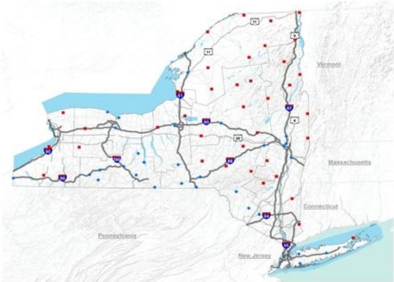
University Transportation Research Center - Region 2

Final Report

Road Weather Information System Statewide Implementation Plan

Performing Organization: New Jersey Institute of Technology



April 2014

Sponsor:
New York State Department of Transportation (NYSDOT)

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Road Weather Information System Statewide Implementation Plan**		5. Report Date **March 2014** 6. Performing Organization Code **NJIT**
7. Author(s) **Steven Chien, Jay Meegoda, Johnny Luo, Paul Corrigan, Liuhui Zhao**		8. Performing Organization Report No.
9. Performing Organization Name and Address **New Jersey Institute of Technology** **University Heights** **Newark, New Jersey 07102-1982**		10. Work Unit No. (TRAIS) 11. Contract or Grant No. C-11-54
12. Sponsoring Agency Name and Address **New York State Department of Transportation** **50 Wolf Road** **Albany, New York 12232**		13. Type of Report and Period Covered **Final Report** 14. Sponsoring Agency Code

15. Supplementary Notes

Project funded in part with funds from the Federal Highway Administration

16. Abstract

The objective of this project was to develop a plan for deploying a statewide RWIS to support both current NYSDOT operations and future MDSS applications. To develop the plan, various information and data sources were investigated, including the current condition of NYSDOT's RWIS network, potential RWIS station sites, data needed for supporting statewide MDSS applications, and NYS meteorological zones. A GIS-based bi-level model was developed to optimize the RWIS network, considering contiguous segments having similar maintenance requirements and the associated characteristics (e.g., meteorology, traffic, etc.) that can affect the required road maintenance. Optimally, the recommended RWIS network shall provide and monitor timely road weather condition for decision making by road maintenance agencies, which ultimately leads to a higher level of service and reduced weather-related congestion delay and accidents, reduced cost, redundancy and environmental/ecological impacts, more efficient use of manpower, contractor services, fleet and asset management, and increased accountability resulting in prudent and efficient spending. It is expected that the proposed RWIS network in conjunction with NYSDOT's MDSS will significantly reduce cost of road maintenance and increase safety, mobility, and productivity of, particularly in the adverse weather during winter time.

17. Key Word	18. Distribution Statement
Road Weather Information System, Planning, Maintenance Decision Support System, ITS, Geographic Information Systems, Regional Weather Severity and Variability, Life-cycle Benefit Cost Analysis	

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**126**	

Form DOT F 1700.7 (8-69)

PROJECT TEAM MEMBERS

New Jersey Institute of Technology (NJIT)

NJIT contributed in the review activities of current RWIS configurations, Meridian's MDSS, best practices of using RWIS to support MDSS, and the development of a GIS-based bi-level model for optimizing NYSDOT's RWIS network. The NJIT team was led by Dr. Steven Chien (Principal Investigator) with members including Dr. Jay Meegoda, and Ms. Liuhui Zhao.

City University of New York (CUNY)

CUNY contributed in the review of existing weather resources as well as the development of a weather severity index and the NYS micro-meteorological map. The CUNY team was led by Dr. Z. Johnny Luo with a graduate research assistant Mr. Jeyavinoth Jeyaratnam.

IBI Group

IBI Group contributed in the early phase literature review activity of this project (connected vehicles) and later led the task of surveying and interviewing NYSDOT staff (including providing a site-visit) to identify candidate RWIS sites of interest to NYSDOT. The IBI team included Dr. Paul Corrigan, Dr. Ning Yang (currently with Parsons Transportation Group), Mr. Bruno Peters, Mr. Kevin Bebenek, and Ms. Melinda Tracey.

ACKNOWLEDGMENTS

This project was sponsored by the New York State Department of Transportation through SPR-funded Project #C-11-54. The research reported herein was performed by the New Jersey Institute of Technology (NJIT), the City University of New York (CUNY), and the IBI Group, Inc. NJIT, as a member of the University Transportation Research Center, Region 2, was the lead consultant for this study.

This project could not have been accomplished without the assistance and expertise of numerous individuals. The research team would like to acknowledge the NYSDOT Technical Working Group (TWG) including Joseph Doherty, NYSDOT Project Manager, NYSDOT TWG members Bob Winans, Eric Meka, John Bassett, Michael Lashmet and Timothy Timbrook, and FHWA TWG members Michael Schauer and Timothy Crothers. Other logistical and administrative guidance was provided by NYSDOT's Deborah Mooney.

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EXECUTIVE SUMMARY

Although New York State is served by an extensive roadway network and experiences severe weather conditions, NYSDOT has a limited network of Road Weather Information System (RWIS) stations to support its winter road maintenance, and the network is in various states of disrepair. Therefore, a comprehensive plan is desirable to expand the existing RWIS network serving both current operational needs and future Maintenance Decision Support System (MDSS) applications.

The objectives of this study include documenting the conditions and configuration of NYSDOT's existing RWIS stations and MDSS, identifying the needs for expanding the RWIS network, and developing a plan for a statewide RWIS network. Several tasks were undertaken, including a review of various data sources, the update of NYS's meteorological maps, the identification of potential locations for RWIS sites, and the development of a solution model to determine the optimal number and locations of sites.

To understand the limitations of NYSDOT's current RWIS network, the configurations of all existing RWIS stations were investigated. Among the total of 31 stations reviewed, a significant number of them were plagued by communication errors, and a few others experienced pavement sensor errors. It was found that gaps exist in the existing RWIS network, and the application of MDSS is hindered by the lack of stations in areas where traffic volume is high and the weather is severe.

While investigating RWIS data and Meridian's MDSS applications, the computer model, data requirements and user experience of MDSS were studied. It was found that the MDSS weather forecasts were accurate for most of the regions except for the lake areas, where a higher density of stations is expected to ensure timely and accurate road weather information for efficient road maintenance. Since a full RWIS station is costly, other sources for road weather observation were investigated. It was found that besides low-cost light RWIS stations, real-time road conditions and chemical usage information collected from mobile weather observation stations (i.e., connected vehicles) could enhance MDSS operations (i.e., expanding the coverage of road weather information and reduce total device expenditure, etc.).

To expand the existing NYSDOT RWIS network, a survey and site visits were undertaken. The questionnaire was grouped mainly into four categories: Satisfaction with the current RWIS network, experience with the MDSS, critical

factors for identifying potential RWIS locations, and potential locations for deploying RWIS.

According to the survey results, benefits associated with cost reduction from the use of RWIS in winter road maintenance were expected and recognized. Though the quality/accuracy of sensor data was acceptable, the reliability and service coverage of existing stations was a concern. The results of the site visits suggested that there are non-uniform operational needs for RWIS stations as some regions experienced heavy service demand and others much lighter or intermittent demand.

A raw list of potential RWIS locations (including typical and problem locations) was developed based on the survey results, and critical weather and operational factors for evaluating potential locations were identified. Based on the collected information, a GIS-based bi-level model was developed to optimize typical RWIS sites in NYS. In the upper level model, a weather severity index was developed to classify NYS micro-meteorological zones, considering four parameters (i.e., mean wintertime land surface temperature, number of weeks with transitional surface temperature, average annual snowfall accumulation, and average annual duration of freezing rain). Based on the weather severity index and regional weather variability, the ideal number and locations of RWIS sites were identified. In the lower level model, the optimal results were refined based on the life-cycle benefit and cost of the RWIS network.

A total of 38 optimal sites (see **Figure 1**) are recommended based on the model results. An example benefit/cost analysis is conducted subject to some hypothetical conditions (which were used in previous studies) due to uncertain information in NYS. The results seem promising and a benefit/cost ratio between 10 and 15 might be achieved depending on the cost of installation and maintenance. It is expected that the optimized RWIS network in conjunction with NYSDOT's MDSS will significantly reduce the cost of road maintenance and increase safety, mobility, and productivity, particularly in the adverse weather during winter time.

Major recommendations are:

- A comprehensive site inspection of existing field ITS and locations should be carried out.
- The integration of NYSDOT disparate winter road-maintenance systems (e.g., RWIS, AVL, MDSS, Snowmat, WTA, 511) should be investigated in order to reduce redundant efforts.

- The ownership and responsibility for Winter ITS planning, deployment, operations, and maintenance needs to be established within NYSDOT in a cost-effective way, ensuring that deployment plans for all these systems are coordinated, and that the systems deliver useful and usable benefits that meet the operator's needs.

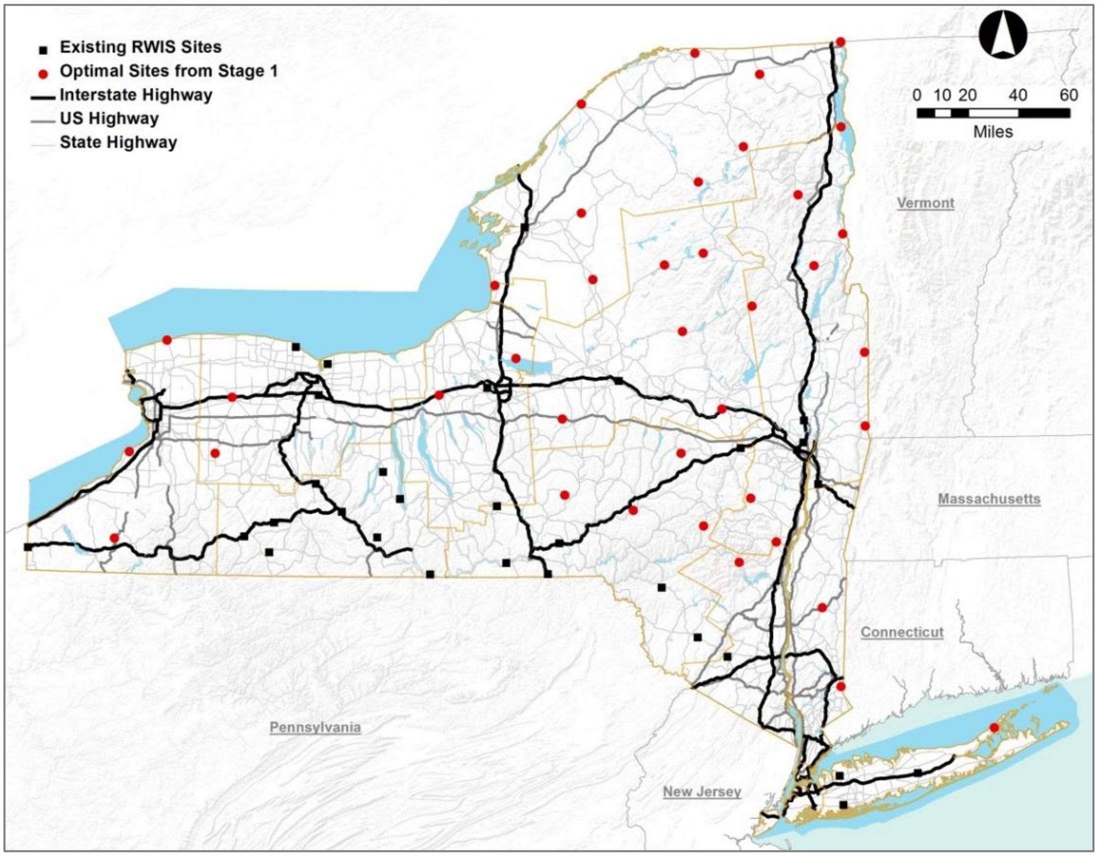

Figure 1 Proposed RWIS Network

CHAPTER 1. INTRODUCTION

1 - 1. Background

Weather significantly affects the traveling public and the transportation agencies that operate and maintain the nation's roadways. Adverse weather is the second largest cause of non-recurring highway congestion, causing approximately 15 percent of traffic delays nationwide. In addition, adverse weather contributes 23 percent to the nation's vehicle crashes and 17 percent of traffic fatalities. More than 1.5 million accidents per year, resulting in over 673,000 injuries and nearly 7,400 fatalities are weather-related. Winter road maintenance alone accounts for about 20 percent of state department of transportation (DOT) maintenance budgets. State and local transportation agencies spend more than $2.3 billion each year on snow and ice control operations, and more than $5 billion to repair weather-damaged roadway infrastructure (FHWA, 2011).

A road weather information system (RWIS) network is a collection of environmental sensor stations (ESS), which provide state DOTs unprecedented access to detailed, accurate, timely, and roadway-relevant weather information to effectively and efficiently promote safety, mobility and productivity in the face of weather-related challenges. ESSs installed across the United States are providing to DOTs valuable road weather data, which have been integrated into winter maintenance decision support systems (MDSS) to assist maintenance managers on road treatment decisions, such as salting, plowing, or a combination of approaches.

The safety and operational benefits from RWIS information could accrue from coordination in both localized deployments (like bridges subject to high winds) and regional integrations (perhaps in support of MDSS and winter maintenance operations). In other words, the requirements for ESS siting need to be traceable to the intended applications and user needs. Some state DOTs have guidelines for ESS siting, but in most cases, it is done informally and using location-based considerations (e.g., based on sensor height, acceptable distance from the road, structural and power requirements, etc.).

Currently, the New York State DOT (NYSDOT) has 43,000 lane miles of responsibility, of which 35,380 lane miles are covered by state forces and 7,620 lane miles rely on municipal contractors. New York State experiences abundant snowfalls during the winter season, with an average seasonal amount of more than 40 inches (except in some coastal regions). Sixty percent of the state receives more than 70 inches of snow (NYS Climate Office). However, the NYSDOT has a very limited network of RWIS stations in various states of repair. A comprehensive plan is needed to upgrade (if appropriate) and expand the existing network to better serve current operational needs and support future MDSS applications.

1 - 2. Objective and Scope of Work

The objective of this project was to establish a detailed plan for deploying a statewide RWIS network in order to support both current NYSDOT operations and future MDSS application. To develop the RWIS implementation plan, various information and data sources were investigated, including the current condition of NYSDOT's RWIS network, potential station sites, data needed for supporting a statewide MDSS application, and NYS meteorological zones. A GIS-based bi-level model was developed to optimize the RWIS network, considering contiguous segments having similar maintenance requirements by associating them with features that can affect the degree of required road maintenance (e.g., meteorology, traffic, etc.). Optimally, the proposed RWIS network allows winter road maintenance agencies to make decisions based on accurate and timely weather information, which ultimately leads to a higher level of service, reduced weather-related congestion delay and accidents, reduced cost, redundancy and environmental/ecological impacts, and more efficient use of manpower, contractor services, fleet and other asset management, and increased accountability resulting in prudent and efficient spending. It is expected that the proposed RWIS network used in conjunction with a future NYSDOT's MDSS will achieve significant operational savings while maintaining acceptable levels of service, particularly in the winter season.

1 - 3. Research Approach

To achieve the objective of this project, a research plan (shown in **Figure 2**) was developed to first identify needs through interviews with highway operations personnel, meteorologists experienced in the respective regions, and third parties with ESS installation experience. The research team then assessed existing weather observations to avoid duplication in siting ESSs, and to integrate them with RWIS information during deployment. Meanwhile, NYS's meteorological zones were investigated. After surveying maintenance and operating personnel and examining the State's highway network, a list of potential sites was identified. The potential sites were then evaluated against the criteria that arose out of the needs identification process. Note that the list of potential RWIS sites (including typical and problem locations) was developed based on survey results and the regional highway network. A GIS-based bi-level model was then developed to optimize the RWIS network.

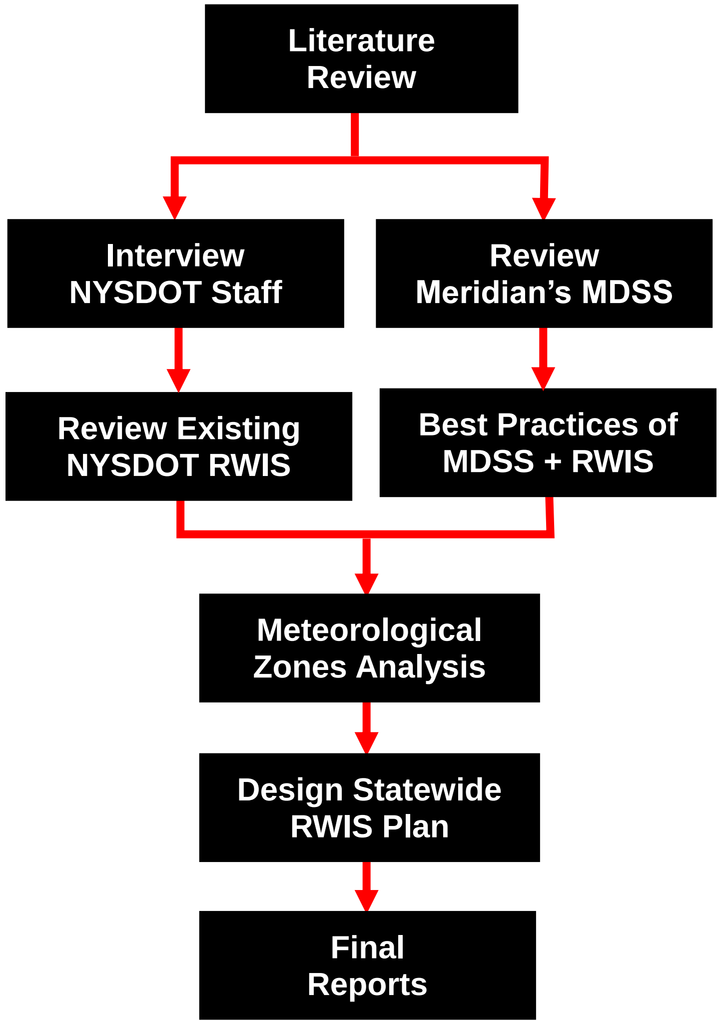

Figure 2 Research Approach

CHAPTER 2. LITERATURE REVIEW

Weather has a major impact on the traveling public and the transportation agencies that operate and maintain the nation's roadways. A recent study estimated that 24 percent of all crashes each year are weather-related, resulting in over seven thousand fatalities (FHWA, 2011). In addition, winter road maintenance alone accounts for approximately 20 percent of the state DOT maintenance budget and over $2.5 billion each year is spent on snow and ice control operations (Rall, 2010).

To reduce weather-related accidents as well as increase the effectiveness of winter road maintenance, accurate and timely weather information is needed. During the last few decades, many states have invested in RWISs to monitor weather and road conditions. The RWIS can aid in winter maintenance operations decisions, support road temperature modeling, improve weather forecasts, and inform the public about roadway conditions.

NYSDOT's existing RWIS sites have been in operation for more than a decade and are now functionally and technologically obsolete. More than 60 percent of the RWIS sites are out of service (NYSDOT, 2007). Before developing the statewide implementation plan for this study, a literature review was conducted by investigating the experience of deploying RWIS in other states, the use of RWIS data to support MDSS, and other supplementary technologies to collect timely road weather information.

This literature review is organized into four sections. First, the weather information sources, including satellite observations, RWIS, *Clarus*, and Connected Vehicles are discussed. Then, previous studies related to RWIS and its applications in supporting MDSS are reviewed. In the third section, experiences of planning and deploying RWIS in other states are reviewed. Finally, the findings are summarized.

2 - 1. Existing Weather Sources

In this section, a review of various weather information sources is presented. The review includes satellite observations, *Clarus*, and connected vehicles.

2 - 1 - 1. Satellite Observations

Satellite observations were used to analyze the weather characteristics across NYS, including climate divisions generated by the National Oceanic and Atmospheric Administration (NOAA) and satellite observations collected by the National Aeronautics and Space Administration (NASA).

NOAA Climate Divisions

Based on monthly temperature and average/total precipitation measured by Cooperative Observer Network (COOP) stations, NOAA divided the continental US (CONUS) into 344 climate divisions (http://www.ncdc.noaa.gov/temp-and-precip/us-climate-divisions.php). In NYS, there are 10 divisions (**Figure 3**), reflecting differences in such climatological factors as latitude, topography, and proximity to large bodies of water. For example, the plateaus (Divisions 1, 2, and 3) are regions with higher elevation so their wintertime surface temperatures are usually below 0˚C. The coastal region (Long Island or Division 4), on the other hand, has low elevation and is closer to the Atlantic Ocean; consequently, its surface temperature is usually above freezing during the winter time.

NASA Satellite Observations of Land Surface Temperatures

The Climate Divisions in **Figure 3** provide a "broad-brush" view of climate in NYS. However, for statewide RWIS planning, a detailed depiction and classification of surface climate is needed. Satellite observations served as a valuable data source for this purpose. In particular, NASA's satellites Aqua and Terra both carry a high-resolution IR imager called Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS provides 1-km by 1-km resolution Land Surface Temperature (LST). Two years of MODIS LST data were downloaded from the MODIS LST Group website (http://www.icess.ucsb.edu/modis/modis-lst.html), to calculate and plot the averaged wintertime LST (**Figure 4**). It was found that surface temperature varied significantly over climate divisions. Moreover, temperature variations within each climate zone are revealed.

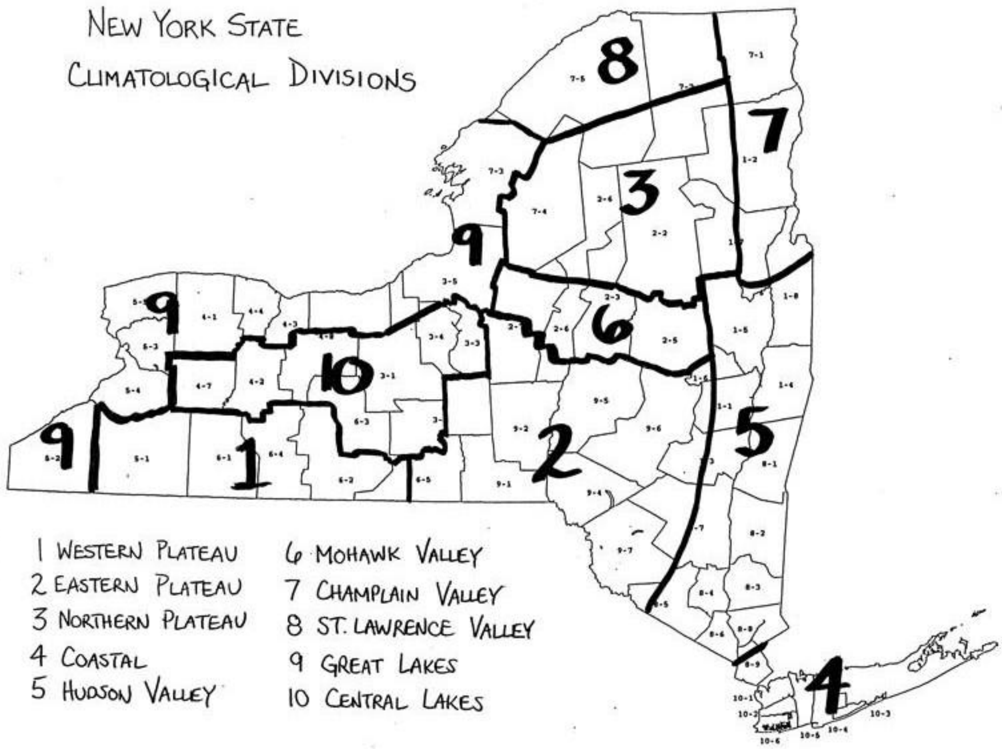

Figure 3 NYS Climate Divisions

(Source: http://www.ncdc.noaa.gov/temp-and-precip/us-climate-divisions.php)

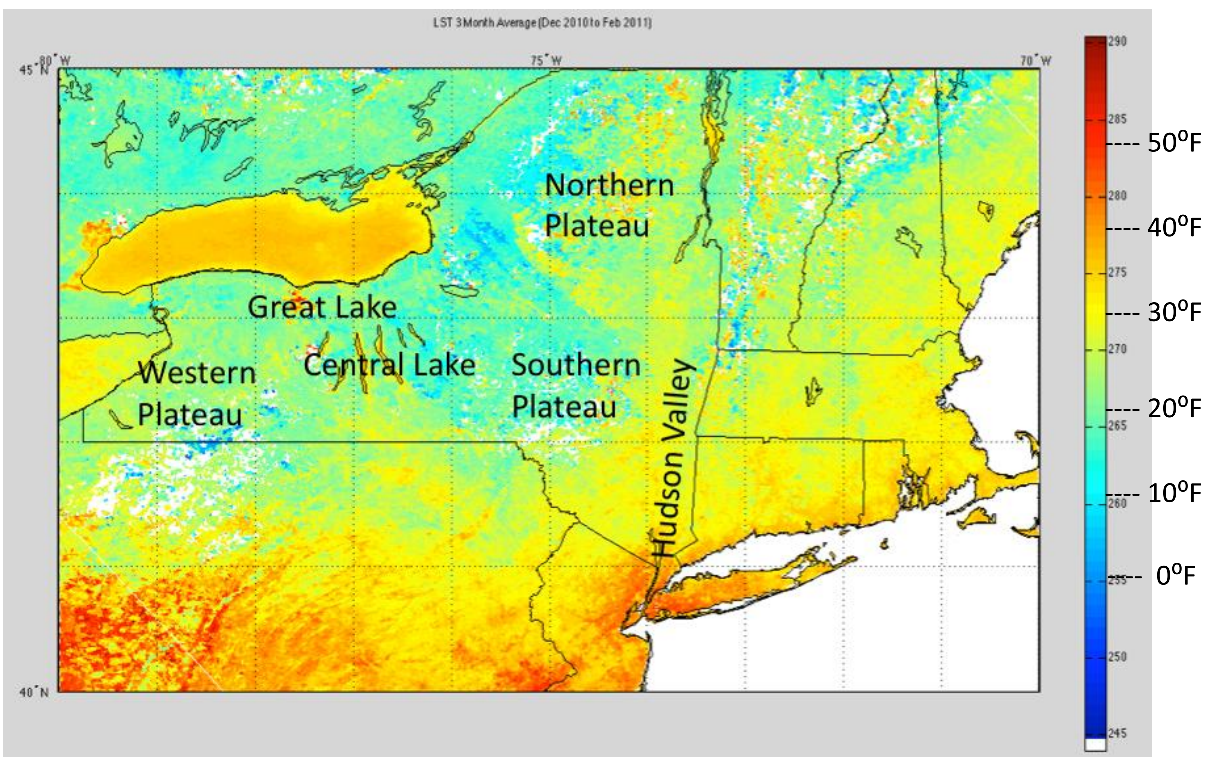

Figure 4 Mean Wintertime Land Surface Temperature

(Source: http://www.icess.ucsb.edu/modis/modis-lst.html)

2 - 1 - 2. RWIS and Clarus Initiative

RWIS is a system containing a network of atmospheric and pavement sensors (i.e., ESS) used to monitor roadway conditions. RWIS information is used to make decisions concerning winter road maintenance procedures.

A traditional RWIS contains three main elements: 1) ESS (**Figure 5**) to collect data, 2) communication system to transfer data, and 3) central processing unit to process data. An ESS may carry various sensors (e.g., precipitation, radiation, temperature, wind, and road surface sensors), which measure surface and subsurface temperatures, air temperature, dew point temperature, relative humidity, wind speed and direction, precipitation occurrence, precipitation accumulation, snow depth, water level conditions, humidity, and visibility (Garrett et al., 2008). Some newer generation sensors are able to collect data on solar radiation, wind speed/direction, water film height, chemical concentration, etc. (https://www.lufftusa.com/pdfs/rwis2009.pdf).

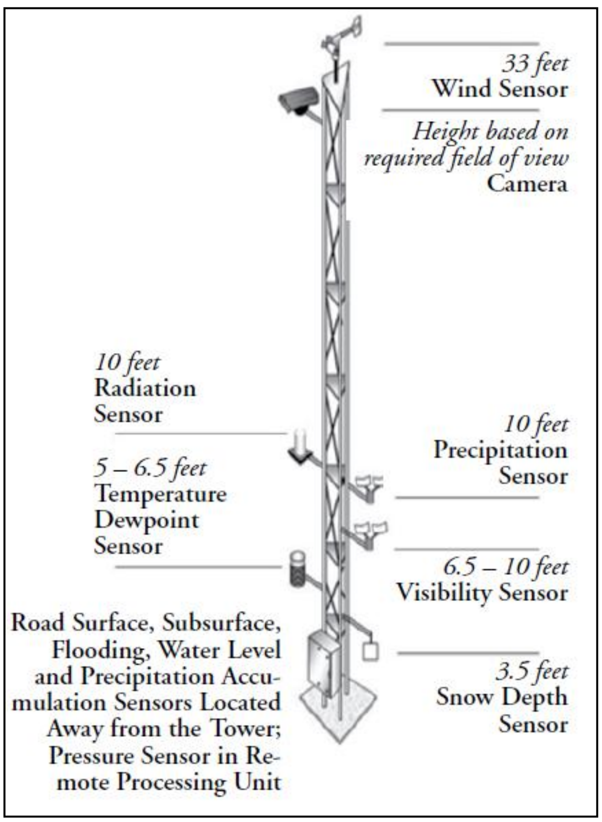

Figure 5 ESS Configuration

(Source: Rall, 2010)

An ESS could be deployed at either a typical or problem location (Manfredi, et al., 2008). A station at a typical location could be used to monitor pavement surface conditions and its data can be used for regional weather forecasts. On the other hand, a station at a problem site could be used for detecting critical road conditions under various adverse weather environments. When a station is sited, collected data will be sent into a Remote Processing Unit (RPU) and then transmitted to a main processor. Therefore, communications between the systems are essential, and are done via various options such as copper wire, fiber optic cable, wireless, satellite, etc. The choice of type and method of communication is usually based on the volume of data transferred and the associated communication cost.

Traditionally, the RWIS data were collected, analyzed, and used by individual state transportation agencies which owned the RWIS infrastructures. To enhance the sharing of road weather information across jurisdictional boundaries, the Intelligent Transportation Systems (ITS) Joint Program Office and the FHWA Road Weather Management Program initiated a Research and Development (R&D) project, the *Clarus* Initiative, in 2004. The *Clarus* Initiative was an integrated weather observation and data management system, designed to collect RWIS data, perform quality checks, and share data across various transportation and meteorological agencies in the United States. Transportation managers were using *Clarus* to make winter road maintenance decisions and support traveler information advisories.

Many State DOTs have been using *Clarus* to improve their transportation operations (Pisano, 2009b). The Iowa DOT has used *Clarus* to support maintenance operations since 2004. Meanwhile, the quality checking flags in the system have helped the DOT to monitor sensor status, and conduct in-time maintenance and repair. The Illinois DOT has also benefited from *Clarus* by increasing its weather forecast reliability and decreasing its operating costs associated with snow and ice operations. The number of states connected to Clarus has increased substantially since its creation. As of 2007, six states had connections to *Clarus*. In 2009, 33 states were connected to it (Pisano, 2009a). In 2012, 36 state DOTs, 5 local DOTs, and 4 Canadian Provinces were contributing their RWIS data to *Clarus* (Murphy, 2012).

Since 2013, a *Clarus* Transition has been in progress under the agreement that NOAA's Meteorological Assimilation Data Ingest System (MADIS) should become the operational home for *Clarus*. The transition efforts focus on incorporating *Clarus* system functionality into the MADIS system so that Clarus transportation users and operators would not lose the *Clarus* capabilities they have grown to rely on to help with decision support issues (http://www.esrl.noaa.gov/gsd/isb/dads/developmentefforts/clarus.html). The transition is scheduled to be completed at the end of 2014. Currently, RWIS data from various agencies could be retrieved from MADIS (https://madis-data.noaa.gov/MadisSurface).

2 - 1 - 3. Connected Vehicle Technology

The connected vehicle system consists of three major components, including On Board Equipment, Roadside Equipment, and the Vehicle Infrastructure Integration. Connected vehicles equipped with appropriate sensors have the capability to collect and transmit a variety of data (see **Table 1**), which provide direct or indirect measurement of the road and atmospheric conditions as inputs of MDSS. The collected data can be treated as ground truth to validate RWIS data as well as support the improvement of weather forecasting and MDSS recommendations.

The use of connected vehicle technology for MDSS practices presently faces hurdles in its utilization of large-volume probe data from moving objects. It was found that there are significant technical challenges in dealing with the data format, transmission, quality, consistency, and data representation (Chapman, et al, 2010). To address these issues, USDOT's IntelliDrive^{SM} initiative and FHWA's Road Weather Management Program have supported a series of coordinated R&D projects and experiments to develop advanced sensing technologies, communication standards, and data fusion algorithms and technologies. To address challenges related to data integrity, the National Centre for Atmospheric Research (NCAR) developed a Vehicle Data Translator (VDT) utility. The main function of this utility is to quality check individual vehicle probe data elements and then convert raw data to usable "derived observation data" that are valid along a specific road segment over a given time. The NCAR is continuously refining the VDT, but considerable work is still needed to improve the reliability of sensors and the validity of data (Drobot et al., 2010).

Table 1 Probe Data Collected by Connected Vehicles

Data Types	Descriptions
General Data	GPS Date, time, location, bearing, speed, altitude, accuracy, etc.
Road Conditions	Road surface temperature, vehicle accelerations (surface friction), pavement wetness, road condition images, etc.
Atmospheric Conditions	Pressure, temperature, relative humidity, dew point, wind speed and direction, etc.
Equipment Condition	Spreader and plow status, chemical distribution amount, etc.
Vehicle Data	Speed, brake status, engine intake air temperature & pressure, steering, traction control, ABS, yaw, accelerations, emissions data, engine data, headlight, wiper status, etc.

(Source: Guevara, 2011)

The current connected vehicle technology focuses on the incorporation of mobile data into effective management systems and decision support tools (e.g., MDSS) as well as the improvement of mobile data usability through data translation and data sharing (NYSDOT, 2007b; Guevara, 2011). Connected vehicles, which could serve as mobile RWIS stations, are expected to enhance the coverage of existing RWIS networks and improve the accuracy of road weather and atmospheric predictions. Many state and local transportation agencies, including but not limited to DOTs in Iowa, Indiana, Michigan, Minnesota, Nevada, New York, Ohio, Washington, and Wisconsin, have initiated pilots or deployed mobile weather stations, which allow vehicles (e.g., patrol cars and snow plow trucks) outfitted with Automatic Vehicle Location (AVL) equipment and add-on sensors to measure real-time meteorological and road parameters as they travel along the roadway network. These data are used to understand road weather phenomena, direct operations, and provide travel information to the public (Strong et al., 2007; NYSDOT, 2007a; McCullouch et al., 2009; Pape, 2010; Hoffman and Drobot, 2011).

2 - 2. RWIS Data and Its Applications

The data collected by RWIS are fairly useful for various organizations and professionals. Scientists could use RWIS data to study meso-scale (intermediate size) meteorological phenomena. Climatologists use such data for long-term records, climatological analysis, and weather forecast verification. As mentioned earlier, winter road maintenance personnel used RWIS data to enhance their operations. In addition, state DOTs use the data for their information network. The National Weather Service, military, and weather service providers utilize

RWIS data for weather forecasts. The risks and impacts of a disaster caused by a serious weather phenomenon, such as a blizzard, could be evaluated by insurance companies. Local, state, and federal disaster and response agencies are able to plan their actions based on the readings derived from ESSs.

To help reduce the cost of snow and ice control operations, road maintenance agencies need accurate and precise weather forecasts for smart and economical decisions. A forecast of a snow event that is a few hours late or a forecast that does not handle the rain-to-snow changeover correctly can significantly affect crew callouts, fuel costs and the consumption of treatment materials. To increase the effectiveness of winter road maintenance, FHWA developed an MDSS prototype, which provides winter maintenance personnel with route-specific weather forecast information and treatment recommendations. The essential features of MDSS include a road condition and handling module and a weather forecast system, which could 1) provide route-specific road weather condition forecasts; 2) provide road treatment recommendations on chemical types and amounts; 3) generate what-if analysis of the recommended strategies; and 4) train maintenance managers to use the system (Dye et al., 2008).

Atmospheric data and pavement data collected from ESSs are used to support winter road maintenance via MDSS. The data are ingested into MDSS to synthesize current road weather conditions for weather forecasts and road treatment recommendations, which include a recommended treatment plan, recommended chemical amounts, timing of treatments, and indication of the need (Mahoney III, et al., 2004; Dye et al., 2008). With the RWIS data, the efficiency of MDSS can be improved and the costs of winter road maintenance reduced (Castle Rock Consultants, 2002).

Currently, 21 state DOTs have employed MDSS to assist them with their winter road maintenance operations (NYSDOT, 2010). Seventeen States have joined the MDSS Pooled Fund Study to implement and enhance FHWA's MDSS prototype. Other states use software from private vendors with MDSS capacity, most noticeable being the Meridian Environmental Technology and Telvent DTN.

2 - 3. RWIS Planning and Deployment

RWIS network planning may begin with identifying provisional sites by interviewing road maintenance personnel, operating staff and resident engineers. The suitability of each site may be evaluated against a set of criteria.

An interview of 13 state DOTs indicated that deploying RWIS stations was seriously impeded by lack of standards, data formats and cost (Castle Rock Consultants, 2002). Therefore, in 2004, FHWA published a guide for siting RWIS stations, which has served as a basis for many states to deploy RWIS stations (Manfredi, et al., 2008). After visits and interviews of three state DOTs (Michigan, Idaho, and New Hampshire), a modified siting plan was developed by FHWA, in which new considerations were discussed (see **Table 2**).

For locating typical ESS sites, uniform roadway conditions and relatively flat and open terrain were recommended. For problem ESSs, critical conditions (e.g., slippery pavement, poor visibility, high wind, high water level, bridges, steep road segments, and river bed scouring) were suggested as important parameters to consider.

Experience from other states could be helpful for deploying new or expanding existing RWIS networks, as summarized in **Table 3**. Michigan DOT deployed RWIS to collect road weather information, primarily in its Superior region, and coordinated it with its ITS Strategic Plan. Idaho DOT operated RWIS for a long time and developed an implementation plan for expanding the RWIS network as well as upgrading the communication methods to disseminate road treatment recommendations. New Hampshire DOT used its RWIS data to support winter road maintenance as well as address traveler information, and decided to expand its RWIS to cover a larger area, including heavily traveled roads and taking into account financial considerations.

Table 2 New Considerations in FHWA Siting Guide Version 2.0

Sections	New Considerations
Assessing Road Weather Informational Requirements	• Co-location of other traffic management technologies with ESS was discussed in 'Regional and local Site Requirements' • The importance of *the Clarus initiative* was emphasized
Site Selection	The tradeoffs between meteorological requirements and practical siting considerations (e.g., the availability of power and communications) were illustrated
Additional Considerations	• The importance of maintenance and maintainability was discussed • Metadata recommendations were modified to take *the Clarus initiative* into consideration

Table 3 RWIS Siting Process in Different States

	Michigan	New Hampshire	Idaho
Assessing Road Weather Informational Requirements	Referred the FHWA Siting Guide	Consider the objectives of forecasting and maintenance supporting	Referred the FHWA Siting Guide
Site Selection	Regional and local sites are reduced to a short list according to program budget	Specific highway links were given priority and geographical characteristics were considered when choosing site locations	Priority was given to regional sites and the purpose of the sites was mainly for maintenance
Recommended Siting Criteria	Referred the FHWA Siting Guide	A minimum of two sites per district More ESSs in the western part of the State according to the wind pattern	Telephone landlines used as the preferred way to communicate between RWIS ESS and central systems
Additional Considerations	Referred the FHWA Siting Guide	Providing information to travelers and sharing data with other states	Soil evaluation was considered to deploy specific ESSs

(Source: Garrett et al, 2008)

In 2004, the Alaska Department of Transportation and Public Facilities (ADOT&PF) undertook an RWIS deployment project (Sullivan, 2004). After analyzing users' needs, a potential list of "best" sites was generated through a field observation and evaluation model. The potential sites were identified by interviewing maintenance decision-makers and meteorological personnel. Three functionalities of RWIS were required, and criteria for ranking the potential stations were developed (**Table 4**). The road perspective criterion listed in Table 4 assessed whether the roadway was in a high weather impact area, or of less importance in terms of overall snow and ice control; the meteorology perspective evaluated whether the weather information was vital for forecasting and monitoring or not; and the engineering perspective included power/communication/right of way issues of potential sites.

The outcomes suggested (Sullivan, 2004) that from the technical perspective, it is vital to rely on partnerships to share power and communication resources, especially in remote areas. From the institutional aspect, a user need and usage survey with key maintenance and operation personnel would be essential during the RWIS deploying process. Finally, from the financial perspective, it is important to consider expenses which cover ongoing changes and maintenance and operating cost of RWIS stations.

Table 4 Criteria for the Alaska RWIS Deploying Project

	Detecting		Forecasting		Monitoring		Engineering Perspective	Total Score and Ranking
Criteria / Potential Site	Road Perspective	Meteorology Perspective	Road Perspective	Meteorology Perspective	Road Perspective	Meteorology Perspective		
1	Individual score							
2								
⋮								

(Source: Sullivan, 2004)

The site selection model of an Alberta, Canada project had a macro and micro component (Pinet, 2003). The macro model considered the natural environment and operational conditions of potential sites as well as identifying the representative area. After that, the micro one investigated the specific characteristics of each site (i.e., roadway condition, right-of-way issues, utility, obstructions) to ensure that both typical and problem sites were included in the final list of recommended sites.

A current survey developed for determining the optimal density and locations of RWIS investigated the experience and the requirements of deploying RWIS[1]. The criteria for deploying RWIS stations were used to serve two purposes: Determining the number of RWIS (using budget, complaints from motorists, request from maintenance personnel, and lack of coverage) and determining the locations of RWIS (using weather factors, traffic factors, and maintenance operations factors). Jin et al. (2013) proposed a safety concern index to identify the optimal RWIS locations with weather-related crash data. Zhao and Chien (2013) evaluated potential RWIS sites considering the effects of weather severity, traffic volume, and distance to existing stations. Meanwhile, Kwon and Fu (2013) proposed a framework to evaluate possible locations for deploying RWIS considering weather (i.e., variability of surface temperature, mean surface temperature and precipitation) and traffic (i.e., traffic volume, accident rates, and highway type) factors.

[1]Survey Website: https://www.surveymonkey.com/s.aspx?sm=DSplG0rC%2bh33aGQ5NHMXqiWDrSHxakgtpsbi2wfxm4E%3d, accessed in Jun. 03, 2013

2 - 3 - 1. Benefit and Cost Analysis

The costs associated with the assessment, design, equipment and construction are highly dependent on the actual site requirements, as well as the complexity and scope of the network (see **Figure 6**). The capital cost of an RWIS fluctuates depending on the number and type of sensors, the level of service, the complexity of the system, and the site conditions. The cost of the assessment activities to determine the requirements should also be added to the actual procurement and construction cost. The annual maintenance and operational costs vary depending on a number of factors, such as RWIS services provided, the maintenance schedule, service scope, and location.

Typically, an entry-level RWIS station costs are as follows:

- Design cost around $20,000;
- Equipment cost varying between $27,000 and $80,000;
- Installation cost varying between $15,000 and $30,000;
- Annual maintenance cost around $3,000 per site per year, with approximately $600 more per site per year for data communication. In practice, state DOTs report annual RWIS maintenance budgets of between $1,040 and $6,300 per ESS; some of these budgets include system upgrades (Rall, 2010).
- Annual operation cost around $2,000.

The above cost range estimation was based on industry practice, the review of previous studies, and the cost information available at USDOT ITS Benefits, Costs, and Lessons Learned Databases (detailed information can be obtained at http://www.benefitcost.its.dot.gov). As an example, the cost of a recent RWIS project in Seattle is provided in **Table 5Error! Bookmark not defined.**.

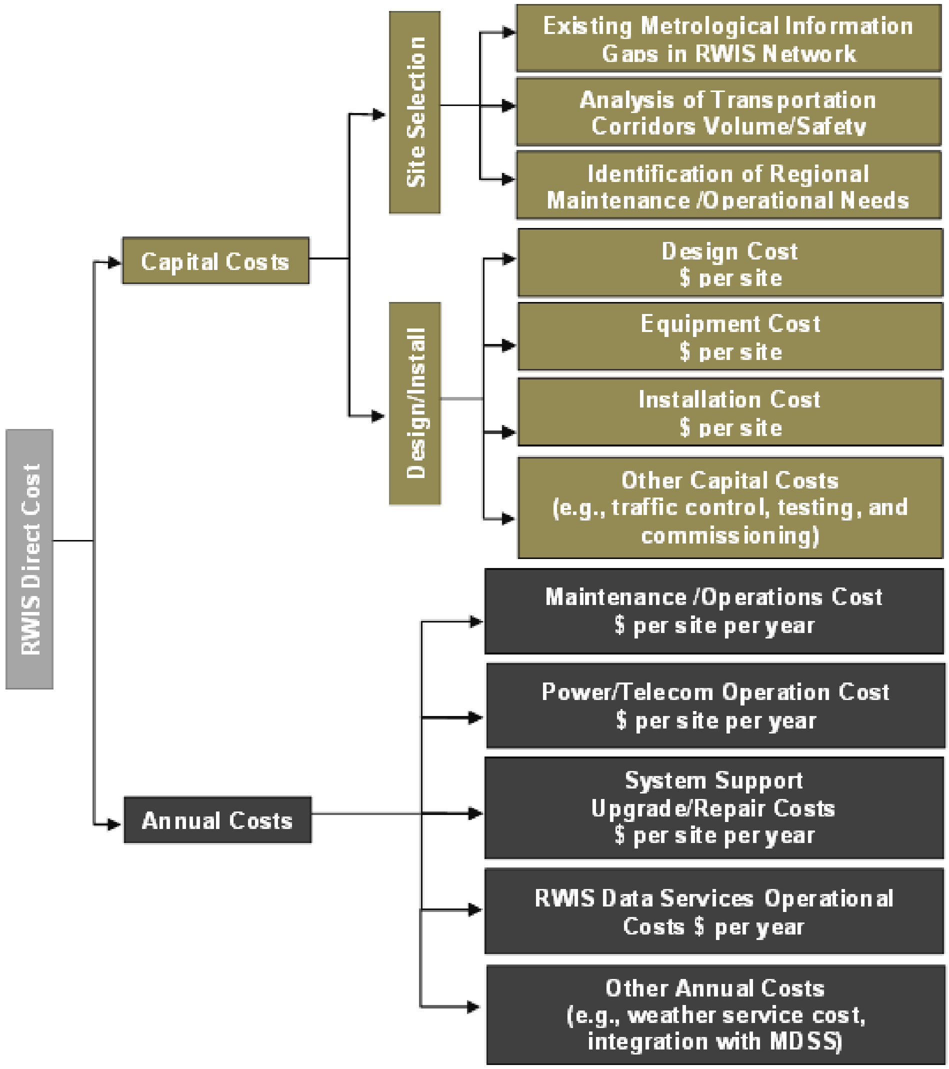

Figure 6 Major Components of RWIS Direct Cost

RWIS has been proven to be very beneficial for states and municipalities, with estimated benefit-cost (B/C) ratios varying between 2:1 and 10:1 (ITSJPO, 2009). For instance, The North Central Region Winter Maintenance Plan estimated a B/C ratio of 1.4 over four years based on the assumption of 10 percent savings in direct snow and ice control costs, and could further increase to 2.0 by including additional functions such as thermal mapping (Boon & Cluett, 2002). The State of Utah was able to save $2.2 million per year, or about 18 percent of its annual winter maintenance budget for labor and material costs associated with snow and ice control activities. Case studies carried out by Epps and Ardila-Coulson (1997) indicated that RWIS helped save $7 million in maintenance costs over 25 years because of improved efficiency in chemical usage and crew scheduling.

Table 5 Error! Bookmark not defined. **RWIS Cost Component of the Sample Project**

Items	Cost (US$)
Tower & Foundation (fold-down with winch)	15,000
Pressure/ Humidity/ Temperature Sensor	2,500
Precipitation Sensor (rate/type) Radar	4,500
Wind Sensor (sped/direction/gusts) Ultrasonic	2,000
Passive Pavement Sensor with 2 sub-probes	20,000
CCTV Camera	9,000
RPU and Cabinet	1,500
Communications	1,000
Power (source to be confirmed)	20,000
Total Equipment Costs	**75,500**
Site Survey	3,775
Detailed Design	20,000
Installation	30,000
Testing & Commissioning	7,550
Remote Site Factor	7,550
Traffic Accommodation	3,000
Total Install Costs	**71,875**

A life-cycle B/C model for RWIS implementation proposed by McKeever et al. (1998) considered the associated costs (i.e., installation, maintenance, and device upgrading costs) and benefits (i.e., winter road maintenance cost savings, accident cost savings). A case study in Abilene, TX indicated that the study RWIS station could provide a net present value of $923,000 over a fifty-year life cycle. Kwon et al. (2014) adopted a B/C based approach to optimize the density of RWIS stations and found that deploying a total of 45 stations in Northern Minnesota resulted in a life-cycle benefit/cost ratio of 3.5.

Several states investigated potential returns of the investment in RWIS. It was found difficult to estimate the social impact and the monetary savings from the deployment of RWIS. Cost savings were estimated based on previous experiences of using RWIS to support winter road maintenance, (see **Table 6**).

Table 6 Benefits of RWIS

Agencies	Cost Savings
Maryland DOT	• A $4.5M system will pay for itself in 5-7 years
Massachusetts Highway Department	• Saved $53K in first year with 9 RWIS in Boston area; $21K in one storm alone • Estimated savings of around $200K over a typical Boston winter
Minnesota DOT	• Estimated a 200-1300 percent return on investment
North Dakota DOT	• Saved around $15K on one bridge in 4 storms
West Virginia	• Saved $2.3K per storm in labor, $6.5K of salt per storm • Estimated $200K per year over a typical winter

(Source: Boselly, 2001)

2 - 4. Summary

Valuable weather information sources, including satellite observations, RWIS and *Clarus*, and connected vehicles, could serve as the foundation for winter road maintenance and operations. RWIS has been deemed as a system effectively supporting winter maintenance operations by transmitting timely weather information to facilitate decisions associated with snow and ice control activities. Significant reductions in staffing, material/chemicals and equipment costs, degradation of the surrounding environment, corrosion effects and infrastructure damage were recognized. The B/C ratio of RWIS varied from 2:1 to 10:1.

Siting RWIS stations used to rely on the experience of maintenance and operating staff and it was seriously impeded by the lack of standards. FHWA published a RWIS ESS siting guide in 2008; however, it focused more on individual stations rather than a network.

CHAPTER 3. CURRENT RWIS CONFIGURATIONS AND MERIDIAN'S MDSS

To develop a statewide RWIS implementation plan, it is essential to conduct a comprehensive review of the existing RWIS network and the MDSS used for winter road operations and maintenance. This chapter first summarizes the configurations of existing NYSDOT RWIS stations (i.e., locations of stations, sensor functionalities and status, and traffic/weather information). Then, potential partnerships with other agencies and the status of mobile weather observation systems are investigated, followed by a review of the Pooled Fund Study (PFS) MDSS, which is also called Meridian's MDSS.

3 - 1. Existing NYSDOT RWIS Stations

There are a total of 32 RWIS stations under the supervision of NYSDOT (NYSDOT, 2011). Since there was no latitude/longitude information for Site 'R4' located in the Route 104 Corridor, Webster, NY, and this station was not operational, this investigation focused on the remaining 31 stations. The map of NYS, divided into 11 Regions as shown in **Figure 7**, is used to show the distribution of RWIS stations by region.

As indicated in **Figure 8**, the numbers of existing stations vary significantly over the 11 regions. Most of these are located in Regions 1, 6, and 9, while few are in Regions 2, 3, 5, 7, and 8. Note that the majority of road operations, maintenance activities and implementations of ITS networks in Region 11 (New York City) would be carried out by NYCDOT, which is not included in the scope of this study.

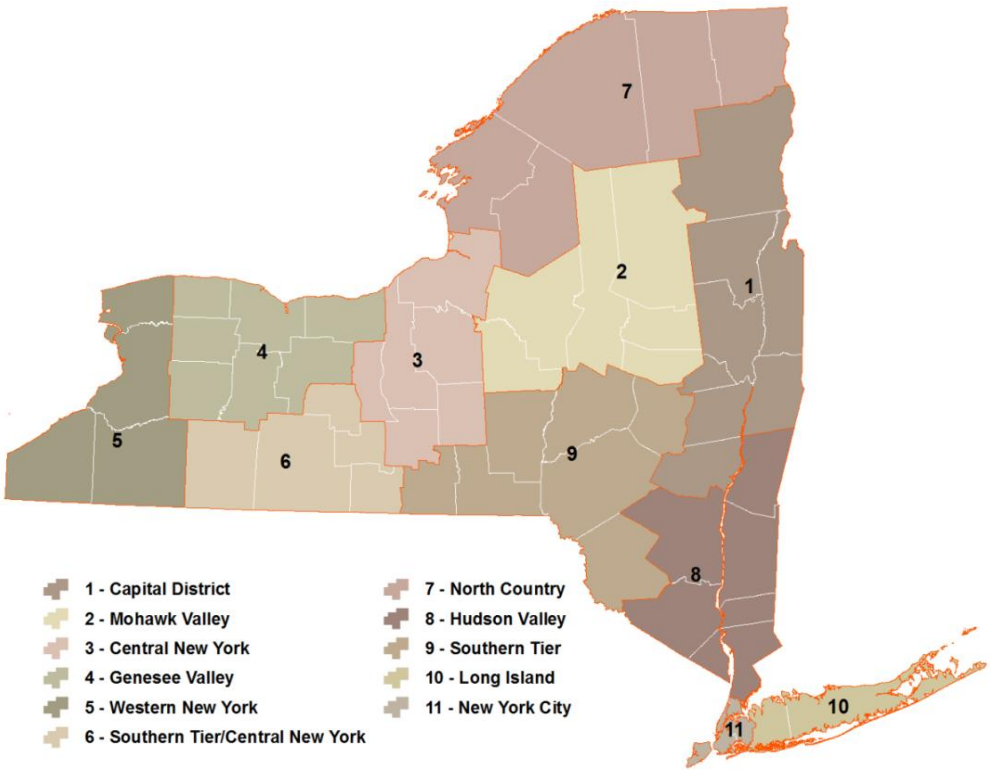

Figure 7 NYS Regions

(Source: https://www.dot.ny.gov/jobs/repository/Tab/Tab/NYSDOT%20Regional%20Map.pdf, accessed on Nov. 10th, 2012)

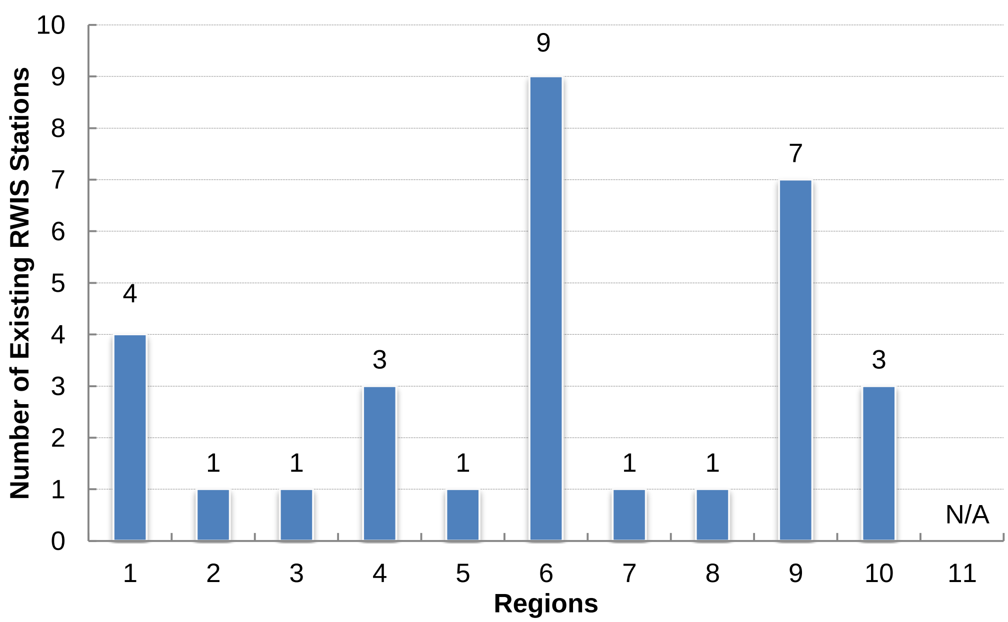

Figure 8 Number of Existing RWIS Stations

In **Table 7**, the average route miles and square miles per station were used to indicate density in each region. Not surprisingly, significant low densities were found in Regions 2, 3, 5, 7, and 8.

Table 7 Number and Density of RWIS in NYS by Regions

Region	Number of RWIS Stations	Land Area (Square Miles)	Square Miles per Station	NYSDOT Route miles	Route Miles per Station
1	4	6,580	1,645	2,049	512
2	1	6,146	6,146	1,455	1,455
3	1	4,285	4,285	1,566	1,566
4	3	4,072	1,357	1,815	605
5	1	4,104	4,104	1,595	1,595
6	9	3,638	404	1,090	121
7	1	8,643	8,643	1,671	1,671
8	1	4,295	4,295	2,194	2,194
9	7	6,238	891	1,848	264
10	3	546	182	688	229
11	N/A				

(Source: https://www.dot.ny.gov/regional-offices, accessed on Dec. 14th, 2012; NYSDOT Roadway Inventory System, 2012)

3 - 1 - 1. RWIS Sensors

According to an internal report (NYSDOT, 2011), it was indicated that 28 of the 31 stations are equipped with a pavement sensor (Lufft IRS 31 – passive sensor), two sites (i.e., 6-2-0-1 & 1-4-1-1) have two Lufft IRS31 sensors, and one site (i.e. 6-1-2-1) has a Lufft ARS31 active pavement sensor. After reviewing the NYSDOT RWIS website managed by Lufft USA, Inc., it was found that there were differences in the pavement sensor status included in the NYSDOT inventory and the information gathered from the website (a total of 44 observations between Nov., 2012 and Dec., 2012) (see **Table 8**). It was also found that over 30% of the sensors were plagued by communication problems.

Table 8 Pavement Sensor Status of Existing RWIS

Station ID	Observed Status			NYSDOT Inventory Status
	Status OK	Comm. Error	Sensor Error	
1-1-1-1	√			Operational
1-4-1-1	√			Operational
2-6-0-1	√			Operational
4-3 T&E	√			Down
4-4-0-1	√			Operational
6-1-0-1	√			Operational
6-1-2-1	√			Operational
6-2-1-1	√			Operational
6-2-2-1	√			Down
6-3-0-1	√			Down
6-3-1-1	√			Down
6-4-0-1	√			Down
9-1-0-1	√			Operational
9-1-0-2	√			Operational
9-1-0-3	√			Operational
9-1-0-4	√			Down
9-6-0-1	√			Operational
10-1-0-1	√			Operational
10-6-0-1	√			Operational
1-1-0-1		√		Down
1-5-0-1		√		Operational
3-4-1-1		√		Operational
5-2-0-1		√		Operational
6-1-1-1		√		Operational
7-3-0-1		√		Operational
8-5-0-1		√		Down
9-7-0-1		√		Operational
9-7-0-2		√		Operational
10-3-0-1		√		Operational
4-3-1-1*		√	√	Operational
6-2-0-1 *		√	√	Operational

*: frequently experienced communication and sensor errors

Besides pavement sensors, several RWIS stations are also equipped with air temperature/relative humidity (AT/RH) sensors, wind speed and direction (WS/WD) sensors, precipitation sensors, and net radiation sensors. Others carry CCTV providing camera information (summarized in **Table 9**). Currently, there are 11 stations equipped with CCTV, mainly located in Regions 4, 6, and 9. Detailed sensor configurations and status are listed in **APPENDIX - B**. According to the Lufft website, except for the stations plagued by communication/sensor errors (see **Table 8**), the AT/RH, precipitation and WS/WD sensors provided data regularly.

Table 9 Sensors Carried in Existing RWIS

	Number of Stations (Of total 31 Sites)
AT/RH Sensor	12
WS/WD Sensor	11
Precipitation Sensor	12
Net Radiation Sensor	6
CCTV	11

(Source: NYSDOT, 2011)

3 - 1 - 2. Existing Site Characteristics

Figure 9 shows the existing stations and the 2010 Annual Average Daily Traffic (AADT) for the NYS highway network (retrieved from https://www.dot.ny.gov/tdv). As indicated in the figure, the red lines represent roads with high AADT (50,000 – 300,000). It is worth noting that the existing RWIS stations are mostly located along the road segments with high AADT. However, there are still gaps in the existing RWIS network, and particularly in Region 8, where there is only one station.

By overlaying the shaded relief data from the National Atlas with 30-year average annual snowfall accumulation (1981-2010 NOAA's climate normals), **Figure 10** illustrates the general weather and topographic information across NYS. High snowfall accumulation exists in the upper-middle and western part of the State, mostly in Regions 2, 5, 7, and upper Region 9 where fairly few stations are located.

From the standpoint of MDSS users, there was an argument on location selection for typical and problem sites when deploying RWIS stations. It is preferable to have typical RWIS stations for road weather forecasting than problem stations given a limited budget. However, if roadway monitoring is one of the major purposes for deploying RWIS, problem locations can also be critical because of problematic road weather conditions (NYSDOT, 2008).

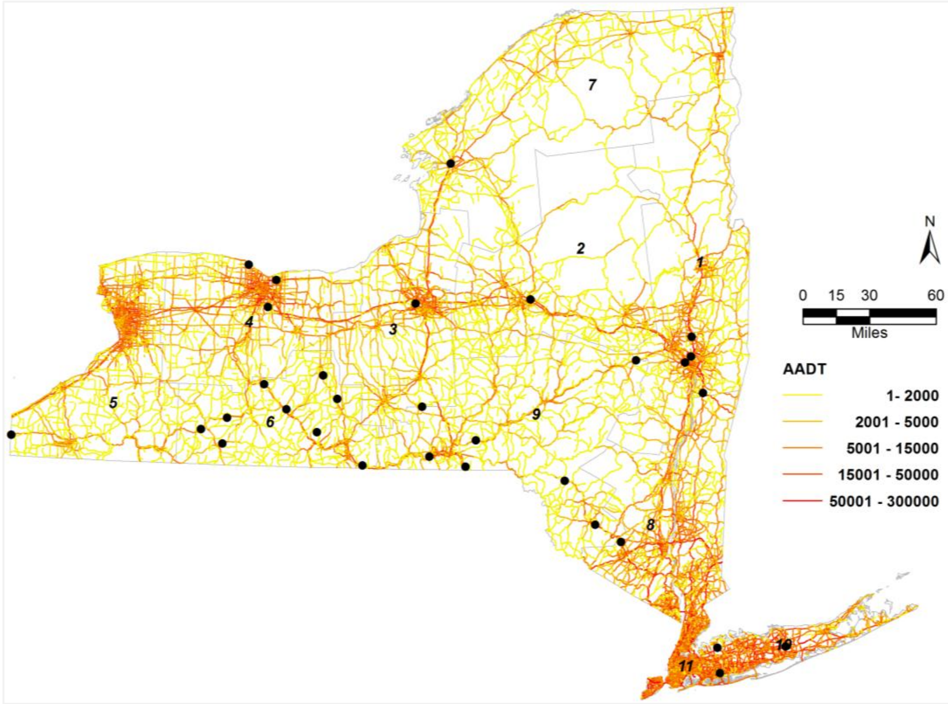

Figure 9 Existing RWIS with AADT

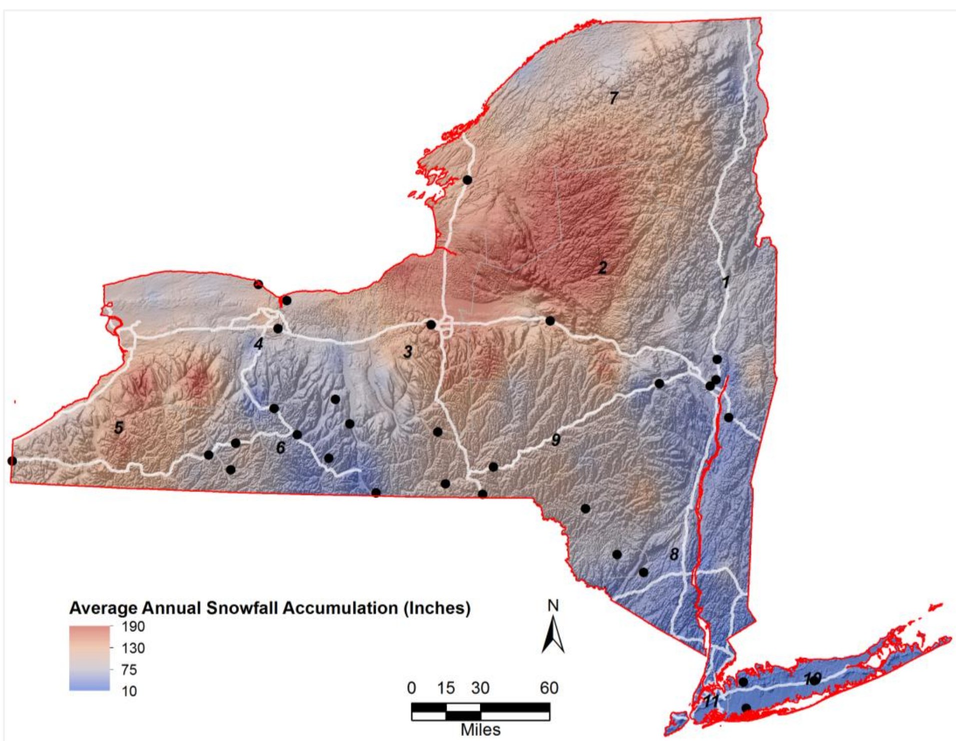

Figure 10 Existing RWIS with Average Annual Snowfall Accumulation

3 - 2. RWIS in Neighboring States

The experience of Alaska's RWIS deployment project indicated that partnerships were beneficial to the success of the entire project, such as reducing costs by avoiding redundant sensors (Sullivan, 2004; Manfredi et al., 2008). Therefore, existing RWIS stations in states neighboring NYS were investigated. **Table 10** shows the participation status of NYS and its neighboring States in *Clarus*, where 28 out of 31 of NYSDOT's RWIS stations were included.

Table 10 NYS and Neighboring States in *Clarus*

States and Provinces	Participation Status
New York, USA	28 stations (NYSDOT)
New Jersey, USA	36 stations (NJDOT)
Massachusetts, USA	22 stations (MADOT)
Vermont, USA	19 stations (VTAOT)
Pennsylvania, USA	75 stations, Pending (PADOT)
Connecticut, USA	26 stations, Considering (CTDOT)

(Source: http://www.clarus-system.com/, accessed on Sep. 4th, 2012)

Figure 11 indicates the locations of RWIS stations of the three neighboring States (Vermont, Massachusetts and New Jersey) participating in *Clarus*. As shown in **Table 10**, Connecticut (26 stations) and Pennsylvania (75 stations) are not connected to Clarus. However, data sharing with these two states may be available in the future. The locations of these RWIS stations are shown in **Figure 12** (retrieved from http://www.eol.ucar.edu/projects/hydrometnet/).

As indicated in **Table 11**, several RWIS stations are administrated by the NYS Bridge Authority and the NYS Thruway Authority. However, their stations are not in *Clarus*. Currently, only CCTV information from the NYS Thruway Authority is available for public use. It would be beneficial to incorporate weather data collected from stations owned by other agencies into Meridian's MDSS to facilitate statewide winter road maintenance. It is worth noting that among the 44 weather stations of the NYS Thruway Authority, there is only one full RWIS station. The remaining 43 are called Season Weather Information Systems (SWIS), and provide air, pavement and dew point temperature only.

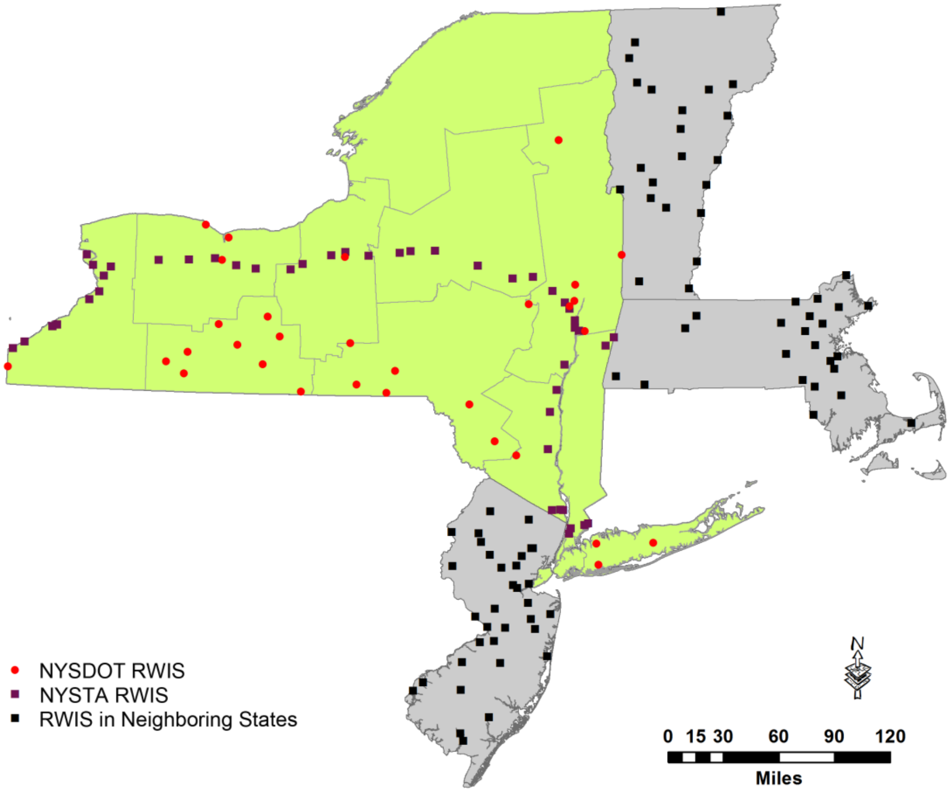

Figure 11 RWIS Stations in NYS and Neighboring States

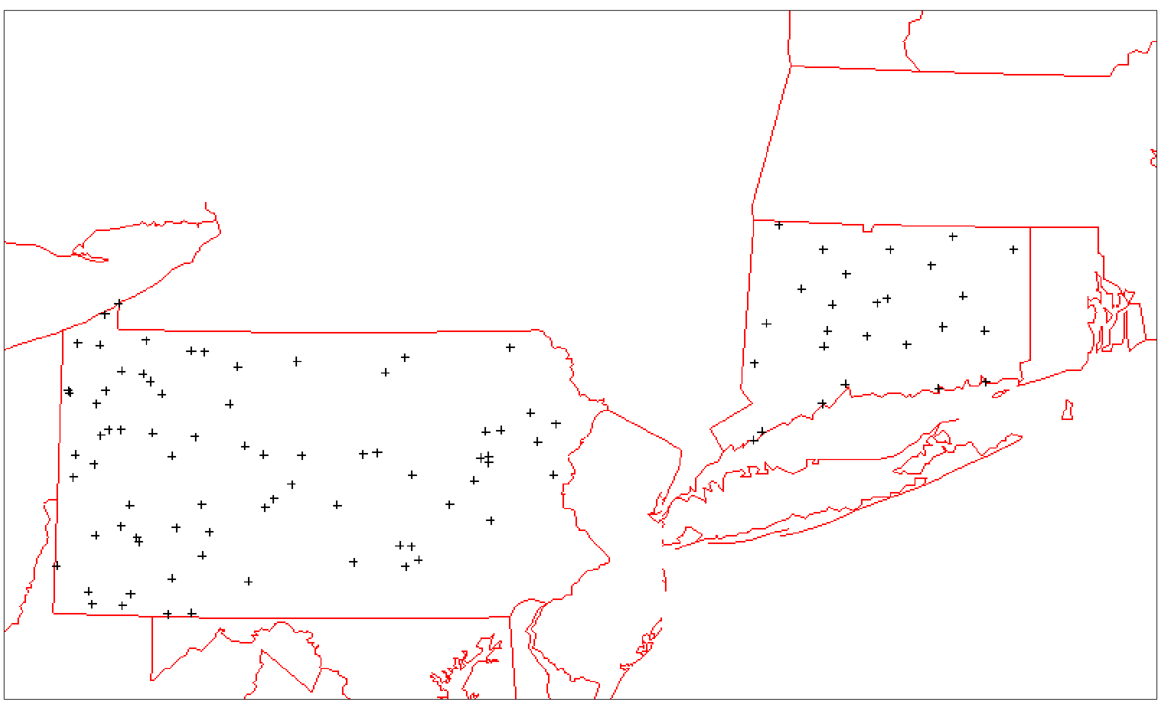

Figure 12 RWIS Stations in Connecticut and Pennsylvania
(Source: http://www.eol.ucar.edu/projects/hydrometnet/, accessed on Dec. 12th, 2012)

Table 11 Other Agencies with RWIS in NYS

Agency	Highway Lane Miles	Bridges	Number of RWIS Stations
NYS Bridge Authority	20	5	2
NYS Thruway Authority	2,821	1,041	44 (1 RWIS, 43 SWIS)

(Source: http://www.nysba.state.ny.us/Index.html & http://www.thruway.ny.gov/index.shtml, accessed on Jan. 28th, 2013)

3 - 3. Connected Vehicle Technologies

Vehicles equipped with sensors can be utilized as mobile weather stations to collect and transfer timely information (i.e., vehicle, weather, and road conditions) at precise locations. With the information on the amount of material used, road condition, and air temperature, these data can be helpful to update treatment recommendations. At the same time, information sent from MDSS to vehicles could help maintenance personnel to apply proper mitigation measures.

Steps have been taken by transportation agencies to incorporate connected vehicle technology into weather-related traffic operations and management strategies (Guevara, 2011). NYSDOT has a pilot program in which 27 out of 1,400 snow trucks have been equipped with AVL sensors. The collected data would be integrated into MDSS, including the status of anti-icing material usage and vehicle locations. Several state DOTs, such as Minnesota, Nevada, Indiana, Michigan, Kansas and Wyoming have employed connected vehicles (Radin, 2005). **Table 12** illustrates the status of mobile weather observation systems use in winter road maintenance operations.

3 - 4. Meridian's MDSS

3 - 4 - 1. The Objectives

To enhance and implement FHWA's MDSS prototype, several state DOTs (i.e., Minnesota, South Dakota, North Dakota, Indiana and Iowa) formed a PFS to develop an alternative MDSS approach in 2002, which was technologically supported by Meridian's Environmental Technology Inc. (McClellan et al., 2009). NYSDOT joined this project in 2007. The driving force of the PFS was to enhance the dynamic use of MDSS operations by considering practical winter road maintenance concerns, such as material constraints, personnel scheduling, etc. (Hart et al., 2008).

Table 12 Connected Vehicle on Road Weather Applications

Agencies	Descriptions
MnDOT	• Combines MDSS and AVL to develop an in-vehicle MDSS with two-way communication • By 2011, the AVL system had been installed in 78 snow plows and MnDOT planned to increase this number to over 400 by 2013 (Pape, 2010)
NVDOT	• Use of real-time atmospheric and vehicle data collected from agency fleet vehicles in an MDSS and a Maintenance Management System (MMS) since 2011 • NVDOT supplies 20 vehicles (including snowplow trucks and light duty vehicles) with winter assignments along I-80 in the Elko and Reno areas • NVDOT's 800 MHz Statewide radio system, along with cell card (in areas with cellular coverage), are used for wireless data transmission (Hoffman & Drobot, 2011)
INDOT	• An AVL system with added data fields from either sensors or driver input to create a mobile reporting system for winter operations has been developed in 2007 (McCullouch, Leung, & Kang, 2009)
MIDOT	• Agency fleet vehicles are instrumented with low-cost IntelliDrive^{SM}-compatible devices to generate a core set of probe vehicle data • In the process of developing a Vehicle-based Information and Data Acquisition System (VIDAS, which will coordinate mobile data relating to road conditions and the data from fixed ESS, and evaluate their accuracy by comparing them with visual observation

To achieve the goal of developing an MDSS for assisting State DOTs to maintain level of service and reduce the operating costs of winter maintenance, the primary objectives were to: Assess user needs and potential MDSS benefits of participating State DOTs; Define functional and user requirements for a MDSS; Build and evaluate an operational MDSS; and Improve the ability to forecast road conditions in response to changing weather and treatment conditions.

3 - 4 - 2. Key Features

The PFS MDSS has the following essential elements: reporting actual road conditions, assessing past and present weather conditions, predicting weather, recognizing resource constraints and identifying feasible maintenance treatments (Huft, 2009). The major data inputs and outputs are listed in **Table 13**.

Table 13 Major Inputs and Outputs of Meridian's MDSS

Major Inputs	Major Output
• Weather observation data • Weather forecast data • Road condition observations/analyses data • Roadway characteristics data • Available resources data • Maintenance actions • GPS-based AVL data	• Road conditions and maintenance treatments reports • Past/present weather conditions and present roadway state • Storm-event weather prediction • Resource constraints identification and feasible maintenance treatment recommendations

(Source: Osborne, 2007; Huft, 2009)

The key components of MDSS include a Data Processing and Ingest System (including Road Weather Observation and Forecast Components, Road Condition and Treatment Component) and a Graphical User Interface (GUI). The Data Processing and Ingest System collects and provides information for maintenance routes/route segments continuously. An energy-mass balance model (i.e., Meridian HiCAPS^{TM}) is used to simulate the actual pavement conditions (e.g., pavement temperature, percent ice, etc.), and handles factors of precipitation and maintenance activity to simulate and project pavement conditions (Huft, 2010). Based on the established criteria, the MDSS generates treatment recommendations to maintain user-defined levels of service, and provides information on road temperature and conditions, percent ice, maintenance actions, and depth of ice/liquid/snow (Huft & Osborne, 2008). **Figure 13** illustrates the functional architecture of PFS MDSS (Hart et al., 2008). The major components of the MDSS GUI include a map viewer, an alert panel, and a support panel (Osborne, 2008) (see **Figure 14**). The map viewer provides options of route-specific maintenance information, timeline controlling, as well as changing geographic background. The alert panel provides four categories of adverse weather alert: weather alerts, road alerts, blowing snow alerts, and NWS alerts (Hart et al., 2008). A detailed introduction to the user interface of a 2010 version of MDSS can be found online (Available at: http://www.dot.state.mn.us/stateaid/CSAH/mdssreferenceguide.pdf).

a. Map view

For each MDSS maintenance route, the current conditions (e.g., air and road surface temperature, and precipitation), forecasted conditions, treatment recommendations and actions are provided. Integrated with user-defined route geographic and pavement information (e.g., pavement type, grade), MDSS is able to estimate the road conditions around RWIS stations.

Forecasted conditions are timely updated based on three types of actions: MDSS recommended actions, standard actions, and no actions. With inputs of actual maintenance decisions, MDSS is able to update the prediction of pavement surface conditions. Therefore, comparisons of road conditions can be made using the above three types of actions with the achieved figures/tables from MDSS.

b. Alert panel

On the left side of the MDSS GUI, various alerts on weather, road temperature, and maintenance actions are generated based on weather forecasts. These alerts are available in different levels of detail. For instance, if the map is zoomed into a region, the alerts will be adapted to reflect the weather forecasts for that region; if the map is zoomed into a residency, the alerts will also change to show the information for that residency. These alerts can be pushed to an email or text message.

c. Support panel

In the menu bar, users can change the settings of MDSS. There is also a tool panel on the map view for users to change the map shown in the interface, such as zooming in, zooming out, search, etc.

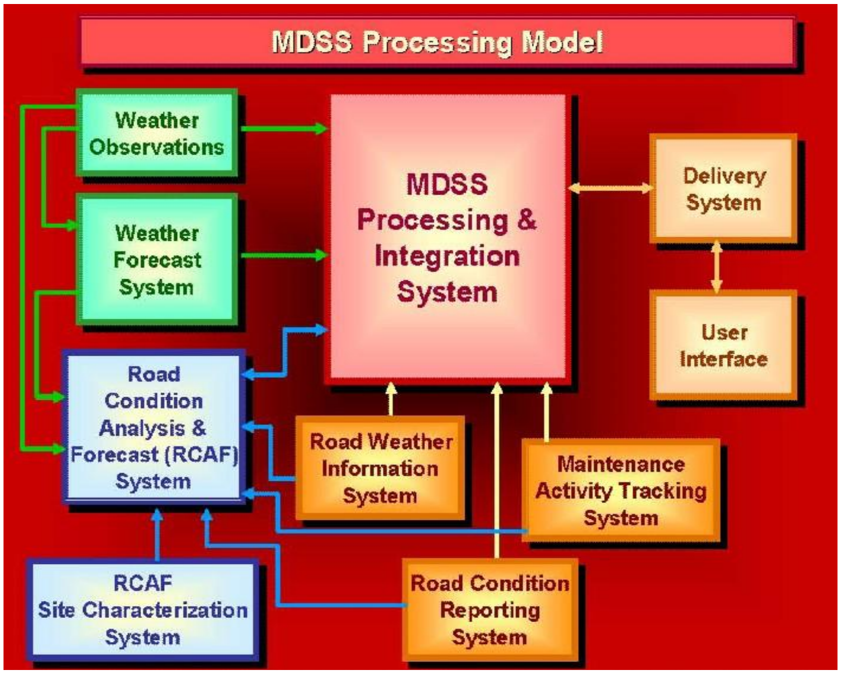

Figure 13 PFS MDSS Functional Architecture

(Source: Osborne, 2004)

Figure 14 MDSS GUI

(Source: Huft, 2009)

3 - 4 - 3. Implementation of MDSS

The PFS program started with 5 States and currently has 19, (**Figure 15**) with South Dakota DOT (SDDOT) being the lead agency. A summarized implementation status of MDSS in several PFS States in 2009 is shown in **Table 14** (Ye et al., 2009).

With the increasing need of two-way communication of MDSS and maintenance vehicles, the PFS developed the functionality of information transmission between MDSS and maintenance vehicles. With the Automatic Vehicle Location/Mobile Data Collection Systems (AVL/MDC), MDSS could ingest real-time road weather information and maintenance activities (e.g., vehicle locations, road and air temperature, plowing activity, chemical type and rate, etc.). Simultaneously, real-time vehicle-specific information fed back into vehicles could support maintenance decisions (Huft, 2010).

Currently, the PFS still works on enhancing the capabilities of MDSS on supporting AVL and leveraging the information collected by MDC/AVL (http://www.pooledfund.org/Document/Download/2911, accessed on Oct. 22nd, 2012). State DOTs have started implementing AVL, which provides interactive reports of maintenance activities and on-going pavement conditions. In 2010, an

AVL system was installed in nearly 10 percent of all MnDOT plow trucks (MnDOT, 2010). In INDOT, about 10 percent of the fleet has been equipped with AVL sensors (Cook, 2012).

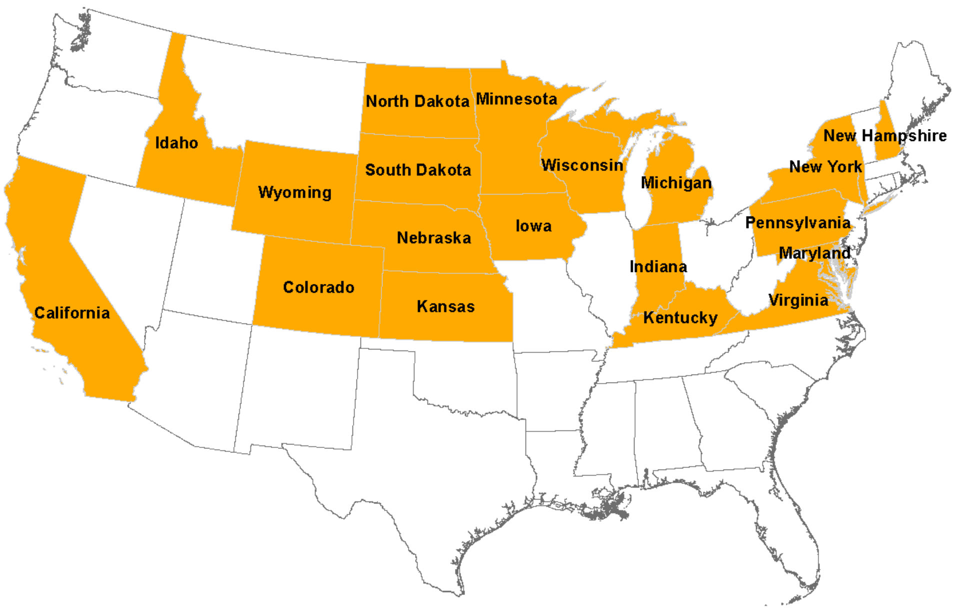

Figure 15 PFS Participating States

(Source: http://www.pooledfund.org/Details/Study/240, accessed on Dec. 10th, 2012)

Table 14 Implementation Status of MDSS

State	Implementation Status
Colorado	MDSS deployed in all 6 DOT Regions
Indiana	MDSS implemented in two districts, and three sub-districts with limited implementation
Iowa	Limited deployment around the State with less than 10 routes
New Hampshire	Only on I- 93 with 2 MDSS routes (13 highway segment, mostly on I-93 –updated status)
South Dakota	10 MDSS routes in 2 sheds

(Source: Ye et al., 2009)

3 - 4 - 4. Cost and Benefit Analysis of MDSS

Through pavement prediction and recommendations on road maintenance, MDSS could help save a substantial amount of chemicals used and reduce the environmental effects of winter road maintenance. Major benefits of MDSS operations include: 1) reduced material use, labor costs and equipment use; 2) reduced fleet replacement costs and infrastructure damage.

As indicated in a study (McClellan et al., 2009), the implementation of MDSS in INDOT reduced salt use by 40 percent and overtime compensation by 25 percent. In New Hampshire, MDSS helped save 23 percent of salt use while maintaining the same level of service (SDDOT, 2010). In Minnesota, the annual savings of salt usage with MDSS was 53 percent over five seasons, which could be translated to about $8 million in annual savings (Pape, 2011).

Costs associated with MDSS operations include software and training, communication, administration, in-vehicle computer hardware, and weather forecast provider costs (Huft & Strong, 2008). Ye et al. (2009) assessed the benefits and costs of the PFS MDSS by comparing a baseline scenario with a simulated scenario for three States located in various climatological areas: New Hampshire with a transition climate, Minnesota in the Northern Plains, and Colorado in the Mountainous areas (detailed information is available at http://www.meridian-enviro.com/mdss/pfs/files/WTI-4W1408_Final_Report.pdf).

3 - 4 - 5. Application of MDSS in NYS

A demonstration of MDSS was carried out during a site visit to Region 6. By integrating real-time data collected from RWIS, MDSS provided weather forecasts (e.g., when the precipitation will occur, what is the precipitation level) and treatment recommendations (e.g., when and where should the first truck be dispatched). Then, the supervisors in each residency made maintenance and operation decisions based on the forecasts/recommendations. The experience of using MDSS suggested that the forecast module of MDSS was accurate and greatly useful in winter road maintenance.

MDSS Forecasts

In addition to RWIS data, camera information collected online and real-time data collected from AVL trucks (road condition, amount of materials plowed) are also integrated into MDSS for monitoring road conditions and updating treatment recommendations. To predict road conditions on road segments without AVL trucks, MDSS assumes that actions have been taken according to the recommendations.

According to MDSS users, the forecasts from MDSS were accurate for most of the area in Region 6, and the range of forecasts was 10-15 miles around each RWIS station. However, the forecasts were questionable in the lake area because lake effects might lead to quick changes and significant spatial variations of the air/road temperature. Due to lack of monitoring stations, the predictions of road weather conditions relied heavily on engineers' experiences. It is also worth noting that currently MDSS is capable of storing storm data for 3 to 4 days, which is helpful to replay the storm, compare the recommended treatments and actual operation decisions, and learn from the experience.

3 - 5. Summary

Among the total of 31 NYSDOT's RWIS stations reviewed, 11 of them are plagued by communication errors, while a few others experienced pavement sensor errors. Some stations are equipped with AT/RH, WS/WD, precipitation sensors, CCTVs, and Net Radiation Sensors. However, a large amount of these sensors need factory calibration for proper use, because their data quality may affect adversely their support of the MDSS.

Besides fixed RWIS stations, mobile weather observation stations can help to extend the coverage of road weather information and reduce the expenditure of installing and maintaining road weather observation systems. In the process of deploying RWIS, using connected vehicles and leveraging RWIS stations administered by other agencies (i.e., NYS Bridge Authority and NYS Thruway Authority) in NYS and those in neighboring states/provinces (i.e., New Jersey, Massachusetts, Vermont, Connecticut, Pennsylvania, Ontario Province, Quebec Province) should be considered.

The AVL/MDC system becomes an essential part of MDSS functionality. Though the AVL system is not a part of MDSS itself, leveraging the information from AVL/MDC could be useful for collecting real-time pavement conditions and maintenance activities, as well as updating the treatment recommendations based on feedback from the field.

CHAPTER 4. NYSDOT RWIS SURVEY

This chapter presents findings from the NYSDOT RWIS survey and site visits to Region 5 (Buffalo Operations Center and NITTEC TMC) and Region 6 (Friendship Facility). The needs and challenges facing the Winter Maintenance ITS program at NYSDOT were ascertained placing specific emphasis on Regions 5 and 6. A summary of survey results are listed in this chapter followed by major findings from the site visits.

4 - 1. RWIS Survey Summary

The satisfactory performance of existing RWIS stations was assessed from a survey of NYSDOT staff. Of 68 total respondents, 37 had access to RWIS data. Their satisfaction with various aspects of RWIS data was investigated, including the variety of sensor data, data quality and accuracy, equipment reliability, data transmission reliability, and coverage of existing RWIS network (See **Appendix - C** for questionnaire).

Among the 37 respondents with access to RWIS data, 5 used RWIS data regularly, 12 occasionally, 19 rarely, and 1 never used RWIS data. Detailed statistics about survey results of access to RWIS data are presented in **Figure 16**.

The question concerning satisfaction with RWIS data was answered by 23 respondents. Among them, 3 did not have access to RWIS data, 8 rarely used RWIS data, 7 used data occasionally, and 5 regularly used the data.

Most of the survey respondents had a neutral attitude towards existing RWIS stations in terms of sensor data quality, equipment reliability, and data transmission reliability (see **Table 15**). Dissatisfaction with the coverage of the existing RWIS network was high. About 20% of the respondents also expressed dissatisfaction with equipment reliability and the type of data provided.

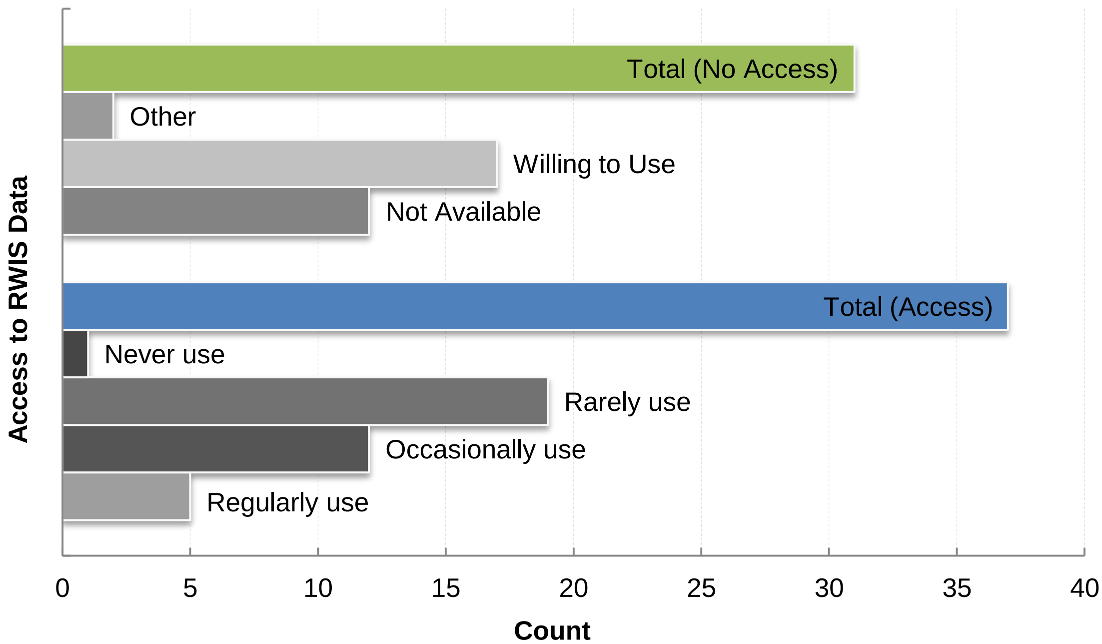

Figure 16 Survey Responses vs. Access to RWIS data

Table 15 Satisfaction of Existing RWIS in NYS

	Type of sensor data provided by existing RWIS stations	Quality/ Accuracy of sensor data	Equipment reliability	Data transmission reliability	Coverage of Existing RWIS Network
Extremely satisfied	2	1	0	0	0
Satisfied	6	8	6	9	4
Neutral	7	9	9	8	8
Dissatisfied	4	2	4	2	7
Total	20	20	19	19	19

The responses were grouped by the frequency of RWIS usage, and **Figure 17** shows the satisfaction of the two groups (i.e., regular users, occasional users). It was found that most users were satisfied with RWIS data. However, most responders were dissatisfied with the coverage of the existing RWIS network, and 30% of responders were concerned about the data transmission and equipment reliability. The benefits of using RWIS data were also ascertained through interviews which individuals mentioning: 1) reduction of the response time with the camera information; 2) minimizing trucks/materials used for maintenance; 3) reducing accidents.

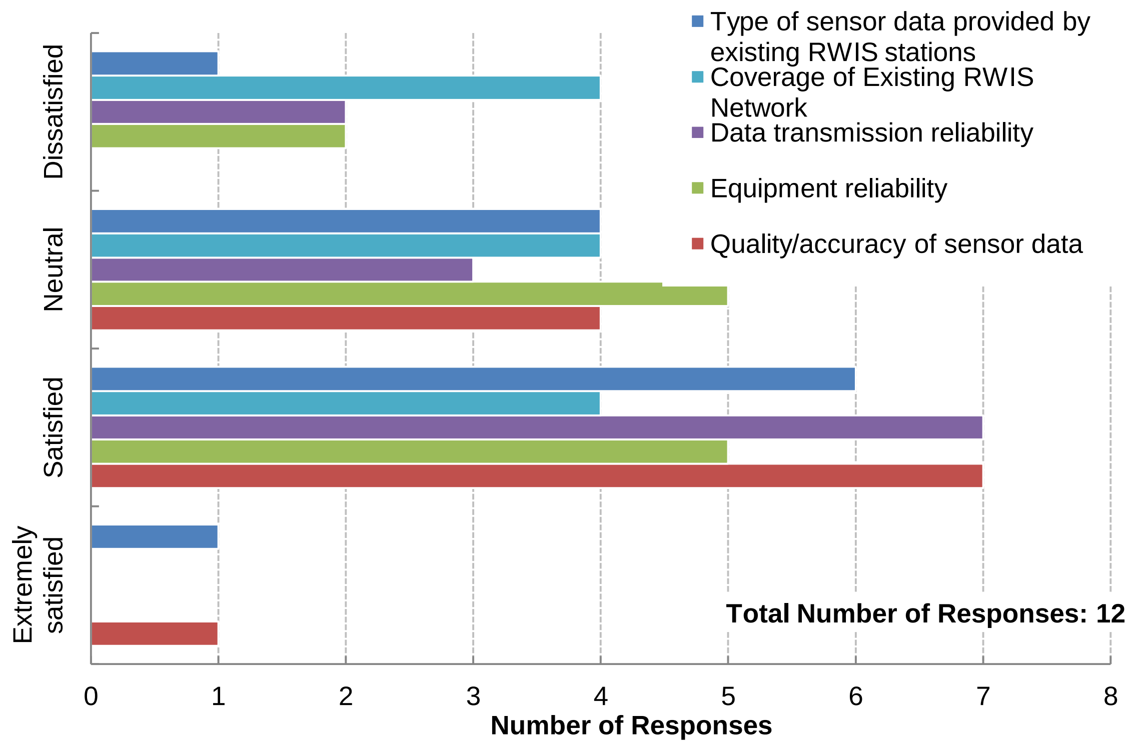

Figure 17 Satisfaction towards Existing RWIS in NYS

4 - 2. Site Visits

The survey and site-visit results explored the conditions of and relationships between NYSDOT's RWIS, MDSS, and AVL technologies, the winter maintenance operations processes, and NYSDOT's winter maintenance program. The findings from these efforts have been grouped into three categories associated with: the winter road maintenance business, the human winter road maintenance operation, and the winter road maintenance technology systems. While our findings point to challenges between these groups today, harmony in the future between these three areas will form the basis for an effective winter road maintenance operation.

4 - 2 - 1. Business Findings

Business findings are associated with the winter road-maintenance business aspects and include enterprise goals, business objective/targets that NYSDOT has, challenges it faces at the upper tiers of the organization, and resourcing constraints (personnel, attrition, and financials), among others. The key findings in this area are:

a. The regional & statewide ITS group needs to be part of any decisions on winter ITS. They are strongly positioned to be the central connection and coordination for vendor/product knowledge (maintenance, training), identifying synergies with other ITS field activities, and providing tangible benefits from integrating disparate systems.
b. Regional Champions will be critical to the success of the MDSS program; these individuals need to be identified and supported. Super-user/key-user groups should also be identified.
c. The PFS MDSS product and an established relationship with Meridian provided a highly informative, well-liked and used tool for the NYSDOT Region 6 staff. Any potential leverage or priority on using this product may provide cost savings and a comfort level (shared knowledge, regional engagement) to other Regions, if used in a statewide or phased deployment.
d. There is widespread agreement among the Region 6 user group that the tool benefits their decision making processes. The costs as well as benefits in resource savings are addressed in the proposed GIS-based bi-level model in Chapter 7.
e. Ownership and responsibility for Winter ITS planning, deployment, operations, and maintenance needs to be established within NYSDOT in a cost-effective way in order to ensure that deployment plans for all these systems are coordinated and deliver useful and usable benefits that meet the operator's needs with minimum defects.
f. AVL planning appears to be the least mature element among RWIS, MDSS, and AVL. This may be a result of the fact that AVL has a separate funding stream to the MDSS. However, AVL is crucial for validation of RWIS data and also for the optimization of MDSS. In addition, there are several highly beneficial derivative benefits for NYSDOT to explore using this system, particularly associated with fleet tracking, optimization of beats and procedures, and minimizing resource effort.

4 - 2 - 2. Operational Findings

Operational findings include the needs and challenges of field maintenance operators and their supervisors, issues that impact how the winter road-maintenance business is carried out, how systems are maintained, reporting of information and the process that supports it, and how technology and processes work together, among others. The key findings in this area are:

a. While winter road maintenance requirements are significant in Regions 5 and 6, the need for operational support from a RWIS and MDSS program may in fact be more beneficial to those regions that do not have the same consistent need for deployment of roadway inspections and treatment and as a result have less experience and predictability of road-weather conditions.
b. The success of any future RWIS or MDSS deployment will be contingent upon user confidence in the predictions and weather data that it supplies to them, as well as user ability to absorb that information and make decisions in an informed way. Operators mentioned that they know from experience that some readings from the instruments are inaccurate and trigger investigations into road conditions that are unnecessary. Retirement/attrition and decline in the user knowledge-base is a key concern, and how future users will make decisions using MDSS needs to be addressed when evaluating the success of the whole system.
c. There are non-uniform operational needs for ITS systems as some regions experience very heavy service demand and others much lighter or intermittent demand. There is variability in regional capability to support and use these systems; some facilities may lack sufficient networking to support MDSS. Tailoring of technology systems to fit the needs of a specific region should be the practice. A geographic and functional phasing plan should be considered.
d. Concerns around program costs, especially ongoing maintenance and operations of RWIS, MDSS, and AVL were expressed by several key stakeholders in both Regions 5 and 6. Maintenance appears to be carried out on a region-by-region basis, but the program planning and initial capital deployment are initiated on a statewide level. This disparity should be corrected; a winter ITS program such as RWIS or MDSS should be statewide funded and supported. Identifying the B/C and resources to support ongoing M&O from the state level is crucial to the success of this initiative.
e. The maintenance of ITS and other technical systems is performed in an ad-hoc fashion; authority rests with individual shops, regions, and sometimes with the central office. Allocating resources to maintain systems or provide spare parts is based on a combination of factors, rather than a clear policy.

4 - 2 - 3. Technical Findings

Technical findings cover the technology-specific aspects and include the configuration, condition and utility of technical systems, performance characteristics, data quality, data ownership, and interfaces, among others. The key findings in this area are:

a. Regional confirmation that RWIS data was integral to efficient operations; the number/frequency of stations of typical locations was less important to staff/operations (used as part of their confirmation) but beneficial to MDSS and the problem sites provided more valuable data to operations but was not beneficial to the MDSS. The feedback loop from the AVL was important to MDSS, yet still very problematic, making the quality of RWIS data more essential.
b. It is not clear if Region 6 is more technologically progressive or equipped than other regions, making it better disposed to realizing MDSS and RWIS investment benefits earlier. Region 5 in contrast, has a more limited MDSS deployment and staff has seen less beneficial results from it. A key issue they face is that there is currently no RWIS data from Pennsylvania. This suggests that the efficacy of the MDSS relies not only on deploying RWIS around NYS, but aggregating information from elsewhere.
c. NYSDOT has several disparate Winter Road-Maintenance systems (e.g.: RWIS, AVL, MDSS, Snowmat, WTA, 511). Reducing redundant effort, for example, through integration of multiple systems from the operator to regional TMC, and statewide (e.g.: 511) levels should be investigated, and where possible, carried out. This includes not only technical integration, but also operational/process integration in order to save resources. The benefits of this approach would include reducing data entry workload of the same information as well as consistency of information reporting.
d. Hosting of road-weather ITS data should be carefully examined within NYSDOT. Although currently being done by a 3rd party contractor, in-house hosting could provide many advantages (more internal control, more security, less reliance on contract cycles, etc.). Staffing and other resource constraints should be weighed when determining what balance to strike between in-house and contracted services.

4 - 3. Summary

Based on the findings of the survey and site visits, an initial recommendation for NYSDOT is to take an integrated, whole-system view of winter road maintenance, including ITS, and develop an approach that recognizes and leverages the opportunities across business, operational, and technical groups. For example, RWIS technology should be selected with a full life-cycle maintenance strategy in place to support it; transitioning to an MDSS operation should recognize risks in operator confidence and human factors including cognition design of systems and winter road experience of the user. A whole-system approach will maximize the quality and efficiency of NYSDOT’s systems and processes by minimizing defects and project risk earlier in the design and deployment phases. This will ultimately provide a more transparent and cost-effective winter road operation and ITS system for NYSDOT.

CHAPTER 5. BEST PRACTICES OF USING RWIS TO SUPPORT MDSS

This Chapter provides the findings of best practices reviews of using RWIS to support MDSS from four states (i.e., Minnesota, Wisconsin, South Dakota and North Dakota) which have implemented statewide implementation PFS MDSS. Following a brief introduction, the survey questionnaire and summarized findings on the performance and issues of RWIS are presented.

5 - 1. Introduction

A comprehensive literature search was performed to determine how different agencies use RWIS to support MDSS. RWIS sites gather and record physical local weather information, convert it to electronic data and transmit it to the MDSS. Electronic data is either transmitted directly to MDSS via a local webserver or national webserver such as *Clarus.* It seems there are no major issues of data transmission other than the transmission interval. However, there is no QA/QC applied when electronic data is transmitted. The most critical local information for accurate MDSS predictions would be the precipitation type, pavement temperature and the freezing point due to the type and amount of chemicals used. Hence precipitation type and pavement temperature are the two most critical parameters needed for successful implementation of MDSS. The major QA/QC issues are the transmission of inaccurate data or no data. Current MDSS systems in use are quite resilient and hence can predict local information with inaccurate data or no data. There may be over or under treatment with MDSS prediction due to inaccurate data or no data. The literature survey did not identify such issues as all publish reports reported success for MDSS.

The following procedure was used to narrow the search to further investigate and report best practices. As of today, out of 50 states and DC only Hawaii and Mississippi have no RWIS sites. Of those having RWIS sites, 27 states have implemented MDSS. Please see **Appendix - D** for details. However, since NYSDOT has implemented Meridian's MDSS, the search for best practices was narrowed to states that have implemented Meridian's MDSS. Currently, 19 States have joined in the PFS using Meridian's MDSS with SDDOT as the lead agency. Of the 19 States, only five implemented a statewide system. Hence a survey questionnaire was developed and administered to two officers involved with or in charge of RWIS sites in the five states. The survey was developed by the project team to capture the performance of the RWIS sites and the issues associated with them.

5 - 2. Survey Findings

The five states that have implemented MDSS statewide are Indiana, Minnesota, Wisconsin, South Dakota and North Dakota. Responses from four state DOTs (i.e., MnDOT, WIDOT, SDDOT, and NDDOT) were received. Before a meaningful comparison can be made, the area and population information of each state should be taken into consideration (see **Table 16**).

Table 16 Area and Population of Investigated States

State	Area in Square Miles	Population
WI	65,556	5,711,767
SD	77,184	824,082
ND	70,703	683,932
MN	84,402	5,344,861
NY	49,108	18,169,000

A copy of the survey can be found in **Appendix - E** and responses to the survey are summarized in **Table 17**. What follows is the detailed response from the state of Minnesota.

"MnDOT's RWIS network was carefully selected using input from multiple sources including meteorologists, maintenance supervisors, and through thermal mapping. MnDOT conducted a series of interviews with representatives from all maintenance operations offices within the Department. These in-person meetings allowed the Department to identify those potential locations which are subject to impaired travel conditions such as reduced visibility or hazardous pavement conditions (wet or frozen pavement, frost, blowing snow etc.). In addition, the Regional Weather Information Center (RWIC) and the University of North Dakota in conjunction with MnDOT conducted site assessment and evaluation of potential RWIS sites throughout the State of Minnesota. These sites were evaluated as to whether the information from those sites could be used as inputs to meso-scale weather forecasting models or would be used only for detection of localized conditions. Also the sites were evaluated in respect to their location to the nearest National Weather Service Automated Weather Observing

System (AWOS) site. Consideration was given to obstructions, both natural and man-made, which may affect atmospheric and road sensing capabilities."

Table 17 Summary of Responses to Survey

Question No.	WIDOT	SDDOT	NDDOT	MnDOT
1	58	43	24	94
2	1988	Early 1990's	1997	2000
3	50km grid	Value to travelers and to SDDOT	District preference and then fill dead spots	A comprehensive analysis
4	No	No	No	No
5	Accident reduction and reduction in salt usage	Accident reduction and reduction in salt usage	Accident reduction and reduction in salt usage	Accident reduction and reduction in salt usage
6	None	None	FHWA guide	A Balance between weather and problem areas
7	Yes, but no access	No	Yes	Yes
8	No	No	Yes	No
9	No	No	No	No
10	Yes, via DOT and University sites	Yes, via Clarus	Yes, via DOT site	Yes, via Clarus
11	Separate Contracts	In house	Installation by contract and rest in house	In house
12	All	All	All	All
13	Service contract	In house	In house	In house
14	In kind replacement	In kind replacement	In kind replacement	In kind replacement
15	N/A	N/A	N/A	N/A
16	Processed	Processed	Processed	Processed
17	Local to National	Local to National	Local to National	Local to National
18	Vendor	Vendor	In house	In house
19	FTP	FTP	FTP	FTP
20	Acceptable except chemical sensors	Acceptable except precipitation sensors	Acceptable except occasional sensor errors	Acceptable
21	Yes, but prefer open architecture	Yes, except precipitation sensors	Yes, but prefer open architecture	Yes
22	No	No	No	No
23	All with AVL	All with AVL	Many with AVL	Many with AVL
24	Yes	No	No	No
25	All	All	All	All
26	No except pavement temperature	Limitation on Cellular coverage	Limitation on Cellular coverage	No
27	Yes	Yes	Yes	Yes

Based on **Table 17** the following observations can be made:

- The number of RWIS sites needed depends on the number of micro weather zones, road miles and population.
- Most states installed their RWIS sites between the late 1980's and late 1990's.
- There are no firm criteria to select RWIS sites. However, MnDOT used a methodology similar to that proposed by NYSDOT. NYSDOT should consider the impacts of obstructions, both natural and man-made, which may affect atmospheric and road sensing capabilities in their design.
- Only the state of IN performed a comprehensive cost/benefit analysis of the deployment of RWIS sites to support MDSS. However, the inputs could not be obtained.
- Major benefits of RWIS are accident reduction and reduction in salt usage.
- All survey states have RWIS sites managed by other agencies but there is no or limited access to the data collected from those sites.
- Only ND relies on RWIS data from neighboring states.
- All four states indicated that the current number of RWIS sites is insufficient to support MDSS.
- In addition to supporting MDSS, all four states had other applications for data from RWIS, including Claus traffic operation and dissemination of information via their DOT website.
- There seem to be major differences in the way ESS sensors were installed and maintained. The majority preferred in house design, installation, operation and maintenance. Only one state subcontracted all tasks. In house maintenance seems to offer better performance.
- All of them installed air temperature, humidity, wind, barometric pressure, precipitation (type and intensity), visibility (0-10 miles), pavement temperature, subsoil temperature, and solar radiation sensors.
- All experienced issues with ESS. The majority preferred in house maintenance.
- All replaced damaged sensors with in-kind replacements, but when EES sensors are older than 15 years and when older sensors were not produced anymore, damaged sensors were replaced by new sensors which provided better information and were less expensive.
- Replacements were in kind or new sensors were specified to meet the criteria of current RWIS data needs.
- Collected ESS sensor data were transmitted via the local web server to a national webserver.
- Two states used an outside vendor for data transmission and the other two used in house support.
- Data was sent directly from RWIS servers to Meridian by FTP.

- The quality and accuracy of ESS sensor data seem acceptable except for chemical and moisture sensors.
- All are satisfied with the installed ESS sensors.
- There were no major issues of RWIS data supporting MDSS, but two states with outside vendors for data transmission preferred an open architecture.
- All four states were quite eager to use RWIS-AVL sensors.
- All except one state did not perform cost/benefit analysis of the use of RWIS-AVL sensors. WI performed a cost benefit analysis, but detailed information was not provided.
- RWIS-AVL sensors provided vehicle location, speed, chemical type and application rate, road and air temperature, road and weather condition. Some also obtained the dew point and relative humidity, precipitation and camera images.
- Two extremely rural states are facing limited cellular coverage.
- All four states plan to expand mobile RWIS in a larger scale for MDSS support. The MnDOT informed us of a new mobile infrared sensor that determines the road conditions, friction, and depth of moisture. It would be worth investigating further the capabilities of this sensor.

5 - 3. Summary

A comprehensive survey questionnaire consisting of 27 questions was developed to determine best practices of using RWIS to support MDSS. Two officials of Indiana, Minnesota, Wisconsin, South Dakota and North Dakota who were involved with or in charge of RWIS sites were contacted. The INDOT performed a comprehensive cost/benefit analysis of the deployment of RWIS sites to support MDSS but did not respond to our request for information.

In summary, the best practices of RWIS are quite similar in all four States, except for the way ESS sensors were installed, maintained and had their data transmitted. The MnDOT is doing everything in house and is proud of its achievement, whereas, the WIDOT has subcontracted all services. Hence, the consideration of WIDOT and MnDOT as two states with two best practices is recommended. In house installation, maintenance and data transmission would be the best option if NYSDOT has sufficient resources. However, if that is not possible, it is recommended that installation, maintenance and data transmission to be subcontracted to one vendor for best performance.

CHAPTER 6. METEOROLOGICAL ZONES AND WEATHER CONDITIONS

In this Chapter, an updated NYS meteorological map is presented. It was developed based on a proposed weather severity index, which was used to design a statewide RWIS network. In addition, real-time weather resources, including the National Weather Service (NWS) and the National Center for Atmospheric Research (NCAR), are summarized, and could be utilized to supplement observations from the NYS RWIS stations.

6 - 1. Introduction

NOAA classified New York State (NYS) into 10 Climate Divisions (**Figure 18**), which were overlaid on NYS's elevations. However, this classification was made long time ago, considering management convenience, and the zones were aligned with nearby NWS offices. In this Chapter, a method to develop an updated micro-meteorological map for NYS is proposed.

6 - 2. Data Sources and Analysis Methods

According to previous studies and survey results, four parameters were recommended to determine the weather severity in the NYS Meteorological Zones. The parameters are the Mean Wintertime Land Surface Temperature, Number of Weeks with Transitional Surface Temperature, Average Annual Snowfall Accumulation, and Average Annual Duration of Freezing Rain. To display the distribution of the four parameters over NYS, the weather data collected by NASA, NWS, and a study conducted by Mewes (2011) were used.

Figure 18 New York Climate Divisions Classified by NOAA

(Source: http://www.esrl.noaa.gov/psd/data/usclimdivs/boundaries.html, http://viewer.nationalmap.gov/viewer/)

6 - 2 - 1. Data Processing

a. Mean Wintertime Land Surface Temperature

The NASA MODIS LST data in wintertime (from December to February) over ten years (2003-2012), derived from satellite measurements in the infrared (Wan, 1999), were collected. As shown in **Figure 19**, the "severity score" runs from 1 to 10, reflecting the distribution of LST over NYS, where "1" represents the least severe condition (i.e., the warmest 10th percentile) and "10" represents the most severe condition (i.e., the coldest 10th percentile). One can clearly relate the distribution of LST to elevation and closeness to the Atlantic Ocean as shown in **Figure 19**.

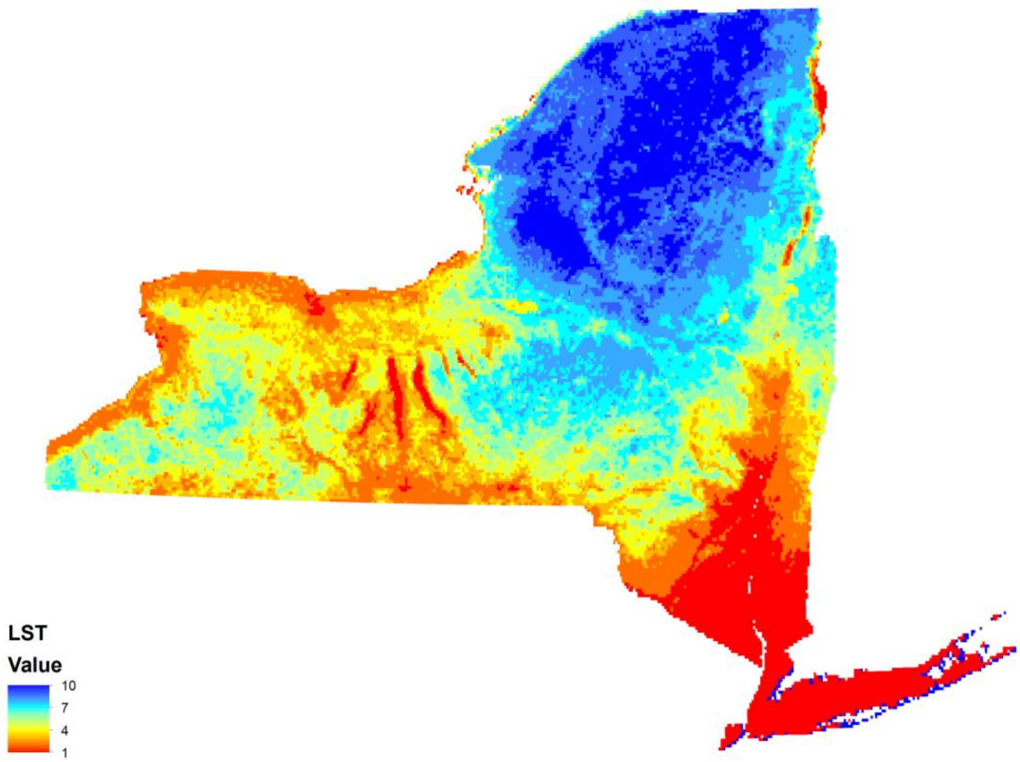

Figure 19 Mean Wintertime LST

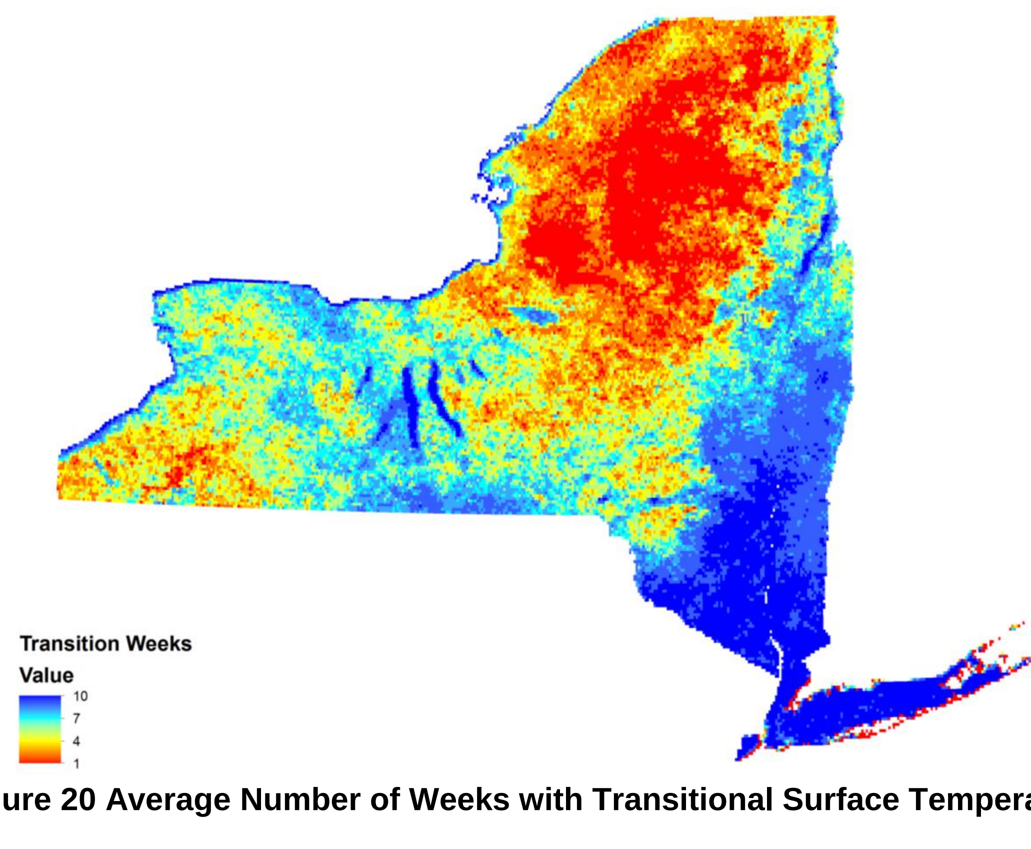

Figure 20 Average Number of Weeks with Transitional Surface Temperature

b. Number of Weeks with Transitional Surface Temperature

Transitional surface temperature refers to the condition that temperatures change from below to above the freezing point. After analyzing the LST data, the duration (in weeks) that the area experienced such a transition was determined. The duration of transitional surface temperature is represented by a “severity score” with “1” representing the lowest 10th percentile of the number of transition weeks and “10” representing the highest 10th percentile (See **Figure 20**). The Hudson Valley and coastal regions were found experiencing relatively longer duration than the rest of NYS. Upstate regions, on the other hand, were consistently below freezing, so there is little transition across the freezing point.

c. Average Annual Snowfall Accumulation

Average annual snowfall accumulation was determined based on NWS’s United States Climate Normals (1971-2000), which provides station-based data, and the Snow Data Assimilation System (2004-2011), which provides gridded data. The former data were used to estimate snow accumulation in the area near the stations, and the latter data were used for areas between stations (Mewes, 2011). Then, the average annual snowfall accumulation associated with weather severity zones in NYS were converted into “severity scores” with “1” indicating the lowest 10th percentile of snowfall accumulation and “10” the highest 10th percentile. The lake-effect snow can be easily identified on the downwind side of Lake Ontario. The Hudson Valley and Long Island regions experienced the least snow accumulation (see **Figure 21**).

d. Average Annual Duration of Freezing Rain

The duration of freezing rain was determined based on METAR observations from NWS (2000 – 2010) and the North American Model of the National Centers for Environmental Prediction (2004 – 2011). The distribution of freezing rain duration in NYS was also represented by a “severity score”, ranging from 1 to 10, and shown in **Figure 22**.

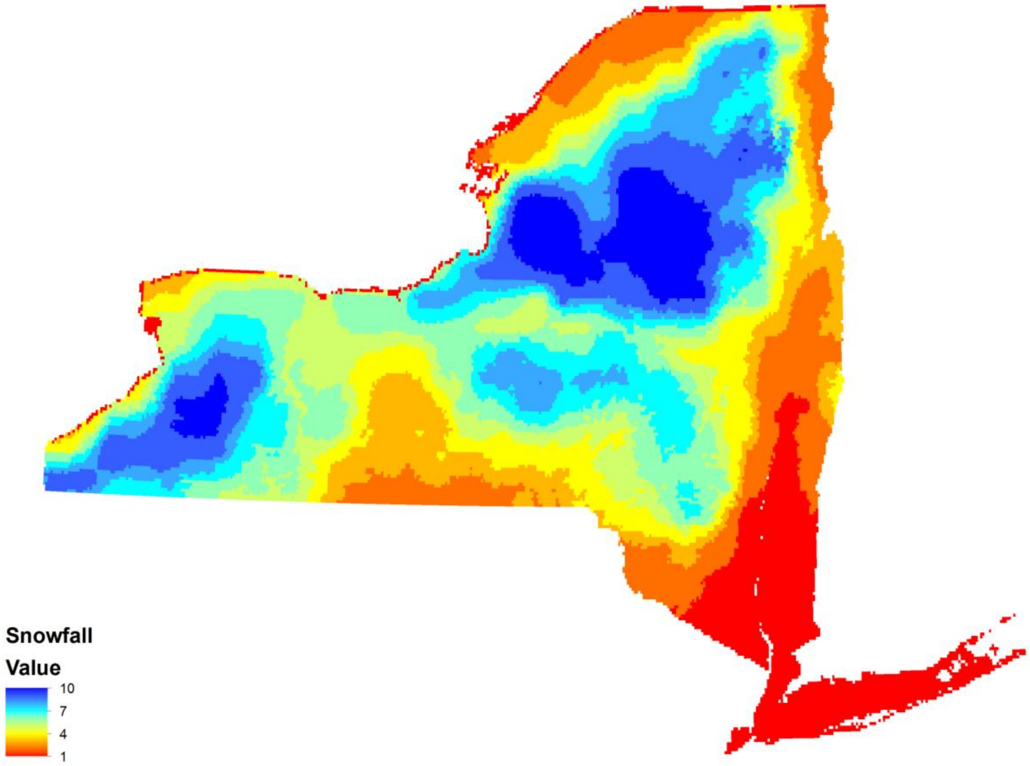

Figure 21 Average Annual Snowfall Accumulation

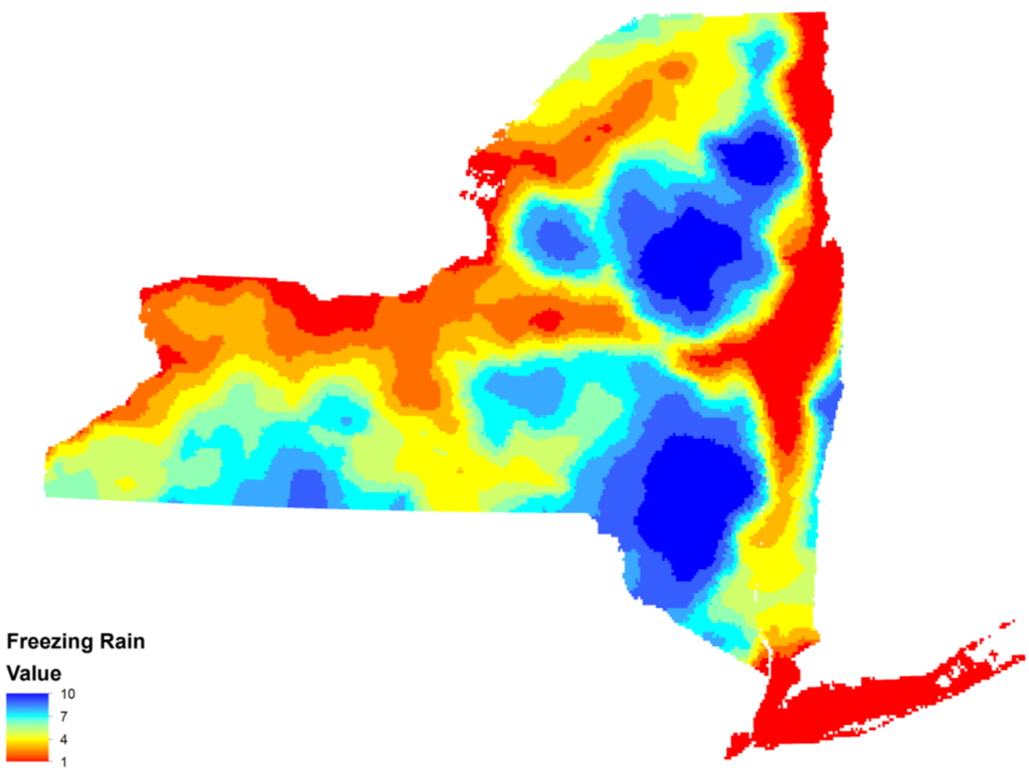

Figure 22 Average Annual Duration of Freezing Rain

6 - 2 - 2. Weather Severity Score

Mewes (2011) suggested four meteorological parameters and associated weights for identifying weather severity zones (see **Table 18**). The amount and duration of snowfall were assigned equal weights in representing weather severity. An hour of freezing rain was considered twice as important as an hour of snowfall because of extra caution needed for freezing rain conditions. In **Table 18**, the range of each parameter is also included.

Table 18 Meteorological Parameters and Weights

Parameters	Weights	Range
Average annual snowfall accumulation (Inch)	0.5	0 – 150
Hours of snowfall	0.05	0 – 1500
Hours of blowing snow	0.05	0 – 1000
Hours of freezing rains	0.10	0 – 75

By interviewing NYSDOT staff, various alternatives ideas concerning the weights of meteorological parameters were considered. Partially different from Mews' parameters, four parameters (see **Table 19**) were recommended to determine the weather severity of NYS, including Mean Wintertime Land Surface Temperature, Number of Weeks with Transitional Surface Temperature, Average Annual Snowfall Accumulation, and Average Annual Duration of Freezing Rain with all having the same weight. Note that these weights are modifiable in the future as additional data and/or evidence become available.

Table 19 Parameters to Determine Weather Severity Score

Parameters (Variables)	Weights (Variable)	Range
Average Wintertime Land Surface Temperature (W_1)	$\alpha_{W1} = 0.25$	1 – 10
Number of Weeks with Transitional Surface Temperature (W_2)	$\alpha_{W2} = 0.25$	1 – 10
Average Annual Snowfall Accumulation (W_3)	$\alpha_{W3} = 0.25$	1 – 10
Average Annual Duration of freezing rains (W_4)	$\alpha_{W4} = 0.25$	1 – 10

The weather severity score, denoted as S_w, is defined as the weighted sum of the four parameters. Thus,

$$S_w = w_1 \cdot \alpha_{w1} + w_2 \cdot \alpha_{w2} + w_3 \cdot \alpha_{w3} + w_4 \cdot \alpha_{w4}$$

where w_1, w_2, w_3, and w_4 are the scores, α_{w1}, α_{w2}, α_{w3}, and α_{w4} are the weights associated with the parameters.

6 - 3. Updated NYS Meteorological Zones

As shown in **Figure 23**, a higher score leads to a more severe weather condition. As expected, the Southern Plateau and Northern Plateau achieved higher weather severity scores than the NYC metro area and Long Island.

Figure 23 was used to develop NYS meteorological zones which are shaped by wintertime weather severity. This classification is different from the discrete categories of the NYS Climate Divisions shown in **Figure 18**. Now, NYS is divided into many micro-zones (i.e. 1-km by 1-km) and the associated severity scores are calculated. After overlaying the NYS highway network (i.e., Interstate, US and state highways) onto the meteorological zones, it was found that most Interstates and US highways are located in areas with lower weather severity scores.

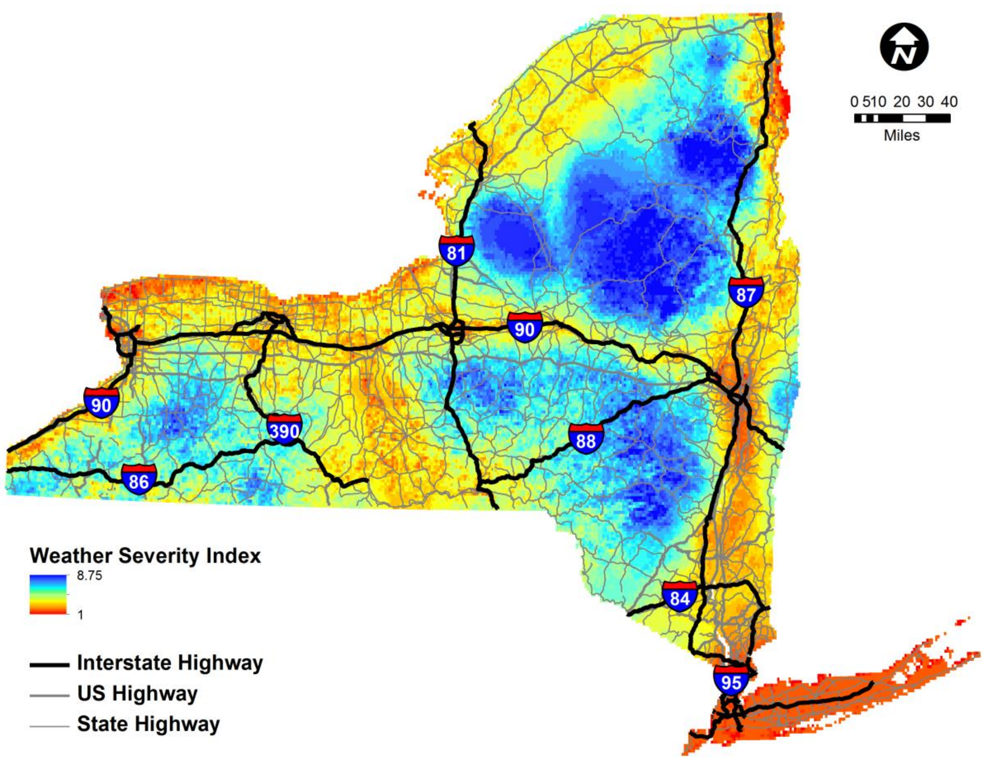

Figure 23 Winter Weather Severity

6 - 4. Real-time Weather Information Resources

In addition to the archived data used for identifying weather severity conditions, meteorological observations from NWS and NCAR could be integrated with atmospheric and pavement data collected from RWIS stations as MDSS inputs. Major sources for real-time weather information include:

NCAR:

- Research Applications Laboratory (RAL) Real-Time Weather Data (http://weather.rap.ucar.edu/). This website provides real-time weather information from multiple sources, including: 1) satellite, 2) weather radar, 3) surface weather stations, and 4) upper-air sounding from weather balloons. It also provides forecasting results ranging from 3 hours to 186 hours.

NWS offices:

- (NYC Metro) http://www.erh.noaa.gov/er/okx/
- (Buffalo) http://www.erh.noaa.gov/buf/,
- (Binghamton) http://www.erh.noaa.gov/er/bgm/
- (Albany) http://www.erh.noaa.gov/er/aly/

These are the standard NWS websites which provide weather information as mandated by NOAA. They are not as comprehensive or user-friendly as those provided by NCAR, but information is better tailored to local scales covered by each NWS office.

6 - 5. Summary

Based on survey results and previous studies, a winter weather severity index was developed to represent the micro-meteorological conditions across NYS, considered four meteorological parameters, including mean wintertime LST, average number of weeks with transitional surface temperature, average annual snowfall accumulation, and average annual duration of freezing rain. After data collection and processing, an updated meteorological map of NYS was generated, which was used to identify potential locations for developing a statewide RWIS network. In addition, sources for real-time weather information were identified, which could be integrated with the RWIS data into a MDSS for weather monitoring and forecasting.

CHAPTER 7. DESIGN OF A STATEWIDE RWIS NETWORK

In this Chapter, a solution framework of optimizing typical RWIS sites in NYS is proposed. Within this framework, a bi-level optimization model was developed, considering regional weather severity and return on investment of RWIS implementation.

7 - 1. Introduction

There were 292 potential RWIS sites identified by the survey results, including both typical and problem locations. However, these sites seemed not to provide statewide coverage. To fix this problem, potential locations were also determined by dividing the NYS highway network into many one-mile segments. Then the weather variability centered at each potential site can be determined based on the weather severity index developed in Chapter 6. A GIS-based bi-level model was developed, with the upper level model used to determine the optimal number and locations of RWIS stations, and the lower level model used to refine the optimal results.

7 - 2. Solution Method to Optimize Typical RWIS Sites

7 - 2 - 1. Proposed Framework

The potential RWIS sites and factor weights for site evaluation criteria were determined based on data collected from the survey. By integrating meteorological data associated with each site, the corresponding weather severity index and spatial weather variability were calculated. As shown in **Figure 24**, a five-step procedure was developed to optimize RWIS sites.

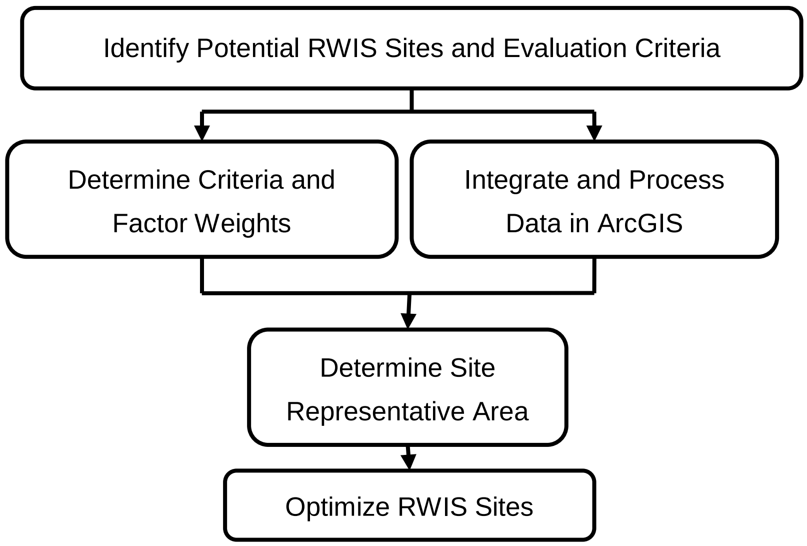

Figure 24 Solution Framework for Optimizing Typical RWIS Sites

Step 1: Identify Potential Sites and Evaluation Criteria

A list of potential sites and factors for site evaluation were obtained from the survey as well as previous studies discussed in the literature review, participated by the NYSDOT maintenance and operation personnel.

Step 2: Determine Factor Weights

The factor weights were determined based on a previous study (Mewes, 2011) and the survey outcomes.

Step 3: Integrate and Process Data in ArcGIS

Quantifiable data associated with each factor were collected, integrated into GIS, and used to compute the winter weather severity index and determine the spatial weather variability.

Step 4: Estimate Site Representatives

Based on the winter weather variability index in Step 3, a representative area was determined based on site location and the associated weather variability subject to different radii centered at each site.

Step 5: Optimize and Prioritize RWIS Sites

> Subject to practical constraints (e.g., budget constraint), the number and locations of RWIS sites can be determined by a bi-level optimization model, which will be discussed in Section II-2.

Unlike typical sites, the evaluation of problem sites considers environmental conditions, such as slippery pavement, low visibility, high wind, and water level conditions (**Manfredi et al., 2008**). In this study, the problem sites suitable for RWIS were treated as exogenous variables, which can be determined based on engineering judgment and a benefit/cost analysis. Note that the problem sites identified by the NYSDOT personnel were classified into three groups (i.e., high, medium, and low priority) based on the scores determined by traffic volume and weather severity (See **Appendix - F**).

7 - 2 - 2. Optimization Model

A bi-level sequential optimization model was developed. The upper level model optimizes the number and location of potential sites that maximize the coverage area. The lower level model refines the optimal site determined in the upper level, to maximize profit.

Upper Level Model – Maximizing Coverage

Let ***I*** be a set of potential sites, and x_i a binary variable representing the decision to locate at *i*, where $i \in \boldsymbol{I}$. If site *i* is selected, x_i is 1; otherwise, x_i is 0. Thus,

$$x_i = \begin{cases} 1 & \text{Site } i \text{ is selected} \\ 0 & \text{Site } i \text{ is not selected} \end{cases}, \forall i \qquad (1)$$

Based on identified meteorological parameters, and the weather severity index (discussed in Task 6), the spatial weather variability was analyzed **(**See **Appendix - G)**. In general, the smaller the spatial variability, the longer the distance can be between two stations.

The results of the spatial weather variability analysis revealed a *critical radius* for each site, which provides guidance from a weather perspective on the distance between a pair of sites where an RWIS station should be placed. For each potential site, the standard deviations of the weather severity index as a function of radius ranging from 1 to 25 miles were calculated. Usually, the standard deviation increases with the radius. The critical radius is determined by the greatest change in standard deviation. A site representative area is a circle with critical radius centered at the site. It is worth noting that if two potential sites are too close to each other, their representative areas would be overlapping.

The objective is to find the minimum number of sites which maximize the total representing area. Therefore, the objective function is the coverage area, denoted as ***S***, which is the total representative area minus the total overlapping area. Thus,

$$MAX.\ S = \sum_i x_i \cdot A_i - \sum_i \sum_j x_i \cdot x_j \cdot O_{ij},\ \forall i, j \qquad (2)$$

where A_i is the representative area of site *i* (for a sample computation see **Appendix - G**), and O_{ij} is the overlapping area of sites *i* and *j* (**Figure 25**).

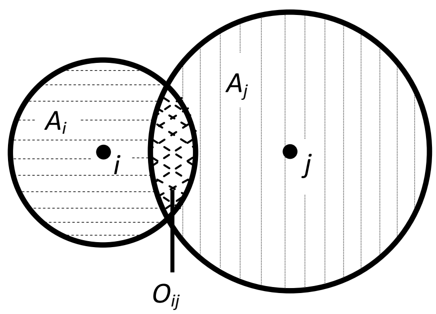

Figure 25 Site Representative and Overlapping Area

Lower Level Model – Maximizing Profit

Introducing the cost and benefit issues into the optimization, the optimal sites might be fewer than those obtained in the upper level model, because the RWIS installation/maintenance cost might exceed the benefit. Therefore, the lower level model, embedded with a B/C model (see **Appendix - H**), can be used to refine the optimal sites.

Each potential site is associated with a cost as well as benefit. Let ***K*** be the set of feasible sites resulting from the upper level model. B_k and C_k represent respectively benefits and costs associated with site *k*. The objective function is the total benefit minus the total cost, denoted as $\boldsymbol{P_T}$. Thus:

$$MAX.\ P_T = \sum_k x_k \cdot B_k - \sum_k x_k \cdot C_k \tag{3}$$

where x_k is the choice of site *k*.

The benefit/cost ratio, denoted as ***R***, could be calculated based on the refined choice of sites.

$$R = \frac{\sum_k x_k \cdot B_k}{\sum_k x_k \cdot C_k} \tag{4}$$

7 - 3. Data Processing and Model Inputs

The purpose of this section is to process the collected data, so that the results may be used as inputs of the proposed optimization model. The developed model inputs include:

1. Locations of potential sites
2. Weather factors and weights
3. Traffic conditions

7 - 3 - 1. Locations of Potential Sites

In addition to existing RWIS sites in NYS (See **Figure 26**), 292 potential sites were identified, which include 177 typical sites marked as blue circles and 115 problem sites marked as brown triangles. As indicated in **Table 20**, 208 potential sites are located on NY state highways, 36 on US highways, and the remaining 48 were on the Interstate highways.

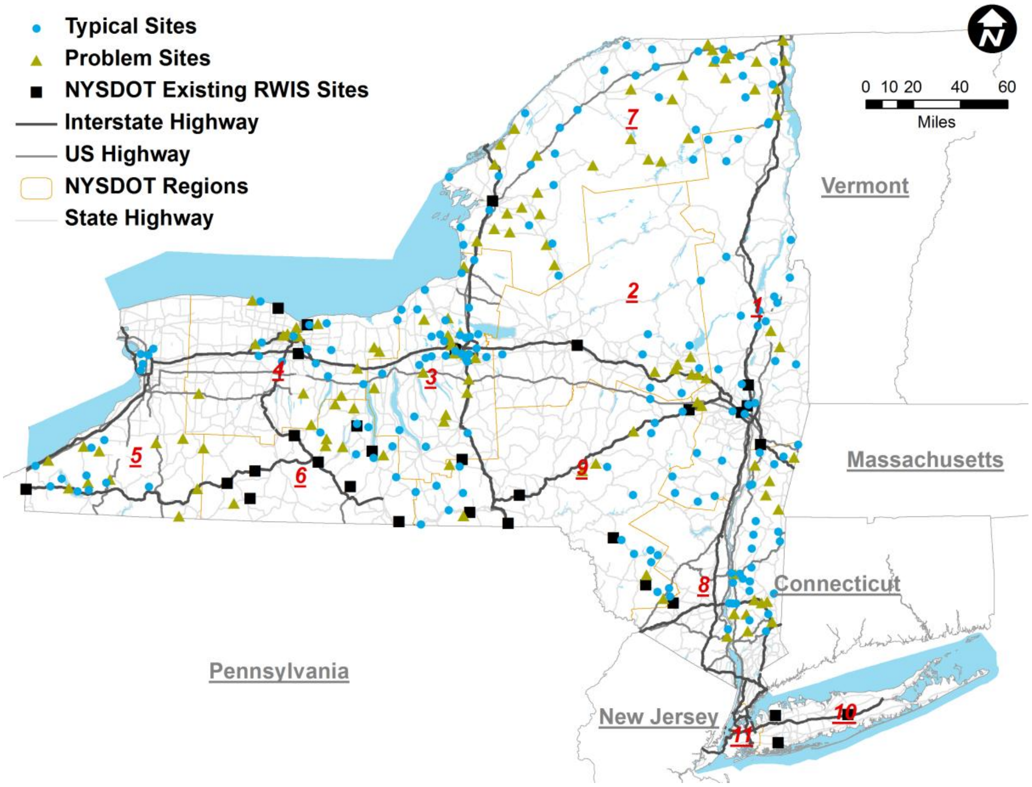

Figure 26 Existing & Potential RWIS Sites

Table 20 Potential Sites Classified by Highway Types

Segments	No. of Typical Sites	No. of Problem Sites	Total Potential Sites
Interstate Hwy.	29	19	48
State Hwy.	127	81	208
US Hwy.	21	15	36
Total	177	115	292

Note that no potential sites were located in Regions 10 and 11 (Note: Region 11 is out of the scope of this project). Considering regional spatial weather variability and the statewide coverage of RWIS in the site selection process, the NYS highway network was divided into 1-mile segments. Then a potential site was designated to each segment to develop the list of potential sites.

7 - 3 - 2. Weather Factors and Weights

As discussed earlier, the weights (i.e., the importance) of factors were determined based on the survey results and previous studies. Four weather parameters were given the same weights:

a. Average annual snowfall accumulation (AASA),
b. Number of freezing rain events,
c. Number of weeks with transition temps, and
d. Average wintertime land surface temperature

7 - 3 - 3. Traffic Conditions

The NYS highway network and the Average Annual Daily Traffic (AADT) were used to estimate benefit and cost in the lower level Model.

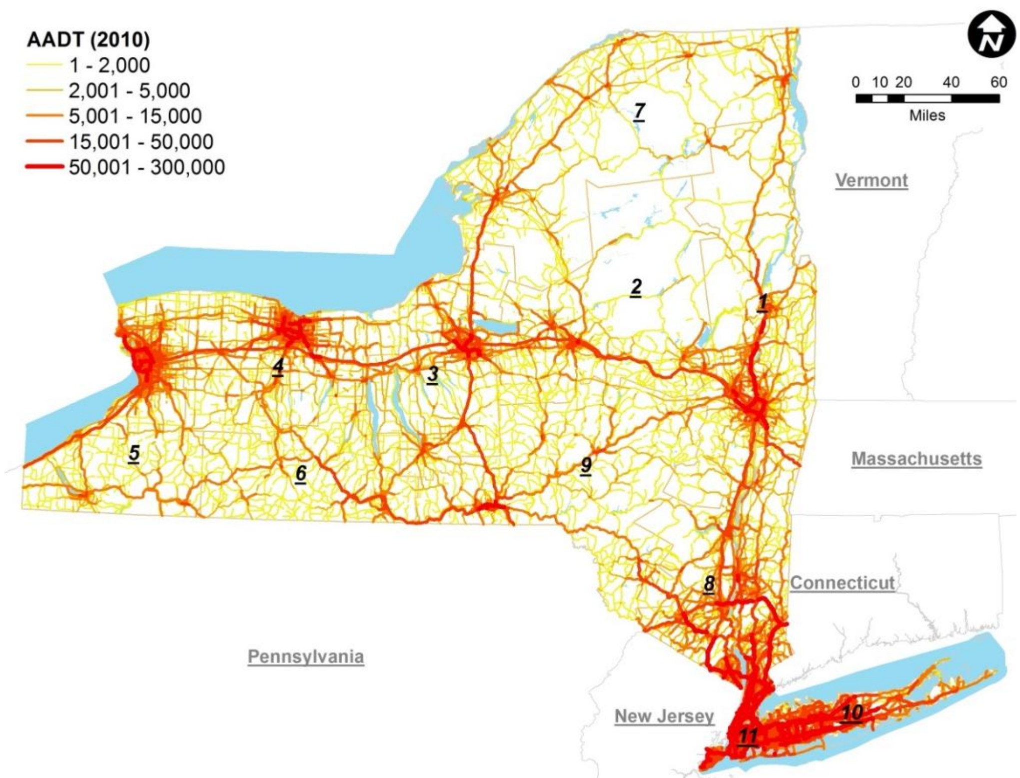

Figure 27 NYS Highway Network and AADT

7 - 4. Optimal Results and Analysis

7 - 4 - 1. Optimal RWIS Sites from Upper Level model

The RWIS sites should be optimized based on the types of existing sites (i.e., typical or problem site). Since this information was unavailable, the optimization process was undertaken under the assumption that all existing sites are typical sites. As a result, a total of 38 optimal sites were identified (see **Figure 28**). As indicated in **Figure 27**, the density of existing RWIS stations in Region 6 is fairly high. Therefore, new sites have not been recommended in this region. Due to severe weather conditions, high spatial weather variability, and few existing stations, more optimal sites appeared in Regions 1, 2, and 7 (see **Table 21**).

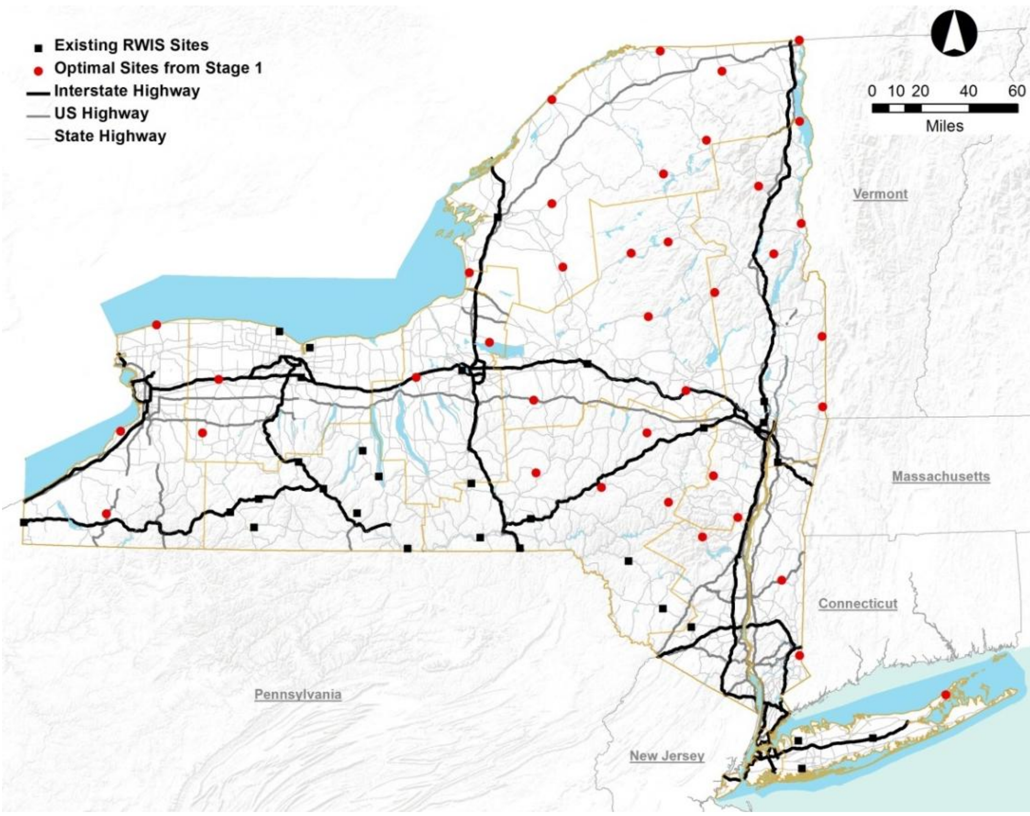

Figure 28 Optimal Sites Considering Existing RWIS

As shown in **Figure 29**, the optimal sites (i.e., triangular points) not only cover most clusters of potential sites identified through the survey (i.e., blue dots), but also fill the gaps where no potential sites were proposed (i.e., gray/light brown circles represent the coverage area of optimal sites). As discussed above, though several locations were identified in Regions 4, 6, and 8, no new sites are recommended due to the high density of existing RWIS sites. Note that the locations for optimal sites could be slightly shifted to meet operational needs.

The location information of these sites is summarized in **Table 22,** with the check mark showing that several optimal sites exist in the list of the survey suggested sites. The associated attributes of the sites, including location, weather, and traffic conditions, are listed in **Appendix - I**.

Table 21 Existing & Optimal Sites by Region

Region	No. of Existing Sites	No. of Optimal Sites	Total
1	4	8	12
2	1	5	6
3	1	3	4
4	3	2	5
5	1	3	4
6	9	0	9
7	1	9	10
8	1	3	4
9	7	4	11
10	3	1	4
11	NA	NA	NA

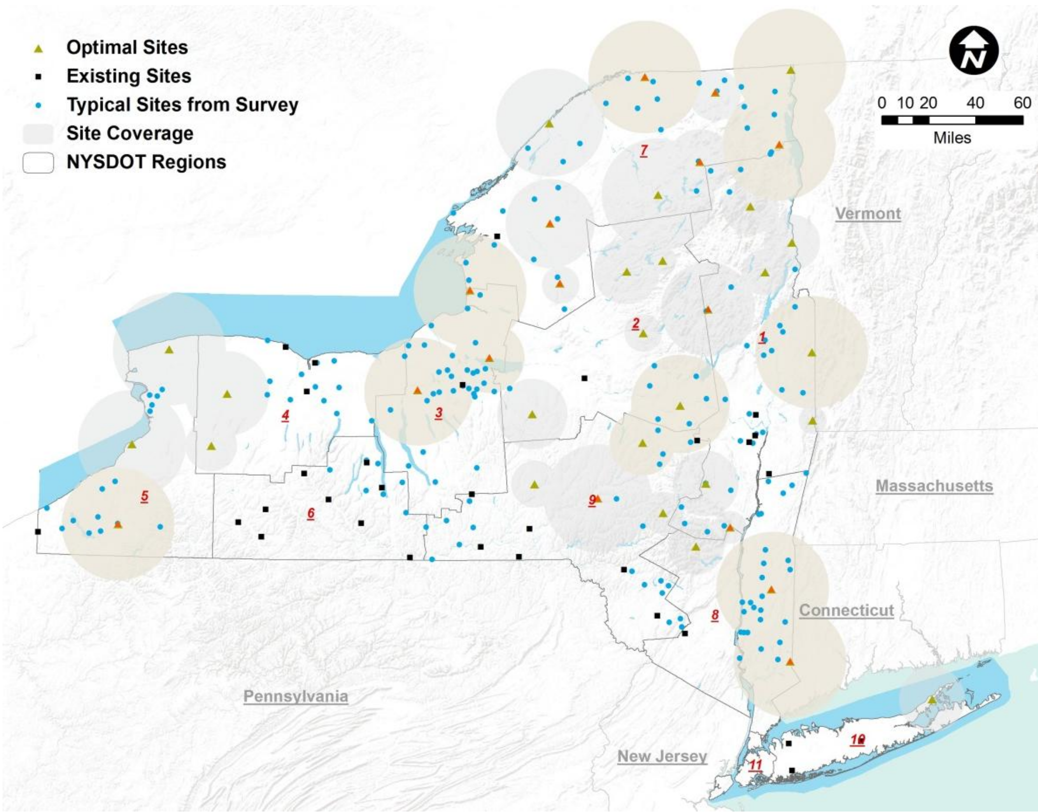

Figure 29 Survey Suggested Sites vs. Optimal Sites

Table 22 Locations of Optimal RWIS Sites

ID	Route	Residency	Residency Name	Survey Suggested Site Check
1	NY 22	1-2	Essex	
2	NY 73	1-2	Essex	
3	NY 23A	1-3	Greene	√
4	NY 145	1-3	Greene	
5	NY 346	1-4	Rensselaer	
6	NY 8	1-7	Warren	√
7	NY 8	1-7	Warren	
8	NY 22	1-8	Washington	
9	NY 8	2-2	Hamilton	
10	NY 28	2-2	Hamilton	
11	I- 90	2-5	Fulton-Montgomery	
12	NY 28	2-6	Oneida East	
13	US 20	2-7	Oneida West/Madison	
14	I- 90	3-1	Seneca/Cayuga	√
15	NY 49	3-5	Oswego	√
16	NY 3	3-5	Oswego	√
17	I- 90	4-1	Genesee/Orleans	
18	NY 98	4-7	Wyoming	
19	US 62	5-2	Chautauqua	√
20	NY 5	5-4	Erie South	
21	NY 78	5-5	Niagara	
22	I- 87	7-1	Clinton	√
23	US 11	7-1	Clinton	
24	NY 186	7-2	Franklin	√
25	NY 190	7-2	Franklin	√
26	NY 37	7-2	Franklin	√
27	NY 12	7-4	Lewis	√
28	NY 3	7-4	Lewis	√
29	NY 3	7-5	St Lawrence	
30	NY 68	7-5	St Lawrence	
31	US 44	8-2	Dutchess North	√
32	NY 28	8-7	Ulster	
33	NY 116	8-8	Westchester North	√
34	NY 220	9-2	Chenango	
35	NY 357	9-5	Otsego	√
36	NY 165	9-5	Otsego	
37	NY 30	9-6	Schoharie/Delaware North	
38	NY 25	10-3	Suffolk East	

7 - 4 - 2. B/C Model

Assume that the estimated lifetime of an RWIS site is about 25 years, and the RPU/ CPU should be replaced or upgraded every 5 years. The interest rate is 5%. An example B/C analysis was conducted using the parameters from a previous study (McKeever et al., 1998).

Table 23 Parameters in the B/C Model

Item	Value	Unit
• Unit man-hour cost	25	$/hour
• Unit truck-hour cost	25	$/hour
• Unit deicing material cost		
Sand	8	$/cubic yards
Salt	60	$/ton
MgCl	400	$/ton
• Patrolling hour per storm per residency	24	hours
• Man-hours per storm per residency	576	hours
• Truck-hours per storm per residency	288	hours
• Frequency of winter storms	3	No./year
• Materials applied per storm per mile		
Sand	2	cubic yards
Salt	0.3	ton
MgCl	0.1	ton
• Traffic volume	---	vehicles per day
• Total roadway length the sites cover	*7,778*	miles
• Annual pollution cost savings	---	$/year
• Annual travel time cost savings	---	$/year
• Equipment and installation cost	High - 42,000; Low - 36,000	$
• Annual operation and maintenance Cost	High - 4,000; Low - 1,800	$/year
• Unit cost of RPU and CPU	10,400	$

By overlaying the potential sites with the NYS highway network, a total of 7,778 mile highway segments within 45 residencies were identified. The associated lane-mile distance and AADT were used to estimate the cost and benefit of each site. To refine the optimal sites from the upper level model, any site whose cost is greater than its benefit shall be removed. It was found that all 38 optimal sites shall stay.

The calculation of B/C ratio for the whole set of optimal sites was included in **Appendix - J**. Additional data inputs need to be updated in order to generate the B/C ratio for specific regions or individual stations. For instance, various sensors (i.e., precipitation, air/pavement temperature and camera images) to be deployed could result in different installation and maintaining costs among sites. The B/C ratio estimation for the 38 sites was computed. It was found that the B/C ratio varies from 10.80 to 15.52 dependent on the cost of installation and maintenance options.

Light RWIS stations could provide weather information with relatively low cost. The sample cost for such type of RWIS is included in **Table 24**, as a comparison with the traditional RWIS station. The benefit/cost ratio for light RWIS stations would be much higher than that for traditional RWIS stations. However, whether its functionality is comparable to a traditional RWIS station and its lifetime are uncertain. Thus, this B/C analysis is not included in this report.

Table 24 Costs for Light RWIS

Component	Cost
Initial Cost	$1,000
System Overhaul Cost	$200 - $500 every 5 years
Lifetime	10 years

7 - 5. Summary

The optimal statewide RWIS network (i.e., typical RWIS stations) was recommended based on a bi-level optimization model considering weather severity and variability as well as the associated cost and benefit of each site. There were 115 problem sites indicated by the survey takers, which were prioritized in **Appendix - F**. The problem sites should be further examined against geographic conditions (e.g., slippery pavement, low visibility, or high wind conditions), based on the regional weather severity and traffic conditions.

The upper level model considered heterogeneous weather patterns across NYS, providing optimal solutions which could reflect regional spatial weather variability (i.e., micro-climate effects). By assuming all existing sites are typical sites, the model recommended 38 additional typical (optimal) sites (See **Appendix - I**). Further study should be undertaken after confirming the type of the stations (i.e., typical or problem), site operational status, and infrastructure status of the current RWIS stations.

The lower level model embedded a prototype RWIS life-cycle B/C model, which was used to refine the optimal solutions from the upper level model and estimate the B/C ratio for all recommended sites. Using the example data, it was found that all the optimal sites from the upper level model shall stay to yield maximum profit. The benefit/cost ratio ranges between 10 and 15 based on parameter values used by McKeever et al. (1998). To improve the accuracy of this benefit/cost analysis for NYS, detailed information (i.e., storm frequency, unit labor cost, labor hours per storm, number of trucks needed, unit truck cost, and truck hours per storm) should be collected and used.

CHAPTER 8. RECOMMENDATIONS

To estimate the costs and benefits associated with a RWIS ESS network one must first determine what is needed and can be supported by NYSDOT for the design, preparation, installation, and operation of these systems. Four key activities that address these issues and provide much of the analysis necessary for a defensible exploration of costs are described in this chapter and include:

a) **Site inspection of existing field ITS and locations** - supplemented by surveys of agreed potential sites, to provide estimates on site preparation, installation, and maintenance costs
b) **Establishment of a statewide Winter ITS Maintenance Strategy** – cost structuring is crucial to detailing how the system will be governed and maintained, and thus what the cost burdens will be, who will carry them, and where the associated benefits will be seen
c) **Geographic and Functional Phasing Plan** – what early benefits can be realized in which regions by certain points in time, which regions should have all the benefits while other regions need only some, presenting flexibility in deployment and cost savings
d) **Integration of disparate Winter ITS and Processes** – the savings in operational efficiencies examined in the context of whole-system costs, not just as raw equipment and materials

The estimation of costs and benefits should also reflect details of previous equivalent ITS deployments at NYSDOT and include consideration of local historic and current costs taken into account as well as lessons learned. While it can be attractive to view raw figures from product literature or deployments at other properties as a guide, without dedicated analysis of cost variables, estimations at a specific site are not reliable.

Figure 30 illustrates how products of the recommended areas (in blue) fit relative to the current project (in red). There are also optional areas and products that the NYSDOT may consider developing, but these are not necessary at this time (in white). The combined knowledge base can support a whole Winter ITS program (in green) through its full life cycle.

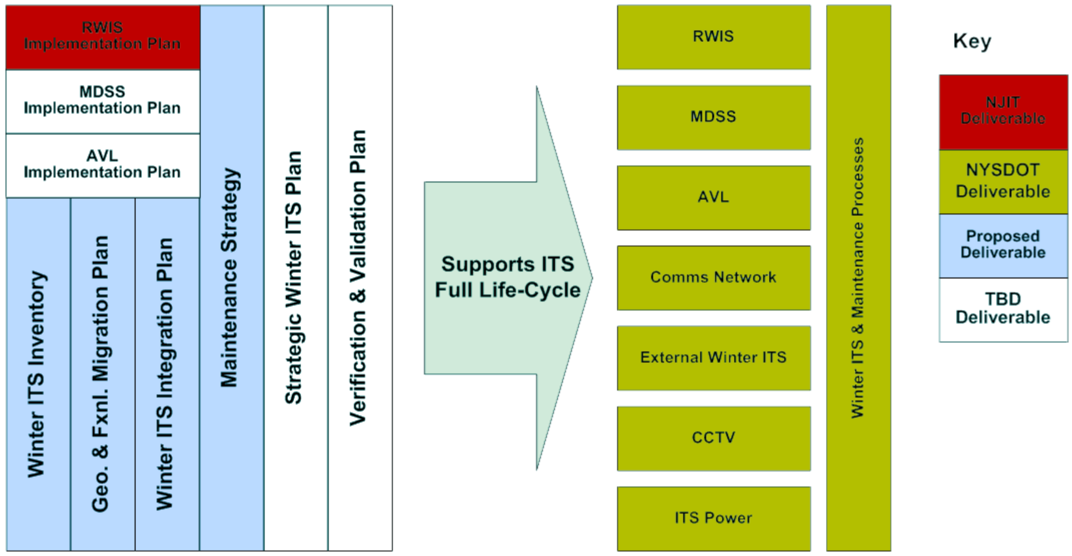

Figure 30 Next Step Deliverables[2]

<u>Site Inspections of Existing Field ITS and Locations</u>

Current and legacy ITS systems that support Winter Road Maintenance include the RWIS sensors and networks, MDSS pilots, AVL pilots, the Snowmat reporting system, CCTV, WTA, NY511 and supporting systems such as power and communications. However, there is no single source of statewide accurate information about the location, configuration, functionality, condition, purposefulness (how they are used), or fit-for-purpose of all these systems.

The deployment of new RWIS, MDSS and AVL needs to leverage existing assets and infrastructure in a way that minimizes expending unnecessary resources. Recognizing the savings in capital and recurring costs that current and legacy systems will bring is crucial to funding upcoming deployments. A baseline ground-truth of the field ITS will minimize the risk of duplicating or expending unnecessary resources and effort, and thereby maximizing the potential to reuse and leverage systems.

There are, for example, a number of legacy RWIS networks in the State in a variety of conditions. Approximately half of the more recent Lufft systems have failed partially or totally with the reasons why being still unclear. Operators mentioned that they know from experience when readings from the instruments are incomplete or inaccurate and that false positives are a concern because they undermine the confidence in the system. Concerning field locations, there are

[2] The current deliverable (red) is enhanced and extended by next steps (blue), which ultimately support the technology and processes design, development, operations and maintenance (green).

retired RWIS sites across the state with access power and/or communications networking. Maintenance Shop facilities may have networking bandwidth and quality-of-service issues. How field location resources should be used, or upgraded will remain an open question without surveying their current state.

Performing an inventory of the current ITS systems statewide is proposed, which can be done on a region-by-region basis. The condition, description of use, and fit-for-purpose of each technology should be assessed.

Establish a Statewide Winter ITS Maintenance Strategy

NYSDOT needs a strategy for statewide maintenance investment and the clear articulation of B/C to users and systems across the state. Without this strategy, user confidence in Winter ITS systems will decline as systems deteriorate.

Financing the ongoing support and maintenance of systems is an immediate challenge for NYSDOT. It is believed that a sustainable strategy and B/C case are possible, providing an understanding of where and how it is best for the responsibility for Winter Road-Maintenance Technologies (RWIS, MDSS, AVL) to reside. Currently maintenance is done on an ad-hoc, as-needed, region-to-region basis (with some state-level intervention) by Maintenance personnel who feel they are not ideally resourced or trained to perform this function. This is an impractical, non-sustainable model and needs to be addressed.

NYSDOT recognized the cost-savings that ITS can deliver and the importance of ongoing maintenance. NYSDOT needs a tailored strategy that goes beyond national best-practices and works for New York. Based on site-visit discussions, NYSDOT specific questions we believe should be explored to develop this strategy and business cases are:

- Should control or maintenance of Winter Road-Weather ITS be transferred to another NYSDOT division? If so, where, and why?
- Which responsibilities should be outsourced, and how? Could the performance targets/penalties be put on 3rd party contracts, and if so, what is reasonable to ask for?
- Should maintenance responsibility be held at the regional or statewide level?
- How could the maintenance costs be minimized early in the planning stages?
- How are current technologies being supported or expanded to manage future RWIS, MDSS, or AVL deployment?

Geographic and Functional Migration Plan

The needs, demands, and adoption of Winter ITS technology are not the same across New York State. Regional weather demands change the return-on-investment value of the equipment. Skills, training and confidence of personnel involved with Winter ITS vary depending on their need and prior experience. Given the functional and geographic variations as well as budget and time constraints, NYSDOT would benefit from considering a phased migration path towards the Winter ITS and operations end-goal. Prioritizing the investment geographically, functionally, or using a combination of both would deliver more benefits earlier to NYSDOT. There is a greater likelihood of ITS whole-system cost savings if defects in planning and design are identified earlier in the migration planning.

The retirement of experienced maintenance personnel with strong local winter road maintenance experience was raised as a major concern during the site visit to Friendship. This diminishing expertise and increase in less-experienced more technology reliant (but accepting) personnel will challenge the NYSDOT's road maintenance practice. However, migration planning allows the minimization of the cost of this transition through assessment and prioritization of resourcing based on projected demand.

Investment in ITS recognizes not only the demands of the systems themselves (e.g., RWIS for MDSS) but also region-by-region variations in climate, operational need, operational capability, skill level, and training of operators to use and interpret the systems. Some of the specific questions that could be explored are (not in order of priority):

- Where should the NYSDOT deploy Winter ITS first to realize early benefits?
- Does NYSDOT need uniform MDSS capability, accuracy and performance across the entire state? Where does it need MDSS in NYS? What makes fiscal sense?
- How should NYSDOT prioritize investment in MDSS, RWIS, and AVL?
- Can there be variation in MDSS or Winter ITS quality across the state?
- What derivative benefits would AVL provide, other than validating MDSS? E.g., planning

Integrate Disparate Winter ITS and Processes

Many of the existing Winter ITS systems that are used in data collection, storage, and dissemination are not currently integrated with each other. This means that, for example, operators must make multiple entries of the same data into systems, or have to curtail road-maintenance operations in order to perform reporting duties. Without addressing this issue or leveraging the opportunity for automatic distribution of information between systems, a coordinated, shared situational awareness is not possible; NYSDOT could benefit from enhancing the synergy between systems.

A related issue of new ITS is data ownership and hosting. The RWIS data is currently owned but not hosted by NYSDOT. Instead, it is contracted through a third party. Concern about this contract expiring and the implications for historic data keeping and analysis was raised during the site-visit. Deploying new technology should include a strategy for how the data will be integrated and managed when the system “goes-live” and begins providing operational benefits.

Cost and efficiency savings can also be realized through better integration of disparate operating processes. Changing processes that the staff perform in order to better integrate technology such as minimizing steps that operators or supervisors have to take during their daily operations would be of benefit to NYSDOT.

Examples of the tasks that could be carried out in this area are:

- Use the baseline knowledge of in-use ITS Technologies built up in III-1 and identify current and potential interfaces between the systems
- Assess the operational benefit of interfacing systems
- Assess the technical feasibility of interfacing systems
- Recommend how to best interface systems based on NYSDOT business and best practices

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APPENDIX

A. Abbreviations and Definitions

AADT	Annual Average Daily Traffic data
AASA	Average annual snowfall accumulation
ADOT&PF	Alaska Department of Transportation and Public Facilities
AT/RH	Air Temperature/Relative Humidity
AVL	Automatic Vehicle Location
AVL/MDC	Automatic Vehicle Location /Mobile Data Collection Systems
AWOS	Automated Weather Observing System
CCTV	Closed Circuit Television Cameras
COOP	Cooperative Observer Network
CPU	Central Processing Unit
CTDOT	Connecticut Department of Transportation
DOT	Department of Transportation
ESS	Environmental Sensor Stations
FHWA	Federal Highway Administration
GIS	Geographic Information System
GUI	Graphical User Interface
INDOT	Indiana Department of Transportation
ITS	Intelligent Transportation Systems
LST	Land Surface Temperature
MADIS	Meteorological Assimilation Data Ingest System
MADOT	Massachusetts Department of Transportation
MAMIS	Maintenance Asset Management Information System
MDSS	Maintenance Decision Support System
MIDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NDDOT	North Dakota Department of Transportation
NDOT	Nevada Department of Transportation
NOAA	National Oceanic and Atmospheric Administration
NVDOT	Nevada Department of Transportation
NWS	National Weather Service
NYSDOT	New York State Department of Transportation
NYSTA	New York State Thruway Authority
PADOT	Pennsylvania Department of Transportation
PFS	Pooled Fund Study
RPU	Remote Processing Unit
RWIC	Regional Weather Information Center
RWIS	Road Weather Information System
SDDOT	South Dakota Department of Transportation
SWIS	Season Weather Information Systems
VTAOT	Vermont Agency of Transportation
WIDOT	Wisconsin Department of Transportation
WS/WD	Wind Speed and Direction

B. NYSDOT RWIS Configuration

RWIS Site No.	Sensor Type										
	AT/RH		Precipitation		Net Radiation		CCTV			WS/WD	
		Status		Status		Status		IR	Status		Status
1-1-0-1											
1-1-1-1	√	*	√	O	√	*				√	O
1-4-1-1	√	*	√	O	√	*				√	O
1-5-0-1											
2-6-0-1											
3-4-1-1	√	O	√	O							
4-3 T&E	√	*	√	O			√	√	O	√	O
4-3-1-1	√	*	√	O	√	D	√		O	√	O
4-4-0-1											
5-2-0-1											
6-1-0-1											
6-1-1-1	√	D	√				√	√	O		
6-1-2-1	√	*	√	O	√	*	√	√	O	√	O
6-2-0-1							√		O		
6-2-1-1	√	O	√	O						√	O
6-2-2-1	√	O	√	O	√	*	√		O	√	O
6-3-0-1											
6-3-1-1	√	*	√	O						√	O
6-4-0-1							√		D		
7-3-0-1											
8-5-0-1											
9-1-0-1							√	√	O		
9-1-0-2	√	O	√	O	√	*	√	√	O	√	O
9-1-0-3							√	√	O	√	O
9-1-0-4	√	O	√	O			√		O	√	O
9-6-0-1											
9-7-0-1											
9-7-0-2											
10-1-0-1											
10-3-0-1											
10-6-0-1											

(Source: NYSDOT, 2011)

√: Included in the station, *: Calibration Required, O: Operational, D: Down

C. NYSDOT Statewide RWIS Implementation Survey

Part A: Contact Information

1. Please provide your contact information so we may follow up with you if required
2. Please select your present role or title
    a. Highway Maintenance Supervisor I
    b. Highway Maintenance Supervisor II
    c. Bridge Maintenance Supervisor I
    d. Bridge Maintenance Supervisor II
    e. Assistant Resident Engineer
    f. Resident Engineer
    g. Assistant Regional Maintenance Engineer
    h. Regional Maintenance Engineer
    i. Assistant Regional Director of Operations
    j. Regional Director of Operations
    k. Traffic Management Center Operator
    l. Traffic Management Center Director
    m. ITS Engineer
    n. Other

Part B: Use of RWIS Station Data

3. Do you have access to and use RWIS station information?
    a. Yes, use regularly
    b. Yes, use occasionally
    c. Yes, use rarely
    d. No, not required
    e. No, it is not available
    f. No, if available I would use it
4. Do you use RWIS station data in your role to make highway maintenance operations decisions?
    a. Yes, use regularly
    b. Yes, use occasionally
    c. Yes, use rarely

    d. No, not required
    e. No, it is not available
    f. No, if available I would use it
5. Is RWIS station information accessible and being used at your agency or location?
    a. Yes
    b. No

Part B-1: Use of RWIS station information for locations with RWIS

6. How useful is the following RWIS station information to you in your role (Highly useful, useful, neutral, not useful, not sure)?
    a. Air Temperature
    b. Air Pressure
    c. Relative Humidity
    d. Dew Point
    e. Wind Speed/Gust Speed and Direction
    f. Precipitation Type
    g. Precipitation Intensity/Accumulation
    h. Road Surface Temperature
    i. Road Subsurface Temperature
    j. Road Surface Condition (Wet, Dry)
    k. Road Surface Condition (Snow, Ice, Frost)
    l. Road Surface Applied Chemical Concentration
    m. Frost Penetration
    n. Snow Depth Measure
    o. Access to Camera Imagery (CCTV)
    p. Real Time Traffic Speed
    q. Other Information
7. What benefits do you see RWIS Station information delivering to NYSDOT?
    a. Provide operational cost savings through improved management of services
    b. Detect real-time road condition data for operations/maintenance decisions
    c. Verify road condition or weather data provided by other sources

    d. Support Maintenance Decision Support System (MDSS) data needs
    e. Support sharing of weather and road conditions with third parties (e.g. NYSDOT TMC, 511, Advanced Traveler Information Systems,
    f. National Weather Service)
    g. Other
8. What other weather information sources do you use (Use regularly, use occasionally, use only rarely, never use)?
    a. Road Patrol Report
    b. Local Radar Sensors
    c. National Weather Service (Direct Contacts)
    d. AccuWeather Professional (Subscribed Service)
    e. Meridian/MDSS (Subscribed Service)
    f. AccuWeather Forecast Map Emails
    g. Contact with Other Residencies/TMCs/State Police
    h. Clarus System
    i. Free Internet Websites (e.g. the Weather Channel website)
    j. Regular Radio
    k. NOAA Weather Radio (National Weather Service alerts, etc.)
    l. TV
    m. Other
9. Please indicate your satisfaction with the following aspects for your existing RWIS stations (Extremely satisfied, satisfied, neutral, dissatisfied):
    a. Access to local forecast and weather information based on existing RWIS stations
    b. Access to real-time RWIS station sensor data
    c. Type of sensor data provided by existing RWIS stations
    d. Quality/Accuracy of sensor data provided by existing RWIS stations
    e. Equipment reliability
    f. Data transmission reliability
    g. Coverage of existing RWIS network
    h. Other
10. Please rate your Agency or Location's current level of support for (Strongly support, support, neutral, do not support, not sure):

a. Installation of new RWIS stations
b. Upgrading existing RWIS stations
c. Local operation and maintenance support for new and/or existing RWIS stations
d. Contracted operation and maintenance support for new and/or existing RWIS stations
e. Agency/state/national coordination of RWIS data sharing
f. Other

Part B-2: Use of RWIS station information for locations without RWIS

11. How useful would the following RWIS Station information be to you in your role (Highly useful, useful, neutral, not useful, not sure)?
    a. Air Temperature
    b. Air Pressure
    c. Relative Humidity
    d. Dew Point
    e. Wind Speed/Gust Speed and Direction
    f. Precipitation Type
    g. Precipitation Intensity/Accumulation
    h. Road Surface Temperature
    i. Road Subsurface Temperature
    j. Road Surface Condition (Wet, Dry)
    k. Road Surface Condition (Snow, Ice, Frost)
    l. Road Surface Applied Chemical Concentration
    m. Frost Penetration
    n. Snow Depth Measure
    o. Access to Camera Imagery (CCTV)
    p. Real Time Traffic Speed
    q. Other Information
12. Which weather information sources do you use while performing maintenance/operations duties (Frequently use, occasionally use, rarely use, never use)?
    a. Road Patrol Report
    b. Local Radar Sensors

c. National Weather Service (Direct Contacts)
d. AccuWeather Professional (Subscribed Service)
e. Meridian/MDSS (Subscribed Service)
f. AccuWeather Forecast Map Emails
g. Contact with Other Residencies/TMCs/State Police
h. Clarus System
i. Free Internet Websites (e.g. the Weather Channel website)
j. Regular Radio
k. NOAA Weather Radio (National Weather Service alerts, etc.)
l. TV
m. Other

13. Please rate your Agency or Location's current level of support for (Strongly support, support, neutral, do not support, not sure):
    a. Installation of New RWIS Stations at strategically selected locations
    b. Local operation and maintenance support for New RWIS stations
    c. Contracted operation and maintenance support for New RWIS stations
    d. Cross Agency/State/Nation Coordination of RWIS Data Sharing
    e. Other

Part C-1: Use of Vehicle-based Mobile RWIS - AVL Devices

14. Has your Agency/Location participated in NYSDOT's RWIS-AVL/MDSS Pilot Study?
    a. Yes
    b. No
    c. Not sure
15. What benefits do you see vehicle-based RWIS-AVL devices serving?
    a. Provide operational cost savings through improved management of services
    b. Identify Vehicle Location and Monitor Vehicle Operations
    c. Real-time Road Condition Data for Operation/ Maintenance Decisions
    d. Verify Road Condition or Weather Data Provided by Other Sources

e. Support Maintenance Decision Support System (MDSS) Data Needs
f. Support Sharing of Weather and Road Conditions to Third Party Agencies (e.g., 511, Advanced Traveler Information Systems, and National Weather Service)
g. Other

16. Please identify the usefulness of the following vehicle-based RWIS-AVL sensors (Highly useful, useful, neutral, not useful, not sure)?
    a. Vehicle Location and Route
    b. Vehicle Speed/Acceleration
    c. Vehicle Traction for Road Surface Friction/Traction
    d. Vehicle Systems' Status (braking, wipers, ABS, etc.)
    e. Plow Up/Plow Down Status
    f. Spreader Discharge Rate
    g. Chemical Distribution Rate
    h. Road Weather Information (surface temperature/condition, etc.)
    i. Air Weather Information (air temperature, precipitation, etc.)
    j. Other
17. Please indicate your satisfaction with the following aspects of vehicle-based RWI- AVL (Extremely satisfied, satisfied, neutral, dissatisfied, not sure):
    a. Quality of the Data collected by RWIS AVL-equipped Vehicles
    b. Type of the Data collected by RWIS AVL-equipped Vehicles
    c. Coverage of Current Vehicle-based RWIS-AVL Network
    d. Sensor/Equipment Reliability
    e. Data Transmission Reliability
    f. Data Accessibility and Usage
    g. Quality of the Maintenance Decision Support System (MDSS)
    h. Other
18. Please rate your Agency or Location’s current level of support for (Strongly support, support, neutral, do not support, not sure):
    a. Implementation of vehicle-based mobile RWIS-AVL sensors
    b. Local operation and maintenance support for mobile RWIS-AVL sensors

c. Contracted operation and maintenance support for mobile RWIS-AVL sensors
d. Cross Agency/State/Nation Coordination of RWIS-AVL Data Sharing
e. Other

Part C-2: Vehicle-based RWIS-AVL devised for locations not in pilot study

19. What benefits do you see vehicle-based RWIS-AVL devices serving?
    a. Provide operational cost savings through improved management of services
    b. Identify Vehicle Location and Monitor Vehicle Operations
    c. Real-time Road Condition Data for Operation/ Maintenance Decisions
    d. Verify Road Condition or Weather Data Provided by Other Sources
    e. Support Maintenance Decision Support System (MDSS) Data Needs
    f. Support Sharing of Weather and Road Conditions to Third Party Agencies (e.g., 511, Advanced Traveler Information Systems, and
    g. National Weather Service)
    h. Other
20. Please identify the usefulness of the following vehicle-based RWIS-AVL sensors to you in your role (Highly useful, useful, neutral, not useful, not sure)?
    a. Vehicle Location and Route
    b. Vehicle Speed/Acceleration
    c. Vehicle Traction for Road Surface Friction/Traction
    d. Vehicle Systems' Status (braking, wipers, ABS, etc.)
    e. Plow Up/Plow Down Status
    f. Spreader Discharge Rate
    g. Chemical Distribution Rate
    h. Road Weather Information (surface temperature/condition, etc.)
    i. Air Weather Information (air temperature, precipitation, etc.)
    j. Other

21. Please rate your Agency or Location’s current level of support for (Strongly support, support, neutral, do not support, not sure):
    a. Implementation of vehicle-based mobile RWIS-AVL sensors
    b. Local operation and maintenance support for mobile RWIS-AVL sensors
    c. Contracted operation and maintenance support for mobile RWIS-AVL sensors
    d. Cross Agency/State/Nation Coordination of RWIS-AVL Data Sharing
    e. Other
22. Please rank the importance of the following criteria for identifying potential RWIS locations (Major criteria, primary criteria, secondary criteria, minor criteria, not a consideration)?
    a. Weather Factors
        i. Typical locations representing local weather conditions
        ii. Number of Freezing Rain events
        iii. Number of weeks with Transition Temps
        iv. Annual Snowfall
        v. High Wind locations
        vi. National Weather Service needs (to fill gaps in their Mesonet data)
    b. Maintenance Operations Factors
        i. Problem locations with specific concerns
        ii. Distance from Staffed facilities
        iii. Areas with requests for RWIS Camera coverage
        iv. Areas with number of Spot Treatment callouts (for Blowing Snow, Melt/Refreeze, etc.)
        v. Areas with annual number of respondable Snow and Ice events
        vi. Areas with high Salt and Liquids usage
    c. Traffic Operations Factors
        i. Traffic Volume (AADT's)
        ii. Weather Related Congestion Locations
        iii. Accident Rate in Winter

        iv. Highway Class
        v. Population Density
        vi. Desire for Traffic Camera coverage at Location
    d. Existing Resources Factors
        i. Proximity to Existing Weather Monitoring (Non-RWIS) Sites (e.g. major airports)
        ii. Location of Existing RWIS Sites (NYSDOT, Thruway, local governments, bordering states/provinces, etc.)
        iii. Availability and Reliability of Power/Communication
    e. Administration Factors
        i. Availability of Capital funding and Regional commitment
        ii. Availability of Annual Operational and Maintenance funding
        iii. Residency Personal Willingness to Adopt New Technology
        iv. Regional Commitment to Support and Training
    f. Other Factors

23. Please select the Agency or Location you work for:

Part D: Suggested Areas for Upgraded or New RWIS station (NYSDOT Main Office, NYSDOT Regional Office/TMC, NYSDOT Residency)

24. Which Region and Residency would you suggest require upgraded or new RWIS stations, please select reason for this need

D. RWIS and MDSS Deployment in USA

Table D-1 RWIS and MDSS Deployment in US

State	# of RWIS Sites	Website	*Participated in Clarus*	MDSS Deployment	
				PFS MDSS	Telvent DTN MDSS
AL	11		Yes		
AK	118	http://www.dot.state.ak.us/iways/roadweather/forms/AreaSelectForm.html and http://511.alaska.gov/	Yes		Yes
AZ	17	http://www.az511.gov/adot/files/traffic/	Yes		
AR	4	http://www.arkansashighways.com/roads/roads.aspx	Yes		
CA	112	http://www.dot.ca.gov/dist2/travelmap.htm	Yes	Yes	Yes
CO	99	http://www.cotrip.org/home.htm	Yes	Yes	Yes
CT	13	Not online	Yes		
DE	13	http://www.deldot.gov/traffic/map.ejs	Yes		
FL	30	http://www.fl511.com/	Yes		
GA	48	Not online			
HI	0	Not online	Yes		
ID	41	http://hb.511.idaho.gov/main.jsf	Yes	Yes	Yes
IL	99	http://www.gettingaroundillinois.com/MapViewer.aspx	Yes		Yes
IN	32	http://netservices.indot.in.gov/rwis/default.asp	Yes	Yes	
IA	96	http://www.weatherview.dot.state.ia.us/	Yes	Yes	
KA	52	http://www.ksdot.org/burcompser/generatedreports/weather.asp	Yes	Yes	Yes
KY	39	http://rwis.kytc.ky.gov/	Yes	Yes	Yes
LA	5	http://511la.org/			
ME	8	http://www.511maine.gov/default.asp?display=roadConditions&area=ME_statewide&date=&textOnly	Yes		Yes
MD	63	http://www.chart.state.md.us/MapNet/MapDOTNET.aspx?Browser=NS6&ViewName=Select&Cmd=switchtheme&tab=RoadwayWeather&DoPanTo=False&Direction=&PanFactor=&DoZoomScaleFactor=&x=&y=&Encoder=&timestamp=1819&x1=0&x2=0&y2=0&y1=0&gCenterLat=39.230125638383925&gCenterLon=-77.1624755859375&gZoomLvl=9	Yes		Yes
MA	29	Not online			
MI	42	http://mdotnetpublic.state.mi.us/drive/cameraviewer.aspx	Yes		Yes
MN	94	http://rwis.dot.state.mn.us/	Yes	Yes	
MS	0				
MO	28	http://maps.modot.mo.gov/timi/	Yes		Yes

Table D-1 - Continued RWIS and MDSS Deployment in US

State	# of RWIS Site	Website	*Participated in Clarus*	MDSS Deployment	
				PFS MDSS	Telvent DTN MDSS
MT	67	http://rwis.mdt.mt.gov/scanweb/swframe.asp?Pageid=RegionalOverlayMap&Mapid=1669&Units=English&Groupid=150000&DisplayClass=Java&SenType=All	Yes		
NE	62	http://www.dor.state.ne.us/511/weather.htm	Yes	Yes	Yes
NV	70	http://apps.nevadadot.com/RWIS/	Yes		
NH	14	http://hb.511nh.com/main.jsf	Yes	Yes	
NJ	76	http://www.511nj.org/	Yes		Yes
NM	10	http://advanced.nmroads.com/			
NY	32	http://www.511ny.org/traffic.aspx	Yes	Yes	
NC	41	http://www.ncdot.org/traffictravel/			
ND	24	http://rwis.dot.nd.gov/scanweb/swframe.asp?Pageid=RegionalOverlayMap&Mapid=167&Units=English&Groupid=597000&DisplayClass=Java&SenType=All	Yes	Yes	
OH	172	http://www.buckeyetraffic.org/	Yes		
OK	7	Not online	Yes		
OR	71	http://www.tripcheck.com/Pages/RCmap.asp?curRegion=0&mainNav=RoadConditions	Yes		
PA	87	http://www.511pa.com/Traffic.aspx?ShowWinterLayer=true		Yes	
RI	8	http://511.dot.ri.gov/			
SC	30	http://www.511sc.org/sc511/login/auth	Yes		Yes
SD	43	http://www.safetravelusa.com/sd/	Yes	Yes	
TN	81	http://www.tdot.state.tn.us/maintenance/WinterMaint.htm	Yes		Yes
TX	50	http://www.dot.state.tx.us/GIS/HCRS_main/viewer.htm	Yes		
UT	67	http://commuterlink.utah.gov/#	Yes		
VT	11	http://www.511vt.com/	Yes		
VA	62	http://www.511virginia.org/home.aspx?r=1	Yes	Yes	
WA	100	http://www.wsdot.com/traffic/weather/default.aspx	Yes		Yes
WV	18	http://www.transportation.wv.gov/highways/traffic/Pages/roadconditions.aspx	Yes		
WI	58	http://www.dot.wisconsin.gov/travel/gis/rwis.htm	Yes		yes
WY	33	http://map.wyoroad.info/hi.html	Yes	Yes	
DC	6	Not online			

E. Questionnaire for Best Practices of Using RWIS to Support MDSS

1. Number of RWIS?
2. When did the RWIS sites get installed?
3. What kind of criteria was used to select RWIS sites and the priority of each criterion? (e.g., annual snowfall, traffic volume, high wind locations)
4. Have you performed cost/benefit analysis of the deployment of RWIS sites to support MDSS?
5. If not what would you see as beneficial aspects such as reduction in winter time accidents?
6. Are there guidelines to deploy RWIS sites at critical locations to capture weather data, especially with respect to high winds?
7. Are there other RWIS sites managed by other agencies? If so do you share the data?
8. Are you relying on RWIS sites from neighboring states?
9. Is the current number of RWIS sites sufficient to support MDSS? If not do you have any plan to expand RWIS sites and if so what is the basis?
10. In addition to MDSS support do you have other applications for data from RWIS such as *Clarus* and/or traffic operations?
11. Was the RWIS contract a design, install and operate including maintenance, a combination or simply installation? What is your recommendation?
12. Types of sensors used in RWIS sites? In addition to pavement temperature and precipitation sensors, are there other important sensors?
13. How reliable were those sensors? Did all of them operate without any issues? If there were problems, who fixed them?
14. Were there any replacements and if so were they in kind replacements (same sensor vendor)?
15. If different types were used as replacement, were there any changes to data gathering protocols?
16. How was the sensor data transmitted? Were the transmitted data raw or processed? Were there issues with data transmission and if so what are your recommendations?
17. Was the data transmitted via local webserver, national webserver or both?
18. Who manages data transmission? Is it done in house or by outside agency?
19. Did those data input directly to Meridian MDSS or after processing?
20. How is the quality and accuracy of sensor data?

21. Are you satisfied with the installed RWIS sensors?
22. Do you have any issues of RWIS supporting MDSS and what are your solutions?
23. Number of mobile RWIS? Type of data obtained from mobile RWIS, vendors and extent of mobile RWIS coverage.
24. Have you performed cost/benefit analysis for applying vehicle-based RWIS-AVL devices? What kind of benefits do you see them serving?
25. What kind of data provided by vehicle-based RWIS-AVL sensors is most helpful (e.g., vehicle locations, plowing status, chemical distribution rate, road weather info.)?
26. Any problems in using mobile RWIS to support MDSS? How is the sensor/communication reliability and data accuracy of mobile RWIS?
27. Do you have the plan to expand mobile RWIS in larger scale for MDSS support?

F. List of Prioritized Problem Sites

Table F-1 List of Prioritized Problem Sites

ID	Region	Township	Route	AADT	LST (ºF)	AASA (Inch)	Score
1	3	Tully	I-81	33,500	20.87	115	97
2	3	Geddes	I-690	51,800	20.06	92	96
3	3	LaFayette	I-81	38,000	21.31	115	95
4	9	Worcester	I-88	9,700	19.28	110	94
5	5	Ellery	NY394	12,000	19.30	120	94
6	1	Duanesburg	I-88	14,700	19.63	82	88
7	3	Syracuse	I-690	101,800	24.07	94	88
8	3	De Witt	I-481	44,900	23.09	96	88
9	3	Camillus	NY695	46,700	22.06	92	88
10	9	Mamakating	NY17	31,000	27.14	54	87
11	8	East Fishkill	I-84	52,700	27.76	44	86
12	4	Rochester	I-490	88,600	26.61	94	86
13	8	East Fishkill	I-84	52,700	27.05	44	84
14	8	Southeast	I-84	56,800	29.23	40	84
15	4	Perinton	NY104	72,400	25.92	92	84
16	2	Johnstown	NY30A	10,100	17.73	88	84
17	4	Gates	I-390	88,700	25.96	94	84
18	5	Ashford	US219	7,100	20.22	145	83
19	8	Putnam Valley	PK987G	29,500	27.43	43	83
20	5	Gerry	NY60	7,500	21.64	130	83
21	4	Riga	I-490	17,500	22.12	98	83
22	1	Duanesburg	US20	5,700	19.42	84	82
23	9	Owego	NY17	9,800	24.58	60	82
24	3	Geddes	I-690	50,400	22.31	96	82
25	5	Hinsdale	NY17	9,000	20.97	110	82
26	9	Fallsburg	NY42	5,200	24.47	70	82
27	7	Ellisburg	I-81	18,700	15.84	115	81
28	5	Farmersville	NY243	2,700	17.72	130	81
29	4	Rochester	I-490	86,700	27.30	94	80
30	7	Champion	NY126	4,200	11.81	115	80
31	8	Putnam Valley	PK987G	31,900	28.34	38	79
32	2	Mayfiled	NY29	6,400	16.61	84	79
33	7	Rutland	NY12	4,000	13.35	125	79
34	3	Clay	NY31	12,900	19.86	100	78
35	8	Philipstown	US9	14,700	28.85	43	78
36	5	Yorkshire	NY16	1,400	20.12	145	77
37	3	Sennett	US20	7,300	21.09	100	77
38	3	Sennett	US20	7,300	21.09	100	77
39	4	Webster	NY104	25,900	23.90	98	77
40	2	Amsterdam	NY30	17,300	21.63	78	77
41	8	Poughkeepsie	NY115	10,400	29.86	43	76
42	3	Lysander	NY31	15,300	22.17	100	75
43	4	Galen	NY31	7,200	22.29	100	75

Table F-1 - Continued List of Prioritized Problem Sites

ID	Region	Township	Route	AADT	LST (ºF)	AASA (Inch)	Score
44	7	Clinton	US11	4,400	13.10	100	74
45	2	Mohawk	NY30A	12,500	17.96	88	74
46	7	Tupper Lake	NY3	4,750	11.14	120	74
47	7	Rodman	NY177	2,800	13.57	160	74
48	7	Dannemora	NY374	1,240	12.23	120	73
49	7	Malone	NY30	2,300	13.56	100	73
50	7	Plattsburgh	I-87	21,400	16.50	64	71
51	9	Franklin	NY28	3,300	21.10	88	71
52	3	Lysander	NY370	7,500	20.71	98	71
53	3	Schroeppel	NY264	3,150	19.16	110	70
54	8	Cortlandt	NY9D	4,150	30.01	39	70
55	8	Copake	NY22	2,900	22.91	54	70
56	8	Ghent	PK987G	4,150	22.78	54	70
57	7	Pinckney	NY177	1,420	11.31	160	70
58	7	Martinsburg	NY26	1,940	12.78	150	70
59	7	West Turin	NY26	1,740	11.54	135	70
60	4	Phelps	NY96	7,800	22.96	90	69
61	8	Claverack	PK987G	3,900	22.96	52	69
62	6	Prattsburgh	NY53	2,200	20.94	88	69
63	1	Greenwich	NY29	8,400	19.59	60	68
64	4	Sheldon	US20A	3,000	21.54	140	68
65	7	Au Sable	I-87	11,100	17.16	62	68
66	8	Canaan	NY22	3,150	21.75	62	68
67	7	Altona	NY190	5,500	15.21	86	68
68	3	Summerhill	NY41A	1,060	17.93	100	67
69	7	Wilna	NY3	3,200	13.63	105	67
70	6	Scio	NY417	3,900	22.62	96	67
71	5	Allegany	NY16	1,920	21.64	100	66
72	7	Chateaugay	US11	5,000	11.05	78	66
73	5	Pomfret	NY83	1,420	24.33	100	66
74	4	Naples	NY21	2,400	24.31	96	65
75	7	Croghan	NY126	3,900	12.95	120	65
76	9	Franklin	NY28	1,840	20.08	88	64
77	7	Alexandria	NY12	2,800	15.83	66	64
78	7	Rossie	NY11	5,700	11.94	80	64
79	6	Benton	NY14A	5,500	21.67	74	64
80	3	Richland	NY3	2,550	19.34	110	63
81	5	Ellington	US62	1,000	20.10	130	63
82	8	Fort Edward	US4	2,750	19.43	58	62
83	4	Hamlin	PK947A	2,800	23.53	86	62
84	3	Summerhill	NY90	2,250	17.45	100	61
85	4	Galen	NY414	3,650	22.82	98	61
86	7	Champlain	US11	8,200	13.71	62	61

Table F-1 - Continued List of Prioritized Problem Sites

ID	Region	Township	Route	AADT	LST (ºF)	AASA (Inch)	Score
87	7	Harrietstown	NY30	790	10.99	110	61
88	7	Piercefield	NY3	2,200	10.97	120	61
89	5	Villenova	NY83	1,080	20.65	120	61
90	6	Wayne	NY54	2,150	29.06	72	61
91	8	Pawling	NY292	1,540	27.67	44	60
92	7	Ellenburg	NY190	1,540	10.60	100	60
93	5	Westfield	US20	2,900	24.95	74	60
94	9	Richford	NY79	3,500	21.01	84	59
95	7	Saranac	NY3	5,800	14.33	86	59
96	2	Florida	NY5S	3,650	18.53	80	59
97	4	Richmond	US20A	1,560	22.48	90	58
98	2	Florida	NY5S	2,900	20.39	78	58
99	6	Potter	NY247	1,940	22.15	82	58
100	7	Orleans	I-81	5,900	13.44	66	57
101	7	Fine	NY3	2,400	12.23	115	57
102	6	Wheeler	NY53	2,200	21.65	86	57
103	4	Gorham	NY245	1,560	22.61	82	56
104	3	Hannibal	NY176	750	19.97	115	55
105	3	Fayette	NY96A	4,100	23.02	78	55
106	7	Bellmont	NY190	1,280	10.82	94	55
107	7	Santa Clara	NY458	910	10.58	115	55
108	8	Stuyvesant	US9	4,000	24.30	47	53
109	7	Hammond	NY12	1,760	16.22	0	52
110	2	Palatine	NY10	1,180	16.84	88	51
111	7	Chateaugay	NY374	860	12.33	70	51
112	7	Colton	NY56	920	9.79	115	51
113	7	Chazy	US9	3,000	14.44	58	48
114	6	Hector	NY79	3,000	24.28	74	48
115	7	Hopkinton	NY11B	2,250	12.41	74	43

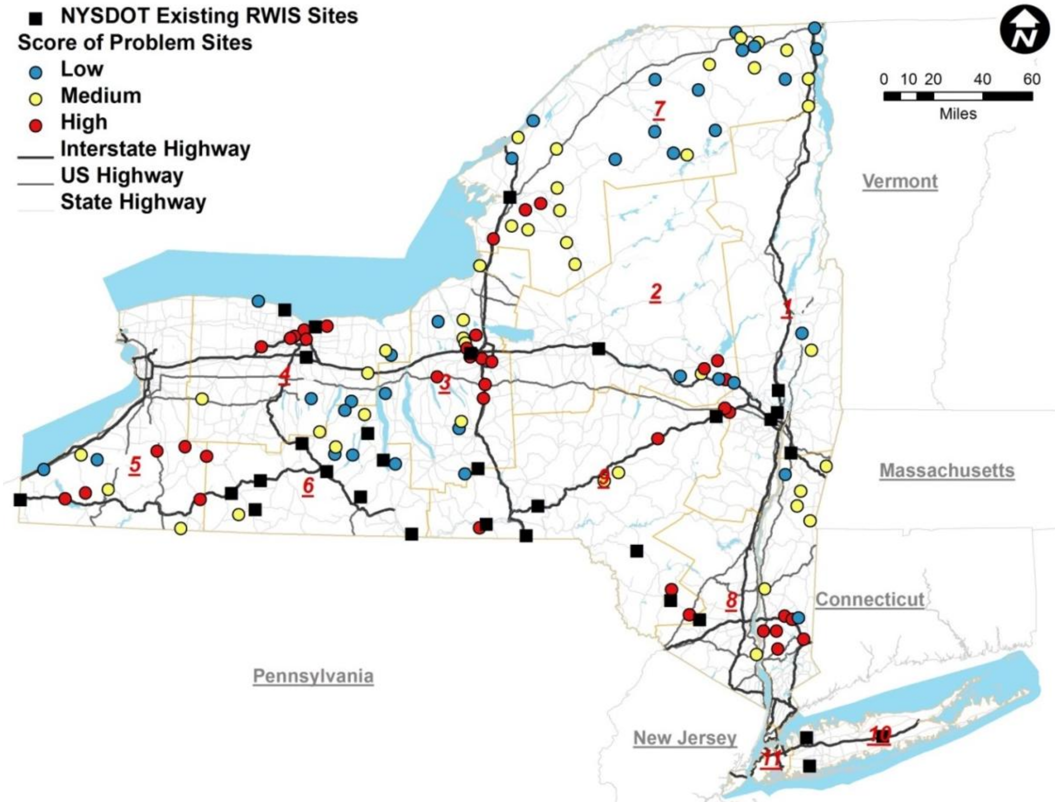

Figure F-1 Prioritized Problem Sites Based on Weather and Traffic Conditions

G. Area Coverage Computation

The proposed weather severity index (WSI) is based on the standardized sum product of weather related factors and corresponding factor weights. With WSI (which ranges from 1 to 10: 1 meaning the least severe and 10 the most severe), the spatial weather variability was analyzed for developing the statewide RWIS plan. **Figure G - 1** shows that in areas near a big body of water (e.g., Long Island or the vicinity of Lake Ontario), WSI tends to be homogeneous over a large distance. The opposite situation was observed over the mountainous areas, that is, greater heterogeneity of WSI. For deploying RWIS stations, the smaller the spatial weather variability, the larger the distance that can be tolerated between two stations.

The result of this analysis leads to a *critical radius* centered at each site *(i.e., area coverage)* (see **Figure G - 2**), which was set as the representative area of a site and provides guidance on the distance over which an RWIS station should be installed from a weather perspective. The procedure that was adopted to calculate the critical radius is:

Step 1: Create Buffers around Potential Sites

From 1 to 25 miles, draw a set of circles with radius ranging from 1 to 25 miles.

Step 2: Calculate the Standard Deviation

For each circle, calculate the standard deviation of the weather severity index

Step 3: Develop Linear Relationship between Standard Deviation and Radius

Formulate the trend of standard deviation as a function of radius. Usually, standard deviations increase with radius.

Step 4: Identify Critical Radius

The critical radius is then defined as the radius where the standard deviation changes most quickly with radius (i.e., the peak of the first derivative).

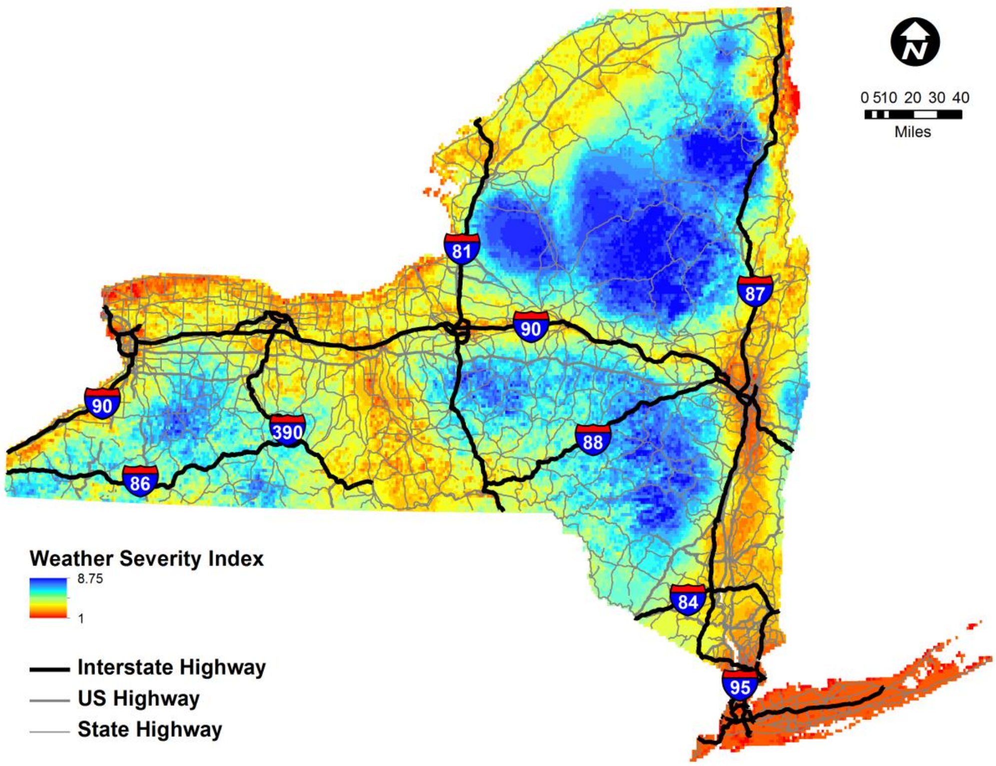

Figure G - 1 Estimated Weather Severity Index (WSI) in NYS

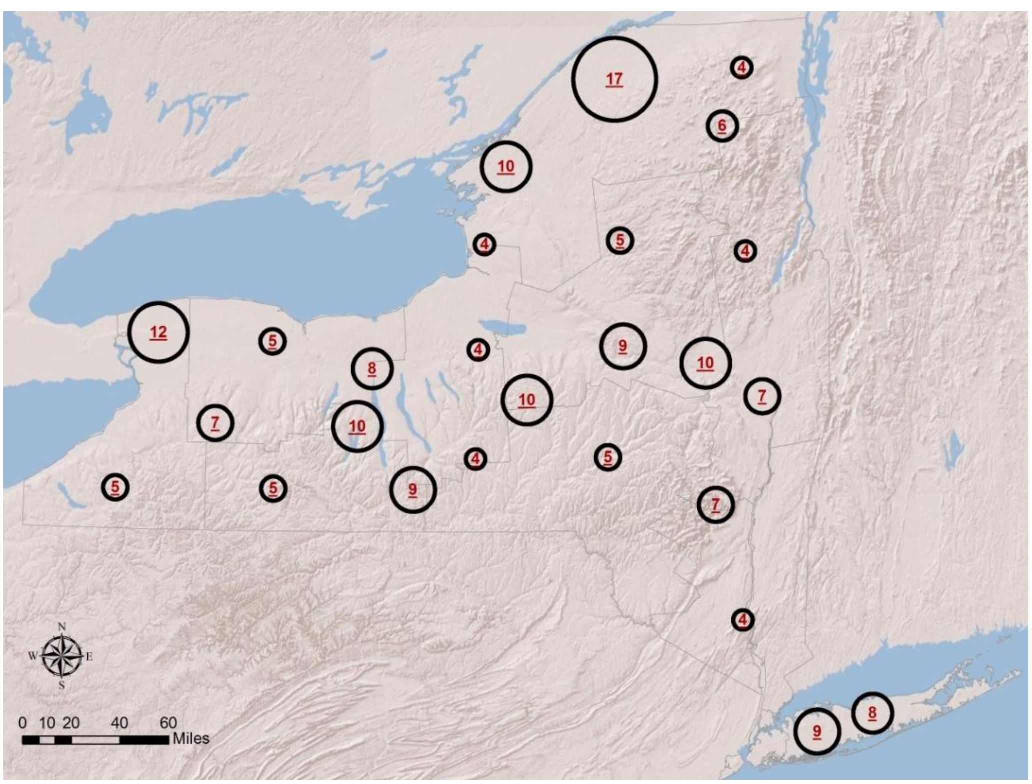

Figure G - 2 Critical Radius (Mile) of Sample Locations

H. Life-Cycle B/C Model

A proposed life-cycle B/C model was developed to estimate the profit associated with RWIS sites, denoted as P_T. By definition, P_T is the life-cycle benefit (B_T) minus the life-cycle cost (C_T), thus,

$$P_T = B_T - C_T \quad \text{(H1)}$$

1. Life-Cycle Cost Module

A typical RWIS station, consists of an ESS, a CPU, work station with software, and communication equipment. An ESS may consist of a pavement temperature sensor, subsurface temperature sensor, precipitation sensor, wind sensor, air temperature and humidity sensor, visibility sensors, and RPU.

The estimated lifetime for an RWIS/ESS is 25 years, and RPU and CPU should be replaced or upgraded every 5 years (McKeever et al., 1998). Hence, the life-cycle cost C_T consists of three components as formulated in Eq. H2:

$$C_T = C_I + C_U + C_M \quad \text{(H2)}$$

where C_T is present value of total life-cycle cost, C_I, C_U, and C_M are present values of initial installation cost, total device upgrading cost, and total operation and maintenance cost for a 25-year cycle, respectively.

2. Life-Cycle Benefit Module

The life-cycle benefits of an RWIS station B_T may be classified into direct and indirect benefit. Direct benefits result from reduced winter road maintenance costs, including labor (i.e., man-hour), equipment, and materials (i.e., chemicals/abrasives). Indirect benefits consist of reduced social cost (i.e., accident, pollution, and travel delay) and risk of liability. Since the latter component is quite difficult to quantify, only reduced social cost was considered in this study. Thus,

$$B_T = B_M + B_A + B_O \quad \text{(H3)}$$

where B_M is the direct benefit, representing the present value of winter road maintenance cost savings. B_A and B_O are the indirect benefits, representing the present value of accident cost savings and other indirect cost savings in a 25-year period, respectively.

3. Direct Benefit

Annual winter road maintenance cost savings B_M

The components in B_M include patrol saving, labor, equipment and materials savings.

1. Patrol savings

The annual patrol savings can be estimated by multiplying the unit cost of a patrol shift, the number of patrol shifts per winter storm that could be eliminated after a RWIS installation, and the average number of winter storms per year.

2. Labor, equipment, and materials (LEM) savings

The annual LEM savings can be estimated by multiplying the percent reduction of LEM usage, the average LEM usage on RWIS routes per winter storm, and the average number of winter storms per year.

4. Indirect Benefit

Accident cost saving (B_A*)*

The annual accident cost saving can be calculated by multiplying estimated annual winter storm related accident cost and the expected reduction of accidents after RWIS implementation.

Other indirect cost saving (B_O)

By making possible quick responses to winter events, road weather information collected from RWIS stations could help relieve congestion caused by snow and ice on the roads and improve the highway level of services. Therefore, the deployment of RWIS could lead to a reduction in travel delay costs and pollution costs resulting from increased travel time and deicing agents by improving traffic flow and reducing the amount of deicing materials used during a winter storm.

Other indirect cost savings including pollution cost savings and travel time savings, which could be estimated by multiplying unit cost of pollution and travel delay and expected reduction of pollution and travel delay, respectively.

5. Derivation of Present Value

It is essential to derive all of the cost and benefit components to present value for meaningful comparison. **Figure H - 1** stands for converting future upgrade cost to present value, and **Figure H - 2** represents converting annual cost/benefit.

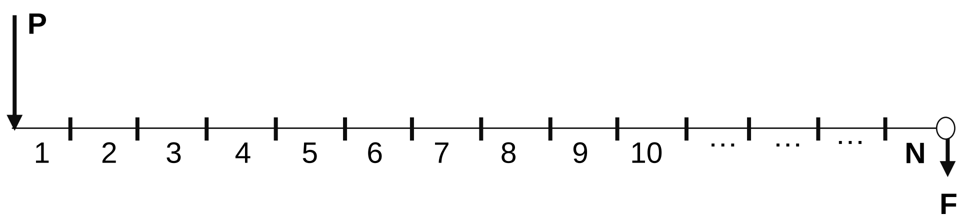

Figure H - 1 Future upgrade cost to present value

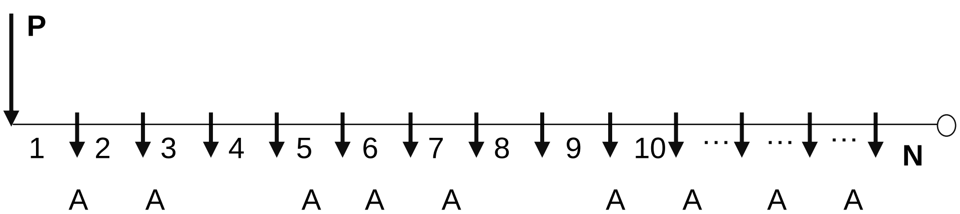

Figure H - 2 Annual cost/benefit to present value

In these figures, ***A*** represents annual cost/benefit, ***P*** is present value, and ***F*** is future upgrade cost, ***N*** is life-time of an RWIS site.

Define ***i%*** as discount rate and ***n*** as the analysis period (i.e., number of years), ***P*** could be calculated by discounting ***F*** back to the present. Alternatively, ***P*** could be formulated as ***F*** multiplied by a discount factor [i.e., $(\text{P/F,i\%,n})$]. Thus,

$$P = F * (\text{P/F,i\%,n}) = F * \frac{1}{(1+i\%)^n} \tag{H4}$$

Similarly, the present value ***P*** for an annual cash flow can be calculated by discounting each ***A*** back to the present, and adding up the present values. Alternatively, a short cut could be used to calculate ***P***, which is multiplying ***A*** by a discount factor, which is denoted as $(\text{P/A,i\%,n})$. Thus,

$$P = A * (\text{P/A,i\%,n}) = A * \frac{(1+i\%)^n - 1}{i\%(1+i\%)^n} \tag{H5}$$

6. Present Value of RWIS Life-cycle Cost and Benefit

Based on Eqs. H4 and H5, the present value of the life-cycle cost and benefits could be calculated. Thus, the present value of RWIS maintenance cost C_M is the annual maintenance cost, denoted as c_M, multiplying the discount factor $(\text{P/A,i\%,n})$:

$$C_M = c_M \cdot (\text{P/A,i\%,n}) \tag{H6}$$

Upgrade cost C_U is calculated by converting all the future upgrade costs (c_U) to present values and adding up all the present values. Thus,

$$C_U = \sum_m c_U \cdot (\text{P/F,i\%,n}_\text{m}) \tag{H7}$$

where, ***m*** is the index of the number of device upgrades in the life-time of an RWIS site.

The present value of life-cycle benefits could also be calculated by discounting the annual direct and indirect benefits (i.e., b_D and b_I, respectively) to the present. Thus,

$$B_D = b_D \cdot (\text{P/A,i\%,n}) \qquad \text{(H8)}$$

$$B_I = b_I \cdot (\text{P/A,i\%,n}) \qquad \text{(H9)}$$

Therefore, the profit ***P*** is represented as:

$$P = (b_D + b_I) \cdot (\text{P/A,i\%,n}) - [C_I + c_M \cdot (\text{P/A,i\%,n}) + \sum_m c_U \cdot (\text{P/F,i\%,n}_\text{m})] \qquad \text{(H10)}$$

The objective life-cycle profit of the lower level model, $\boldsymbol{P_T}$, could be reformulated as:

$$P_T = \sum_k x_k \cdot [(b_D + b_I) \cdot (\text{P/A,i\%,n})]_k - \sum_k x_k \cdot [C_I + c_M \cdot (\text{P/A,i\%,n}) + \sum_m c_U \cdot (\text{P/F,i\%,n}_\text{m})]_k \qquad \text{(H11)}$$

where *k* stands for the index of RWIS site.

I. List of Optimal Typical RWIS Sites

ID	Route	Residency		Region	Critical Radius	AADT	LST (ºF)	AASA (Inch)
		No.	Name					
1	NY 22	1-2	Essex	1	12 miles	4,014	19.14	64
2	NY 23A	1-3	Greene	1	7 miles	3,284	25.75	60
3	NY 73	1-2	Essex	1	12 miles	3,278	16.45	110
4	NY 22	1-8	Washington	1	24 miles	2,261	18.16	70
5	NY 145	1-3	Greene	1	14 miles	1,986	22.10	84
6	NY 346	1-4	Rensselaer	1	6 miles	1,492	21.49	70
7	NY 8	1-7	Warren	1	10 miles	801	17.64	82
8	NY 8	1-7	Warren	1	20 miles	789	15.65	120
9	I - 90	2-5	Fulton-Montgomery	2	21 miles	22,640	19.06	84
10	US 20	2-7	Oneida West/Madison	2	15 miles	5,002	17.01	105
11	NY 28	2-6	Oneida East	2	14 miles	2,986	15.06	150
12	NY 28	2-2	Hamilton	2	6 miles	1,411	14.16	145
13	NY 8	2-2	Hamilton	2	8 miles	984	15.45	160
14	I - 90	3-1	Seneca/Cayuga	3	23 miles	32,802	21.81	100
15	NY 49	3-5	Oswego	3	15 miles	6,223	20.38	100
16	NY 3	3-5	Oswego	3	24 miles	2,154	18.57	100
17	I - 90	4-1	Genesee/Orleans	4	18 miles	38,841	21.56	110
18	NY 98	4-7	Wyoming	4	11 miles	1,959	19.04	145
19	NY 5	5-4	Erie South	5	23 miles	14,138	22.32	82
20	NY 78	5-5	Niagara	5	24 miles	6,610	24.86	74
21	US 62	5-2	Chautauqua	5	24 miles	988	19.41	125
22	NY 37	7-2	Franklin	7	24 miles	11,484	12.87	62
23	I- 87	7-1	Clinton	7	24 miles	11,179	17.16	62
24	NY 68	7-5	St Lawrence	7	23 miles	6,071	15.04	64
25	US 11	7-1	Clinton	7	24 miles	5,535	16.55	60
26	NY 12	7-4	Lewis	7	8 miles	5,455	12.13	135
27	NY 3	7-4	Lewis	7	19 miles	3,184	12.25	100
28	NY 186	7-2	Franklin	7	14 miles	3,024	11.19	110
29	NY 3	7-5	St Lawrence	7	24 miles	2,184	11.47	120
30	NY 190	7-2	Franklin	7	11 miles	1,285	10.82	94
31	US 44	8-2	Dutchess North	8	24 miles	5,938	25.11	44
32	NY 28	8-7	Ulster	8	12 miles	5,662	25.32	96
33	NY 116	8-8	Westchester North	8	24 miles	5,374	28.55	35
34	NY 357	9-5	Otsego	9	23 miles	2,351	19.30	86
35	NY 30	9-6	Schoharie/Delaware North	9	9 miles	1,580	21.36	100
36	NY 165	9-5	Otsego	9	14 miles	880	17.78	110
37	NY 220	9-2	Chenango	9	10 miles	575	19.22	98
38	NY 25	10-3	Suffolk East	10	14 miles	7,736	33.15	14

J. Example B/C Analysis[3]

Table J-1 Component List of B/C Model

For Full-System RWIS Sites					
					Direct Cost
Installation Cost ($)	42,000		36,000		
Annual O&M Cost ($/year)	4,000		1,800		
Device Upgrade Cost Every 5 year ($)		10,400		P/A	P/F
				14.09	0.78 (5 years)
Interest Rate	0.05				0.61 (10 years)
Life Time (year)	25				0.48 (15 years)
Total Number of RWIS Sites	38				0.38 (20 years)
Net Present Value of Cost ($)	**4,629,592**		**3,223,339**		

Direct Savings	
Average Patrol shift	1
Average Patrolling Hours per Storm per Residency (hours)	24
Unit Cost of Labor Hour ($/hour)	25
Total Number of Truck needed to Patrol per Residency	3
Number of Residencies	45
Unit Cost of Truck Hour ($/hour)	25
Average Number of Storm	3
Patrol Savings ($/year)	**729,000**
Percentage of Reduced Labor Hour	0.15
Total Number of Labor needed per Storm per Residency	12
Unit Cost of Labor Hours ($/hour)	25
Average Number of Storms	3
Average Duration of Storm (hours)	48
Number of Residencies	45
Labor Savings ($/year)	**291,600**

[3] Detailed Component Explanation refer to McKeever et al., 1998

Table J-1- Continued Component List of B/C Model

		Direct Savings
Percentage of Reduced Truck Hour	0.15	
Average Number of Truck per Storm per Residency	6	
Unit Cost of Truck Hours ($/hour)	25	
Average Number of Storm	3	
Average Duration of Storm (hours)	48	
Number of Residencies	45	
Equipment Savings ($/year)	**145,800**	
Percentage of Reduced Materials	0.15	
Average Amount of Materials used per Storm per Mile		
Sand	2	cubic yards
Salt	0.3	ton
MgCl	0.1	ton
Unit Material Cost		
Sand	8	$/cubic yard
Salt	60	$/ton
MgCl	400	$/ton
Average Number of Storm per Year per Site	3	
Total Length of Covered Highway Segments (miles)	*7,778*	
Material Savings ($/year)	**259,007**	
		Indirect Savings
SumProduct of AADT and length of Covered Highway Segments	54,447,430	
Average Number of Storm per Year per Site	3	
Coefficient of Accident Cost Savings	0.013	
Accident Cost Savings ($/year)	**2,123,450**	
Total Annual Savings ($/year)	**3,548,857**	
Net Present Value of Savings ($)	**50,017,396**	
B/C Ratio	**10.80 to 15.52***	

*B/C ratio varies from 10.80 to 15.52 because of different installation/maintenance costs associated with each RWIS site.