Sierra Electronics, Inc.</td>
<td>Brett</td>
<td>RWIS product manager</td>
<td>530-273-2080</td>
<td><a href="mailto:sales@hsierra.com">sales@hsierra.com</a></td>
</tr>
<tr>
<td>Campbell Scientific</td>
<td>Michael</td>
<td>Market development manager</td>
<td>780-454-2505</td>
<td><a href="mailto:mike.burton@campbellsci.ca">mike.burton@campbellsci.ca</a></td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>Erik</td>
<td>Sales manager - road weather</td>
<td>805-886-2828</td>
<td><a href="mailto:erik.wright@lufftusainc.com">erik.wright@lufftusainc.com</a></td>
</tr>
</tbody>
</table>

4.1.2. Summary of Manufacturer Survey Responses

The RWIS manufacturer survey asked the manufacturers various questions concerning their RWIS products, including the following:

- General RWIS product information
- Information for each individual RWIS component, including:
  - Air temperature/Relative humidity sensor
  - Surface temperature sensor
  - Pavement condition sensor
  - Wind direction and speed sensor
  - Visibility sensor
- Precipitation sensor
- Ultrasonic snow depth sensor
- Subsurface sensor
- Barometric pressure sensor
- Water level sensor
- Solar radiation kit
- Traffic/Vehicle detection sensor
- CCTV camera

The following information was inquired for each component:
- Product name and model
- Equipment cost
- Recommended preventative maintenance activities and frequencies
- Estimated annual maintenance cost
- Warranty period
- Warranty cost
- Expected life span

- Software product name(s) and cost(s)
- Features/capabilities of the software products
- Software license fee information and limitations/requirements
- Telecommunication requirements and costs
- Data storage solution(s) and cost(s)

Presented in Table 10 is a listing of the general RWIS product information provided by the manufacturers who responded to the survey. Comprehensive survey responses received from the manufacturers are presented in Appendix A.
Table 10. General product information provided by RWIS manufacturers

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>RWIS products</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Sierra Electronics, Inc.</td>
<td>HSE’s typical RWIS:</td>
</tr>
<tr>
<td></td>
<td>5410 StormLink(R) RWIS Datalogger/RPU</td>
</tr>
<tr>
<td></td>
<td>5433 IceSight non-intrusive road condition and/or intrusive road sensor options</td>
</tr>
<tr>
<td></td>
<td>Model 5422 and 5721</td>
</tr>
<tr>
<td></td>
<td>5432 Present weather sensor for precipitation/visibility</td>
</tr>
<tr>
<td></td>
<td>5723 Air temperature and relative humidity</td>
</tr>
<tr>
<td></td>
<td>5714 Ultrasonic anemometer or 5712 mechanical anemometer</td>
</tr>
<tr>
<td></td>
<td>Some alternative sensors include snow depth and solar radiation</td>
</tr>
<tr>
<td>Campbell Scientific</td>
<td>Recently standardized as “Campbell Scientific, Intelligent Route Information Systems” and consisting of component parts manufactured by Campbell Scientific in USA and other parts from national and international manufacturers. All systems are based on Campbell Scientific CR Data Loggers (RPU).</td>
</tr>
<tr>
<td>OTT HydroMet (Luftf)</td>
<td>LCOM – RPU</td>
</tr>
<tr>
<td></td>
<td>WS100 - Precipitation sensor (type and intensity)</td>
</tr>
<tr>
<td></td>
<td>WS200 - Wind speed and direction</td>
</tr>
<tr>
<td></td>
<td>WS300 – Relative humidity/Temp/Pressure</td>
</tr>
<tr>
<td></td>
<td>WS600 - All in one (3 above combined)</td>
</tr>
<tr>
<td></td>
<td>VS2K - Visibility sensor up to 2,000 m</td>
</tr>
<tr>
<td></td>
<td>VS20K - Visibility sensor up to 20,000 m</td>
</tr>
<tr>
<td></td>
<td>NIRS – Non-invasive road condition sensor</td>
</tr>
<tr>
<td></td>
<td>IRS31Pro - Embedded passive pavement sensor with removable electronics</td>
</tr>
<tr>
<td></td>
<td>MARWIS - Mobile road condition sensor</td>
</tr>
</tbody>
</table>

4.2. DOT Survey

A similar survey was developed and distributed to various state DOTs in September 2019 to gather information on their RWISs, including costs, design service life, applicable warranties, recommendations regarding preventive maintenance, software, procurement methods, and plans for future deployments as related to RWIS. The survey was made available to responders in an online format and was distributed to various agencies via the Snow-Ice listserv maintained by the University of Iowa, to which several winter maintenance agencies and professionals subscribe to as a means of sharing and gathering information on winter maintenance operations. This listserv included the Aurora member states, in addition to city, county, and state agencies, as well as international agencies.

4.2.1. DOT Survey Background Information

A total of 10 agencies responded to the survey. Provided in Table 11 are the 10 responding agencies as well as their contact information.
## Table 11. DOT survey participants

<table>
<thead>
<tr>
<th>Agency</th>
<th>Name</th>
<th>Title</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>Travis Lutman</td>
<td>ITS manager</td>
<td>701-328-4274</td>
<td><a href="mailto:tlutman@nd.gov">tlutman@nd.gov</a></td>
</tr>
<tr>
<td>Minnesota DOT</td>
<td>Jon Bjorkquist</td>
<td>Statewide RWIS coordinator</td>
<td>218-828-5722</td>
<td><a href="mailto:jon.bjorkquist@state.mn.us">jon.bjorkquist@state.mn.us</a></td>
</tr>
<tr>
<td>New Hampshire DOT</td>
<td>Lee Savary</td>
<td>Communications technician I</td>
<td>603-271-1669</td>
<td><a href="mailto:Lee.Savary@dot.nh.gov">Lee.Savary@dot.nh.gov</a></td>
</tr>
<tr>
<td></td>
<td>Susan Klasen</td>
<td>TSMO administrator Roadway operations engineer</td>
<td>603-271-6862</td>
<td><a href="mailto:susan.klasen@dot.nh.gov">susan.klasen@dot.nh.gov</a></td>
</tr>
<tr>
<td>Michigan DOT</td>
<td>James Roath</td>
<td>Roadway operations engineer</td>
<td>517-230-5361</td>
<td><a href="mailto:RoathJ1@michigan.gov">RoathJ1@michigan.gov</a></td>
</tr>
<tr>
<td>British Columbia Ministry of Transportation and Infrastructure</td>
<td>Simon Walker</td>
<td>Weather and climate specialist</td>
<td>778-974-5376</td>
<td><a href="mailto:simon.walker@gov.bc.ca">simon.walker@gov.bc.ca</a></td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Lisa Idell-Sassi</td>
<td>ITS coordinator</td>
<td>907-465-8952</td>
<td><a href="mailto:lisa.idell-sassi@alaska.gov">lisa.idell-sassi@alaska.gov</a></td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Jeff Williams</td>
<td>Roadway programs manager for winter/incident management</td>
<td>801-887-3703</td>
<td><a href="mailto:JeffWilliams@utah.gov">JeffWilliams@utah.gov</a></td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>Vincent Mazzocchi</td>
<td></td>
<td>717-705-1439</td>
<td><a href="mailto:vmazzocchi@pa.gov">vmazzocchi@pa.gov</a></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Mike Adams</td>
<td>RWIS program manager</td>
<td>608-266-5004</td>
<td><a href="mailto:michael.adams@dot.wi.gov">michael.adams@dot.wi.gov</a></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Tina Greenfield</td>
<td>RWIS coordinator</td>
<td>515-233-7746</td>
<td><a href="mailto:Tina.Greenfield@iowadot.us">Tina.Greenfield@iowadot.us</a></td>
</tr>
</tbody>
</table>

### 4.2.2. Summary of DOT Survey Responses

The RWIS DOT survey asked public agency members various questions concerning their RWIS, including the following:

- Number of RWIS stations deployed
- Number of years utilizing RWIS technology
- Procurement methods
- Brand(s)/Manufacturer(s) of RWIS products deployed
- General RWIS product information
- Information for each individual RWIS component, including:
  - Air temperature/Relative humidity sensor
  - Surface temperature sensor
  - Pavement condition sensor
  - Wind direction and speed sensor
  - Precipitation sensor
  - Visibility sensor
  - Ultrasonic snow depth sensor
  - Subsurface sensor
  - Barometric pressure sensor
  - Water level sensor
  - Solar radiation kit
  - Traffic/Vehicle detection sensor
  - CCTV camera (IP surveillance system)
  - The following product information was inquired for each component:
Product name/Model
Capital cost
Average annual costs for preventative/routine maintenance
Average number of times non-routine maintenance required per year
Average non-routine maintenance cost per year
Usefulness/Importance
Expected life span
• Product information for entire RWIS station(s):
  o The following product information was inquired for RWIS stations at a station level:
    ▪ System brand/Model
    ▪ Capital/System cost
    ▪ System installation cost
    ▪ Average annual costs for preventative/routine maintenance
    ▪ Average non-routine maintenance cost per year
    ▪ Usefulness/Importance
    ▪ Expected life span
• Software product(s) used to store, manage, and/or analyze RWIS data
• Cost of the software/Licensing cost of software
• Cost of data storage/Number of years of data stored
• Types of communications used by RWIS to transfer data
• Monthly telecommunications cost per site
• Annual staffing costs associated with ongoing RWIS operations
• Does your agency purchase the warranty on RWIS components? Cost of warranty?
• Who performs preventative/routine maintenance on your RWIS?
• Who performs non-routine maintenance on your RWIS?
• Have winter maintenance costs been reduced due to data provided by your RWIS network?
• Agency sharing of document(s) relating to their RWIS
• Does your agency plan to install additional RWIS in the future?
• Number of additional RWIS station(s) your agency plans on installing in the next 5 years

Presented in Table 12 is a listing of the general RWIS product information provided by the DOT members who responded to the survey.
Table 12. General RWIS product information from DOT survey

<table>
<thead>
<tr>
<th>Agency</th>
<th>RWIS manufacturers</th>
<th>RWIS products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Vaisala, Campbell Scientific</td>
<td>Alaska DOT uses Novarylax tipping buckets, RM Young anemometers, windscreens, MRC temperature data probes, Judd snow depth sensors. Cameras by WTI, Axis, and Mobotix.</td>
</tr>
<tr>
<td>British Columbia Ministry of Transportation and Infrastructure</td>
<td>No sole manufacturer/vendor (British Columbia designs, builds, and maintains their own stations in-house)</td>
<td>Campbell Scientific CR1000 dataloggers, Vaisala DST/DSC pavement sensors, various other instrumentation.</td>
</tr>
<tr>
<td>New Hampshire DOT</td>
<td>Original stations were SSI (Subsurface Systems Inc.), now Vaisala; Lufft (Hoosier)</td>
<td>Vaisala LX (21), Vaisala RWS200 (1), Lufft LCOM/UMB (3); Various brands of Vaisala sensors.</td>
</tr>
<tr>
<td>North Dakota DOT</td>
<td>Lufft (Hoosier) (North Dakota DOT does have several Vaisala sites and one Boschung site for their FAST)</td>
<td>A typical Lufft site has the following sensors: Axis Q6055-E camera, IR illuminator, LCOM, NIRS-31 sensor, WS100, WS301, WS200, and 72 in. deep subsurface probe.</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>Vaisala</td>
<td>RWS200 and associated components.</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Vaisala, Campbell Scientific, High Sierra, Boschung</td>
<td>Utah DOT has too many products to list. Utah DOT customizes their instrumentation to their specific needs and requirements. Essentially, Utah DOT designs their own RWIS systems.</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Manufacturer: Lufft (Hoosier)</td>
<td>WisDOT has 20 Lufft sites and 50 legacy Vaisala sites. Lufft sites have the LCOM RPU, IRS 31 pavement sensors, subsurface probe, OWI-430 precipitation sensor, Young 41382 temp/relative humidity sensor, and Young 05103 wind sensor. Vaisala sites have FP2000 pavement sensors and a variety of atmospheric sensors.</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Iowa DOT’s are a mix of vendors; most of their RPUs are Vaisala LX but they also have a number of Lufft LCOMs</td>
<td>Iowa DOT has a wide variety of sensors. Vaisala, RM Young, OSI, Lufft, Thies Clima, Axis cameras, Wavetronix traffic sensors.</td>
</tr>
</tbody>
</table>

The following three tables present summary information gathered from the DOT survey. Comprehensive survey responses from the DOT survey are included in Appendix B.

Table 13 presents the cost information on an RWIS at a station level provided by survey respondents. The information was the average cost for each site.
Table 13. Capital and installation costs for entire RWIS system

<table>
<thead>
<tr>
<th>Agency</th>
<th>System brand/model</th>
<th>Capital/System cost</th>
<th>System installation cost</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Campbell Scientific</td>
<td>$12,579 (equipment cost only)</td>
<td>$78,000–$385,000 (including construction and installation costs)</td>
<td>Typical construction and installation costs range between $90,000 and $135,000. The $78,000 construction and installation cost is a rehab of an existing site adding new power, communication features, and new sensors. The $385,000 construction and installation cost is for a remote site with no commercial power.</td>
</tr>
<tr>
<td>North Dakota DOT</td>
<td>Vaisala</td>
<td>$32,600 (equipment cost only)</td>
<td></td>
<td>See capital/system cost</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Lufft*</td>
<td>$130,000 (including installation cost)*</td>
<td></td>
<td>This cost is for all equipment, installation, power connections, etc. We have to install two structures, one pole for our non-invasive near the road and a tower for all other sensors back near the right-of-way increasing the cost.</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Lufft LCOM</td>
<td>$53,550 (including installation cost)</td>
<td>See capital/system cost</td>
<td>These costs combine equipment and installation, so they are total costs to put in a new site, excluding power.</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Vaisala ESP RPU</td>
<td>$35,000 (including installation cost)</td>
<td></td>
<td>See capital/system cost</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>Vaisala RWS200</td>
<td>$50,000 - $65,000 (equipment cost only)</td>
<td>$55,000</td>
<td>See capital/system cost</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td></td>
<td></td>
<td></td>
<td>These costs combine equipment and installation, so they are total costs to put in a new site, excluding power.</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Custom</td>
<td>$25,000–$50,000 (including installation cost)</td>
<td></td>
<td>See capital/system cost</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Our entire stations are mixes of brands. Mostly Vaisala LX processors</td>
<td>$70,000 (including installation cost)</td>
<td></td>
<td>See capital/system cost</td>
</tr>
</tbody>
</table>

*North Dakota DOT noted that they used Lufft, Vaisala and Boschung systems. The information provided was for the Lufft system only.

Table 14 presents the maintenance and life span information provided by survey respondents.
Table 14. Maintenance and life span information for entire RWIS system

<table>
<thead>
<tr>
<th>Agency</th>
<th>System brand/model</th>
<th>Avg. annual costs for preventive/routine maintenance</th>
<th>Avg. non-routine maintenance cost/year</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Campbell Scientific</td>
<td>$1,778</td>
<td>$1,846</td>
<td>9–11 years</td>
<td>We don’t track these costs, but they are pretty low. Our staff maintains and repairs our sites. We don’t have a good way of tracking all work that is done at each site. Each district replaces sensors during the life of the site, so we don’t have a good way to track their replacement either. We do have sensors fail during that time that we must replace.</td>
</tr>
<tr>
<td>North Dakota DOT</td>
<td>Lufft</td>
<td>We don’t track these costs, but they are pretty low</td>
<td>We don’t track this</td>
<td>12–15 years</td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Lufft LCOM</td>
<td>$3,000</td>
<td>Unknown</td>
<td>16–20 years</td>
<td>Routine PM payment is based on monthly performance of the system, and monthly payment is reduced on a per-site basis. Over the full contract term, performance penalty became less as new sites were added to the system, while annual per-site costs also decreased.</td>
</tr>
<tr>
<td></td>
<td>Vaisala ESP RPU</td>
<td>$3,000</td>
<td>Unknown</td>
<td>16–20 years</td>
<td></td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>Vaisala RWS200</td>
<td>~$6,000 (per site, per year)</td>
<td>N/A</td>
<td>16–20 years</td>
<td>We also have an end of life replacement program, 10-year life span for most instruments, less for cameras and lead acid batteries.</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Custom</td>
<td>$24,657</td>
<td>$57,902</td>
<td>9–11 years</td>
<td>Individual components don’t last that long, but we have some sites that are 30 years old.</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Our entire stations are mixes of brands, mostly Vaisala LX processors</td>
<td>Bundled with all the rest of our ITS equipment, probably around $110,000</td>
<td>N/A</td>
<td>12–15 years</td>
<td></td>
</tr>
</tbody>
</table>

Table 15 presents the general product and cost information for RWIS software provided by the survey respondents.
<table>
<thead>
<tr>
<th>Agency</th>
<th>Software products used</th>
<th>Software cost/software licensing cost</th>
</tr>
</thead>
</table>
| North Dakota DOT    | Parsons ATMS - Used for RWIS, DMS, and Cameras.                                          | $450,000 in 2014, including 3 years of maintenance starting from install completion.  
                        |                                                                                           | $70,000/year for maintenance and upgrade fee after 3 years.                                         |
| Alaska DOT & PF     | Vaisala’s ScanWeb. We are in the process of migrating to the MnDOT IRIS software.       | N/A                                                                                                    |
| Utah DOT            | Campbell Loggernet, and server services. Custom software to store, manage and analyze. | One-time cost many years ago. Would take some work to dig that up.                                     |
| Pennsylvania DOT    | Vaisala RoadDSS Navigator                                                               | Included with web hosting and data services contract requirement, total of $108,000/year.            |
| Wisconsin DOT       | SCAN Web, Lufft                                                                        | Currently no cost.                                                                                   |
| Iowa DOT            | Was ScanWeb. Now have switched to DTN Totalview.                                        | ScanWeb was $25,000 for the license, putting it on our own servers. Totalview is $54,000 per year.  |
CHAPTER 5. RWIS LIFE-CYCLE COST ANALYSIS GUIDELINES

This chapter presents methods and guidelines to assess the associated costs and benefits for determining life-cycle costs for RWIS systems. A review of the data collected from the literature review and surveys was conducted to determine the applicability of the data with respect to the life-cycle cost analysis. Information and guidelines available from existing life-cycle benefit/cost models and other LCCA tools were also reviewed to aid in performing the analysis. The key purposes of these guidelines include the following:

- Help quantify the costs and benefits associated with RWIS sites
- Better assess costs arising from RWIS assets over the life cycle
- Provide a framework for calculating NPW
- Assess alternatives and associated cost implications
- Support decisions on repair versus replacement based on projected expenses

Key RWIS elements to be considered for evaluation as part of the cost analysis were identified and categorized as either capital or O&M elements, with consideration for entire RWIS stations and individual components. Those elements are defined as follows:

- **Capital costs**: Costs associated with equipment installation and capital improvements, such as hardware and software
- **Operations and maintenance costs**: Items with future cost implications, such as ongoing operations, maintenance, rehabilitation, communications, and replacement costs

5.1. **Quantify the Costs and Benefits**

As described in Chapter 4, surveys were distributed to RWIS manufacturers and public agencies in September 2019 to gather information on their RWIS products, including costs, design service life, applicable warranties, recommendations regarding preventive maintenance, etc., as related to their RWIS systems. Quantification of the costs and benefits of RWISs are determined through data gathered from the surveys, literature review from previous studies, and transportation agencies’ experiences. These cost and benefit quantifications were combined to determine the inputs needed to perform the RWIS life-cycle analysis. Table 16 presents the cost variables that should be considered while modeling the RWIS LCCA.
Table 16. Cost variables to consider in LCCA

<table>
<thead>
<tr>
<th>RWIS cost elements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital costs</strong></td>
</tr>
<tr>
<td>• RPU</td>
</tr>
<tr>
<td>• Telecommunications equipment to transmit data (modem)</td>
</tr>
<tr>
<td>• Tower support structure</td>
</tr>
<tr>
<td>• Enclosure - cabinet</td>
</tr>
<tr>
<td>• IP surveillance system (CCTV) – optional</td>
</tr>
<tr>
<td>• Software (one-time cost)</td>
</tr>
<tr>
<td>• <strong>Sensors</strong></td>
</tr>
<tr>
<td>o Pavement condition sensor</td>
</tr>
<tr>
<td>o Water level sensor</td>
</tr>
<tr>
<td>o Air temperature/Relative humidity sensor</td>
</tr>
<tr>
<td>o Wind direction and speed sensor</td>
</tr>
<tr>
<td>o Precipitation sensor</td>
</tr>
<tr>
<td>o Barometric pressure sensor</td>
</tr>
<tr>
<td>o Visibility sensor</td>
</tr>
<tr>
<td>o Presence of precipitation sensor</td>
</tr>
<tr>
<td>o Traffic sensor (e.g., MVDS)</td>
</tr>
<tr>
<td>o Ultrasonic snow depth sensor</td>
</tr>
<tr>
<td>o Subsurface sensor</td>
</tr>
<tr>
<td>o Solar radiation kit</td>
</tr>
<tr>
<td>o Surface temperature sensor</td>
</tr>
<tr>
<td><strong>Installation costs</strong></td>
</tr>
<tr>
<td><strong>Operational costs</strong></td>
</tr>
<tr>
<td>• Telecommunication service</td>
</tr>
<tr>
<td>• Subscription-based software service</td>
</tr>
<tr>
<td>• Private sector weather forecast services</td>
</tr>
<tr>
<td>• Data storage fees</td>
</tr>
<tr>
<td><strong>Maintenance costs</strong></td>
</tr>
<tr>
<td><strong>Other information</strong></td>
</tr>
<tr>
<td>• Sensor life</td>
</tr>
</tbody>
</table>

Individual agencies could refer to their own bid tabs to obtain the costs of the elements listed in Table 16. In addition, many of the variables’ values may be gathered from vendors and through literature reviews.

The use of RWISs requires capital, installation, operations, and maintenance costs. However, there are benefits to RWISs that may be recognized through a reduction in unnecessary winter road maintenance operations (labor, equipment, and material), a potential reduction in weather-related crashes, and mobility improvements in travel-cost and emission reduction. Benefits within winter operations include a reduction of patrol shifts. Patrol shifts are conducted when the weather could potentially change into inclement weather that requires road treatment. Winter
maintenance vehicles are then deployed on routes, and the drivers observe weather conditions in case treatment is needed, which utilizes the time and costs of the operators and equipment. With better weather data, the managers could track the weather variables associated with treatment needs and deploy resources only when needed. Therefore, better weather data may result in fewer patrol shifts. Table 17 presents the variables to consider when reviewing the benefits of RWISs.
Table 17. Beneficial elements to consider in LCCA

<table>
<thead>
<tr>
<th>RWIS direct and indirect beneficial elements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Winter maintenance vehicle patrol shift cost</strong></td>
</tr>
<tr>
<td>- Hours of patrol</td>
</tr>
<tr>
<td>- Route miles</td>
</tr>
<tr>
<td>- Fuel efficiency</td>
</tr>
<tr>
<td>- Cost per gallon of fuel</td>
</tr>
<tr>
<td>- Operator hourly rate</td>
</tr>
<tr>
<td>- Number of events</td>
</tr>
<tr>
<td><strong>Winter maintenance vehicle exposure cost</strong></td>
</tr>
<tr>
<td>- Life span of truck</td>
</tr>
<tr>
<td>- Capital cost per truck</td>
</tr>
<tr>
<td>- Total miles at end of life</td>
</tr>
<tr>
<td><strong>Material cost</strong></td>
</tr>
<tr>
<td>- Cost per ton salt</td>
</tr>
<tr>
<td>- Cost per ton sand</td>
</tr>
<tr>
<td>- Cost per gallon of brine</td>
</tr>
<tr>
<td>- Amount of salt used</td>
</tr>
<tr>
<td>- Amount of sand used</td>
</tr>
<tr>
<td>- Amount of brine used</td>
</tr>
<tr>
<td><strong>Social cost savings</strong></td>
</tr>
<tr>
<td>- # of fatal crashes - weather related</td>
</tr>
<tr>
<td>- # of injury crashes - weather related</td>
</tr>
<tr>
<td>- # of property damage only crashes - weather related</td>
</tr>
<tr>
<td>- Cost assigned to fatal crashes</td>
</tr>
<tr>
<td>- Cost assigned to injury crashes</td>
</tr>
<tr>
<td>- Cost assigned to property damage only (PDO) crashes</td>
</tr>
<tr>
<td>- Inclement weather events per year</td>
</tr>
<tr>
<td>- Length of RWIS road coverage</td>
</tr>
<tr>
<td>- Preventable weather crashes – fatal</td>
</tr>
<tr>
<td>- Preventable weather crashes – injury</td>
</tr>
<tr>
<td>- Preventable weather crashes – PDO</td>
</tr>
<tr>
<td><strong>Mobility improvement cost savings</strong></td>
</tr>
<tr>
<td>- Volume data, including percent passenger vs. commercial vehicles</td>
</tr>
<tr>
<td>- Delay from inclement weather - before and after treatment</td>
</tr>
<tr>
<td>- User delay cost - for commercial and passenger vehicles</td>
</tr>
<tr>
<td>- Reduction in emissions</td>
</tr>
</tbody>
</table>

Note: Inclement weather events consist of an event that requires or can be treated by the transportation agency, such as snow, ice, and freezing rain. However, other inclement weather will see benefits as well by alerting the public of conditions for modified behavior while driving, which will result social cost savings. The length of RWIS coverage is dependent on the project setting’s geographic features; however, one accepted area is a 30 km (18.6 mi) buffer zone (Kwon and Fu 2016) around the RWIS site.
These variables are dependent on the analysis boundaries; therefore, they should be gathered based on the project area being analyzed. Gathering or estimating the values of the above elements are important to enable a comprehensive LCCA. The values associated with the costs of RWISs are presented in the next section.

5.2. Cost Assessment Variables

A critical step in performing an LCCA for RWIS is the collection of cost data. As noted previously, the cost variables that should be considered for an RWIS LCCA include the costs of capital investments, installation, operations, and maintenance. Table 18 presents the costs that can be used to support an RWIS LCCA.
### Table 18. Cost variables for life-cycle cost analysis

<table>
<thead>
<tr>
<th>RWIS cost elements</th>
<th>High</th>
<th>Average</th>
<th>Low</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Entire system capital cost (installed)</strong>*</td>
<td>$130,000</td>
<td>$89,358</td>
<td>$37,500</td>
<td>$40,996</td>
</tr>
<tr>
<td><strong>Individual components capital costs (installed)</strong>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- RPU</td>
<td>$9,429</td>
<td>$6,053</td>
<td>$3,750</td>
<td>$2,399</td>
</tr>
<tr>
<td>- Telecommunications equipment to transmit data (modem)</td>
<td>$1,005</td>
<td>$840</td>
<td>$674</td>
<td>$234</td>
</tr>
<tr>
<td>- Tower support structure</td>
<td>$16,467</td>
<td>$12,424</td>
<td>$8,986</td>
<td>$2,990</td>
</tr>
<tr>
<td>- Enclosure - cabinet</td>
<td>$10,992</td>
<td>$8,472</td>
<td>$5,000</td>
<td>$2,220</td>
</tr>
<tr>
<td>- IP surveillance camera (CCTV) - optional</td>
<td>$7,280</td>
<td>$4,742</td>
<td>$2,276</td>
<td>$1,505</td>
</tr>
<tr>
<td>- Software (unless it is subscription, then go to operational costs)</td>
<td></td>
<td></td>
<td>$450,000</td>
<td></td>
</tr>
<tr>
<td><strong>Sensors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Pavement condition sensor</td>
<td>$12,722</td>
<td>$11,431</td>
<td>$9,995</td>
<td>$1,369</td>
</tr>
<tr>
<td>- Water level sensor</td>
<td>$935</td>
<td>$870</td>
<td>$771</td>
<td>$87</td>
</tr>
<tr>
<td>- Air temperature/Relative humidity sensor</td>
<td>$3,130</td>
<td>$1,590</td>
<td>$418</td>
<td>$992</td>
</tr>
<tr>
<td>- Wind direction and speed sensor</td>
<td>$4,832</td>
<td>$2,274</td>
<td>$1,093</td>
<td>$1,080</td>
</tr>
<tr>
<td>- Precipitation sensor</td>
<td>$6,765</td>
<td>$3,194</td>
<td>$768</td>
<td>$2,352</td>
</tr>
<tr>
<td>- Barometric pressure sensor</td>
<td>$998</td>
<td>$571</td>
<td>$95</td>
<td>$372</td>
</tr>
<tr>
<td>- Visibility sensor</td>
<td>$10,440</td>
<td>$7,195</td>
<td>$3,850</td>
<td>$2,403</td>
</tr>
<tr>
<td>- Presence of precipitation sensor</td>
<td>$4,857</td>
<td>$3,854</td>
<td>$2,527</td>
<td>$1,199</td>
</tr>
<tr>
<td>- Traffic sensor (MVDS)</td>
<td>$9,958</td>
<td>$6,540</td>
<td>$3,675</td>
<td>$2,731</td>
</tr>
<tr>
<td>- Ultrasonic snow depth sensor</td>
<td>$1,262</td>
<td>$1,029</td>
<td>$865</td>
<td>$207</td>
</tr>
<tr>
<td>- Subsurface sensor advance</td>
<td>$7,815</td>
<td>$6,539</td>
<td>$4,583</td>
<td>$1,271</td>
</tr>
<tr>
<td>- Subsurface sensor simple</td>
<td>$896</td>
<td>$680</td>
<td>$334</td>
<td>$245</td>
</tr>
<tr>
<td>- Solar radiation kit</td>
<td></td>
<td></td>
<td>$515</td>
<td></td>
</tr>
<tr>
<td>- Surface temperature sensor advance</td>
<td>$14,797</td>
<td>$7,242</td>
<td>$4,036</td>
<td>$3,619</td>
</tr>
<tr>
<td>- Surface temperature sensor simple</td>
<td>$1,200</td>
<td>$944</td>
<td>$680</td>
<td>$217</td>
</tr>
<tr>
<td>- Data logger</td>
<td></td>
<td></td>
<td>$1,700</td>
<td></td>
</tr>
<tr>
<td>- Temperature data probe (Alaska DOT)</td>
<td></td>
<td></td>
<td>$4,623</td>
<td></td>
</tr>
<tr>
<td><strong>Operational costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Telecommunication service (monthly per RWIS station)</td>
<td>$40</td>
<td>$31</td>
<td>$20</td>
<td>$7</td>
</tr>
<tr>
<td>- Subscription-based software service (yearly)</td>
<td>$108,000</td>
<td>$95,333</td>
<td>$70,000</td>
<td>$21,939</td>
</tr>
<tr>
<td>- Private sector weather forecast services</td>
<td>$298,000</td>
<td>$198,341</td>
<td>$98,682</td>
<td>$140,939</td>
</tr>
<tr>
<td><strong>Maintenance costs (per RWIS station per year)</strong></td>
<td>$6,000</td>
<td>$2,893</td>
<td>$962</td>
<td>$1,804</td>
</tr>
</tbody>
</table>

Notes: *Capital costs for the entire system and individual components listed in the table include the costs for hardware, infrastructure, and installation. **Data storage was considered; however, no cost data were obtained through literature reviews or surveys with DOTs and vendors. Additionally, some data storage is a part of the subscription-based software. All data were gathered from surveys conducted in 2019, recent years of DOT bid tabs, and literature reviews.

The costs presented in Table 18 were gathered from multiple transportation agencies, primarily at the state level, as well as RWIS vendors. These data were collected from a survey created for each group (vendors and public agencies). Additionally, data were available through many agencies’ bid tabs, which present all the past costs for the implementation of RWIS sites.
5.3. Framework for Calculating the Life-Cycle Cost of an RWIS System

5.3.1. Software Products and Costs

An RWIS includes many components, and individual components may have a varied life expectancy. Additionally, each RWIS system may be made up of a combination of various sensors based on an individual agency’s needs. Therefore, the optimal analysis for determining the cost of an RWIS is to bring everything into terms of an annual cost.

In order to convert the cost into an annualized cost, the first step is to use the life span to find the annualized factor for each RWIS component, as shown in equation 1.

\[
Annualized \ Factor = \frac{i}{1-(1+i)^{-n}}
\]  

(1)

where, \(i\) is the discount rate, \(n\) is the number of periods, which in this scenario is the expected life span, in years, of each RWIS component.

The discount rate used in an LCCA typically ranges from 3% to 7%. The U.S. Office of Management and Budget releases a yearly report identifying the discount rate, which should be utilized in an LCCA. The most recent report, from 2019, states that the discount rate for a long-lived (10+ years) project should be 7%. The annualized factor is calculated and applied to each of the individual components and the first-time installation cost of the RWIS site, as shown in equation 2.

\[
Annualized \ Capital \ Cost_j = Capital \ Cost_j \times Annualized \ Factor_j
\]  

(2)

where, \(j\) is the component being reviewed.

The annualized capital cost is the cost associated with the purchase and installation of the RWIS component. These factors require an investment at the start of the life cycle; therefore, as the value of money increases over time, the annualized cost is adjusted to account for investing when the value of money is lowest during the RWIS site’s life cycle. Once the annualized capital cost for each component is determined, the annualized capital cost of an RWIS site can be calculated through equation 3.

\[
Annualized \ Capital \ Cost \ of \ RWIS \ Site = \sum Annualized \ Capital \ Cost_j
\]  

(3)

This analysis allows agencies to evaluate the investment for each RWIS based on the unique sensors/components selected for that site.
5.3.2. Operations and Maintenance Costs

O&M costs are incurred throughout the life cycle of an RWIS. Operational costs are costs associated with day-to-day operations of the system, such as costs of telecommunications, meteorological services, software subscriptions, and training. Some of the yearly operational costs, such as the costs of software subscriptions, meteorological services, and training, should be divided by the number of RWIS sites within the network before adding to the overall per site yearly cost.

Maintenance costs typically include the costs of labor and materials for calibration, preventive maintenance, repairs, and replacement of damaged equipment. Costs associated with spare parts and inventory management also should be considered in determining the maintenance costs. Maintenance data for RWIS components gathered from the vendor survey is included in Appendix A as a resource.

5.3.3. Annualized Cost

The annualized cost, or the equivalent annual cost, of an RWIS site is the cost per year for owning and maintaining the RWIS site over its life span. Calculating the annualized cost is useful in making budget decisions by converting the cost of an RWIS site to an equivalent annual amount. The annualized cost helps compare the cost-effectiveness of two or more RWIS sites or implementation alternatives.

Once the annualized capital cost and the average yearly operational and maintenance costs for an RWIS site are determined, the annualized cost of an RWIS site can be calculated through equation 4.

\[
\text{Annualized Cost of RWIS Site} = \text{Yearly Operational Cost per Site} + \text{Yearly Maintenance Cost per Site} + \sum \text{Capital Cost}_j \times \text{Annualized Factor}_j
\]  

(4)

5.3.4. Benefits

The benefits of RWISs are realized through winter maintenance savings, crash reduction/collision cost savings, and mobility improvements.

With reliable weather data, winter maintenance crews may improve situational awareness, which increases winter maintenance efficiency and results in reduced expenditures for labor, materials, and equipment. These benefits are based on the amount and locations of the RWIS sites. A potential benefit of implementing an RWIS is a reduction of the need for routine patrols for monitoring road conditions, resulting in reduced equipment usage and improved labor productivity. Road maintenance supervisors can be more efficient in mobilizing the available crew and equipment in terms of time and location. In addition, an RWIS can provide road conditions to assist an agency with proactively performing winter maintenance activities, which leads to reduced labor, equipment, and anti-icing chemical usage.
To estimate winter maintenance savings, an agency should first gather the unit costs for labor, equipment, and materials for winter maintenance. An agency can then apply the unit costs to the numbers of patrol shifts reduced, labor hours reduced, amount of materials reduced, etc., to estimate the winter maintenance savings.

\[
\text{Winter Maintenance Savings} = \text{Winter Maintenance Patrol Savings} + \\
\text{Labor Savings} + \text{Equipment Savings} + \text{Material Savings}
\] (5)

Crash reduction and collision cost savings are estimated as a cost reduction in the expected number of crashes due to inclement weather for the project area selected and categorized by crash severity. Reduced crash costs from RWIS implementation can be estimated using the standard cost for each type of crash multiplied by the expected reduction of those types of crashes due to RWIS implementation. Estimated standard unit costs for various types of crashes, as presented in Table 19, are published in the FHWA Crash Costs for Highway Safety Analysis (Harmon et al. 2018). The FHWA publication also includes unit costs for states.

**Table 19. National crash unit costs**

<table>
<thead>
<tr>
<th>Severity</th>
<th>Comprehensive crash unit cost (2016 dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal crash (K)</td>
<td>$11,295,400</td>
</tr>
<tr>
<td>Serious/Incapacitating injury crash (A)</td>
<td>$655,000</td>
</tr>
<tr>
<td>Minor/Non-incapacitating injury crash (B)</td>
<td>$198,500</td>
</tr>
<tr>
<td>Possible injury crash (C)</td>
<td>$125,600</td>
</tr>
<tr>
<td>Property damage only crash (O)</td>
<td>$11,900</td>
</tr>
</tbody>
</table>

Source: Harmon et al. 2018

Mobility improvement-related cost savings include a reduction in travel costs and pollution costs. RWIS implementation may result in a reduction in travel costs and vehicle emissions by improving traffic flow during inclement conditions.

In addition, a fully integrated RWIS includes information delivery mechanisms such as websites, variable message signs, automated phone systems, Highway Advisory Radio broadcasts, etc. The integration of an RWIS with traveler information systems allows for the dissemination of important weather and road conditions information to the traveling public. The benefits associated with providing better traveler information include better informed and prepared drivers, safer travel behavior, and reduced travel during poor conditions, which result in fewer crashes, fatalities, injuries, and property damage, as well as improved mobility and increased customer satisfaction.

Multiple methods and software tools can be utilized for estimating the benefits. A list of available tools and methods specific for RWM projects was summarized in Lawrence et al. (2017).
Once the annualized cost and savings are estimated, the differences provide an overall yearly savings when implementing RWIS systems.

5.4. Alternative Assessment and Associated Cost Implications

There are two alternative system technologies that collect and distribute weather data: connected vehicle (CV) technology equipped with weather sensors and mobile data collection units such as automatic vehicle location (AVL) or mobile data computer (MDC) units. These technologies would require a broad and heavy investment for users in order to provide enough data to be useful for transportation agencies and maintenance crews.

CV technologies and applications have been expanding within the market. CV applications have the ability to share basic information about the vehicle. These real-time data may be relayed to other vehicles (vehicle to vehicle [V2V]) or to infrastructure throughout the travel network (vehicle to infrastructure [V2I]). Vehicle information may indicate the weather condition, such as wiper status and rate, air temperature, tire friction, traction control enable/disable, and speed. V2V communication may assist with a reduction in crashes; however, these data won’t assist with reducing winter maintenance treatment, since maintenance crews will not have access to the data. V2I would allow agencies to obtain vehicle information in real-time and utilize it for maintenance decisions. V2I would require an investment in infrastructure and would rely on vehicles having these technologies while being equipped with the desired weather sensor/data.

Similarly, the AVL or MDC technology would be equipped on weather maintenance vehicles, and then use telecommunications to relay sensor data to winter maintenance managers for decision-making. However, these technologies rely on the winter maintenance vehicles patrolling the area; therefore, patrol shifts may increase instead of decrease.

5.5. Decision Support on Repairs or Replacements

The expected life span for each RWIS component was requested and reviewed from the vendor and DOT surveys. Based on the various responses, Table 20 presents the expected life span for each component.
Table 20. Life span reported through survey and literature review

<table>
<thead>
<tr>
<th>Components</th>
<th>Average (year)</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire RWIS station</td>
<td>15</td>
<td>3.3</td>
</tr>
<tr>
<td>IP surveillance system (CCTV) - optional</td>
<td>7</td>
<td>1.1</td>
</tr>
<tr>
<td>Pavement condition sensor</td>
<td>8</td>
<td>2.5</td>
</tr>
<tr>
<td>Water level sensor</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>Air temperature/Relative humidity sensor</td>
<td>9</td>
<td>1.6</td>
</tr>
<tr>
<td>Wind direction and speed sensor</td>
<td>9</td>
<td>1.6</td>
</tr>
<tr>
<td>Precipitation sensor</td>
<td>10</td>
<td>1.6</td>
</tr>
<tr>
<td>Barometric pressure sensor</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>Visibility sensor</td>
<td>8</td>
<td>2.3</td>
</tr>
<tr>
<td>Ultrasonic snow depth sensor</td>
<td>9</td>
<td>1.5</td>
</tr>
<tr>
<td>Subsurface sensor</td>
<td>8</td>
<td>3.1</td>
</tr>
<tr>
<td>Solar radiation kit</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>Surface temperature sensor</td>
<td>8</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Note: If no life expectancy was provided, a default of eight years is used, which is the average of the sensor life spans presented above (sensors only).

If an agency would like to determine when to replace or repair an RWIS component, the following data would be required:

- Replacement capital cost for the specific component
- Average maintenance cost including the cost to check, pull, and re-install for the specific component
- Probability of failure
- Warranty span

During the survey, the maintenance cost per component was requested. However, insufficient data was provided by the vendors and the agencies. Agencies that responded to the survey provided the overall maintenance costs to the extent possible.

Another factor to consider in performing an LCCA is the probability of system or component failure. The probability of failure may be collected based on the number of failures the component has during its life span. It should be noted that the probability of failure may be impacted by the age of the equipment. Changes in the probability of failure through the equipment life cycle should be carefully considered in a more complex, detailed LCCA. Using an average probability of failure should be sufficient for a planning level analysis.

5.5.1. Life-Cycle Cost Model

Once these points are collected, the total expected life-cycle cost and the annualized life-cycle cost can be estimated. The estimated life span of an RWIS site is between approximately 20 and 25 years. The RPU and CPU will likely need to be replaced or upgraded every 5 years, and other
sensors and RWIS components will need to be replaced every 8 to 10 years as noted in the previous Table 20. As such, the life-cycle cost consists of three components: the initial equipment and installation cost, the total O&M costs, and the component upgrade/replacement costs. Equation 6 presents the equation that can be used to calculate the expected life-cycle cost of an RWIS site.

\[
Expected \ \text{Life \ Cycle \ Cost} = \text{Capital Cost} + \text{Total O&M Cost} + \text{Total Replacement & Upgrade Cost} \tag{6}
\]

The total replacement and upgrade cost can be estimated using equation 7.

\[
Expected \ \text{Total Replacement & Upgrade Cost} = \sum [(Cost \ of \ Replacement \ & \ Upgrade)_{j,k} \times (Probability \ of \ Failure)_{j,k}] \tag{7}
\]

where, \( j \) is the index for an RWIS component, and \( k \) is the index for a failure limit state.

5.5.2. Net Present Worth

The NPW of an RWIS is an important indicator to support implementation decisions. The steps to determine the NPW of implementing an RWIS include: (1) determining the costs and benefits associated with implementing an RWIS site over its life cycle and (2) using these results to calculate the incremental NPW of an RWIS site. The incremental NPW can then be compared to alternatives such as not installing an RWIS or installing an RWIS with varying levels of components.

The NPW of an RWIS can be calculated using equation 8.

\[
Net \ \text{Present \ Worth (NPW)} = -(Capital \ Cost) + ((Annual \ Savings) - [(Annual \ O&M \ Cost) + (Annual \ Replacement & Upgrade \ Cost)]) \times (Aggregate \ Series \ Discount \ Factor) \tag{8}
\]

The annual savings are derived from reductions in winter maintenance costs, crash reduction and collision cost savings, and mobility improvement-related cost savings, as discussed in Chapter 4. The discount factor in equation 8 is the aggregate series discount factor that is assumed to be uniform over the life cycle and is calculated using equation 9.

\[
Present \ \text{Value of Aggregate Series Discount Factor} = \frac{(1+i)^n-1}{i \times (1+i)^n} \tag{9}
\]

where, \( i \) is the discount rate, and \( n \) is the expected life span in years.

Using equation 8, the NPW of RWIS alternatives can be calculated and compared. The alternative with the highest NPW is the most cost-effective alternative.
5.6. Summary

An LCCA is a data-driven tool that provides a detailed account of the total costs of a project over its expected life. An LCCA has been proven to create short-term and long-term savings for transportation agencies by helping decision-makers identify the most beneficial and cost-effective projects and alternatives. Recognizing its benefit, agencies have implemented LCCA programs and have successfully saved significant sums of money. However, there are still many challenges to creating or expanding the use of LCCA in transportation, in particular for technology-related projects and systems.

This chapter of the report provides methods and general guidelines to assist public agencies with determining RWIS site life-cycle costs. The next chapter of the report presents an example, illustrating the use of the methods and guidelines to perform an LCCA and estimate a benefit-cost ratio for an RWIS deployment in a hypothetical case. Public agencies can follow the information in this and the next chapter to gather the necessary data and perform the analysis to help quantify the costs and benefits associated with RWISs.
CHAPTER 6. SIMULATED CASE STUDY

This chapter presents a simulated case study demonstrating the use of the methodology for an LCCA as described in Chapter 5 of this report. A hypothetical example is used to demonstrate the methodology and the analysis. The example illustrates a state DOT that would like to evaluate the costs as well as potential benefits associated with deploying a new RWIS site.

The intent of the hypothetical state agency’s evaluation is to perform a comprehensive assessment that takes into consideration the capital costs, annual cost to maintain the site, and the estimated benefits from the new RWIS site over its useful life span. The agency would like to use the evaluation result to assist with making more informed decisions on its RWIS investment. It was assumed that the new RWIS site under consideration is in an urban area with high volume of travelers on the roadways.

6.1. Annualized Costs

It was assumed that the agency desires to deploy an RWIS station that includes a suite of sensors, equipment, and capabilities, as listed in Table 21.
Table 21. Hypothetical agency’s RWIS cost and life span records

<table>
<thead>
<tr>
<th>RWIS elements</th>
<th>Average costs</th>
<th>Life span (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Individual components capital costs (installed)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPU</td>
<td>$6,053</td>
<td>10</td>
</tr>
<tr>
<td>Telecommunications equipment to transmit data (modem)</td>
<td>$840</td>
<td>10</td>
</tr>
<tr>
<td>Tower support structure</td>
<td>$12,424</td>
<td>20</td>
</tr>
<tr>
<td>Enclosure - cabinet</td>
<td>$8,472</td>
<td>20</td>
</tr>
<tr>
<td>CCTV camera</td>
<td>$4,742</td>
<td>7</td>
</tr>
<tr>
<td><strong>Sensors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pavement condition sensor</td>
<td>$11,431</td>
<td>8</td>
</tr>
<tr>
<td>Water level sensor</td>
<td>$870</td>
<td>4</td>
</tr>
<tr>
<td>Air temperature/Relative humidity sensor</td>
<td>$1,590</td>
<td>9</td>
</tr>
<tr>
<td>Wind direction and speed sensor</td>
<td>$2,274</td>
<td>9</td>
</tr>
<tr>
<td>Precipitation sensor</td>
<td>$3,194</td>
<td>10</td>
</tr>
<tr>
<td>Barometric pressure sensor</td>
<td>$571</td>
<td>10</td>
</tr>
<tr>
<td>Visibility sensor</td>
<td>$7,195</td>
<td>8</td>
</tr>
<tr>
<td>Presence of precipitation sensor</td>
<td>$3,854</td>
<td>8</td>
</tr>
<tr>
<td>Traffic sensor</td>
<td>$6,540</td>
<td>9</td>
</tr>
<tr>
<td>Ultrasonic snow depth sensor</td>
<td>$1,029</td>
<td>9</td>
</tr>
<tr>
<td>Subsurface sensor advance</td>
<td>$6,539</td>
<td>8</td>
</tr>
<tr>
<td>Surface temperature sensor advance</td>
<td>$7,242</td>
<td>8</td>
</tr>
<tr>
<td><strong>Operational costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telecommunication service (monthly per RWIS station)</td>
<td>$31</td>
<td></td>
</tr>
<tr>
<td>Subscription-based software service (yearly)</td>
<td>$95,333</td>
<td></td>
</tr>
<tr>
<td><strong>Maintenance costs (per RWIS station per year)</strong></td>
<td>$2,893</td>
<td></td>
</tr>
</tbody>
</table>

Based on data recorded from the hypothetical agency’s previous RWIS deployment and its RWIS program to date, the agency identified the costs and expected life spans of the RWIS components, as presented in Table 21.

Applying equation 10, also described in Chapter 5, annualized factors for various RWIS components can be obtained.

\[
Annualized\ Factor = \frac{i}{1-(1+i)^{-n}} \tag{10}
\]

where, \(i\) is the discount rate, \(n\) is the number of periods, which in this scenario is the expected life span, in years, of each RWIS component. The discount rate, \(i\), used in an LCCA typically ranges from 3% to 7%.
In this scenario, the agency used a 5% discount rate on all equipment with an expected life span below 10 years and 7% for equipment with an expected life span of 10 years or more to take into account longer-term uncertainty. The calculated annualized factors are shown in Table 22.

Table 22. Annualized factors based on discount rates and expected life span of equipment

<table>
<thead>
<tr>
<th>Expected life span (years)</th>
<th>Discount rate</th>
<th>Annualized factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5%</td>
<td>0.2820</td>
</tr>
<tr>
<td>7</td>
<td>5%</td>
<td>0.1728</td>
</tr>
<tr>
<td>8</td>
<td>5%</td>
<td>0.1547</td>
</tr>
<tr>
<td>9</td>
<td>5%</td>
<td>0.1407</td>
</tr>
<tr>
<td>10</td>
<td>7%</td>
<td>0.1424</td>
</tr>
<tr>
<td>20</td>
<td>7%</td>
<td>0.09439</td>
</tr>
</tbody>
</table>

The annualized factor was applied to each of the individual components to calculate the capital cost of the RWIS site using equations 11 and 12. The annualized cost of the RWIS site, which includes the annualized capital, operational, and maintenance costs, is then calculated through equation 13.

\[
Annualized \ Capital \ Cost_j = Capital \ Cost_j \times Annualized \ Factor_j \tag{11}
\]

\[
Annualized \ Capital \ Cost \ of \ RWIS \ Site = \sum Annualized \ Capital \ Cost_j \tag{12}
\]

\[
Annualized \ Cost \ of \ RWIS \ Site = Yearly \ Operational \ Cost \ per \ Site + Yearly \ Maintenance \ Cost \ per \ Site + \sum Capital \ Cost_j \times Annualized \ Factor_j \tag{13}
\]

Table 23 presents the breakdown and total annualized cost for the new RWIS site.
Table 23. Annualized cost for the case study RWIS site

<table>
<thead>
<tr>
<th>RWIS cost elements</th>
<th>Average</th>
<th>Life span</th>
<th>Annualized capital cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual components capital costs (installed)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• RPU</td>
<td>$6,053</td>
<td>10</td>
<td>$861.81</td>
</tr>
<tr>
<td>• Telecommunications equipment to transmit data (modem)</td>
<td>$840</td>
<td>10</td>
<td>$119.60</td>
</tr>
<tr>
<td>• Tower support structure</td>
<td>$12,424</td>
<td>20</td>
<td>$1,172.74</td>
</tr>
<tr>
<td>• Enclosure - cabinet</td>
<td>$8,472</td>
<td>20</td>
<td>$799.70</td>
</tr>
<tr>
<td>• IP surveillance camera (CCTV)</td>
<td>$4,742</td>
<td>7</td>
<td>$819.51</td>
</tr>
<tr>
<td>• Sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Pavement condition sensor</td>
<td>$11,431</td>
<td>8</td>
<td>$1,768.63</td>
</tr>
<tr>
<td>o Water level sensor</td>
<td>$870</td>
<td>4</td>
<td>$245.35</td>
</tr>
<tr>
<td>o Air temperature/Relative humidity sensor</td>
<td>$1,590</td>
<td>9</td>
<td>$223.70</td>
</tr>
<tr>
<td>o Wind direction and speed sensor</td>
<td>$2,274</td>
<td>9</td>
<td>$319.93</td>
</tr>
<tr>
<td>o Precipitation sensor</td>
<td>$3,194</td>
<td>10</td>
<td>$454.75</td>
</tr>
<tr>
<td>o Barometric pressure sensor</td>
<td>$571</td>
<td>10</td>
<td>$81.30</td>
</tr>
<tr>
<td>o Visibility sensor</td>
<td>$7,195</td>
<td>8</td>
<td>$1,113.22</td>
</tr>
<tr>
<td>o Presence of precipitation sensor</td>
<td>$3,854</td>
<td>8</td>
<td>$596.30</td>
</tr>
<tr>
<td>o Traffic sensor</td>
<td>$6,540</td>
<td>9</td>
<td>$920.11</td>
</tr>
<tr>
<td>o Ultrasonic snow depth sensor</td>
<td>$1,029</td>
<td>9</td>
<td>$144.77</td>
</tr>
<tr>
<td>o Subsurface sensor advance</td>
<td>$6,539</td>
<td>8</td>
<td>$1,011.73</td>
</tr>
<tr>
<td>o Surface temperature sensor advance</td>
<td>$7,242</td>
<td>8</td>
<td>$1,120.50</td>
</tr>
<tr>
<td>Operational costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Telecommunication service (monthly per RWIS station)</td>
<td>$31</td>
<td></td>
<td>$372</td>
</tr>
<tr>
<td>• Subscription-based software service (yearly)</td>
<td>$95,333</td>
<td></td>
<td>$6,000</td>
</tr>
<tr>
<td>Maintenance costs (per RWIS station per year)</td>
<td>$2,893</td>
<td></td>
<td>$2,893</td>
</tr>
<tr>
<td>Total annualized cost</td>
<td></td>
<td></td>
<td>$21,038.63</td>
</tr>
</tbody>
</table>

6.2. Estimation of Benefits and Savings

Once the total costs for the new RWIS system were calculated, the next step is to estimate the indirect and direct benefits for the new site. As described in Chapter 5, benefits associated with an RWIS can be recognized through a reduction in unnecessary winter road maintenance operations (labor, equipment, and material), a potential reduction in weather-related crashes, mobility improvements, and emission reduction. The direct costs and savings associated with winter road maintenance are ones that the agency can observe within their budget. These are the costs and savings associated with winter maintenance vehicle patrol shifts, vehicle exposure, and material usage. Indirect benefits are additional savings not fully or directly impacting the agency’s budget. Indirect benefits include the social savings (via crash reduction), mobility user delay cost, and mobility reduction in emissions. The elements needed to estimate these benefits are presented in Table 24.
### Table 24. Variables for benefit estimation

<table>
<thead>
<tr>
<th>RWIS direct and indirect beneficial elements</th>
<th>Agency’s variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Winter maintenance vehicle patrol shift cost</strong></td>
<td></td>
</tr>
<tr>
<td>Hours of patrol</td>
<td>3 hours per event, plus 6 eight-hour patrol-only shifts</td>
</tr>
<tr>
<td>Route miles</td>
<td>40 mi</td>
</tr>
<tr>
<td>Fuel efficiency</td>
<td>3.5 mpg</td>
</tr>
<tr>
<td>Cost per gallon of fuel</td>
<td>$3.00</td>
</tr>
<tr>
<td>Operator hourly rate</td>
<td>$30</td>
</tr>
<tr>
<td>Inclement weather events per year</td>
<td>40 per season</td>
</tr>
<tr>
<td><strong>Winter maintenance vehicle exposure cost</strong></td>
<td></td>
</tr>
<tr>
<td>Life span of truck</td>
<td>12 year</td>
</tr>
<tr>
<td>Capital cost per truck</td>
<td>$200,000</td>
</tr>
<tr>
<td>Total miles at end of life</td>
<td>250,000</td>
</tr>
<tr>
<td><strong>Material cost</strong></td>
<td></td>
</tr>
<tr>
<td>Cost per ton salt</td>
<td>$55</td>
</tr>
<tr>
<td>Cost per cubic yard of sand</td>
<td>$20</td>
</tr>
<tr>
<td>Cost per gallon of brine</td>
<td>$0.15</td>
</tr>
<tr>
<td>Amount of salt used per event</td>
<td>16 ton</td>
</tr>
<tr>
<td>Amount of sand used per event</td>
<td>100 yd³</td>
</tr>
<tr>
<td>Amount of brine used per event</td>
<td>150 gal</td>
</tr>
<tr>
<td>Average reduction from RWIS</td>
<td>15%</td>
</tr>
<tr>
<td><strong>Social cost savings</strong></td>
<td></td>
</tr>
<tr>
<td># of fatal crashes – weather-related per year</td>
<td>1</td>
</tr>
<tr>
<td># of injury crashes (a) – weather-related per year</td>
<td>5</td>
</tr>
<tr>
<td># of injury crashes (b) – weather-related per year</td>
<td>10</td>
</tr>
<tr>
<td># of injury crashes (c) – weather-related per year</td>
<td>23</td>
</tr>
<tr>
<td># of property damage only (PDO) crashes – weather-related</td>
<td>60</td>
</tr>
<tr>
<td>Cost assigned to fatal crashes</td>
<td>$11,295,400</td>
</tr>
<tr>
<td>Cost assigned to injury crashes (a)</td>
<td>$655,000</td>
</tr>
<tr>
<td>Cost assigned to injury crashes (b)</td>
<td>$198,500</td>
</tr>
<tr>
<td>Cost assigned to injury crashes (c)</td>
<td>$125,600</td>
</tr>
<tr>
<td>Cost assigned to PDO crashes</td>
<td>$11,900</td>
</tr>
<tr>
<td>Inclement weather events per year</td>
<td>40 per season</td>
</tr>
<tr>
<td>Length of RWIS road coverage</td>
<td>40 mi</td>
</tr>
<tr>
<td>Preventable weather crashes – fatal</td>
<td>6.8%</td>
</tr>
<tr>
<td>Preventable weather crashes – injury</td>
<td>7.1%</td>
</tr>
<tr>
<td>Preventable weather crashes – PDO</td>
<td>6.7%</td>
</tr>
<tr>
<td><strong>Mobility improvement cost savings</strong></td>
<td></td>
</tr>
<tr>
<td>Volume data (AADT)</td>
<td>100,000</td>
</tr>
<tr>
<td>Percent passenger vehicles</td>
<td>95%</td>
</tr>
<tr>
<td>Percent commercial vehicle</td>
<td>5%</td>
</tr>
<tr>
<td>Average speed without RWIS</td>
<td>45</td>
</tr>
<tr>
<td>Average speed with RWIS</td>
<td>50</td>
</tr>
<tr>
<td>Hourly user delay cost passenger</td>
<td>$18.40</td>
</tr>
<tr>
<td>Hourly user delay cost commercial</td>
<td>$32.30</td>
</tr>
<tr>
<td>Fuel cost savings per hour per gal of fuel - passenger</td>
<td>$1.28</td>
</tr>
<tr>
<td>Fuel cost savings per hour per gal of fuel - commercial</td>
<td>$6.06</td>
</tr>
<tr>
<td>Carbon dioxide per gal of fuel (metric ton) - passenger</td>
<td>0.00889</td>
</tr>
<tr>
<td>Carbon dioxide per gal of diesel (metric ton) - commercial</td>
<td>0.01018</td>
</tr>
</tbody>
</table>

In this simulated case study, it was assumed that the hypothetical agency is able to obtain data to support the estimates based on historical data, with additional sources to supplement data gaps as explained in the Table 24 note.

6.2.1. Winter Maintenance Savings – Patrol

The overall patrol savings can be broken down into three main areas as presented in equation 14.

\[
\text{Patrol Savings} = \text{Labor Savings} + \text{Fuel Savings} + \text{Truck Exposure Savings} \tag{14}
\]

The labor and fuel savings can be calculated based on the number of patrol hours per season. To determine the truck exposure savings, the winter maintenance truck capital cost and the miles at end of life of the truck provide the cost per mile of truck exposure.

\[
\text{Exposure Cost per Mile for Winter Maintenance Truck} = \frac{\text{Capital Cost of Vehicle}}{\text{Average Miles at End of Life}} \tag{15}
\]

\[
\text{Exposure Cost per Mile for Winter Maintenance Truck} = \frac{\$200,000}{250,000} = \$0.80
\]

With the exposure cost per mile determined, the patrol savings may be calculated with equation 16.

\[
\text{Patrol Savings} = (\text{Hours of Patrol} \times \text{Labor rate}) + (\text{Hours of Patrol} \times \text{Average Speed of Winter Maintenance Vehicle} \div \text{Fuel Economy} \times \text{Cost per Gallon of Fuel}) + (\text{Exposure Rate per Mile} \times \text{Miles Saved}) \tag{16}
\]

\[
\text{Patrol Savings} = (168 \times \$30) + (168 \times 40 \text{ mph} \div 3.5 \text{ mpg} \times \$3.00) + (0.80 \times 80,640) = \$75,312 \text{ per year}
\]

Using these equations, the patrol savings per year is estimated to be $75,312.

6.2.2. Winter Maintenance Savings – Material Savings

Winter maintenance material savings can be calculated using equation 17.

\[
\text{Material Savings} = \text{Percent Reduction} \times \text{Number of Events per Year} \times \frac{\text{Material used per Event}}{\text{Cost of Material}} \tag{17}
\]

Based on RWIS data readily available from previous implementation, the hypothetical agency estimated that there is a 15% reduction in material cost. In this scenario, the agency uses rock
salt, sand, and liquid brine; therefore, equation 13 is applied for each material type used to calculate the savings.

\[
\text{Material Savings} = 0.15 \times 40 \\
\times [(16 \text{ ton} \times $55 \text{ per ton}) + (100 \text{yd}^3 \times $20) + (150 \text{ gal} \times $0.15)] \\
= $17,415 \text{ per year}
\]

Based on the estimated material reduction and current usage amounts, the material savings would be $17,415 per year for the areas within the new RWIS zone.

6.2.3. Social Cost Savings

Multiple methods can be utilized for estimating social cost savings and benefits, as noted in Chapter 5. For illustration purposes, it was assumed that the agency estimates the reduction of crashes by severity type based on findings from previous research through estimated exposure to ice and wetness, combined with the crash rates per million vehicle-miles. Based on their research, the estimated reductions of fatal, injury (all severity types), and PDO crashes due to RWIS are 6.8%, 7.1%, and 6.7%, respectively. Using the cost per crash type and the average number of crashes for the RWIS area, the estimated social savings can be estimated using equation 18.

\[
\text{Social Savings} = \sum \text{Crash reduction percentage} \times \text{Cost of crash by severity} \times \text{Average number of crashes by severity}
\]

The social savings is the summarization of the crash reduction by cost for each severity type.

\[
\text{Social Savings} = (6.8\% \times 1 \text{ crash} \times $11,295,400)_{\text{Fatal}} \\
+ (7.1\% \times 5 \text{ crash} \times $655,000)_{\text{InjuryA}} \\
+ (7.1\% \times 10 \text{ crash} \times $198,500)_{\text{InjuryB}} \\
+ (7.1\% \times 23 \text{ crash} \times $125,600)_{\text{InjuryC}} \\
+ (6.7\% \times 120 \text{ crash} \times $11,900)_{\text{PDO}} = $1,442,328 \text{ per year}
\]

This indirect social savings is estimated to be $1,442,328 per year based on crash reductions within the new RWIS zone.

6.2.4. Mobility Improvement Cost Savings

In this scenario, the agency has seen an increase in average speed of 5 mph during inclement weather when RWIS data is used to support winter maintenance strategies. The average travel speed on the major roads in the hypothetical proposed RWIS area is usually 45 mph during inclement weather. It is anticipated that, with RWIS deployment, the average speed will increase
to 50 mph. Using the number of vehicles affected during inclement weather events and average hourly cost of delay, the user delay cost (UDC) may be found.

\[
\text{Hours saved per vehicle each hour of inclement weather} = \frac{\text{Miles of RWIS Zone}}{\text{Speed with RWIS}} - \frac{\text{Miles of RWIS Zone}}{\text{Speed without RWIS}}
\]  

(19)

\[
\text{Hours saved per vehicle each hour of inclement weather} = \frac{45 \text{ mph}}{40 \text{ miles}} - \frac{40 \text{ miles}}{50 \text{ mph}}
\]

\[= 0.08889 \text{ hours}\]

\[
\text{Vehicles count during inclement weather} = \text{Hourly traffic volume} \times \text{Number of events} \times \text{Average hours per event}
\]

(20)

\[
\text{Vehicles count during inclement weather} = 4167 \text{ vehicles} \times 40 \text{ events per year} \times 12 \text{ hours per event} = 2,000,000 \text{ vehicles}
\]

\[
\text{Mobility Savings} = \text{Hour saved per vehicle each hour of inclement weather} \times \left(\text{vehicle count} \times \text{passenger percentage} \times \text{cost for passenger vehicle} + \text{vehicle count} \times \text{commercial percentage} \times \text{cost for commercial vehicle}\right)
\]

(21)

\[
\text{Mobility Savings} = 0.08889 \text{ hours} \\
\times [2,000,000 \times 95\% \times \$18.40 + (2,000,000 \times 5\% \times \$32.30)]
\]

\[= \$3,394,666 \text{ per year}\]

The total user delay cost estimated savings is $3,394,666 per year.

Emissions savings can be calculated using the total hours of delay saved through the following equations:

\[
\text{Gallons of fuel}_{\text{Passenger}} = ( \text{Total hours delay saved} \times \text{Fuel Cost Saving per hour per gal of fuel saved} \div \text{Cost of fuel})
\]

(22)

\[
\text{Gallons of fuel}_{\text{Commercial}} = ( \text{Total hours delay saved} \times \text{Fuel Cost Saving per hour per gal of fuel saved} \div \text{Cost of fuel})
\]

(23)

\[
\text{Gallons of fuel}_{\text{Passenger}} = (168,888.8 \text{ hours} \times \$1.28 \div \$3.00) = 72,059 \text{ gal}
\]

\[
\text{Gallons of fuel}_{\text{Commercial}} = (8,888.8 \text{ hours} \times \$6.06 \div \$3.00) = 17,956 \text{ gal}
\]
\[ \text{Emissions Savings}_{\text{Passenger}} = (\text{Gallons saved Passenger} \times \text{Carbon Dioxide per Gallon of fuel in metric tons} \times \text{Cost per ton}) \]  
\[ \text{Emissions Savings}_{\text{Commercial}} = (\text{Gallons saved Commercial} \times \text{Carbon Dioxide per Gallon of fuel in metric tons} \times \text{Cost per ton}) \]

\[ \text{Emissions Savings}_{\text{Passenger}} = (72,059 \text{ gal} \times 0.00889 \text{ CO}_2 \text{ per gal (metric ton)} \times \$89) \]  
\[ = \$57,014 \text{ Per ton per year} \]

\[ \text{Emissions Savings}_{\text{Commercial}} = (17,956 \text{ gal} \times 0.01018 \text{ CO}_2 \text{ per gal (metric ton)} \times \$89) \]  
\[ = \$16,268 \text{ Per ton per year} \]

The total emissions savings is determined to be $73,282 per year.

6.3. Summary for Benefit Savings and B/C Ratios for the Proposed RWIS Site

The total estimated benefits for the new RWIS site are presented in Table 25.

<table>
<thead>
<tr>
<th>Table 25. Case study benefit summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits</td>
</tr>
<tr>
<td>Direct benefits</td>
</tr>
<tr>
<td>Patrol savings</td>
</tr>
<tr>
<td>Material savings</td>
</tr>
<tr>
<td>Indirect benefits</td>
</tr>
<tr>
<td>Social savings</td>
</tr>
<tr>
<td>Mobility - UDC savings</td>
</tr>
<tr>
<td>Mobility - emissions savings</td>
</tr>
<tr>
<td>Total benefits</td>
</tr>
</tbody>
</table>

Based on these yearly benefits and the annualized cost, the following B/C ratios in Table 26 are presented for the direct benefits and total (direct plus indirect) benefits. The total annualized cost was determined to be $21,038.63, as shown in Table 23 in section 6.1.

<table>
<thead>
<tr>
<th>Table 26. Case study B/C ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Direct benefits/annualized cost</td>
</tr>
<tr>
<td>Total benefits/annualized cost</td>
</tr>
</tbody>
</table>
CHAPTER 7. KEY FINDINGS AND CONCLUSIONS

This chapter presents a summary of the project’s key findings and conclusions. The findings and conclusions will serve as a reference guide to Aurora Board members to help them make more informed investment decisions regarding various elements of their RWIS systems, including when to replace RWIS components, funding needs based on RWIS system age, and how to address ongoing RWIS enhancements, repairs, and operations with rapid changes in technology.

The methodologies presented in this report provide a framework for analyzing life-cycle costs and NPW, which helps agencies make more informed decisions in repairs and replacement of RWIS sites. It also helps assess and compare alternatives and associated cost implications.

The steps for performing a life-cycle cost analysis for an RWIS site are summarized below. These steps present the principles of LCCA for RWIS sites and serve as a guide to perform the analysis, and they are as follows:

- **Determine RWIS deployment strategy:** Determine the necessary components and other details of an RWIS site, including types of sensors, infrastructure (e.g., tower, pole, and foundation), communications, and power source. The location of the RWIS also should be considered as it may have an impact on installation costs.
- **Collect data:** Collect costs and life span information at an individual component level (preferred) or the entire RWIS site level. Data presented herein or collected from other agencies can also be used to fill data gaps. Capital, installation, maintenance, and operational costs should be collected.
- **Estimate RWIS benefits and savings:** The benefits and savings of RWIS are realized through winter maintenance savings, crash reduction/collision cost savings, and mobility improvements. Methods to estimate the benefits and savings in these areas are described herein. Other models to estimate the benefits and savings, particularly in crash reduction and mobility improvements, can also be used.
- **Estimate expected life-cycle cost and NPW:** Net present worth is an important indicator to support RWIS implementation decisions. NPW is determined using the costs and benefits associated with RWIS over its life cycle.

A Life-cycle cost analysis is one of the well-known economic evaluation tools for transportation infrastructure management, planning, and decision-making support in the development of sound investment strategies. An LCCA provides decision-makers with the ability to determine the least-cost solution for a transportation investment requirement and is therefore a natural fit within the asset management framework.

Technology-oriented RWISs have different characteristics than conventional transportation assets such as pavement or bridges. Applying conventional LCCA and life-cycle planning practices to RWISs may not always be appropriate. The main differences between RWIS (and its associated technology infrastructure) and traditional transportation systems regarding LCCA and life-cycle planning may include the following:
• **Degradation behavior.** The conditions of traditional infrastructure assets typically degrade gradually as a result of wear and environmental conditions. The condition of many RWIS components is binary; they are either operational or not operational.

• **Maintenance strategies.** A condition-based strategy is typically used to maintain traditional transportation assets. Some ITS assets, including RWIS, may be more suited to a cyclic maintenance strategy than a condition-based strategy. Maintenance strategies may also be influenced by historical performance or the service life estimated by the manufacturer.

• **Functionality changes.** RWIS can have components and/or software that can be upgraded to change or improve their functionality. This may impact the life-cycle cost of RWIS and its maintenance and replacement strategies.

• **Risks in technical obsolescence.** Technology assets can become obsolete without physically degrading. Rapid innovations in ITS technology may reduce the life cycle of RWIS components as new products may be made available to market and offer improved functionalities or cost-efficiency.

• **Uncertainty.** When new RWIS technologies are first used, they have insufficient records or historical data on their unit costs and how they perform under different conditions over time.

• **Inflation behavior.** Assuming technology- or component-specific inflation rates to be the same as general transportation inflation rates may not be appropriate.

• **Life span.** The life cycle of technology systems is usually shorter than that of traditional transportation assets. They may be subject to more frequent needs for maintenance, repair, and replacement.

• **Inventory management.** An important consideration for the ongoing operations and maintenance of RWIS is the need for spare parts. Spare parts inventory management of essential components of RWIS equipment should be considered in the life-cycle planning and life-cycle cost analysis.

• **Downtime due to unavailability of spare parts.** Unavailability of spare parts for RWIS components resulting in lengthier system downtime may lead to increased safety impacts, increased delay, and increased fuel consumption, which may lead to increased user cost and social cost.

Sound life-cycle planning and cost analysis is critical to support identification of appropriate levels of funding to operate and maintain RWIS, and therefore optimize investment. Proper maintenance and timely upgrades can result in lower overall RWIS investment because existing systems can be kept in service longer. In addition, dedicated operations funding allows agencies to plan for the life of the assets rather than just for their deployment. Therefore, it is vital to establish a practical life-cycle planning framework and LCCA methodology for RWIS that considers stochastic treatments of the above factors.
REFERENCES


Chien, S., J. Meegoda, J. Luo, P. Corrigan, and L. Zhao. 2014. Road Weather Information System Statewide Implementation Plan. Region 2 University Transportation Research Center, New Jersey Institute of Technology, Newark, NJ.


Schneider, W., M. Crow, and W. A. Holik. 2015. *Investigate Plow Blade Optimization*. Ohio Department of Transportation, Columbus, OH.


## APPENDIX A. SUMMARY OF MANUFACTURER SURVEY RESPONSES

### Table A.1. Air temperature/Relative humidity sensors

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Sierra Electronics, Inc.</td>
<td>5723 Air temperature &amp; relative humidity</td>
<td>$1,300</td>
<td>Clean one time per year and calibrate every 2–3 years</td>
<td></td>
<td>1</td>
<td></td>
<td>9 to 11 years</td>
<td>When calibrated properly</td>
</tr>
<tr>
<td>Campbell Scientific</td>
<td>HygroVUE10</td>
<td>$418 (10 ft cable)</td>
<td>We recommend replacing the sensor element annually, but clients may wish to adhere to a less frequent schedule. Less than 1% drift/year</td>
<td>Purchase replacement unit 35219</td>
<td>1</td>
<td>$0</td>
<td>9 to 11 years</td>
<td>Replacement sensing element $130. We integrate Air temp and RH sensors from a number of manufacturers based on what is best for the client’s specific application.</td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>WS300</td>
<td></td>
<td>Clean the sensor and check cable connections yearly</td>
<td>Minimal. Whatever it takes to wipe down a sensor</td>
<td>2</td>
<td>$0</td>
<td>6 to 8 years</td>
<td>Also capable of measuring barometric pressure</td>
</tr>
</tbody>
</table>
Table A.2. Surface temperature sensors

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Sierra</td>
<td>5439 Surface Sentinel</td>
<td>$1,200</td>
<td>Clean once per year</td>
<td>2</td>
<td>9 to 11 years</td>
<td>$0</td>
<td></td>
<td>Also capable of measuring air temp and RH in addition to surface temp; Non-intrusive</td>
</tr>
<tr>
<td>Electronics, Inc.</td>
<td>5721 Road Sensor</td>
<td>$1,000</td>
<td>Inspect for damage once per year</td>
<td>1</td>
<td>9 to 11 years</td>
<td>$0</td>
<td></td>
<td>Also capable of measuring road/pavement conditions (dry/wet indication); Intrusive</td>
</tr>
<tr>
<td>Campbell Scientific</td>
<td>Apogee SIF1H1 SS</td>
<td>$680</td>
<td>Recommend re-calibration every 2 years</td>
<td>4</td>
<td>$0</td>
<td>9 to 11 years</td>
<td></td>
<td>We are currently completing development of another surface temperature sensor that will be released soon</td>
</tr>
<tr>
<td>OTT HydroMet</td>
<td>NIRS</td>
<td></td>
<td>Re-calibrate yearly if you want, can be remote. Replace $200 bulb every 2 years</td>
<td>Should be done on a yearly maintenance trip so bundled in with everything else</td>
<td>2</td>
<td>$0</td>
<td>&gt; 11 years</td>
<td>Also capable of measuring road/pavement conditions. If maintained and bulb changed every 2 years you should be able to keep these running for a long time. They are non-invasive and can be moved. They also do the surface conditions, water film height, freeze temp etc.</td>
</tr>
<tr>
<td>(Lufft)</td>
<td>IRS31Pro</td>
<td></td>
<td>Clean the sensor head and check wiring, same as all the others</td>
<td>Just a trip to the site</td>
<td>2</td>
<td>$0</td>
<td>3 to 5 years</td>
<td>IRS31Pro is an embedded passive sensor. Capable of measuring road/pavement conditions, ice percentages, water film heights, up to 2 sub-probe measurements and it has removable electronics for when a road is re-paved.</td>
</tr>
<tr>
<td></td>
<td>WST2</td>
<td>&lt; $1,000</td>
<td>Minimal, wipe down the sensor head and check cable connections</td>
<td>Just a yearly PM trip out</td>
<td>2 years (limited warranty based on defects in workmanship)</td>
<td>$0</td>
<td>3 to 5 years</td>
<td></td>
</tr>
</tbody>
</table>


### Table A.3. Pavement condition sensors

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Sierra Electronics, Inc.</td>
<td>5433 IceSight</td>
<td>$11,000</td>
<td>Clean, inspect and calibrate once per year</td>
<td></td>
<td>2</td>
<td></td>
<td>9 to 11 years</td>
<td>Also capable of measuring surface temp/air temp/relative humidity; Non-intrusive</td>
</tr>
<tr>
<td></td>
<td>5422 Intelligent Road Condition</td>
<td>$8,000</td>
<td>Inspect once per year</td>
<td></td>
<td>1</td>
<td></td>
<td>6 to 8 years</td>
<td>Intrusive</td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>NIRS – Non-invasive road sensor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 to 5 years</td>
<td></td>
</tr>
</tbody>
</table>

### Table A.4. Wind direction and speed sensors

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>WS200</td>
<td></td>
<td>No moving parts so minimal - should be a yearly maintenance trip for all sensors</td>
<td>Cost of a person to go and check everything out</td>
<td>2</td>
<td>$0</td>
<td>9 to 11 years</td>
<td>Life span depends on maintenance, these should last a long time as there are no moving parts</td>
</tr>
<tr>
<td></td>
<td>Ventus</td>
<td></td>
<td>No moving parts so minimal - should be a yearly maintenance trip for all sensors</td>
<td>Cost of a person to go and check everything out</td>
<td>2</td>
<td>$0</td>
<td></td>
<td>The Ventus is a heavy duty, metal anemometer which can handle extreme conditions. We have utilized this in coastal areas that get lots of cold and wet blowing snow. It has 2 heaters built in and can handle extreme temps.</td>
</tr>
<tr>
<td>Manufacturers</td>
<td>Product name and model</td>
<td>Equipment cost</td>
<td>Recommended preventative maintenance activities and frequencies</td>
<td>Estimated annual maintenance cost</td>
<td>Warranty period (years)</td>
<td>Warranty cost</td>
<td>Expected life span</td>
<td>Additional information</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------------</td>
<td>----------------</td>
<td>---------------------------------------------------------------</td>
<td>----------------------------------</td>
<td>-------------------------</td>
<td>----------------</td>
<td>-------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Campbell Scientific</td>
<td>CS120A</td>
<td>$3,850</td>
<td>System is self-regulating but we recommend calibration every 2 years</td>
<td>1</td>
<td>$0</td>
<td>9 to 11 years</td>
<td></td>
<td>Same as the others, if taken care of they will last</td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>VS2K</td>
<td></td>
<td>Sensor has a built-in random vibration to prevent bugs from nesting in its optics.</td>
<td>Annual trip out to clean everything</td>
<td>2</td>
<td>$0</td>
<td>6 to 8 years</td>
<td>2k (2,000 meter) range and 20k range with 100k range on the way.</td>
</tr>
</tbody>
</table>
Table A.6. Precipitation sensors

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>WS100</td>
<td></td>
<td>Minimal, no moving parts or open tipping buckets</td>
<td>Annual trip to check</td>
<td>2</td>
<td>$0</td>
<td>&gt; 11 years</td>
<td>This is a Doppler-based precipitation sensor giving you intensity and type (rain, sleet or snow). Again, if cared for we have some still in the field 10 years+ at the moment</td>
</tr>
<tr>
<td></td>
<td>R2S</td>
<td></td>
<td>Minimal, no moving parts or open tipping buckets</td>
<td>Annual trip to check</td>
<td>2</td>
<td>$0</td>
<td>&gt; 11 years</td>
<td>This is a Doppler-based precipitation sensor giving you intensity and type (rain, sleet or snow). Again, if cared for we have some still in the field 10 years+ at the moment</td>
</tr>
<tr>
<td></td>
<td>WTB100</td>
<td></td>
<td>Minimal, no moving parts or open tipping buckets</td>
<td>Annual trip to check - may need to go remove leaves or build up as they are tipping buckets</td>
<td>2</td>
<td>$0</td>
<td>6 to 8 years</td>
<td>This is a tipping bucket which will give you accurate accumulation but won’t differentiate between type or give intensity</td>
</tr>
<tr>
<td></td>
<td>WS601</td>
<td></td>
<td>Minimal, no moving parts or open tipping buckets</td>
<td>Annual trip to check - may need to go remove leaves or build up as they are tipping buckets</td>
<td>2</td>
<td>$0</td>
<td>6 to 8 years</td>
<td>This is a tipping bucket which will give you accurate accumulation but won’t differentiate between type or give intensity</td>
</tr>
</tbody>
</table>

Table A.7. Ultrasonic snow depth sensors

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Scientific</td>
<td>SR50A</td>
<td>$960 (10 ft cable)</td>
<td>Check Desiccant and replace if required. Replace Transducer every 3 years.</td>
<td>1</td>
<td>1</td>
<td>$0</td>
<td>9 to 11 years</td>
<td>Great ultrasonic snow height sensor giving up to 15m in depths. Not 100% sure but like always, maintain and things last</td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>SHM31</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>$0</td>
<td>6 to 8 years</td>
<td></td>
</tr>
</tbody>
</table>
Table A.8. Subsurface sensors

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Scientific</td>
<td>CS231</td>
<td>$800 - $6339</td>
<td>No maintenance or calibration required</td>
<td>1</td>
<td>$0</td>
<td></td>
<td>&gt; 11 years</td>
<td>This is a Doppler-based precipitation sensor giving you intensity and type (rain, sleet or snow). Again, if cared for we have some still in the field 10 years+ at the moment</td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>IRS31Pro (can have 0, 1 or 2 sub probes)</td>
<td>None</td>
<td>Minimum maintenance required. Inspection of connections to make sure they are secure, check cables to ensure they are dry and clean</td>
<td>2</td>
<td>$0</td>
<td></td>
<td>3 to 5 years</td>
<td>IRS31Pro is an embedded passive sensor. Capable of measuring road/pavement conditions, ice percentages, water film heights, up to 2 sub-probe measurements and it has removable electronics for when a road is re-paved.</td>
</tr>
<tr>
<td></td>
<td>8160.TF50S</td>
<td>None</td>
<td>None</td>
<td>2</td>
<td>$0</td>
<td></td>
<td>3 to 5 years</td>
<td>Standard stand-alone sub probe with either 25m or 50m cables. In ground sensors tend to get beat up a little more so shorter period</td>
</tr>
<tr>
<td></td>
<td>8160.TF25S</td>
<td>None</td>
<td>None</td>
<td>2</td>
<td>$0</td>
<td></td>
<td>3 to 5 years</td>
<td>Standard stand-alone sub probe with either 25m or 50m cables. In-ground sensors tend to get beat up a little more so shorter period</td>
</tr>
</tbody>
</table>

Table A.9. Barometric pressure sensors

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Scientific</td>
<td>CS100</td>
<td>$640</td>
<td>Minimum maintenance required. Inspection of connections to make sure they are secure, check cables to ensure they are dry and clean</td>
<td>3</td>
<td>$0</td>
<td></td>
<td>6 to 8 years</td>
<td>This product is made for us by Setra in Massachusetts</td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>WS300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Also capable of measuring RH/temp and pressure</td>
</tr>
</tbody>
</table>
### Table A.10. Water level sensors

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Scientific</td>
<td>CS451</td>
<td>$771 - $935 (plus cable costs)</td>
<td>We recommend factory calibration every two years. Visual inspection at every site visit for desiccant condition and possible replacement</td>
<td></td>
<td>1</td>
<td>$0</td>
<td>3 to 5 years</td>
<td>Will have a 1-year life span if desiccant is not maintained</td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>RLS (radar level sensor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>This is from OTT HydroMet, our new &quot;One Company&quot; profile and comes from the hydro side. This sensor is easily integrated to new or existing Lufft sites</td>
</tr>
<tr>
<td></td>
<td>PLS (pressure level sensor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>This is from OTT HydroMet, our new &quot;One Company&quot; profile and comes from the hydro side. This sensor is easily integrated to new or existing Lufft sites</td>
</tr>
</tbody>
</table>

### Table A.11. Solar radiation kits

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Scientific</td>
<td>CS320</td>
<td></td>
<td>Online tool to determine if calibration is required</td>
<td></td>
<td>1</td>
<td>$0</td>
<td></td>
<td>We have multiple solar radiation sensors from our extensive work in renewable energy.</td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>WS301 (and stand-alones)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lufft bought Kipp and Zonen, leaders in solar radiation monitoring. They can be bought with our all-in-one sensors that have every parameter needed, or as stand-alone sensors.</td>
</tr>
<tr>
<td></td>
<td>WS401 (and stand-alones)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table A.12. Traffic/Vehicle detection (MVDS) sensors

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Scientific</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>We integrate sensors from a variety of manufacturers. If you do not have sufficient information from those manufacturers, we would be happy to liaise with them and provide data to you.</td>
</tr>
</tbody>
</table>

Table A.13. CCTV cameras

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Product name and model</th>
<th>Equipment cost</th>
<th>Recommended preventative maintenance activities and frequencies</th>
<th>Estimated annual maintenance cost</th>
<th>Warranty period (years)</th>
<th>Warranty cost</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Scientific</td>
<td>CCFC</td>
<td>$2,875</td>
<td>Clean lens as required</td>
<td>1</td>
<td>$0</td>
<td>6 to 8 years</td>
<td></td>
<td>We recommend this camera for solar and remote applications. We typically use Panasonic cameras for AC powered stations requiring PTZ. Camera technology typically changes faster than the technology fails so replacement every 5-7 years is probable</td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>We can incorporate and integrate almost any camera into our RWIS sites</td>
</tr>
</tbody>
</table>
Table A.14. Software products, features, and costs

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Software products</th>
<th>Features/Capabilities</th>
<th>License fees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Scientific</td>
<td>Campbell Cloud (under development, currently used in municipal applications).</td>
<td>SV3 and ViewMondo can poll data in real time, give brief pavement forecast estimates, show historical data, camera images and graphs and diagrams. We also can partner with major forecasting companies such as DTN and Iteris. We are all about giving the customer what they want and what is the best fit.</td>
<td></td>
</tr>
<tr>
<td>OTT HydroMet (Lufft)</td>
<td>Smartview3, ViewMondo (we can work with any other provider out there).</td>
<td>ViewMondo and SV3 = $495 a year per site or mobile sensor.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B. SUMMARY OF DOT SURVEY RESPONSES

Appendix B presents a comprehensive listing of the results from the RWIS DOT Survey, as well as a side-by-side comparison of all agency responses for each question.

Table B.1. Number of RWIS stations/Years using RWIS

<table>
<thead>
<tr>
<th>Agency</th>
<th>Number of RWIS stations</th>
<th>Number of years using RWIS</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>Less than 30</td>
<td>23 to 30 years</td>
<td></td>
</tr>
<tr>
<td>Minnesota DOT</td>
<td>101 to 150</td>
<td>23 to 30 years</td>
<td></td>
</tr>
<tr>
<td>New Hampshire DOT</td>
<td>Less than 30</td>
<td>7 to 14 years</td>
<td></td>
</tr>
<tr>
<td>British Columbia Ministry of Transportation and Infrastructure</td>
<td>61 to 100</td>
<td>23 to 30 years</td>
<td></td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>61 to 100</td>
<td>15 to 22 years</td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td>101 to 150</td>
<td>More than 30 years</td>
<td>Our RWIS data is critical for our UDOT Snow and Ice Performance Measure. Our instrumentation remains greater than 95% up time as a result. We have nearly 1500 RWIS instrumentation deployed. We will soon be deploying stand-alone road/visibility sensors only where an existing RWIS site is in the vicinity.</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>61 to 100</td>
<td>Less than 7 years</td>
<td>PennDOT's goal with RWIS is to optimize geographic coverage and employ data to measure operational performance and drive improvements.</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>61 to 100</td>
<td>More than 30 years</td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>61 to 100</td>
<td>More than 30 years</td>
<td>We may be moving to smaller, 'mini' sites in the future as our network gets denser.</td>
</tr>
</tbody>
</table>
### Table B.2. Procurement methods

<table>
<thead>
<tr>
<th>Agency</th>
<th>Request for proposals</th>
<th>Invitation for bids</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>X</td>
<td></td>
<td>We bid the RWIS projects the same way we bid all construction projects.</td>
</tr>
<tr>
<td>Minnesota DOT</td>
<td>X</td>
<td></td>
<td>MnDOT has two RWIS vendors (Hoosier &amp; Vaisala) on state contract.</td>
</tr>
<tr>
<td>New Hampshire DOT</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>British Columbia Ministry of Transportation and Infrastructure</td>
<td>X</td>
<td></td>
<td>Design, build, maintain our own stations in-house. Purchase equipment from various vendors.</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td></td>
<td></td>
<td>We have 5-year contract with instrumentation vendors and a separate contract for RWIS maintenance and installation.</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table B.3. General RWIS manufacturer information

<table>
<thead>
<tr>
<th>Agency</th>
<th>Vaisala</th>
<th>Lufft (Hoosier)</th>
<th>Campbell Scientific</th>
<th>Boschung</th>
<th>High Sierra</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minnesota DOT</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Hampshire DOT</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>British Columbia Ministry of Transportation and Infrastructure</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>No sole manufacturer/vendor (we design, build, &amp; maintain our own stations in-house).</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agency</td>
<td>RWIS manufacturers</td>
<td>RWIS products</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Vaisala, Campbell Scientific</td>
<td>We use Novalynx Tipping Buckets, RM Young Anemometers, Windscreens, MRC Temperature Data Probes, Judd Snow Depth Sensors. Cameras by WTI, Axis, and Mobotix.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>British Columbia Ministry of</td>
<td></td>
<td>No sole manufacturer/vendor (we design, build, &amp; maintain our own stations in-house). Campbell Scientific CR1000 dataloggers, Vaisala DST/DSC pavement sensors, various other instrumentation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation and Infrastructure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minnesota DOT</td>
<td>Vaisala, Lufft (Hoosier)</td>
<td>AXIS Q6125-LE PTZ network camera, Glen Martin Tower, Great Plains Tower, RM Young 05103 Wind Lufft (Hoosier): LCOM RPU, WS100 UMB precipitation, VS2K visibility Vaisala: RWS110 LX RPU, RWS200 RPU, HMP155 air temp/relative humidity, PWD22 precipitation/visibility, PTB110 barometer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Hampshire DOT</td>
<td></td>
<td>Vaisala LX (21), Vaisala RWS200 (1), Lufft LCOM/UMB (3); Various brands of Vaisala sensors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Dakota DOT</td>
<td>Lufft (Hoosier) (we do have several Vaisala sites and one Boschung site for our FAST)</td>
<td>A typical Lufft site has the following sensors: Axis Q6055-E Camera, IR illuminator, LCOM, NIRS-31 sensor, WS100, WS301, WS200, and 72” deep subsurface probe.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>Vaisala</td>
<td>RWS200 and associated components</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Vaisala, Campbell Scientific, High Sierra, Boschung</td>
<td>We have too many products to list. We customize our instrumentation to our specific needs and requirements. Essentially, we design our own RWIS system.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Manufacturer: Lufft (Hoosier)</td>
<td>WisDOT has 20 Lufft sites and 50 legacy Vaisala sites. Lufft sites have the LCOM RPU, IRS 31 pavement sensors, subsurface probe, OWI-430 precipitation sensor, Young 41382 temp/relative humidity sensor, and Young 05103 wind sensor. Vaisala sites have FP2000 pavement sensors and a variety of atmospheric sensors.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Ours is a mix of vendors. Most of our RPUs are Vaisala LX but we also have a number of Lufft LCOMs.</td>
<td>We have a wide variety of sensors. Vaisala, RM Young, OSI, Lufft, Thies Clima, Axis cameras, Wavetronix traffic sensors.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table B.5. Air temperature/Relative humidity sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Vaisala HMP155</td>
<td>$2,420</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>9 to 11 years</td>
<td>We are starting to install the HMP155 when the Thies die. So, I don't have a whole lot of data with the HMP155 yet</td>
</tr>
<tr>
<td>New Hampshire DOT</td>
<td>$3,000</td>
<td>100</td>
<td>0</td>
<td></td>
<td></td>
<td>5</td>
<td>9 to 11 years</td>
<td>Relatively few problems with these sensors</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>$422</td>
<td></td>
<td>$185 per entire RWIS site per year. Unknown on an instrumentation level.</td>
<td>Estimate 50 RWIS sites require response maintenance. Unknown on an instrumentation level.</td>
<td>$435 per entire RWIS site per year. Unknown on an instrumentation level.</td>
<td>4</td>
<td>9 to 11 years</td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>$1,005</td>
<td>Unknown</td>
<td>0.5</td>
<td>Unknown</td>
<td></td>
<td>4</td>
<td>6 to 8 years</td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>$800</td>
<td>Bundled with the rest of our maintenance</td>
<td>Of a network of 72, about 7-8 go bad each year</td>
<td>Bundled</td>
<td></td>
<td>3</td>
<td>6 to 8 years</td>
<td>Similar for Thies, RM Young, and Vaisala version of this sensor.</td>
</tr>
</tbody>
</table>
### Table B.6. Surface temperature sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah DOT</td>
<td>$4,036</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>4</td>
<td>9 to 11 years</td>
<td>We also use 2 other sensors, High Sierra Sentinel ($1,525), High Sierra Icesight road temp/condition combo ($11,575)</td>
<td></td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>$896 - $4,642</td>
<td>Unknown</td>
<td>0.25 - 0.5</td>
<td>Unknown</td>
<td>5</td>
<td>6 to 8 years</td>
<td>Non-invasive pavement temp sensor. Life span is dependent on whether a road project mills up the sensor</td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>$5,000 - $5,866</td>
<td>Unknown</td>
<td>200+ sensors, we have at least 12-15 that need to be replaced each year</td>
<td>Average around $6,000 for each one that needs to be replaced (sensor + labor)</td>
<td>5</td>
<td>3 to 11 years</td>
<td>Lufft sensors seem less reliable than FP2000</td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>$3,451 each, plus install</td>
<td>Bundled with contract</td>
<td></td>
<td>Majoriy all FP2000. A few Lufft. Construction/maintenance kills a lot. Their natural life span is probably much longer.</td>
<td>5</td>
<td>6 to 8 years</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Table B.7. Pavement condition sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah DOT</td>
<td>High Sierra Icesight</td>
<td>$9,995</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>9 to 11 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vaisala DSC111</td>
<td>$11,575</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>3 to 7+ years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td></td>
<td>$12,722</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Non-invasive; Too early to tell what their life span will be. In addition to the DTS210, our pavement sensors include the FP2000 which I do not have costs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td></td>
<td>$16,565</td>
<td>Bundled</td>
<td>Bundled</td>
<td></td>
<td>4</td>
<td>6 to 8 years</td>
<td>We only have a few of these sensors. Based on one failed sensor. The rest are too new to tell.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table B.8. Wind direction and speed sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>RM Young 05103</td>
<td>$1,240</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>6 to 8 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RM Young 05106</td>
<td>$1,482</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>6 to 8 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vaisala WMT700 Ultrasonic Heated</td>
<td>$2,807</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>6 to 8 years</td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Standard wind sensor (Brand/model unknown)</td>
<td>$1,093</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>4</td>
<td>9 to 11 years</td>
<td>We use alpine version in areas of high ice riming.</td>
</tr>
<tr>
<td></td>
<td>Alpine high-performance sensor (Brand/model unknown)</td>
<td>$2,131</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>4</td>
<td>9 to 11 years</td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td></td>
<td>$1,183</td>
<td>Unknown</td>
<td>1</td>
<td>Unknown</td>
<td>3</td>
<td>9 to 11 years</td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td></td>
<td>$1,107</td>
<td>Bundled</td>
<td>At least 4 in our network of 70-ish sites with anemometers</td>
<td>Bundled</td>
<td>4</td>
<td>6 to 8 years</td>
<td>Similar for RM Young or Vaisala brands. Bearings are replaced through regular maintenance.</td>
</tr>
</tbody>
</table>
Table B.9. Precipitation sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah DOT</td>
<td>Novalynx Tipping Rain Bucket</td>
<td>$382</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>9 to 11 years</td>
<td>Rain buckets are very useful for alerting for potential debris flows</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Texas Electronic 525</td>
<td>$1,711</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>9 to 11 years</td>
<td>This model is replacing all of our Hawkeyes</td>
</tr>
<tr>
<td></td>
<td>Vaisala DRD11A</td>
<td>$1,178</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Novalynx 260-2500E</td>
<td>$768</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Lufft R2S</td>
<td>$4,474</td>
<td>Bundled</td>
<td>4?</td>
<td>Bundled</td>
<td>4</td>
<td>6 to 8 years</td>
<td>This is just for our Lufft R2S version.</td>
</tr>
<tr>
<td></td>
<td>OSI WIVIS</td>
<td>$7,480</td>
<td>Bundled</td>
<td>At least 10</td>
<td></td>
<td>4</td>
<td>6 to 8 years</td>
<td>This is for our OSI WIVIS, and Vaisala PWD12s. The life is long, but sometimes they need maintenance/parts in the interim.</td>
</tr>
<tr>
<td></td>
<td>Vaisala PWD12</td>
<td>$7,480</td>
<td>Bundled</td>
<td>At least 10</td>
<td></td>
<td>4</td>
<td>6 to 8 years</td>
<td></td>
</tr>
</tbody>
</table>
Table B.10. Visibility sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Vaisala PWD12</td>
<td>$7,089</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 to 8 years</td>
<td>We are hoping the PWD's last longer, but we won't know for a few more years</td>
</tr>
<tr>
<td></td>
<td>Vaisala PWD22</td>
<td>$10,378</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 to 8 years</td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Campbell CS125</td>
<td>$4,350</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>9 to 11 years</td>
<td>We also use this sensor for estimating snowfall rates for our performance measure</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td></td>
<td>$8,160</td>
<td>Unknown</td>
<td>1.5</td>
<td>Unknown</td>
<td>4</td>
<td>3 to 5 years</td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td></td>
<td>$7,480</td>
<td>Bundled</td>
<td>At least 10</td>
<td></td>
<td></td>
<td>6 to 8 years</td>
<td>Phasing these out because they're maintenance intensive. Similar for OSI or Vaisala</td>
</tr>
</tbody>
</table>

Table B.11. Ultrasonic snow depth sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Judd Ultrasonic Snow Depth Sensor</td>
<td>$1,262</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9 to 11 years</td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td></td>
<td>$865</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>3</td>
<td>9 to 11 years</td>
<td>More useful for mountain locations, doesn't have the sensitivity needed for valleys</td>
</tr>
</tbody>
</table>

73
<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Vaisala DTS210</td>
<td>$896</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 to 8 years</td>
<td>Life span depends on whether or not there is roadwork that destroys the sensor.</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Soil temp sensor (Brand/model unknown)</td>
<td>$82</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>9 to 11 years</td>
<td>Critical for determining snowfall rate for road snow. Soil moisture for blowing dust.</td>
</tr>
<tr>
<td></td>
<td>Soil moisture sensor</td>
<td>$252</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>9 to 11 years</td>
<td>Critical for determining snowfall rate for road snow.</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>$688</td>
<td>Unknown</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>9 to 11 years</td>
<td></td>
<td>This is just the single-point version. Very long-lived and trouble free if it were not for road work taking them out.</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>$629</td>
<td>Bundled</td>
<td>5</td>
<td>About $2,000 per unit, more or less depending if they're doing a surface sensor too</td>
<td>3</td>
<td>9 to 11 years</td>
<td></td>
<td>This is for the multi-array deep probe. These seem to require a lot of maintenance to keep going.</td>
</tr>
<tr>
<td></td>
<td>$2.890</td>
<td>Bundled</td>
<td>At least 2 times (for only 15 total in the state).</td>
<td>$5,000; more or less depending on if they're also doing a surface sensor</td>
<td>3</td>
<td>&lt; 3 years</td>
<td></td>
<td>This is for the multi-array deep probe. These seem to require a lot of maintenance to keep going.</td>
</tr>
</tbody>
</table>
### Table B.13. Barometric pressure sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Vaisala PTB110</td>
<td>$998</td>
<td></td>
<td></td>
<td></td>
<td>9 to 11 years</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table B.14. Solar radiation kits

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah DOT</td>
<td></td>
<td>$515</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>2</td>
<td>9 to 11 years</td>
<td>Most useful in canyons</td>
</tr>
</tbody>
</table>

### Table B.15. Traffic/Vehicle detection sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa DOT</td>
<td>Wavetronix HD</td>
<td>$7,875</td>
<td>Bundled</td>
<td>4</td>
<td>2</td>
<td>9 to 11 years</td>
<td></td>
<td>Generally fairly maintenance-free. Wavetronix HD.</td>
</tr>
<tr>
<td>Agency</td>
<td>Product name and model</td>
<td>Capital cost</td>
<td>Average annual costs for preventive/routine maintenance</td>
<td>Average number of times non-routine maintenance required per year</td>
<td>Average non-routine maintenance cost per year</td>
<td>Usefulness / importance (1-5, 5 = most important)</td>
<td>Expected life span</td>
<td>Additional information</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------</td>
<td>--------------</td>
<td>----------------------------------------------------------</td>
<td>---------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>-------------------</td>
<td>-----------------------------------------------------------</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>AXIS fixed-view camera</td>
<td>$899</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>3 to 5 years</td>
<td>Fixed view often has better night vision.</td>
</tr>
<tr>
<td></td>
<td>AXIS Q6125-LE PTZ</td>
<td>$2,276</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>3 to 5 years</td>
<td></td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>AXIS Q6114</td>
<td>$3,373</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>6 to 8 years</td>
<td>Life span to be determined</td>
</tr>
<tr>
<td></td>
<td>AXIS Q6125-LE</td>
<td>$3,325</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>6 to 8 years</td>
<td>Life span to be determined</td>
</tr>
<tr>
<td></td>
<td>AXIS Q6055 PTZ</td>
<td>$3,709</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>6 to 8 years</td>
<td>Fixed view often has better night vision.</td>
</tr>
<tr>
<td></td>
<td>AXIS Q8685-LE PTZ</td>
<td>$7,280</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>6 to 8 years</td>
<td>Life span to be determined</td>
</tr>
<tr>
<td></td>
<td>WTI Viper</td>
<td>$3,940</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>6 to 8 years</td>
<td>Life span to be determined</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>AXIS PTZ Heated camera</td>
<td>$6,505</td>
<td>Bundled</td>
<td>About once per year each</td>
<td>Unknown on an instrumentation level.</td>
<td>4</td>
<td>6 to 8 years</td>
<td>Lots of visits, but not often the whole camera needs to be replaced; sometimes it's just a reset. Generally, the hardware is more reliable than the software. Needs lots of resets and lens cleanings/repair. Axis PTZ heated cameras.</td>
</tr>
</tbody>
</table>
Table B.17. Additional sensors

<table>
<thead>
<tr>
<th>Agency</th>
<th>Product name and model</th>
<th>Sensor type</th>
<th>Capital cost</th>
<th>Average annual costs for preventive/routine maintenance</th>
<th>Average number of times non-routine maintenance required per year</th>
<th>Average non-routine maintenance cost per year</th>
<th>Usefulness / importance (1-5, 5 = most important)</th>
<th>Expected life span</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Vaisala TDP</td>
<td>Temperature Data Probe</td>
<td>$4,623</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>6 to 8 years</td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Datalogger</td>
<td></td>
<td>$1,700</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>Unknown on an instrumentation level.</td>
<td>5</td>
<td>&gt; 11 years</td>
<td></td>
</tr>
</tbody>
</table>

Table B.18. Data storage cost/Number of years of data stored

<table>
<thead>
<tr>
<th>Agency</th>
<th>Data storage cost/Years of data stored</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>We store all RWIS data and only 24 hours of camera images. This is stored at NDIT and is included in our server fee.</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>N/A</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Unknown. We store infinite amount of RWIS data. 3 years’ worth of specified RWIS camera snapshots.</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>Included with web hosting and data services contract requirement, total of $108,000/year. No limit to data storage during contract terms.</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>SCAN Web has no archive and Luft has about 7 years.</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>DTN has 3 years, ScanWeb has 15 years. Not priced by storage.</td>
</tr>
</tbody>
</table>
### Table B.19. Types and costs of communications

<table>
<thead>
<tr>
<th>Agency</th>
<th>Fiber optic</th>
<th>Cellular</th>
<th>Radio</th>
<th>Other (please specify)</th>
<th>Monthly telecommunications cost per site</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Most of our sites are on cellular but we do have a couple that are on fiber.</td>
<td>Cellular is $40/month. Fiber is on our own network and is $1,000/month for the link and $30/month to each end point.</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Satellite</td>
<td>$30 - $112</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>Cell: $20 - $30/month</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>Included with web hosting and data services contract requirement, all services $9,000/month.</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td></td>
<td>X</td>
<td></td>
<td>Landline</td>
<td>$35</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>X</td>
<td>X</td>
<td></td>
<td>DSL</td>
<td>Cellular is ~$15/month. Dsl can be as much as $70/month.</td>
</tr>
</tbody>
</table>

### Table B.20. Annual staffing costs for RWIS operations

<table>
<thead>
<tr>
<th>Agency</th>
<th>Annual staffing costs for RWIS operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>We do not track this, but we have one ITS Manager and essentially 10 technicians that take care of our ITS devices.</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>We have a contractor who maintains all sites. Those costs are included in the estimated per site costs provided earlier.</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Very difficult to answer. Staff performs multiple functions that could be non-RWIS related.</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>No internal staffing costs are directly associated with operations of RWIS.</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>$5,000</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Nobody dedicates a full FTE to RWIS. Most maintenance is contracted out as previously described. Otherwise it is just a part of a few people's workload.</td>
</tr>
</tbody>
</table>
### Table B.21. Warranty for RWIS components

<table>
<thead>
<tr>
<th>Agency</th>
<th>Warranty purchase? (Yes/No)</th>
<th>Cost of warranty/Other comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>Yes</td>
<td>We require a 3-year warranty at the time of purchase.</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Yes</td>
<td>Our 5-year RWIS parts contract has a 2-year warranty built into the contract.</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>No</td>
<td>All components are covered by performance-based maintenance contract. No warranty is purchased separately.</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Yes</td>
<td>Unknown</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

### Table B.22. Preventative/Routine RWIS system maintenance

<table>
<thead>
<tr>
<th>Agency</th>
<th>RWIS vendor</th>
<th>Contracted services</th>
<th>Agency force</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

### Table B.23. Non-routine RWIS system maintenance

<table>
<thead>
<tr>
<th>Agency</th>
<th>RWIS vendor</th>
<th>Contracted services</th>
<th>Agency force</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
### Table B.24. Reduction of winter maintenance costs due to RWIS data

<table>
<thead>
<tr>
<th>Agency</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Utah DOT</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

### Table B.25. Future RWIS installations

<table>
<thead>
<tr>
<th>Agency</th>
<th>Additional RWIS installation timeframe</th>
<th>Number of additional RWIS planned within next 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota DOT</td>
<td>Within next 3 years</td>
<td>Our plan is to get to 60 RWIS, so we plan to install another 31 in the coming years.</td>
</tr>
<tr>
<td>Alaska DOT &amp; PF</td>
<td>Within next 3 years</td>
<td>5 to 8</td>
</tr>
<tr>
<td>Utah DOT</td>
<td>Within next 3 years</td>
<td>We are currently installing about 20+ RWIS sites per year and will continue to do so for several years to support our Snow and Ice Performance Measure.</td>
</tr>
<tr>
<td>Pennsylvania DOT</td>
<td>Within next 3 years</td>
<td>5 to 10</td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Within next 3 years</td>
<td>10</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Within next 3 years</td>
<td>About 3</td>
</tr>
</tbody>
</table>
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