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Road Weather Information System (RWIS) Evaluation

Literature / Best Practices Review Technical Memorandum

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EXECUTIVE SUMMARY

Introduction

A Road Weather Information System (RWIS) is a technological solution developed to meet the needs of users seeking road weather information to support transportation-related decisions. The term RWIS initially referred to the physical infrastructure designed to transfer road weather information (limited to pavement and weather conditions) from highway locations to department of transportation (DOT) maintenance personnel, but RWIS is more aptly an information service designed to measure, transport, and display road weather information. The functionality of the RWIS program has evolved considerably over its 40-year existence, driven by an expanded user community, a change in the needs of the user community, the integration of new data sources, and sweeping changes in support technologies such as communications and computers. Additionally, the integration of mobile data acquisition technologies over the last decade promises to substantially change RWIS going forward.

Background

The Michigan Department of Transportation (MDOT) has a sizeable RWIS network in place in the Superior and North Regions and desires to extend this network to encompass the entire state. This document reviews what other states/provinces with established RWIS programs consider their best practices regarding RWIS implementations and anticipated expansions as future needs change. The assessment is derived from a literature review and interviews with lead RWIS personnel in 20 agencies in the United States and Canada who have climates and transportation support requirements similar to Michigan.

RWIS has not been a static road weather program, rather it has changed significantly during its history and much of its configuration today reflects this evolution. Dominant influences created key periods in RWIS are shown in the figure below.

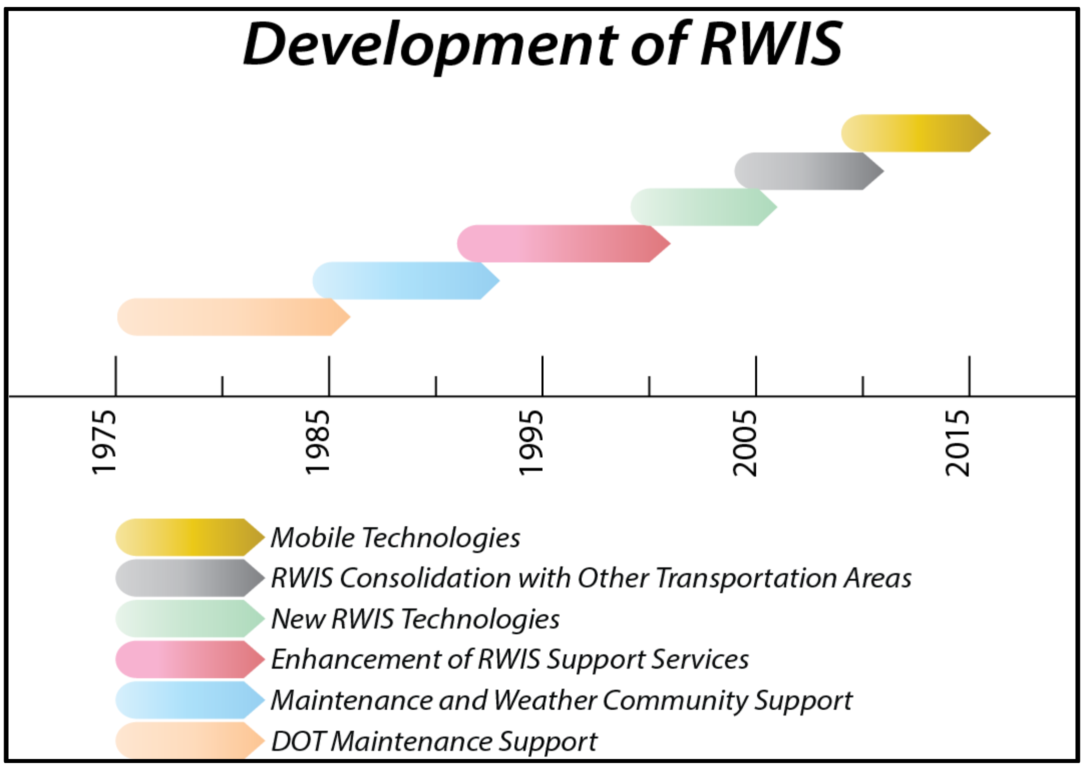

Figure 1-1 Development of RWIS

RWIS Programs in Other States/Provinces

The literature review yielded a good history of the RWIS program and best practices at various times throughout its development. To get at the specifics of individual RWIS programs the project team defined 10 areas that are distinct parts of an effective program or have important influence on its direction. The discussion areas were:

1. The characteristics of ESS programs
2. The criteria for selecting ESS sites
3. The management of data from field to end user and the contractual approaches to support this data management
4. Equipment servicing arrangements
5. Weather support services
6. Camera distributions and image availability
7. Mobile data collection programs
8. Monitoring traffic information
9. Road condition reporting
10. Traveler information programs

The team agreed upon a set of questions that were designed to elicit responses that would provide the type of information MDOT desired to evaluate their RWIS expansion considerations. Interview sessions with the selected agencies lasted 1 to 2 hours and the notes from the sessions were composed into Microsoft Word files and sent to the interviewees for approval. The notes were adjusted to meet the DOT representatives input and were used to create a master spreadsheet summarizing the responses. Information from the MDOT program was added to the spreadsheet to support a comparison with the responses from the other agencies. The spreadsheet, notes, and information from the literature review form the foundation for this assessment of the current status of RWIS, notable trends, and approaches to RWIS that are considered to be best practices.

Each of the ten discussion areas creates the basis for existing RWIS programs and shape the direction of developing novel approaches to RWIS. Although the discussion focuses on the individual areas, much of what is transpiring in RWIS reflects the interaction of forces within all of the independent topics. These forces may be internal or external to the DOT and manifest significant changes in the content, stakeholders, and the changing needs of the RWIS user community. Synthesis of the material in the spreadsheet, notes, and literature review highlighted a number of key trends occurring in RWIS and a set of best practices within the DOT RWIS community.

Best Practices

Best practices found within the RWIS programs of the various DOT agencies are summarized in Table 1-1.

Table 1-1: Best Practices Summary

1.	The optimal design of an ESS network is an open system architecture design.
2.	The most accurate and cost effective solution to measure pavement conditions is a combination of a non-invasive pavement condition sensor and an implanted pavement temperature device.
3.	The majority of sites should be sited to provide representative road weather conditions.
4.	ESS sites should be situated as far from the roadway as possible at a location that fits into the local environment more so than the conditions in the highway right-of-way. However, certain sensors, such as the non-invasive pavement sensor, may need to be located closer to the highway to work properly.
5.	The weather instrumentation package should include sensing devices to measure air temperature/RH, horizontal wind information, precipitation type and rate, and visibility. The sensors can be individual instruments or a combination sold as a single package. The sensors may be mounted on a fold-over tower, pole designed to support the sensors and provide easy access for servicing, or an existing rigid structure that does not significantly impact airflow. The individual sensing elements must meet the performance specifications in the RWIS ESS Siting Guidelines.
6.	Measurement of conditions at locations considered maintenance trouble spots needs careful consideration. If local weather conditions are representative of the broader area, then approach the ESS site as a representative weather location. If not, consider monitoring only the road conditions at the site unless it would be helpful to know the unrepresentative weather conditions that are impacting this particular ESS site.
7.	Each ESS site should preferentially include a camera with multiple views and with at least one being a close-up view of the highway surface. Cameras should be able to present usable images under low intensity light.
8.	The utilization of performance-based contracts improves the quality of the system output and performance of the system.
9.	The use of third party data management contracts consolidates the supervision of all aspects within one organization, which optimizes quality control, quick response to data processing issues, rapid restoration of accurate data flow, and assured delivery of RWIS data to end users. This arrangement is especially effective under a performance-based support contractual agreement.
10.	Mobile data collection has become an adjunct road weather data collection service that augments RWIS information and weather support services such as MDSS; MDC has also become a significant resource to monitor the use of materials and equipment.
11.	DOTs have commenced integrating traffic monitoring devices into RWIS to evaluate the level of service status of their maintenance practice or determine post-storm performance metrics.

Notable Trends

Notable trends within RWIS apparent from the best practices are presented in Table 1-2.

Table 1-2: Notable Trends Summary

1.	DOTs are moving toward ESS field controller configurations that fit into non-proprietary, open architecture designs.
2.	Many DOTs are deploying or testing non-invasive sensors in their ESS instrument suite.
3.	Most agencies are integrating present weather sensors into their atmospheric instrument package as part of new ESS sites or replacement of aging Y/N precipitation sensors.
4.	Camera imagery has become a highly desired RWIS resource for many stakeholders and is particularly requested by travelers.
5.	Historically, RWIS supported DOT personnel tasked with winter maintenance; currently there is more emphasis on resource considerations to support traveler information requirements.
6.	Technological advances in data communications have played a significant role in improving data transfer from ESS field sites to central processing locations. This factor is key to the acceptance of RWIS as a tool to support maintenance decision-making and in meeting traveler information requirements.
7.	Performance based contracts and the demand for accurate information to support traveler information have increased the need for a dedicated quality-checking program.
8.	Service contracts are gravitating toward performance–based agreements and often as part or all of an end-to-end data management arrangement.
9.	Mobile data collection and automated vehicle location technologies have been integrated into a growing portion of the DOTs and agencies are finding novel ways to use information from these systems to support operations and management.
10.	DOTs are moving towards more effective sharing of maintenance and traffic operations functions and the exchange of camera and traffic information.
11.	Interactive weather support has become more prevalent in recent years through direct phone support and social media forms of communication. The UDOT program puts weather support at the intersection of maintenance and traffic weather support needs and may serve as a model for future weather support of a state's transportation needs.
12.	RWIS information and road condition reports are displayed through nearly all 511 programs or from links available on the 511 web site.
13.	Performance measures to assess level of service, degree of maintenance performance, or time to return roadways to 'normal' winter driving conditions are adding value to RWIS data and affecting the instrumentation requirements at ESS sites.

1. INTRODUCTION

RWIS is not a static program, but rather a dynamic transportation support system that is continually evolving. The concept of RWIS was introduced in North America in the early 1970's and the program has become an integral part of decision support for winter maintenance in all areas of the United States and Canada faced with snow and ice control. In its initial stages in the 1970s and early 1980s, RWIS denoted the field equipment used to measure pavement and weather conditions at highway or runway locations and the data management hardware and software to transport the data and display it for use by DOT maintenance users. RWIS vendors recognized that the raw weather information retrieved from the network of RWIS field sites was a subset of the broader set of weather information and began providing the RWIS observations in context with observations from the National Oceanic and Atmospheric (NOAA) weather database. This expanded observation service was enhanced by the introduction of point-specific pavement condition forecasts. The definition of RWIS began to take on a broader perspective, reflecting all information resources that may be used to support maintenance decisions.

This expansion in the meaning of RWIS accelerated with improvements in technology and the addition of other resources to support maintenance decisions, such as cameras, visibility sensors, traffic monitoring devices, mobile devices, and maintenance decision support systems (MDSS). Additionally, the National Weather Service (NWS) and other weather service providers recognized the value of the weather information from RWIS. As NWS use of the information increased, ensuing RWIS expansions needed to address their interests in the RWIS program as well. To separate the roadside data collection devices from the broader description of RWIS, they were designated as Environmental Sensor Stations (ESS) starting in 2003 (1), using terminology the Federal Highway Administration (FHWA) had used in its Best Practices for Road Weather Management documents in previous years to designate highway-related environmental monitoring devices.

Today, the RWIS program is considerably different than it was at inception and the future of the program is impacted by an ever-expanding group of stakeholders. To assist MDOT in the evaluation of its RWIS program and the future placement of additional ESS sites, project team members, with extensive experience in road weather programs, collected information from eighteen states and two provinces to establish their best practices related to RWIS. To put this input from other states in context to the MDOT RWIS program, the project team extracted the information from the MDOT workshops (2) and created a composite summary of the various aspects of road weather relating to RWIS. This direct feedback has been coupled with information from RWIS-related literature to create a synopsis of the current best practices. This memorandum will address some of the history of RWIS and then the entire spectrum of factors that currently impact the direction of RWIS programs in other agencies. The factors considered include:

1. The characteristics of ESS programs
2. The criteria for selecting ESS sites
3. The management of data from field to end user and the contractual approaches to support this data management
4. Equipment servicing arrangements
5. Weather support services
6. Camera distributions and image availability
7. Mobile data collection programs
8. Monitoring traffic information
9. Road condition reporting
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Many of these factors may seem unrelated to RWIS and the determination of where ESS sites are most feasible going forward, but the best practices review reveals that all of the items have distinct needs that can be supported by information from RWIS.

2. BACKGROUND

As a simple definition, RWIS may be considered the information resources and technical solutions that support the needs of the set of stakeholders who actively deal with road weather conditions or use road weather data for other operational requirements. In essence, RWIS is the conduit for a number of sources of information to a diverse group of end users who may have distinctly different responsibilities. These responsibilities create information needs that can be satisfied by specific pieces of information within the RWIS data set. The definition is shown diagrammatically in Figure 2-1. ESS data is merely one of the data inputs into RWIS; others include weather data from the NWS, camera imagery, traffic information, pavement condition forecasts, mobile data, MDSS information, and additional environmental information. RWIS aggregates this information and makes it available to a wide variety of stakeholders with interest in one or more of these data sources. The stakeholders have interest in RWIS because they have information needs that must be satisfied to more effectively aid them in performing their operational obligations. For example, DOT maintenance personnel find value in all four of the information resources shown in Figure 2-1.

The NWS on the other hand is typically only interested in the ESS data and possibly the camera imagery. It is interesting that the NWS is a user of ESS data but also an information provider for data that may be passed through RWIS programs to other end users. A common resource that the NWS provides to RWIS is radar information, something all of the other stakeholders Figure 2-1 find valuable.

It is important to point out that at its inception RWIS included only ESS information that was delivered to DOT maintenance personnel to support their snow and ice control programs (the top Information, Stakeholder, and Need icons in Figure 2-1). The need was knowledge of the pavement temperature and pavement conditions at two or three points in the roadway at an ESS site and RWIS was designed to meet that singular requirement. This section reviews what happened as the number and type of stakeholders increased and their specific needs impacted what information was desired from the RWIS program.

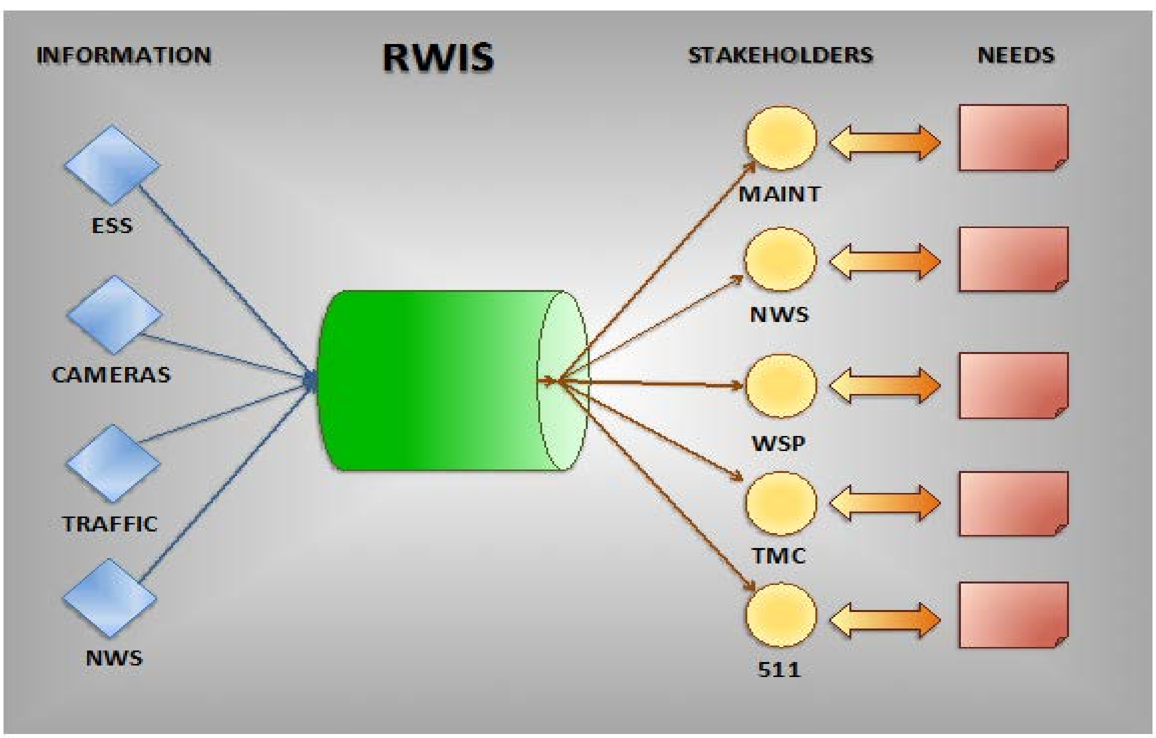

Figure 2-1: Diagram of the Components that Comprise RWIS

2.1. EVOLUTION OF ROAD WEATHER INFORMATION SYSTEMS

The change in the perception of RWIS in its 40 years of existence in North America has been impacted by:

- Changes in the technologies that support the RWIS program
- Changes in the stakeholder community who use the RWIS data
- Changes in the needs and requirements of the stakeholders

Key technological advances occurred in data communications, computing, sensor capabilities, and infrastructure to move and display data. Most of the changes happened gradually; however, the following technological changes dramatically impacted RWIS:

- Cellular communications
- Mobile computing (laptops, tablets, smart phones)
- Present weather precipitation sensors
- Non-invasive pavement condition sensors
- Integration of cameras into RWIS

The states and provinces contacted in this study anticipate that mobile communications and the social networking it engenders will have significant influence on the future of road weather support.

As more road weather resources were added on the information side of RWIS the number of stakeholders also increased from the small set of DOT maintenance personnel in the early years to gradually encompass all individuals who utilize surface transportation and road weather information. The direct stakeholder community has expanded to encompass those organizations or services responsible for the dissemination or repackaging of RWIS information to serve a variety of transportation and/or weather-related needs. In essence, the entire populace has become an indirect user of RWIS information and increasingly desires accurate and reliable information from the core data sources.

Stakeholders need specific types of information to address their operational obligations. When it was introduced, RWIS provided an information resource to satisfy a need for information regarding pavement conditions for maintenance personnel. As more information resources were added to RWIS and the number of stakeholders increased, RWIS fulfilled the decision support needs of a much broader community. But as the information users' technological tools changed and improved, the needs of the stakeholders themselves were modified. As an example, camera imagery was gradually incorporated into RWIS to permit maintenance personnel to see road conditions at remote locations. When this imagery was made available to travelers they found the information of interest to view conditions at specific locations where they commonly traveled. However, as the density of cameras increased travelers recognized that camera imagery was an exceptional tool to evaluate travel decisions and travelers viewed camera images as a required resource for travel decisions. In many ways RWIS has functioned as a feedback loop. As RWIS information was made available to a broader user base, the new users outlined needs that the existing RWIS data set only partially fulfilled and recommended enhancements that would more adequately meet their needs. This feedback led to the integration of new information resources, the enhancement of data monitoring techniques, or the integration of new techniques that improved the data flow.

2.2. DEVELOPMENT PHASES

During its history, RWIS has gone through a number of phases in response to changes in technology, stakeholders, and needs. Although these phases were not planned or orchestrated, they reflect significant milestones in the evolution of RWIS and provide insight into what RWIS is today and where it is headed. Using the review of literature and the author's experience in the RWIS program, the evolution of the RWIS program has been separated into development phases. The phases and their approximate time frames are shown in Figure 2-2 and each phase represents a relatively distinct period in the history of RWIS. This section looks at each of the phases and discusses how changes in technology, user needs, and the user community itself changed the very nature of the RWIS program.

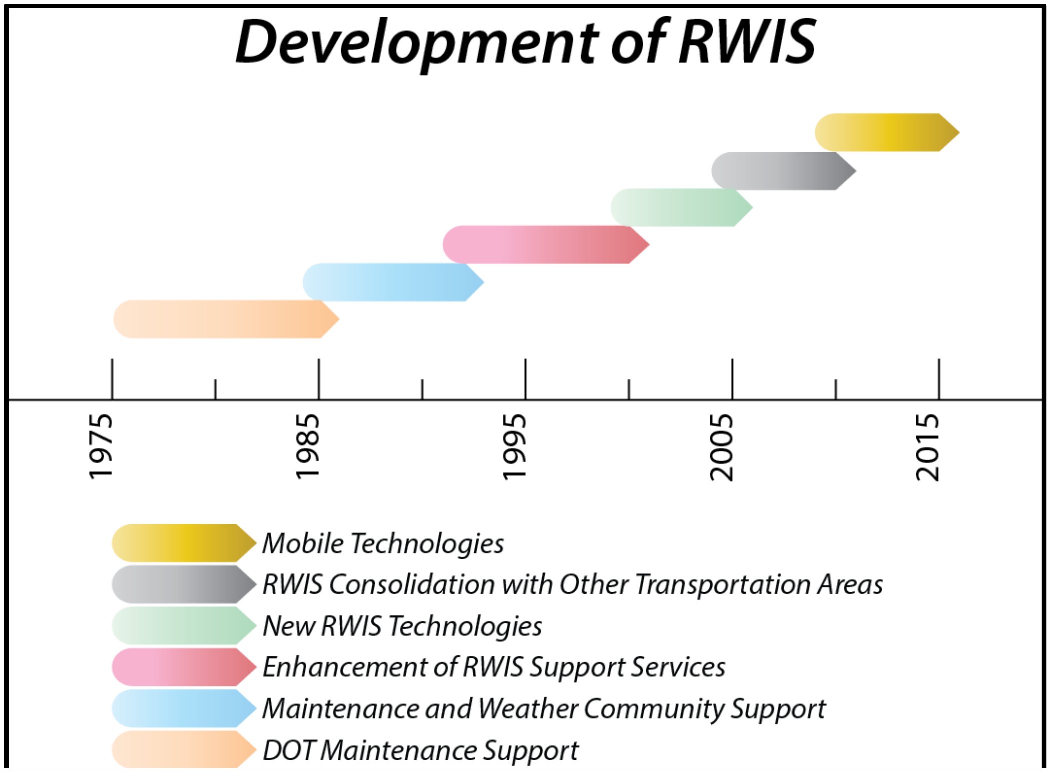

Figure 2-2: Timeline of the Development Phases of RWIS.

2.2.1 Maintenance Support (1975 – 1985)

This was the initial implementation of RWIS. Pavement sensor technology was initially rudimentary, but improved rapidly during the period. The initial ESS configuration was a pavement sensor and a remote processing unit (RPU). Atmospherics were added in the late 1970s to improve assessment of road conditions using inference techniques. A central processing unit (CPU) used landline phone communications and sequential polling to retrieve data from each of the RPUs. DOT users had stand-alone applications that connected to the CPU using telephone lines and modems and downloaded RWIS data for display at the user's site. During this period RWIS information was only used internally by the DOTs to support maintenance.

2.2.2 Maintenance and Weather Community Support (1985 – 1992)

This period of rapid development in and miniaturization of processing chips led to rapid improvement in computers, communications, and industrial solutions based on micro-processing. Pavement sensor technology benefitted from chip set improvements both at the sensor level and in the RPUs. Communications moved to wireless communication, replacing a portion of the copper-based landline infrastructure as a dominant RWIS data communication solution. Radio became the preferred data transfer mechanism with wide area networks (WAN) becoming a solution to moving multiplexed data over the telephone wire infrastructure.

Surface Systems, Inc. (SSI) introduced pavement specific forecasts and added it to its CPU-based services. Based upon agreements with the DOTs, access to the RWIS data was provided to the NWS and private weather service providers.

2.2.3 Enhancement of RWIS Support Services (1992 – 2000)

Computer and communications enhancements came rapidly in this period. Cellular communications began to get a foothold in urban areas and was used to support data transport from a few ESS sites to the CPU. Computers were quickly being integrated into field operations and became a primary interface to the RWIS data and weather support services.

The RWIS technology was becoming accepted within the DOT community and states/provinces were establishing networks throughout their jurisdictional boundaries. This was augmented by the inclusion of cameras and other environmental sensors into the ESS monitoring package. SSI had been the primary RWIS vendor through the early years of development of RWIS in North America because they were the only vendor to commit to servicing their systems with dedicated field personnel. DOTs preferred a competitive option and took steps to establish an open architecture approach for RWIS. This included a standard protocol for the communication of data from ESS sites to central sites. This resulted in the development of the National Transportation Communications ITS Protocol (NTCIP) version 1204 standard for RWIS data communications.

The commercial version of the Internet was introduced in 1995 (3) and weather service providers introduced web-based user interfaces to the RWIS data using applications on the CPU.

In an unrelated transportation support area, the University of North Dakota under contract with the FHWA, demonstrated the potential of providing road condition guidance (weather and road conditions and weather forecasts) to travelers for route specific locations. Using the phone moniker of #-SAFE, the test showed that it was possible to provide guidance to travelers concerning specific routes of travel. This became one of the predecessors of the 511 advanced traveler information service.

2.2.4 New Technologies (2000 – 2005)

Initial investigations into Weather Information for Surface Transportation (WIST) initiated by the FHWA in 1997 (4) as part of work on the National ITS Architecture led to cooperative studies and meetings early in the 2000s that included the FHWA, Office of the Federal Coordinator for Meteorology, the national research laboratories, DOT members, and private weather service providers. This cooperative effort resulted in the development of the MDSS functional prototype (5) and the organization of the MDSS Pooled Fund Study (6) effort on the part of a number of states. The MDSS solution developed by the Pooled Fund Study expanded the techniques associated with Automatic (or Automated) Vehicle Location (AVL) technologies and initiated work on a mobile data collection (MDC) technique to permit acquisition of material spread rates, plow status, pavement/air temperatures, and driver observations of road conditions, weather conditions, snow depths, and plow lane.

Technological advancements continued to generate new RWIS support solutions. Research was initiated on non-invasive pavement condition sensor. Cellular networks expanded rapidly and became an ever-increasing solution for ESS to CPU data communication. The FCC approved the phone number of 511 for access to traveler information (7) in 2000 and active 511 systems were introduced within the next two years. The states themselves established data sharing agreements to make RWIS information available to DOT users in adjoining states or permit access to the states RWIS user interface. The NTCIP standard and associated data objects were implemented and then integrated into the communications interfaces provided by RWIS vendors.

2.2.5 Consolidation of RWIS with Other Transportation Functions (2005 -2010)

The *Clarus* Initiative was initiated through the efforts of the FHWA to create a single data clearing-house for RWIS information (8). Through cooperative sharing agreements states made their RWIS data available to *Clarus* who then allowed any user to access the information in the *Clarus* database. Over time nearly all states joined *Clarus* as well as several provinces in Canada. The sharing of information was also developing within the DOTs with the growing exchange of data between the maintenance, traffic, and traveler information groups. The weather support function for DOT maintenance requirements was placed within the Traffic Management Center in a few states and with the expansion of 511 programs RWIS data (weather, road conditions, and camera images) was transferred to 511 for distribution to the public.

The development and testing of non-invasive sensors was completed and the sensors were released for integration into RWIS networks. Performance-based management became a technique to monitor how maintenance programs were doing in their attempt to meet level of service and time to return roads to normal and RWIS became a tool to support this endeavor. The new non-invasive sensors provided a measure of the coefficient of friction called "grip" that could be used to estimate when the road was within or outside of the agency's desired acceptable level of service levels. Precipitation sensors were also used to assist in the determination of the onset and termination of precipitation. The termination was particularly useful to determine when vehicles for a given roadway returned to normal speeds.

2.2.6 Mobile Technologies (2010 – present)

Computing and communications tended to merge into a single technological solution with the proliferation of hand-held devices such as smart phones, tablets, and small laptops. As the portion of the population with one or more of these devices increased rapidly, the major operating system providers developed and/or supported applications (apps) that provide specific functions for end users. Apps have proliferated on smart phones and tablets and provide an easy mobile format to acquire or process information related to nearly every facet of interest, including RWIS and traveler information services. The growth of information exchange via the Internet and mobile apps have created a social networking and crowdsourcing construct that offers the potential for exchange of road weather data via a whole new communications approach.

The MDC/AVL programs in several states are now approaching complete coverage of vehicles in the maintenance fleet The in-vehicle devices and data collection networks are becoming much more reliable as the technology matures. Associated research under the Connected Vehicle program is also showing the potential to collect data from all vehicles on the roadway and exchange the information with other vehicles. Although there are still a lot of issues in data credibility and reliability that need to be answered and resolved, the Connected Vehicle program has the potential to usher in a whole new phase of RWIS.

2.3. IMPACT OF CHANGES TO RWIS CAUSED BY EVOLUTION

The continually changing environment around the RWIS program has had significant impact on the development of RWIS. This is particularly true of the computing and communication technologies that RWIS uses to transport and display the data collected from the field. The hardware and data processing software provided by the RWIS vendors typically has a life expectancy of 20 years or more if the equipment is maintained through routine servicing. The ongoing changes in computers and communications have caused stable data management or data transport solutions to become too slow or out of date more on the order of 5 – 10 years. This has impacted the life span of the field controllers (or RPUs), CPU servers, communications interfaces, and the graphical user interface solutions.

And a recent movement to integrate RWIS information into traveler information support services has placed more emphasis on:

- Camera imagery
- Road conditions
- Measures of safety (grip level)
- Traffic speeds
- Traffic volume (congestion)
- Other factors affecting travel (flooding, avalanches, excessive winds, severe weather)

This transition in support has impacted the selection of sensors necessary at ESS sites and the requirements for data processing to address these new support requirements. The information management teams within the DOT tasked with effective communication, processing, and storage of data to support all aspects of DOT operations are now looking at traffic, RWIS, and road condition information, as well as information from other DOT centers as pure numeric data that needs to be handled in a single, well-structured database. This move toward a uniform data management facility creates another mechanism to draw the previously separate operations closer together.

The introduction and expansion of mobile data collection has had a significant influence on the MDSS program and management programs within the DOT dealing with resource utilization (treatment materials, equipment, and labor). The acquisition of information from mobile platforms has raised questions about the optimal configuration of resources to most effectively satisfy the road weather needs of the maintenance community. In a couple of states the state-funded MDC/AVL program is being supplemented by a certified corps of private observers who submit road condition and weather reports directly to state. States and their weather support providers are exploring ways to display the mobile data and private observer reports to gain maximum value from the information. The results are likely to prove advantageous when Connected Vehicle information becomes an information resource.

3. EVALUATION OF RWIS PROGRAMS IN OTHER STATES/PROVINCES

Much of the evaluation of best practices related to the RWIS program came from the direct interviews with the 20 agencies that willingly participated in the study. Representatives in the participating agencies who have been active in RWIS were initially contacted by email with a request for participation in the evaluation program. A number of the contacts responded immediately and were interested in setting a date and time for an interview session. A few of the contacts felt that there was a better resource in their organization or they wanted to coordinate a call with one or more additional people in their organization. Considering typical scheduling issues, establishing dates and times and performing the interviews was surprisingly successful.

A series of questions were developed for the interview sessions. The questions were associated with the 10 areas that are or have become integral parts of the RWIS program; this list was previously discussed in the last paragraph of the Introduction (Section 1). The first list of potential questions proposed by PB was extensive. PB and the MDOT project manager discussed the questions and reduced it to a set of questions that addressed the key topics of interest. These questions served as a guide for a structured, but somewhat free-form discussion of the RWIS programs in each state/province. Interviews were planned as one-hour sessions; however, many of the sessions extended to an hour and a half to two hours. The interviewers took notes during the interview sessions and transposed the notes to an electronic format that was subsequently sent back to the state/provincial participants in each discussion. The agencies made corrections, additions, or deletions to the notes to create a formal record of the interview that was acceptable to the Agency.

The formal notes were extensive with a considerable amount of detailed, agency-specific information about RWIS programs in the state or province. To help evaluate best practices across the set of participants, a master spreadsheet was established to create a summary of the responses. The objective was the establishment of a list of resources, techniques, and operational programs used within the 20 agencies that would serve as a baseline for the study and a way to evaluate the key directions of RWIS. The entire master spreadsheet is presented in Appendix A. The specific parts of the master spreadsheet dealing with each of the RWIS categories have been extracted and presented as tables in the relevant topic in the memorandum..

Each of the tables provides a summary of the responses derived from the interviews for the specified RWIS category. The Agency names are listed alphabetically in the first column. Data from the Michigan workshops and other sources are included in the table for comparison purposes. The table then provides a list of potential response options for the specified RWIS category. The cells in the Agency/category matrix are used to designate responses from the interviews. For example, in Table 4-1 the RPU category has a column for the number of RPUs actively deployed by that jurisdiction and a set of six (6) columns, one for each of the manufacturers who have provided RPUs to the agencies. During the interviews the respondents indicated the total number of RPUs (which is equivalent to the number of ESS sites) but did not have a breakdown of exact count of RPUs from each manufacturer. However, they did indicate that most of the RPUs were from a given vendor and a few were from another vendor. Thus symbols were selected to denote responses to indicate whether an agency had a predominance of RPUs from one specific vendor or a few units from another vendor. This technique of indicating many or few was used for responses within all categories where undefined counts existed. The approach was beneficial since it makes it easier to visually determine what solutions are dominant and what solutions have lesser implementation.

The legend beneath the table of state/province responses provides a full description of the abbreviations used at the top of the columns. The legend also includes a description of the icons used as Cell Fillers. Diamonds are used to represent options that have many or a predominant share of the entries and open circles were used to represents options where there are only a few entries. Where agencies responded with nearly an even split of solutions for a given category, diamonds were placed under two or more column headers. For example, in Table 4-1 in the RPU category Ontario has built their system using ESS equipment provided by multiple vendors. Of the 140 ESS sites they have significant installations of Campbell Scientific, Lufft, and Vaisala units. In addition, they have a couple ESS sites provided by Boschung.

The tables are snapshots of the current state of RWIS and characterize what solutions DOTs have found useful up until now. They do not specifically contain assessments of trends or changes in RWIS infrastructure, support program changes, or subjective interpretations of the users. This information is contained in the discussion associated with the information from the tables. Specific trends derived from the literature and the interviews are highlighted in the discussion as Notable Trends. Based upon these trends, ongoing evolution of the RWIS program, and assessment of comments made by the interviewees, the authors highlight what they interpret as Best Practices.

4. ENVIRONMENTAL SENSOR STATIONS

Environmental sensor stations (9, 10) serve as the data collection units for the classic approach to RWIS. They are physical structures almost always located in a DOT's right-of-way. Most are permanent installations with mounting structures affixed to a poured concrete base; however, some agencies have mobile units that may be moved into a location and left in that location for a period of time. A few agencies have used augured poles that are essentially permanent structures, but which permit removal of the support structure and relocation to a new spot when construction would shut down the pavement condition measurements. Occasionally, the controller and atmospheric sensors are mounted on a DMS structure or if no atmospheric sensors are used the controller may be mounted on any available structure.

This section looks at the specifics of the predominant ESS components used by 18 states and 2 Canadian provinces that have RWIS programs similar to that of MDOT. It also looks at the reasons for selecting the physical locations chosen for individual ESS sites within their ESS network.

4.1.1 CONFIGURATION

An ESS is composed of a field controller (originally denoted as a remote processing unit, or RPU) that processes signals from a suite of instruments or sensors, composes these signals into digital representations, and stores the signals for transmission to a central processing site. The ESS and sensing devices are mounted on a tower, pole, or some structure that elevates the devices above ground level. The controller requires a power source, which also supplies the necessary power to the sensors. In some configurations, certain sensors require their own controller and the output of this sensor-specific controller is passed to the primary controller. The ESS must also contain a communications interface to some form of communication medium. This is typically a modem specific to the communication option selected. The ESS may also have an antenna for the transmission and receipt of wireless signals from a remote transfer point (cellular or radio tower). In the early stages of RWIS the ESS site also required a landline connection and a phone demarcation point. Some landline connections still exist but they are being replaced by wireless options. In some remote locations, hardware for satellite communications is needed. Most ESS installations include some form of grounding to protect the controllers and instrumentation from lightning strikes.

4.1.2 ESS CONTROLLER

The Remote Processing Unit vendor section of Table 4-1 headed by the category name RPU lists the number of ESS sites in each state or province in the study plus the current situation in Michigan. The 66 ESS sites in Michigan are close to the median number of sites in other states/provinces; however, the large number of sites in 4 or 5 of the states and the 2 provinces skew the distribution to the high side making the average closer to 90. The primary supplier is Vaisala, but that predominance reflects the early success that SSI had in the North American market prior to about 2000. Quixote acquired SSI in 2001 and then Vaisala acquired Quixote in 2009. However, the core of the SSI engineering team has remained intact through these changes. The Vaisala and Boschung controllers remain proprietary in nature. The other four controller manufacturers provide controllers that use open system architecture. The field controller for the Olsson Associates ESS is an Allen Bradley SLC 500 Control System.

Table 4-1: Environmental Sensor Station Pavement Sensors

ENVIRONMENTAL SENSOR STATION							
AGENCY	RPU						
	#	B	CS	IDI	L	OA	V
Alaska	55		○				◆
Alberta	101	○			◆		◆
Colorado	93						◆
Idaho	106						◆
Indiana	33						◆
Iowa	65+						◆
Kansas	43+10						◆
Michigan	66	○	○		◆		◆
Minnesota	93						◆
Montana	71	○					◆
Nebraska	60					◆	
Nevada	82						◆
New York	37				◆		○
North Dakota	26				○		◆
Ohio	172						◆
Ontario	140	○	◆		◆		◆
Pennsylvania	96				◆		◆
South Dakota	46			◆			
Utah	83		◆				
Washington	120						◆
Wisconsin	59				○		◆

LEGEND

Cell filler	**RPU -- Remote Processing Unit Vendor**
◆ -- many	B -- Boschung
○ – few	CS -- Campbel Scientific
	IDI -- Intelligent Devices, Inc. (Delcan)
	L -- Lufft
	OA -- Olsson Associates
	V -- Vaisala

All of the Boschung controllers in this study are associated with Fixed Automated Spray Technology (FAST) systems and their output is displayed independently of the agencies' RWIS displays. The states and provinces that have controllers from multiple vendors are generally moving away from the proprietary solutions or are bidding each expansion independently based upon the best bid or pricing option. Agencies that collect RWIS information from ESS controllers from different manufacturers either collect the data themselves from the different controllers using NTCIP standard communications format or integrate the data from the vendor's servers after the individual providers have collected it.

The introduction of open system solutions might suggest a transfer of the market from the Vaisala controllers to open system units. However, a number of agencies have found that uniformity of equipment has advantages that outweigh transitioning to or integrating a new provider into their ESS network. Several states with ongoing RWIS network expansion are remaining with the single vendor configuration.

NOTABLE TREND: DOTs are moving toward ESS field controller configurations that fit into non-proprietary, open architecture designs.

4.1.3 PAVEMENT SENSORS

Since the Vaisala ESS controllers were designed to process information from Vaisala pavement sensors, the preponderance of the pavement sensor types in Table 4-2 are considered Vaisala sensors. The Vaisala sensors are primarily FP2000 sensors (11) manufactured by SSI since the 1990s. The FP2000 is considered a passive sensor since its measurement technique does not change the environment it is measuring. That is, it does not change the pavement temperature or the condition of the snow, ice, water, and chemical layer atop the sensor. The FP2000 sensor and most other passive sensors sold by other vendors are implanted in the roadway and connected via a buried cable to the controller. Another type of passive sensor is the Groundhog sensor, originally manufactured by Nu-Metrics. Quixote acquired Nu-Metrics in 1998 and the Groundhog became part of Vaisala in the acquisition of Quixote in 2009. The Groundhog (12) is a wireless sensor that requires no cable for communication to the field controller. The sensor screws into a base that is implanted in the pavement. During construction and overlays the sensor can be removed and placed in a new base after the construction is completed, thereby saving the cost of sensor replacement. The Ohio DOT has built much of their RWIS network using the Groundhog.

A limitation of passive sensors was the inability to determine the exact temperature where ice crystals would start occurring in a solution comprised of water and one or more chemicals. Passive sensors could provide this information when only salt was used, but if another deicing chemical was used or a combination of chemicals were used applied passive sensors could not provide the correct freeze point temperature. To resolve this inadequacy sensor manufacturers developed an active sensor. The active sensor heated the layer of snow, ice, and water until all ice was gone from the mixture and then cooled the layer until ice started forming in the layer. The temperature at which this transition from a complete liquid state to a combination of water, ice, and chemical occurred was the freeze point temperature. Because the heating and cooling mechanism in the in-pavement active sensor affected the temperature of the sensor itself, active sensors could not measure pavement temperature accurately. They had to be installed in conjunction with a passive sensor located at least several inches away from the active sensor. The Boschung FAST systems use an active and passive sensor pair to provide guidance to the spray controller concerning when to activate the spray systems.

Table 4-2: Environmental Sensor Station Pavement Sensors

ENVIRONMENTAL SENSOR STATION							
AGENCY	PAVEMENT SENSOR TYPES						
	BA	BP	LP	LIR	VP	VGH	VIR
Alaska					◆		O
Alberta	O	O	◆		◆		
Colorado					◆		
Idaho							◆
Indiana					◆		
Iowa					◆		
Kansas					◆	O	
Michigan	O	O	◆	O	◆	O	O
Minnesota					◆	O	
Montana	O	O			◆		
Nebraska					◆		
Nevada					◆		O
New York			◆				
North Dakota			O		◆		
Ohio					O	◆	O
Ontario	O	O	O		◆		
Pennsylvania			◆		◆	◆	
South Dakota			◆		O		
Utah			◆	◆			◆
Washington					◆		
Wisconsin			O		◆		

LEGEND

Cell filler	Pavement Sensor Types
◆ – many	BA – Boschung active
O – few	BP – Boschung passive
	LP – Lufft passive
	LIR – Lufft non-contact IR
	VP – Vaisala passive
	VGH – Vaisala Ground Hog
	VIR – Vaisala non-contact IR

The FP2000 sensor interacts with logic on the Vaisala field controller; therefore, the FP2000 sensor is not interchangeable with ESS controllers manufactured by other vendors. States that have opted to develop systems based upon open architecture and who desire to install in-pavement passive sensors have typically selected Lufft passive sensors (13).

The latest development in sensor technology has been the introduction of non-invasive sensors, which are now manufactured by Vaisala (14), Lufft (15), and Innovative Dynamics, Inc. (16). These sensors use infrared (IR) lasers to assess the amount of snow, ice, and water on the pavement surface. Because the visual angle needed to operate properly is typically not satisfied by the location of the support structure for the atmospheric instruments, most IR sensors are mounted on posts at an appropriate distance from the roadway. The non-invasive sensors are almost always installed as a pair of units or a device with dual capabilities, one to measure pavement condition and one to measure pavement temperature.

Manufacturers have correlated the amounts of snow, ice, and water to a grip value, a unit similar to the coefficient of friction through several winters of empirical testing. The grip values provide a mechanism to evaluate level of service. Idaho has put together a rigorous program to develop techniques to develop criteria to monitor their level of service using Vaisala non-invasive sensors. Nearly all of their 106 ESS sites have non-invasive sensors and they expect to expand this capability with additional sites instrumented with non-invasive sensors over the next few years.

Nebraska has taken a slightly different approach. They found value in pavement temperature but had limited success with pavement condition information from the original installation of FP2000 sensors. They have replaced a good share of their sensors with a Lakewood Systems PTS sensor that provides them with pavement temperature only at less than one-tenth the cost of a normal passive sensor.

NOTABLE TREND: Many DOTs are deploying or testing non-invasive sensors in their ESS instrument suite.

4.1.4 ATMOSPHERIC SENSORS

The common set of instruments at an ESS site includes an air temperature/relative humidity sensor, a wind speed sensor, and a precipitation sensor. The air temperature/RH sensor and the precipitation sensor are needed to support an algorithm on the RPU used to determine pavement condition and the wind direction/speed/gust sensor is an important tool to provide guidance to maintenance decisions makers. Some states have opted to include a barometric pressure sensor, a visibility sensor, a snow depth sensor, and occasionally radiation flux sensors. In special situations agencies have included water depth sensors and sensors to capture gaseous concentrations such as carbon monoxide.

The information in the AT/RH and WIND columns of Table 4-3 suggests that all agencies include air temperature/RH sensors and wind sensors with the majority of their ESS configurations. Early in the development of RWIS all of the wind sensors were propeller-type sensors. This type of sensor performed well as long as the bearings were replaced at least once a year or more in high wind locations. They also had a tendency to ice up during freezing rain situations. Once ultrasonic sensors became price competitive, they began to replace the propeller anemometers. The advantage of the ultrasonic sensors is no moving parts and resistance to icing when heated. Servicing costs are considerably less as well.

Table 4-3: Environmental Sensor Station Atmospheric Sensors

ENVIRONMENTAL SENSOR STATION							
AGENCY	ATMOSPHERIC SENSOR TYPE						
	AT/RH	WIND	R2S	OSI	VPWD	VTB	Y/N
Alaska	◆	◆					◆
Alberta	◆	◆	◆				O
Colorado	◆	◆		◆			O
Idaho	◆	◆		O	O		O
Indiana	◆	◆		O			◆
Iowa	◆	◆	O	◆	O		O
Kansas	◆	◆	◆				◆
Michigan	◆	◆	◆	◆	◆		
Minnesota	◆	◆	◆				O
Montana	◆	◆		◆			
Nebraska	◆	◆					O
Nevada	◆	◆					◆
New York	◆	◆	◆	O			O
North Dakota	◆	◆		O			◆
Ohio	◆	◆		◆	◆		
Ontario	◆	◆		O		O	◆
Pennsylvania	◆	◆					◆
South Dakota	◆	◆	◆				
Utah	◆	◆				O	◆
Washington	◆	◆					
Wisconsin	◆	◆	O	◆			◆

LEGEND

Cell filler	Atmospheric Sensor Type
◆ -- many	AT/RH -- Air temperature/Relative Humidity
O -- few	Wind -- Wind direction/speed/gust
	R2S -- Lufft R2S
	OSI -- Optical Scientific Inc.
	VPWD -- Vaisala PWD present weather sensor
	VTB -- Vaisala tipping bucket sensor
	Y/N -- Any yes/no precip sensor

Probably the key sensor for RWIS is the precipitation sensor. In the original RWIS configuration all that was needed was a sensor that sensed the presence or absence of precipitation to support the pavement condition algorithm. This is why there are so many Y/N sensors in existing configurations. Maintenance personnel pointed out that knowing whether there was precipitation or not really didn't help their decision process that much. They needed to know the type of precipitation and the intensity. The need for better precipitation information led to the integration of a sensor that was developed for the NWS automated surface observation system (ASOS). OSI, the manufacturer of the ASOS unit created a unit similar to the one provided to the NWS at the request of SSI. The sensor was known as an optical weather identifier

(OWI). This was enhanced with a similar sensor that included a modification to measure visibility. The enhanced sensor was a weather identifier and visibility (WIVIS) sensor (17). These optical 'present weather' sensors output the type of precipitation, its rate/intensity, and accumulation (and visibility for the WIVIS). The sensors perform well if their lenses were kept clean. However, winter highway environments become infused with salt spray as traffic moves through the slush and residual layer of deiced water. Therefore, the lenses of the WIVIS and OWI need to be cleaned regularly. Recently, Lufft has introduced a radar based present weather sensor (the R2S) that is considerably less affected by the salt spray environment (18).

Several states have replaced their Y/N sensors with a present weather sensor. The common options include the OSI WIVIS, Lufft R2S, or Vaisala PWD22/52 series sensors. The WIVIS and PWD sensors report both precipitation and visibility information. However, currently only the WIVIS and R2S sensors measure the precipitation rate along with the type.

The observation of precipitation type and rate at a remote ESS site is an important piece of information for maintenance personnel for their decision support process. It becomes a critical resource for MDSS and important guidance for travelers. The reliability and accuracy of precipitation information has improved under the performance based service contracts (see Section 6) but it is a critical part of the RWIS data set that will require continual attention to assure it remains a reliable source of information.

NOTABLE TREND: Most agencies are integrating present weather sensors into their atmospheric instrument package as part of new ESS sites or replacement of aging Y/N precipitation sensors.

4.1.5 SUB-SURFACE SENSORS

Maintenance personnel use sub-surface temperatures to determine when the materials beneath the pavement are frozen and when the layer directly below the pavement slab goes into a period of thawing and then becomes completely frost-free.

Sub-surface sensors have been a part of RWIS configurations from the early days of RWIS. They were originally included in the ESS package to support pavement temperature forecasting, providing an estimate of the heat source or heat sink in the heat flux equations used to compute the thermal energy balance and *vis-à-vis* the pavement temperature at each hour in a 24-hour or longer forecast. Section 7 provides more detail on thermal energy balance models used to determine pavement temperature values. All agencies have at least one sub-surface probe at most ESS sites where a non-deck sensor is installed (see Table 4-4).

Table 4-4: Environmental Sensor Station Subsurface Sensors and Cameras

ENVIRONMENTAL SENSOR STATION								
AGENCY	SUBSURFACE			CAMERAS				
	1	2	COL	FIXED	PTZ	ESS	TRAF	IR
Alaska	◆		◆	◆	◆	38	0	
Alberta		◆			◆	100	0	O
Colorado	◆			◆	◆	90	280	
Idaho	O				◆	105	100+	
Indiana	◆				◆	21	200	
Iowa	◆				◆	55	250	
Kansas	◆				◆	8	100	
Michigan	◆		◆		◆	55	455	◆
Minnesota	◆				◆	90	250+	O
Montana	◆			◆	◆	50	50+	
Nebraska	◆				◆	~50	~100	
Nevada	◆					0	210	
New York	◆				◆	25	200+	O
North Dakota	◆				◆	10	50	
Ohio	◆				O	6	~150	
Ontario	◆				◆	70	250	◆
Pennsylvania	◆			◆		96	800+	
South Dakota	◆				◆	45	20	
Utah	◆			◆	◆	~80	900	
Washington	◆			◆		110	700	
Wisconsin	◆				O	15	240	

LEGEND

Cell filler	Subsurface	Cameras
◆ – many	1 – 1 sensor/site	FIXED -- fixed focus
O – few	2 – 2 sensors/site	PTZ -- pan/tile/zoom
	COL -- temp column	ESS -- number of ESS cameras
		TRAF -- number of traffic cameras
		IR -- infrared illuminator

A few states/provinces have installed either an additional sensor at a different depth or a column of sensors to monitor sub-surface temperatures at a series of depths. Single sensors are positioned 16 – 18 in (40 – 50 cm) below the surface of the pavement. Alberta has an additional sensor at 150 cm (60 in). Sub-surface temperature profile columns are typically 72 in (180 cm) in length and contain 10 – 14 separate thermistors at varying depths. Alaska has a network of 34 Temperature Depth Probes (TDP) manufactured by Measurement Research Corporation to monitor sub-surface frost. The Temperature Data Probes are 72" columns containing 16 thermistors spaced 3" apart from 3" to 12" and 6" apart from 12" to 72". The top of the TDP column is placed directly beneath the pavement slab. For more information regarding Alaska's TDP columns please visit the following link:
http://www.dot.state.ak.us/iways/roadweather/forms/AboutTDP.html.

4.1.6 CAMERAS

Nearly all the agencies surveyed have cameras installed on some or all of their ESS locations. The cameras typically have pan/tilt/zoom (PTZ) capability and provide multiple images from each site. Most agencies have one image focused on the pavement at each ESS location with the other focus points being either direction along the primary highway, on an intersection, or along an intersecting roadway. Thus far, the majority of the cameras are daylight cameras that do not provide useable images during darkness. However, agencies are beginning to install infrared light illumination and cameras that process IR illuminated images. The other approach is the installation of cameras that function reasonably well in low intensity illumination. These low intensity cameras work well at night where the DOT has some form of lighting in use.

Table 4-4 indicates the relative number of ESS cameras and traffic cameras currently in use within the states/provinces surveyed. The highly urbanized states/provinces have considerably more traffic cameras than ESS cameras; however, traffic cameras tend to be concentrated in the large metropolitan areas. Because of the more uniform spatial distribution of ESS cameras, the images from ESS are often provided as a camera resource on agencies' 511 page.

NOTABLE TREND: Camera imagery has become a highly desired RWIS resource for many stakeholders and is particularly requested by travelers.

4.1.7 TRAFFIC MONITORING DEVICES

Traffic monitoring devices (usually side looking radar units) have been placed on the ESS towers in at least Iowa, Michigan, and Ontario and the data is processed via the field controller and sent to the CPU as part of the routinely transferred data packet. Section 9 addresses traffic monitoring in more detail.

4.1.8 ENVIRONMENTAL SENSORS

Most ESS controllers have the ability to process output from any type of sensor that is attached to the ESS mounting structure. The only constraints are the available memory on the controller and the necessity to create new data objects for use in the NTCIP data transmissions. Sensors outside of the normal 'RWIS configuration' are included at ESS locations for special requirements or as part of research projects. Some of the devices that have been installed include snow depth sensors, water depth sensors, radiation flux, ozone monitors, and blowing snow monitors).

Table 4-5: Mounting Structures and ESS Power Sources

ENVIRONMENTAL SENSOR STATION						
AGENCY	MOUNTING			POWER		
	GM	POLE	ANY	COM	SOLAR	GAS
Alaska	◆					
Alberta	◆			◆		
Colorado	◆			◆		
Idaho		◆		◆	O	O
Indiana	◆			◆		
Iowa	◆			◆		
Kansas	◆			◆		
Michigan	◆	◆	O	◆		
Minnesota	◆			◆		
Montana	◆			◆		
Nebraska	◆			◆		
Nevada	◆			◆		
New York	O	◆		◆		
North Dakota	◆			◆		
Ohio		◆	◆	O	◆	
Ontario	◆			◆	O	
Pennsylvania	◆	◆		◆		
South Dakota	◆			◆		
Utah	◆			◆	◆	
Washington	◆			◆		
Wisconsin	◆	O		◆		

LEGEND

Cell filler	Mounting	Power
◆ – many	GM – Glenn Martin	COM -- commercial
O – few	Pole -- pole/post	Solar -- solar panels
	Any – any structure	Gas -- Fuel cells

4.1.9 MOUNTING STRUCTURE

SSI designed their ESS to attach to a 10 m (30 ft) fold-over tower manufactured by Glen Martin (19). The primary reason was the need to have a structure that allowed mounting sensors at heights that met WMO siting standards, the same standards that were specified in the RWIS ESS Siting Guidelines published in 2005 (9). The greatest number of ESS sites in North America use these fold-over towers for support of atmospheric, sensors, cameras, and traffic monitoring devices and for the ability to drop the tower to service instruments above the first 10 ft (3.3 m) section (see Table 4-5). European RWIS manufacturers opted to place their equipment on a post or rigid pole and did not put a similar emphasis on meeting the WMO guidelines for sensor locations. As states/provinces started adding installations from vendors such as Lufft and Boschung the number of controllers and atmospheric sensors supported by simple poles has increased. In certain situations it becomes difficult to set a tower or pole within the right-of-way that is not a safety concern or the installation does not require atmospherics or devices that need to be elevated. In these cases it is possible to mount the controller on an existing structure, barrier wall, or mounting structure for another requirement.

4.1.10 POWER

Commercial power is the primary source of electricity for the majority of ESS installations. In siting new ESS locations the cost to get power to potential sites may be a limiting factor in selecting the proposed location. In these cases it may become more cost effective to use solar, gas generated, or fuel cell supplemented power. Table 4-5 implies that this has become an option in some of the mountainous states and states/provinces with extensive areas with limited commercial power. Solar power becomes the first choice; however, in northern latitudes the solar angle and the duration of sunlight do not permit the capture of enough solar energy to sustain the operational requirements of the ESS equipment. Further, these areas tend to experience extended periods of extreme cold that reduce the performance of batteries. In these situations fuel cells and propane gas generators have been used to supplement or replace solar solutions.

Ohio has developed a unique approach to RWIS. They designed their system to function on a reduced energy level compared to the systems typically provided by the RWIS manufacturers. ODOT uses Groundhog sensors that function on their own battery source and communicate wirelessly to the RPU. ODOT redesigned the RPU to operate on less power and has limited the use of cameras and heating devices used to preclude icing on sensors. A predominant portion of their ESS network is powered by solar energy.

Table 4-6: Reasons for Selecting the ESS Site Locations

ENVIRONMENTAL SENSOR STATION - PART 2

AGENCY	REASON FOR SITE SELECTION				
	MAINT	WX	PERF	CON	ATIS
Alaska	◆				
Alberta	◆		O		O
Colorado	◆	◆			
Idaho	◆		◆		O
Indiana	◆			◆	
Iowa	◆			O	
Kansas	◆				O
Michigan	◆	O			O
Minnesota	◆	O		O	
Montana	◆	◆			
Nebraska	◆	◆			
Nevada	◆				O
New York	◆	O			
North Dakota	◆				
Ohio	◆	◆			
Ontario	◆				
Pennsylvania	◆	◆		O	
South Dakota	◆				
Utah	◆				
Washington	◆				◆
Wisconsin	◆			O	

LEGEND

Cell filler	Reason for site selection
◆ -- many	MAINT -- support maintenance
O -- few	WX -- monitor weather conditions
	PERF -- performance measures
	CON -- with construction projects
	ATIS – support traveler info

4.1.11 SITE SELECTION CRITERIA

The reasons for selecting ESS sites have changed during the evolution of the RWIS program. The summary of reasons in Table 4-6 indicates that the use of RWIS as a maintenance support tool was the dominant consideration in ESS site selection. The "support maintenance" reason in this table lumps together all maintenance requirements and does not address the issue of locating ESS sites to serve as a representative information source for an area surrounding the ESS site or to provide information for local areas known to have special treatment requirements. In most states/provinces their ESS network contains sites that represent both of these selection criteria.

Installations made prior to the year 2000, were almost totally done to support maintenance requirements. However, several agencies also considered placement of ESS sites or the planned deployment of their sites to monitor the progress of weather systems across their state. They viewed RWIS as a mechanism to assess the arrival of a storm or a way to assess the initiation of adverse road conditions and use this information to project the advance of these conditions to other locations within the state/province. It was more of a maintenance support tool, utilized to track the movement of adverse weather and road conditions. Nebraska, for example, placed the majority of its ESS sites in the western part of the state as a front line warning system for the remainder of the state.

The thought process behind ESS site selection changed as RWIS progressed through the phases described in Section 2.2. In the 1970s and 80s the selection was all about the observed RWIS conditions. Moving into the 1990s the selection process became a combination of the necessity to provide observations and also resource information to support pavement-forecasting requirements. Forecasting was better served by an evenly distributed set of ESS sites reporting what would be considered representative weather conditions. The requirement to select ESS sites with representative weather conditions to support weather forecasting made actual ESS site selection more difficult primarily due to the atypical weather environment in the highway right-of-way compared to the conditions in the "more typical" surrounding environment.

Once DOTs commenced sharing RWIS information outside of their agency, stakeholders outside of the DOT had greater influence on the selection of ESS sites. Weather service providers sought to use RWIS to fill voids in the meteorological data set and locations where travelers requested information on highway segments that were notoriously problematic or along corridors of interest to them. Recently the emphasis on the development of performance measures to evaluate maintenance effectiveness has influenced the location of ESS sites. Idaho, for example, is selecting locations to establish a more complete performance measures program and provide information, specifically camera imagery, for most of the mountain passes in Idaho.

Recently, funding has become a significant factor on ESS site selection. The direct allocation of funding for RWIS expansion has become more limited in a number of states/provinces than in the past. Monies are more readily available for construction projects and agencies are integrating ESS installations into these projects if the location enhances the RWIS network and the overall RWIS scheme.

NOTABLE TREND: Historically, RWIS supported DOT personnel tasked with winter maintenance; currently there is more emphasis on resource considerations to support traveler information requirements.

4.2. ENVIRONMENTAL SENSOR STATION BEST PRACTICES

- The optimal design of an ESS network is an open system architecture design.
  RWIS technology and functionality are changing rapidly. Novel solutions to measurement techniques are coming from new players in the market place and integration of these solutions requires an infrastructure that permits easy connection of these solutions to existing processing systems. DOTs need the ability to select a preferred solution to measuring a particular road weather parameter without constraints from the vendor. The RWIS design has addressed pavement-related and weather information in the past; this paradigm is shifting to make ESS more of data acquisition point for transportation information with growing input from cameras and traffic monitoring devices. Future ESS processors will need to have the ability to easily handle all of these sources without excessive modifications to the processing unit.

- The most accurate and cost effective solution to measure pavement conditions is a combination of a non-invasive pavement condition sensor and an implanted pavement temperature device.

All pavement sensor technologies have limitations in measuring road conditions when the depth of the snow, ice, and water layer is greater than about 0.25 in (6 mm). And in-pavement sensors have difficulty assessing the proper road condition when the depth of the layer is less than 0.01 in (0.3 mm) – roughly the transition point from wet to damp pavements. Infrared non-invasive sensors provide good road condition assessments as long as the depth of the snow/ice/ water layer is less ¼ to ½ in. Infrared radiation is used to provide a pavement temperature estimate with non-invasive sensors. The sensor actually "sees" the top surface of the snow/ice/water layer. Often the temperature of this layer is the same as the temperature at the interface between the top of the pavement surface and the layer above, but there can be a significant difference. For accurate assessment of the pavement temperature the best solution is a temperature sensor embedded at the surface with good thermal contact with the surrounding pavement. A simple thermistor or an array of thermistors provides the best pavement temperature reading at a limited cost.

- The majority of sites should be sited to provide representative road weather conditions.
  Sites should be placed in locations that support the general highway conditions and pavement temperatures. The weather information obtained is representative of the conditions in the area and fills voids in the weather observation network, improves road weather, and pavement condition forecasts which research indicates is the greatest benefit for the RWIS program. This will allow the information to be used for a broader array of maintenance purposes.

- ESS sites should be situated as far from the roadway as possible at a location that fits into the local environment more so than the conditions in the highway right-of-way. However, certain sensors, such as the non-invasive pavement sensor, may need to be located closer to the highway to work properly
  Since the ESS site must be in the Agency's right-of-way it should be located as close as possible to the edge of the right-of-way or in an open area (e.g., an open area at one corner of an intersection). The ESS site should be outside of any ditches with its base level with the surrounding landscape (commonly along the right-of-way fence line). If possible the site should be on the upwind side of the prevailing wind direction during the winter months.

- The weather instrumentation package should include sensing devices to measure air temperature/RH, horizontal wind information, precipitation type and rate, and visibility. The sensors can be individual instruments or a combination sold as a single package. The sensors may be mounted on a fold-over tower, pole designed to support the sensors and provide easy access for servicing, or an existing rigid structure that does not significantly impact airflow. The individual sensing elements must meet the performance specifications in the RWIS ESS Siting Guidelines.
  The defined instrument suite is necessary to aid maintenance operations and forecasting requirements. All of these instruments are critical in the support of key maintenance and forecasting functions. The sensor used to provide precipitation type and rate is the most important resource in the package. The sensor should be selected for its accuracy and the siting of the instrument should receive careful attention to assure that it will perform correctly for extended periods (i.e., out of road spray, away from anomalous wind flow patterns, and away from moving objects that might affect the performance of the sensor). Visibility sensors need to be capable of determining visibility to a minimum of 10 miles and preferably 30 miles. The instruments must meet the desired specifications; attempts to achieve cost savings with these instruments will prove counterproductive.

- Measurement of conditions at locations considered maintenance trouble spots needs careful consideration. If local weather conditions are representative of the broader area, then approach the ESS site as a representative <u>weather</u> location. If not, consider monitoring only the road

conditions at the site unless it would be helpful to know the unrepresentative weather conditions that are impacting this particular ESS site.
For trouble spots it may be more cost effective to monitor the road conditions and not add instrumentation to measure weather conditions that are only pertinent to a short segment of roadway. However, if knowing the local weather information is a critical piece of information along with the road conditions at this spot then include the necessary weather information.

- Each ESS site should preferentially include a camera with multiple views and with at least one being a close-up view of the highway surface. Cameras should be able to present usable images under low intensity light.
  Maintenance personnel have found that the ability to see what conditions exist at remote sites is a cost savings resource and travelers have come to depend upon the images to support their travel plans.

5. RWIS DATA MANAGEMENT

A critical component of RWIS is the movement of the ESS data from the field sites to a central repository followed by the distribution of this information to those stakeholders. The component is critical because information from ESS sites has a relatively short 'shelf life' and latencies, delays, or interruptions in data transport impact the worth of RWIS data. Therefore, the design and management of the communications, central processing, and data dissemination systems play a key role in the acceptance of the RWIS program within an agency or its interface to the public. This section considers the infrastructure to transport and manage the data and procedures to assure its quality and reliability.

5.1. ESS TO CENTRAL SERVER COMMUNICATIONS

During the first decade of the RWIS program almost all communications from the ESS to the CPU was done via landlines or radio communications. After 1985 the communications shifted slowly from landlines to radio and some wide area network communication. Early in the Twenty-first Century cellular communications networks expanded and became a resource for data communications. In the last decade most of the ESS to CPU data communications has shifted to cellular (except where cell coverage is still being implemented) or fiber. Fiber has proven particularly effective along highway corridors where DOTs have rights to use fiber laid in their right-of-way.

The preference for cellular communications is illustrated in the Type of Communications section in Table 5-1. The move to cellular and fiber communications has increased reliability significantly and has provided the bandwidth necessary to support the inclusion of camera imagery and reduce the data collection cycle time. Where the infrastructure for cellular and/or fiber communications is still not established, states/provinces have turned to satellite communications.

NOTABLE TREND: Technological advances in data communications have played a significant role in improving data transfer from ESS field sites to central processing locations. This factor is key to the acceptance of RWIS as a tool to support maintenance decision-making and in meeting traveler information requirements.

Table 5-1: Central Processing Management

DATA COMMUNICATIONS AND PROCESSING

AGENCY	TYPE OF COMMUNICATIONS						CENTRAL PROCESSING MANAGER								
	LL	Cell	Fiber	Radio	WAN	Sat	IDI	IT	KH	L	OA	PEL	SE	V	VG
Alaska	◆	◆			O	O									◆
Alberta		◆											◆		
Colorado		◆	◆					◆							
Idaho		◆	O												◆
Indiana	O	◆		O										◆	
Iowa		◆			◆									◆	
Kansas	O	◆		O										◆	
Michigan		◆	O	O	O								◆		
Minnesota	O	◆				O		◆							
Montana	◆	◆		◆				◆							
Nebraska		◆									◆				
Nevada	O	◆	◆	◆					◆						
New York		◆	O							◆					
North Dakota	O			◆	◆			◆							
Ohio		◆						◆						◆	
Ontario		◆										◆			
Pennsylvania		◆						NEW CONTRACT FOR 2013/14							
South Dakota		◆					◆								
Utah		◆	◆					◆							
Washington	◆	O	O											◆	
Wisconsin	O	◆		O						◆				◆	

LEGEND

Cell filler	Type of Communications	Central Processing Manager
◆ – many	LL -- land line	IDI – Intelligent Devices Inc. (Delcan)
O – few	Cell -- cellular	IT – DOT Information Technology department
	Fiber -- fiber optic cable	KH – Kimley-Horn and Associates
	Radio -- radio communications network	L – Lufft
	WAN -- wide area network	OA – Olsson Associates
	Sat -- satellite	PEL –Pelmorix
		SE – Schneider Electric
		V – Vaisala processing unit at DOT
		VG – Vaisala Global, processing at Vaisala

5.2. CENTRAL SERVER SOLUTIONS

The central server is the hub of the RWIS network. It manages:

- The collection of the data from the ESS sites
- The validation of successful data transfer or requests additional attempt at data transfer
- Storage of the data in a database
- Quality checks on the data and flags questionable data
- The user interface to DOT personnel
- The transfer of information to external user interface servers

The central server may reside at a vendor's facility or at the DOT. The typical DOT location is within the DOT's Information Technology (IT) or Communications Division facilities behind the DOT's firewall. The central server may be a single PC or server or a distributed set of processors with various levels of backup or redundancy..

The original RWIS configurations sold in the United States were totally proprietary in design and operation and had to be managed and serviced by the system provider. Several states desired to manage the communication of data themselves and negotiated an agreement with the manufacturer to manage the data collection and operation of the central processing server under licensing agreements. By the mid-1980s there was considerable pushback by the DOTs who felt the available RWIS solutions were closed systems that precluded interchangeability and interoperability. A group of DOTs moved to develop a communications protocol to permit interoperability between the central processor and ESS units from different providers. At the same time several DOTs pressured RWIS providers to integrate devices that were not sold as available options. The implementation of NTCIP for ESS to CPU data communications and advances in ESS technology permitted easy integration of non-standard instrumentation made the revised RWIS more acceptable and closer to an open architecture solution.

Therefore prior to roughly 2005, the RWIS manufacturers or the DOTs, under licensing agreements, handled all of the data collection and data management. After 2005, with the availability of open system solutions, third party data managers have surfaced to perform the RWIS data management function. In Table 5-1 Vaisala, Lufft, and IDI manufacture RWIS equipment and historically either managed the central processing function or licensed it to the DOT IT group. The remaining firms in the table have backgrounds in data processing but were not previously involved directly in RWIS data management.

The transition to third party managers has been driven by a number of factors. The prominent reasons include:

1. States/provinces through bid procurement procedures or choice acquired RWIS networks with equipment from different vendors. And since RWIS vendors were reluctant to collect and process the data from competitor's ESS sites, states/provinces had to find ways to integrate the data from different vendor systems.
2. The movement of field information to different central collection points for ESS units from different providers meant users had to go to separate interfaces to access and use the data. The interfaces for each provider were different, making it difficult for DOT users to effectively use the data, especially from the newer interface.
3. Data reliability of each vendor's network is partially dependent upon the service performed on that set of equipment. To assure equivalent performance across all vendor networks, servicing must be uniform and effective across all ESS equipment. If a service representative from one vendor was to take the responsibility for servicing the equipment from another vendor's network, it required the servicing agent to invest in replacement inventory and learn the detailed servicing steps to keep the new equipment running properly. Thus, DOTs were faced with the prospect of having two servicing agents and the necessity to manage this arrangement.
4. Agencies were finding it a challenge to keep their RWIS networks running reliably and accurately and were looking for ways to transfer the data management issues to a contractor who would assume responsibility to assure high performance of the system.

The interviews indicate that approximately half of the states/provinces have opted to either contract the data collection and management to third parties or handle it internally within their information technology division (see the Central Processing Manager section of Table 5-1). PennDOT is expected to add to this trend as it seeks a contractor to manage its RWIS data collection and distribution late this year. Alberta initiated what has become the third party management process in 2005 (see Section 6 for more detail on this step) and a number of states/provinces have opted to follow this approach in the last few years. The inclusion of Kimley-Horn, Olsson Associates, Pelmorix, and Schneider Electric in the list of data managers is a reflection of the emergence of a new group of players in the RWIS program. The agreement between the states/provinces and these contractors are almost all performance-based arrangements. All four of these companies have responsibility for maintenance of the equipment as well as managing the data collection, data archive, user interface programs, and data dissemination requirements.

5.3. GRAPHICAL USER INTERFACE OPTIONS

The delivery of RWIS data from the SSI CPU to maintenance users was first done using printers with thermal or electro-sensitive paper. This was replaced in 1989 by a stand-alone application installed on a desktop computer, which interacted directly with the SSI CPU. By the mid-1990s the CPU had been upgraded to a computer-based server that was able to support web-based application known as SCAN Web. The SCAN Web software still exists today and remains the direct interface to many Vaisala (SSI-developed) servers. Vaisala has a newer RWIS support application called Navigator that allows users considerable flexibility in designing how information is portrayed to its DOT users. Lufft uses a web-based interface called SmartView. All of the newly developed management solutions have similar user interface programs. All of these solutions have tied forecasting and alert capabilities to the RWIS display function to create a broader road weather support program.

With the implementation of the *Clarus* program and the proposed transition of its functionality to the Meteorological Assimilation Data Ingest System (MADIS) program, ESS data is available to any subscriber to these RWIS data support systems. Therefore, any weather support provider or party wanting to provide RWIS data to end users has the ability to display the data collected by an agency's data management service. Most companies that provide weather support have implemented this capability either through use of *Clarus*/MADIS data or through direct access to an agency's data dissemination server. Still, the web-based graphical user interfaces resident on the data collection server do provide quicker access to the most current data and often can display a more extensive data set than what is transferred to *Clarus*/MADIS and other outside interests. Data timeliness is impacted by a number of delays in moving the data from database to database. Thus, if immediate access to weather information is an operational concern, the user interfaces supported by the central collection server remain the best option for RWIS data access.

5.4. DATA DISTRIBUTION AND DISSEMINATION

To assure data integrity and often the security of the data management provider's computer facilities, the RWIS central server or set of servers dedicated to the collection, storage, and distribution of ESS data are maintained inside of the managing entity's firewall. In order to make the data available to those parties wanting ready access to the data, the data manager generally uses file transfer protocol (FTP) servers to support delivery of data to *Clarus*/MADIS, the NWS, private weather service providers, and other interested users. At routine intervals the central server pushes the data out to the FTP server that is outside of the managing agency's firewall. This FTP server then distributes the data to users with access permission.

5.5. DATA QUALITY CHECKING

The meteorological community utilizes a number of rigorous quality checking routines on its observations to minimize the use of errant data to support its operational decisions. This quality checking comes at a cost but its use is considered a necessity to assure accurate and reliable weather support information and guidance. The RWIS program was not built with this same emphasis on quality checking. Service contracts were established to provide routine maintenance on the equipment and fix hardware issues as they developed but there was no rigorous requirement to continually monitor the accuracy of the data and move quickly to rectify deficiencies. Because RWIS was viewed as a support tool and maintenance decisions did not absolutely depend upon the information provided by RWIS instrumentation and pavement sensors, the demand for quality assurance did not receive the attention that weather data supported by the federal government did. Limited quality checking impacted the real time value of the data and detracted from the acceptance of RWIS amongst the field people for whom the information was intended. A number of states recognized the importance of assuring the data be reliable and accurate and developed programs or organizational support structures to assure reliable operation of ESS instrumentation and thus the desired level of data quality. These states created RWIS coordinator positions and sought individuals who would establish and monitor service programs to keep the state's RWIS investment operating effectively. The result is that states/provinces with strong RWIS champions have maintained relatively good data and strong RWIS programs.

Table 5-2: RWIS Service and Data Quality Programs

RWIS SERVICE ARRANGEMENTS

AGENCY	SERVICE REPRESENTATIVE								SERVICE CONTRACT			QUALITY CHECKING			
	COR	DOT	NW	L	OA	PEL	SE	V	NONE	C-R	C-PB	DOT	MADIS	PWS	DATA
Alaska								◆		◆		◆			
Alberta							◆				◆			◆	
Colorado		◆							◆			◆			
Idaho								◆		◆	○	◆			○
Indiana								◆		◆		◆	○		
Iowa								◆		◆		◆	○		
Kansas		◆							◆			◆	○		
Michigan							◆				◆				◆
Minnesota		◆							◆			◆	○		
Montana		◆							◆			◆			
Nebraska					◆					◆		◆			
Nevada		◆							◆			○	○		
New York				◆						◆		○			
North Dakota		◆							◆			◆			
Ohio	◆										◆	◆			◆
Ontario						◆					◆	◆			◆
Pennsylvania	NEW CONTRACT										◆	◆			◆
South Dakota		◆							◆			◆			
Utah			◆							◆			◆		◆
Washington		◆							◆			◆	○		
Wisconsin				◆				◆			◆	◆			○

LEGEND

Cell filler		Service Contract	Quality Checking
◆ – many	COR -- M.H. Corbin	C-R – regular contract	DOT -- done by DOT
○ – few	DOT -- service done internally by DOT	C-PB – performance-based contract	MADIS -- use of NOAA MADIS checks
	NW -- NorthWest Weathernet		PWS -- checks by weather provider
	L -- Lufft (Traffic Technology 2000)		DATA -- checks by data provider
	OA -- Olsson Associates		
	PEL -- Pelmorix		
	SE -- Schneider Electric		
	V -- Vaisala		

Shortly after 2000 a number of things happened that impacted the need for quality assurance and quality checking. One was the *Clarus* Initiative which utilized quality checking algorithms to validate data for users and assisted the DOTs in determining potential data quality issues within their ESS network (20). A second factor was the establishment of the 511 traveler information services and the dissemination of the RWIS data to the public. The visibility of the RWIS network was extensively increased putting more pressure on the RWIS coordinator to keep the system running well. The third factor was the move toward the use of data management firms operating under performance-based agreements as a contractor for the state/province. This operational paradigm essentially transfers the state's management responsibility to an external entity and makes the state or province a data user rather than system owner. The states/provinces still remain owners of the system but delegate the management of the system's performance, data acquisition, and dissemination responsibilities to another party. To assure the contractor performs in the best interest of the state/province the contracts stipulate that the contractor assure the RWIS network perform at a defined performance level or be penalized for non-performance.

The result of these three factors is that quality checking is gaining more emphasis within the state/provincial RWIS programs. Most quality checking is still performed by the DOT and often by the RWIS coordinator, but the increased visibility of the data has caused agencies to monitor system performance more closely. Several states had set up computer programs to ingest the quality checks done by *Clarus* and have now shifted these to MADIS and/or the Weather Data Environment (WxDE) project to help flag potential issues that need attention and possibly servicing. Where data management has been transferred to an outside organization, the data manager or the weather service provider primarily have responsibility for the quality checking.

The Quality Checking columns on the right side of Table 5-2 show who has the responsibility to perform the quality checking for each agency. In nearly all of the states/provinces where the data provider or weather service provider does the quality checking, the work is performed under a performance-based contract (column C-PB in the Service Contract section).

NOTABLE TREND: Performance based contracts and the demand for accurate information to support traveler information have increased the need for a dedicated quality-checking program.

5.6. RWIS DATA MANAGEMENT BEST PRACTICES

- The utilization of performance-based contracts improves the quality of the system output and performance of the system.
  The potential of monetary penalties in RWIS support contracts with service or data management contracts has positively influenced the performance of the contracting agent and thereby improved the performance of the system and the quality of the data generated by the RWIS network.

- The use of third party data management contracts consolidates the supervision of all aspects within one organization, which optimizes quality control, quick response to data processing issues, rapid restoration of accurate data flow, and assured delivery of RWIS data to end users. This arrangement is especially effective under a performance-based support contractual agreement.
  An RWIS network is an end-to-end data processing system. Historically, the issues with RWIS have been breakdowns in the processing or transfer of data at various points in the pathway. Individual components of the entire transfer and delivery process were the responsibility of different entities or under separate contracts. Some of the parties involved had little or no incentive to resolve issues or contracts did not have the teeth to force immediate resolution of issues. By implementing an agreement where a contractor agrees to maintain a specified level of performance or accept monetary penalties DOT agencies have managed to establish a support model that provides the agency with a reliable source of RWIS data. The ongoing availability of reliable data makes RWIS a much more valuable tool to the stakeholders.

6. RWIS EQUIPMENT SERVICING

Maintenance of RWIS hardware has had an important influence on the development and acceptance of the RWIS program in North America. Unlike Europe where a number of different vendors competed for the RWIS market, the North American market was almost totally dominated by a single vendor, SSI, primarily because SSI was the only RWIS provider who committed to servicing their equipment with servicing agents located in or near states/provinces interested in installing RWIS equipment. From the beginning SSI was contracted to service their equipment or worked with agencies to train and support service representatives within the DOTs. However, equipment servicing came at a cost and often a cost that was not fully anticipated by agency representatives handling the RWIS program. Thus, equipment servicing did not receive the emphasis necessary to keep RWIS performing at its potential in a number of cases.

The growth of RWIS during the 1990s and the travel costs to support expanding networks of field equipment also impacted SSI's ability to meet the performance expectations of the states/provinces that contracted with SSI under the service contract language at that time. States who were committed to keeping their systems operating at peak performance rewrote bid specifications and contract language and required the servicing agent to have a qualified technician in state or close enough to address and/or resolve issues within 24 to 48 hours. At the time these agreements did not include specific penalties for non-performance other than termination of the agreement. Several states/provinces opted to service the equipment with their own personnel. The Service Representative section in Table 5-2 indicates that roughly half of the participants in the study maintain their own equipment.

As indicated in Section 5.2, Alberta issued a tender for the establishment of an RWIS network that would provide Alberta Transportation with RWIS data at a guaranteed level of reliability and accuracy. The original tender was for a lease agreement; however, Alberta considered the bid lease costs to be too high and modified the agreement to purchase the equipment and have the contractor manage the system at the specified performance level with penalties for non-compliance with the performance specifications. The management paradigm laid out by Alberta is now being implemented by a number of agencies and has drawn several system integrators into the RWIS community. The list of service representatives in Table 5-2 indicates that there are at least 5 integrators providing equipment servicing in addition to the RWIS equipment vendors. Of these service contracts, roughly half now include performance requirements with some degree of fiscal penalty for non-compliance.

NOTABLE TREND: Service contracts are gravitating toward performance–based agreements and often as part or all of an end-to-end data management arrangement.

7. WEATHER SUPPORT SERVICES

Maintenance operations within the DOT have used weather information ever since the NWS (or its predecessor bureaus) provided it. Private weather service providers (PWS) have also been around roughly the same duration and fill specific needs of weather information users not covered by the NWS. A number of the PWS organizations have tailored support services specifically for surface transportation requirements and to support DOT maintenance obligations. Likely the most important resource introduced by the PWS was the introduction of pavement condition forecasts to the RWIS support program in the mid-1980s. Initially the forecast models used thermal energy balance techniques along with point specific weather forecasts to create projections of the pavement temperature. This modeling approach was enhanced in the mid-1990s with the introduction of a combined energy and mass balance model. The mass balance component addressed the flux of water (in its different states) and treatment materials onto and off the road surface due to weather events, maintenance actions, and traffic. The mass balance component also dealt with changes in the state of water and the associated heat exchanges during these transitions. The latent heat associated with the state changes of water has a significant impact on the thermal balance part of the model. Thus pavement forecasts have become an integral part of the RWIS support services and the impact of weather support providers and their services have had a significant impact on the direction of the RWIS program.

Table 7-1: Weather Support Services

WEATHER SERVICES

AGENCY	WEATHER SERVICE PROVIDER						SERVICES					MDSS
	ACWX	ITERIS	NW	NWS	PEL	SE	WX	PAV	NOTIF	CALL	REC	YES
Alaska				◆			◆					◆
Alberta						◆	◆	◆	◆	◆		◆
Colorado		◆					◆	◆	◆	◆	◆	◆
Idaho				◆			◆			◆		
Indiana		◆					◆	◆	◆	◆	◆	
Iowa						◆	◆	◆	◆	◆	◆	O
Kansas						◆	◆	◆	◆	◆	◆	O
Michigan						◆	◆	◆	◆	◆	◆	◆
Minnesota		◆					◆	◆	◆	◆	◆	◆
Montana				◆			◆			◆		
Nebraska		◆					◆	◆	◆	◆	◆	◆
Nevada						◆	◆	◆	◆	◆	◆	
New York	◆						◆		◆	◆		◆
North Dakota		◆					◆	◆	◆	◆	◆	◆
Ohio						◆	◆	◆	◆	◆	◆	
Ontario					◆		◆	◆	◆	◆		
Pennsylvania	◆						◆	◆	◆	◆		◆
South Dakota		◆					◆	◆	◆	◆	◆	◆
Utah			◆				◆		◆	◆		
Washington			◆				◆	◆	◆	◆		
Wisconsin		◆					◆	◆	◆	◆	◆	◆

LEGEND

Cell filler	Weather Service Provider	Services
◆ – many	ACWX -- AccuWeather	WX – Weather data & forecasts
O – few	Iteris -- Iteris	PAV – Pavement specific road weather data & forecasts
	NW -- NorthWest Weathernet	NOTIF – Notifications sent
	NWS -- National Weather Service	CALL – Interact with meteorologist
	PEL -- Pelmorix	REC – Maintenance recommendations in fcst
	SE -- Schneider Electric	

7.1. WEATHER SERVICE PROVIDERS

The Weather Service Provider portion of Table 7-1 indicates which weather service providers each agency uses to support its maintenance decision-making requirements. Three of the states use NWS products and interact with NWS personnel to get specific guidance on the weather patterns affecting their area. In the other states/provinces a number of PWS providers compete for the services. Some of these agency-PWS relationships have persisted for a number of years while others represent recent changes in the service provider for a given agency.

7.2. ROAD WEATHER SUPPORT SERVICES

Nearly all of the PWS provide weather data, pavement forecasts, some form of alerting or user notification of critical events, and a method for the user and a meteorologist to discuss specific situations (see the Services section in Table 7-1). A couple of the PWS providers include treatment recommendations as part of the forecast service. The PAV column under the Services section indicates that the agency does not contract specifically for a pavement forecast product from its provider; however, Alaska and New York receive pavement-specific analyses and forecasts via their MDSS service. Utah does not receive detailed pavement condition forecasts for the pavement but guidance on the general conditions anticipated on the roadway as a function of the weather conditions. They have found that segment- or spot-specific pavement forecasts are difficult to use in a transportation system in a mountainous region.

Most of the PWS providers ingest the RWIS information and deliver it back to maintenance personnel in formats that add value over the displays supported by the CPU. Probably the one of the most useful formats is the combination of observations from RWIS and other data sources available from sources such as MADIS on a regional map with indicators showing the source of each data point. PWS providers are beginning to augment these displays with observations from mobile DOT vehicles.

7.3. MAINTENANCE DECISION SUPPORT SERVICES

The development of the MDSS program was discussed in the New Technologies (2000 – 2005) sub-section of Section 2.2. Those agencies that are using a form of MDSS in their operations are shown in the MDSS column in Table 7-1. The diamond icon indicates those agencies that indicate they are actively using MDSS to support operations in part or their entire jurisdiction. The open circle icon indicates that the agency receives MDSS guidance as parts of their weather support package but have other internal mechanisms that provide the DOT with a preferred solution. Blank cells indicate that the agency has not opted to use MDSS at this point.

MDSS, like RWIS in its formative years, has been slow to capture general acceptance amongst front line personnel in a number of agencies. Although it is designed as a support tool that integrates the multitude of inputs that affect maintenance decisions to yield the most feasible option for the existing or forecasted conditions, MDSS is often viewed as an override to the decisions currently in use, or worse, as guidance that contradicts the individual's years of experience.

Operationally MDSS is highly dependent upon input of accurate road condition information for specific maintenance routes or road segments. A detailed description of the road condition and the projected weather conditions are absolutely essential for accurate MDSS performance and once an event has started road conditions become the primary determinant for treatment plans. The existing sources of road condition status at any time include:

1. Observations by maintenance personnel
2. Road condition reports from ESS sites along the route
3. Camera imagery
4. Inference techniques using:
    a. Weather conditions
    b. Recent precipitation types and amounts
    c. Pavement temperature
    d. Recent chemical applications

Maintenance personnel typically have ready access to items 1, 2, and 3 through communications or weather support services. MDSS depends upon items 2 and 4. The MDC/AVL program provides a mechanism to transfer driver observations (item 1) into MDSS; however, the detail of the information provided by this technique is limited and reduces the ability of MDSS to fully appreciate what drivers actually see and communicate verbally within their maintenance operations. Currently, all of the resources available to support MDSS have factors that limit the level of accuracy of the information feed to MDSS.

Because MDSS must continually generate recommendations based upon the best estimate of the existing road conditions at the current time, the fourth option is used by MDSS to provide the best guess of road conditions. Adjustments are made to the assessment using approach 4 when information from 1 and 2 is available. However, it must be noted that road conditions generated from output by RWIS sensors have issues of their own and MDSS must use caution in the use of certain road condition categories output by these sensors. The inference technique offers the best solution for the ongoing updating process necessary to support continually changing road conditions. Two parameters need considerable improvement to make the inference approach more accurate: a network of reliable precipitation or present weather sensors and reliable input of treatment actions. MDC/AVL has the potential to satisfy 4.d once an agency has all vehicles instrumented and assures that the units work reliably. 4.b will require continuation of the move to present weather sensors as part of ESS configurations.

Two other options offer the potential to provide alternative methods to assess road conditions. One is the use of the ever-increasing network of cameras to determine road conditions remotely. The other is the use of social networking or connected vehicle approaches to get a dynamic picture of conditions throughout a highway network.

7.4. WEATHER SUPPORT SERVICES BEST PRACTICES

- DOT agencies are moving toward the integration of a broader spectrum of transportation-related information into their support packages, including maintenance recommendations, camera imagery, and traffic speed and volume data.
  Maintenance recommendations have evolved out of the MDSS program and remain an area of research and evaluation. Cameras have become a more common installation on ESS structures and maintenance personnel are finding new ways to integrate the field imagery into their operations. Where camera imagery is passed to traveler information services, the public has found them useful and has requested expansion of the service. The performance measures requirements under MAP-21 has created a need for traffic data at the ESS sites to assess regain times and level of service metrics. The camera imagery and traffic data are taking the RWIS program in a new direction.

8. MOBILE DATA

Automatic vehicle location was implemented in the 1990s and slowly was accepted as means to monitor the movement of fleet vehicles. In the same timeframe manufacturers of spreader controllers on snowplows were integrating GPS technologies into their spreader mechanisms to record material usage as a function of time and space. During the development of the PFS MDSS the Technical Panel recognized a need to capture information from drivers and the spreader controllers to support the MDSS recommendation process. The DOT members of this group also saw the potential to collect treatment actions in near real-time to facilitate management of material and vehicle resources. A mobile data collection industry for maintenance and MDSS support developed to meet this requirement.

The automobile industry has been developing techniques to monitor and log essentially all of the functions occurring in the operation of the vehicle for many years. In 2002 the Research and Innovative Technology Administration (RITA) of the US DOT started working with the automobile industry to develop vehicle-to-vehicle (V2V) technologies to avoid vehicle collisions (21). During the development of interface topologies the idea of using instrumentation or parameters being captured on the controller area network (CAN) bus could be telemetered to stationary points along the road using vehicle-to-infrastructure (V2I) transfers via dedicated short range communications (DSRC) or other wireless means was created. This research effort has evolved into the Connected Vehicle program. Programs are underway in a few states to demonstrate the viability of providing information from any vehicle for ITS or weather support purposes.

Table 8-1: Mobile Data

MOBILE DATA

AGENCY	MDC/AVL UNITS & VENDOR								MDC PARAMETERS					CV
	#	AT	CC	GI	IDI	IWAPI	LT	P	SPDR	PLOW	CAN	T/RH	T-SCR	
Alaska	26											◆		N
Alberta	200+			◆					◆				◆	N
Colorado	200					◆							◆	N
Idaho	30+		◆				O		◆	◆		◆	◆	N
Indiana	0													N
Iowa	850+						◆		◆	◆		◆		N
Kansas	0													N
Michigan	300				◆							◆		Y
Minnesota	389	◆							◆	◆	◆	◆	◆	IMO
Montana	0													N
Nebraska	104	O			◆				◆	◆		◆	◆	N
Nevada	0													IMO
New York	37	◆							◆	◆		◆	◆	N
North Dakota	100						◆		◆	◆		◆	◆	N
Ohio	0													N
Ontario	?	AVL on all vehicles; 3 vendors												N
Pennsylvania	0													N
South Dakota	100				◆				◆	◆		◆	◆	N
Utah	0													N
Washington	400								◆	◆		◆	◆	N
Wisconsin	950							◆	◆	◆		◆	◆	N

LEGEND

Cell filler	MDC/AVL units & vendor	MDC Parameters
◆ – many	AT -- AmeriTrak	SPDR – Spreader controller
O – few	CC -- Cirus Controls	PLOW – Plow position
	GI -- Grey Island (WebTech Wireless)	CAN – CAN bus output
	IDI -- Intelligent Devices, Inc (Delcan)	T/RH – Temperature/RH
	IWAPI -- Iwapi	T-SCR – Touch screen i/o
	LT -- Location Technologies	
	P -- PreCise MRM	**CV -- Connected Vehicle**
		IMO -- Integrated Mobile Observation

8.1. AGENCY INVOLVEMENT

The MDC/AVL Units and Vendors section of Table 8-1 lists the number of vehicles that currently have MDC/AVL units installed within each state/province. The numbers suggest that a third of the agencies are firmly committed to the MDC/AVL program, one-third have no involvement at this time, and the remaining third are in the initial stages of their involvement in the program.

8.2. MDC/AVL PROVIDERS

The MDC/AVL Units and Vendors section in Table 8-1 also indicates that there is a wide distribution of providers currently involved in the MDC/AVL program with no dominant vendor. Nearly all of the providers collect the data from their system and provide it to the agency and MDSS provider. Most of the data collection is done via cellular communications. This causes occasional delays in the transfer of data where cellular communications is weak or where mountains or structures block communications. All of the MDC/AVL vendors provide service their own equipment and/or provide training on the installation the equipment and how to deal with common issues.

Michigan uses a Droid smart phone as its controller. The smart phone is connected to an Android application called DataProbe. Using the smart phone, CAN bus interface, and DataProbe app the IMO project on I-94 provides air temperature, pavement temperature, RH, dew point, location, vehicle speed, and

CAN bus parameters. Of particular interest are the ABS and Trac Control parameters. The smart phone also has the capability of taking pictures and sending the images back to the central site. Currently the only communication back to the vehicle via the smart phone display is text messages. The use of a smart phone as a controller represents a unique solution in the development of the MDC/AVL program.

8.3. USES FOR MOBILE DATA

The MDC Parameters section of Table 8-1 indicates what information the MDC/AVL provider manages and sends to the DOT and MDSS programs. Most states with active programs collect spreader controller information, plow position, air temperature, and pavement temperature. Most of the MDC/AVL providers install their controller units with a small computer and a touch-screen monitor. The computer is programmed to create a display on the monitor screen that allows users to select information the DOT desires to support MDSS or their resource monitoring programs. For MDSS the parameters on the touch screen are typically items such as lane, material, material application rate, weather, type/rate of precipitation, and road condition; however other parameters may be used by individual agencies. When a user touches one of the categories, the monitor displays a list of the options for that parameter. Users then select the preferred options. Vehicle operators may enter a number of observations using this technique and send the information when done. The monitors also have limited Internet access and have been set up to display weather conditions, road conditions, radar imagery, location of other vehicles, and forecasted conditions for the operator's route(s). For MDSS the two-way exchange of data provides a mechanism to update the MDSS processor to permit inclusion of current reports and integrate this information into the generation of route-specific guidance that is then made available to the vehicle operator via the monitor.

As part of the FHWA's Integrating Mobile Observations (IMO) program MnDOT has deployed MDC/AVL units on 6 light duty vehicles and configured the MDC/AVL controller to collect data from the CAN bus. Through this effort the controller on each vehicle will now be capable of interfacing with the CAN bus on that vehicle and the entire fleet could potentially collect CV-type data using the MDC/AVL interface.

States/provinces are finding that their MDC/AVL units provide an excellent tool to manage the use of materials and equipment resources. Alberta and Ontario contract their maintenance to private contractors and then use the controllers to monitor equipment use and material applications to validate activities as part of their compensation program. The counties in Wisconsin perform highway maintenance on behalf of WisDOT; thus, Wisconsin is evaluating ways to use the information from the counties' mobile units to assist in determination of resource use and the appropriate compensation. MnDOT has worked with its provider to develop an end-of-shift function that allows the operator to quickly create end-of-shift logs.

MDC/AVL does not need to be viewed as just a winter maintenance support tool. MnDOT has placed MDC/AVL units on their mowers and programmed the interface to provide the mower operator with information about the location of noxious weeds, which helps prevent mowing in weed patches and spreading the weeds to unaffected areas. The MDC/AVL interface also allows the operator to specify areas where weeds are now observed that were considered weed-free previously. By working with the MDC/AVL providers, agencies are developing new ways to make the units a year-round tool.

NOTABLE TREND: Mobile data collection and automated vehicle location technologies have been integrated into a growing portion of the DOTs and agencies are finding novel ways to use information from these systems to support operations and management.

8.4. CONNECTED VEHCILE PROGRAM

The last column in Table 8-1 points out that only Michigan and the states involved in the IMO project are actively involved in the CV program. However, the interviews revealed that nearly all of the agencies see a tremendous potential for the Connected Vehicle program to have an impact on road weather support. For now these agencies are all taking a wait-and-see attitude.

8.5. RECEIPT OF DATA IN-VEHICLE

As indicated in Section 8.3, many of the MDC/AVL units installed in maintenance vehicles have computers with monitors. Web browsers installed in the computers permit the display or weather and maintenance support information. However, a growing number of operators use smart phones for communications either to supplement existing radio communications or to facilitate discussions with particular individuals. The smart phones have the added ability to acquire information from weather support providers via easy-to-use apps, many of which can be tailored to provide the specific information the operator desires. Some operators are also using tablets to acquire desired road weather information. Weather service providers have recognized this growing trend toward hand-held communications and developed interfaces and apps specifically for each of the devices and their display capabilities.

There are legitimate concerns about the safety of using mobile display devices in a moving vehicle. Several agencies are addressing these concerns and establishing policies and/or operational guidelines for use of the mobile devices or design criteria that limits when incoming information may be displayed. From the operator's perspective much of the information is invaluable for the support of their decision making process. This is particularly true in rural areas where plow drivers often make their own decisions. Timely access to resources such as radar information, weather observations, RWIS data, updated short-term forecasts, updated treatment recommendations, the current location of other vehicles in their fleet, incidents, and other operational support information have become essential to these drivers optimize their treatment actions. For some maintenance facilities the use of mobile data within the cab of the maintenance vehicle has become an operational best practice.

8.6. MOBILE DATA BEST PRACTICES

- Mobile data collection has become an adjunct road weather data collection service that augments RWIS information and weather support services such as MDSS; MDC has also become a significant resource to monitor the use of materials and equipment.
  Systems have been in place to track vehicle locations and spreader controller functions for a number of years. With the advent of the MDSS program several companies created solutions to collect road weather monitored from the vehicle and treatment information stored in the spreader controller and telemeter this information for input into a road condition simulation program. The information was used dynamically to support road condition assessments and generate treatment recommendations, but also was stored to support the assessment of materials and equipment use. A handful of states have a significant portion of their fleet instrumented and the remaining states/provinces are in the process of installing units in their vehicles or establishing a plan to initiate the program as funding is allocated.

9. TRAFFIC MONITORING

Historically, the traffic division of the DOT was the only group that performed traffic monitoring. Recently researchers in maintenance have found that that information available from traffic monitoring devices can be useful in assessing the level of service or performance level of maintenance operations. In addition, traffic and maintenance are finding new ways to exchange data for the mutual benefit of both areas of responsibility. Finally, the DOT's responsibility to provide traveler information requires an integration of information from both groups, which requires coordination of deliverables.

9.1. ESS RECORDED DATA

Iowa, Michigan, and Ontario have added Wavetronix side-looking radars to their set of ESS sensors and integrated the output into the data packet sent as part of the routine observation package. Iowa has integrated the display of the traffic data into their current RWIS information page on the Iowa DOT Watherview web site. They display the most current 2-minute average speed and volume information for each site with traffic monitoring devices is available on Iowa DOT's Weatherview web site. At this time the information from the Iowa ESS sites is not shared directly with the TMC. As indicated in the ESS and SHOW columns in Table 9-1 other than the 3 agencies mentioned none of the other states/provinces have integrated traffic monitoring devices into their RWIS configuration. However, there is growing interest in using traffic speed information as a form of performance metric for regain time and level of service assessment. Several states stated they are exploring the addition of traffic monitors to their RWIS tool set to support these programs.

9.2. ACCESS AND USE OF DATA MONITORED BY TRAFFIC OPERATIONS

Most of the DOTs surveyed indicated that maintenance personnel have access to the data from the TMC's traffic monitoring devices either through internal interfaces or via the traveler information website (Table 9-1 Traffic Monitors, "Avail" column). However, only in less than half of the states/provinces do maintenance personnel use the information to support their decisions regarding maintenance action or performance assessment.

Table 9-1: Traffic Monitoring

TRAFFIC MONITORING				
AGENCY	TRAFFIC MONITORS			
	ESS	SHOW	AVAIL	USE
Alaska				
Alberta				
Colorado			◆	◆
Idaho			◆	◆
Indiana			◆	
Iowa	◆	◆	◆	◆
Kansas				
Michigan	◆		◆	
Minnesota			◆	◆
Montana			◆	O
Nebraska			◆	O
Nevada			◆	O
New York			O	O
North Dakota				
Ohio	NA	NA	NA	NA
Ontario	O	?	O	O
Pennsylvania			◆	
South Dakota			◆	
Utah			◆	◆
Washington			◆	
Wisconsin			◆	O

LEGEND

Cell filler	Traffic Monitors
◆ -- many	ESS – on ESS
O – few	SHOW -- display on ESS site
	AVAIL – traffic division data available
	USE -- use traffic data

9.3. COORDINATION BETWEEN TRAFFIC AND MAINTENANCE

Traditionally, traffic operations and maintenance functioned separately from one another and each used independent resources to support their individual operational needs. Over the last decade several factors have increased the interaction and sharing of resources between the two functional areas. These factors include:

- The expansion of camera imagery as a support tool
- DOT consolidation of IT resources to support data processing and storage for all DOT users
- The increased monitoring of traffic speed, volume, and occupancy in real-time
- The realization in maintenance that traffic speed is a reasonably effective measure of maintenance level of service performance

- The joint support of traveler information services
- Incident management during adverse weather conditions
- Road condition reporting support

As the density of the cameras and traffic monitoring devices increased there was a push within each of the groups to exchange information for the mutual benefit of both parties. The exchange of camera imagery or at least the availability of camera imagery collected by separate systems now exists in most states. As indicated in Table 9-1 most maintenance agencies have access to traffic information even if they do not currently actively integrate the data into their decision support process. In a number of states/provinces the sharing of data has been augmented by the rapid expansion of traveler information services and the need to share camera and traffic speed/volume information with the public.

The most definitive move toward integration of traffic and maintenance activities is taking place in Utah. UDOT has collocated traffic operations and maintenance weather support personnel in the same operational work area within the TMC facility. The weather support group has a primary responsibility to support maintenance forces throughout the state. UDOT working with its contracted PWS has developed a highly interactive weather support program for maintenance that puts more emphasis on direct interaction with maintenance personnel and less emphasis on the generation of products. A significant reason for this approach is the highly variable nature of weather conditions induced by the topography in Utah and the expanses of highway infrastructure with limited traffic volume. It is easier to concentrate on issues that are likely to impact maintenance and provide a maintenance user with information related to specific interests rather than generate volumes of numbers for specific locations - numbers that maintenance users would need to synthesize and interpret into guidance to support maintenance decisions. UDOT has found greater success when the meteorologists and maintenance personnel work together interactively.

The maintenance support group in the TMC can see any of the traffic cameras throughout the state (many on the video wall in the TMC). These images provide them with a live assessment of weather conditions throughout the state and knowledge of road conditions or incidents that might impact maintenance operations or require the attention of maintenance personnel. The maintenance support group can also hear discussions of traffic incidents amongst the traffic group or they have access to situations on their workstation. Traffic also benefits from the presence of the weather group through interactions on the development and timing of weather events likely to impact the transportation grid. The interaction between traffic and the maintenance support group creates a better understanding of the requirements and operational needs of the other group. UDOT has continually modified its support programs to use the synergy that has evolved from the joint housing of maintenance support and operations.

NOTABLE TREND: DOTs are moving towards more effective sharing of maintenance and traffic operations functions and the exchange of camera and traffic information.

NOTABLE TREND: Interactive weather support has become more prevalent in recent years through direct phone support and social media forms of communication. The UDOT program puts weather support at the intersection of maintenance and traffic weather support needs and may serve as a model for future weather support of a state's transportation needs.

10. ROAD CONDITION REPORTING

Road condition reporting is done primarily by maintenance personnel in the majority of the agencies covered in the study. Table 10-1 shows the source for the road condition observations and/or the group responsible for coordinating the collection and dissemination of the reports. Rules vary amongst states/provinces regarding the frequency of required reports, but most agencies require 2 or more routine reports when a winter event is impacting some part of the state/province. All agencies issue updates whenever conditions change from the existing reported road condition. The last column in the road condition reporting section indicates how many of the agencies have a road condition reporting interface that allows qualified personnel to enter observations directly into a road condition reporting system and subsequently have the system generate and send a modified road report with minimal delay. Only two states indicated that they have this ability.

Table 10-1: Road Condition Reporting

ROAD CONDITION REPORTING

AGENCY	ROAD CONDITION REPORTING					
	WHO	1X	2X	4X	UPD	DC?
Alaska	M	◆			◆	N
Alberta	MC	◆			◆	N
Colorado	M		◆		◆	N
Idaho	M		◆		◆	N
Indiana	M			◆	◆	N
Iowa	M	in transition				
Kansas	M			◆	◆	N
Michigan	HP		◆		◆	N
Minnesota	M			◆	◆	N
Montana	M		◆		◆	N
Nebraska	M			◆	◆	Y
Nevada	M	very limited				
New York	M			◆	◆	N
North Dakota	M			◆	◆	N
Ohio	NA	NA	NA	NA	NA	NA
Ontario	M	NA	NA	NA	NA	NA
Pennsylvania	M			◆	◆	N
South Dakota	M			◆	◆	Y
Utah	M		◆		◆	N
Washington	TMC					N
Wisconsin	HP		○		○	N

LEGEND

Cell filler	Road Condition Reporting
◆ -- many	WHO -- who makes report
○ -- few	M -- maintenance staff
	MC -- maintenance contractor
	HP -- Highway Patrol
	TMC -- traffic management
	1X -- reports once daily
	2X -- reports twice daily
	4X -- reports at least four times a day
	UPD -- updates issued as needed
	DC? -- automated road cond reporting?

Road condition reporting programs and reporting rules were designed with good intention, but these programs have not performed as well as hoped primarily because those tasked with reporting the conditions get so busy during an event that they do not have time to enter a report or forget about this responsibility. The North/West Passage pooled fund study group recently performed a study to determine what potential exists to generate road condition reports automatically (22). A solution does not appear imminent but there are approaches that have distinct potential. The most promising is to use an interactive voice recognition system similar to OnStar or SYNC to report road conditions and have them processed and generated into road condition reports that can go to traveler information systems without intervention.

11. TRAVELER INFORMATION

DOTs have moved to nearly complete disclosure of their road weather-related resources. Nearly all agencies have a 511 program for dissemination of traveler information and most states/provinces indicated that they provide RWIS data, ESS camera imagery, and road condition reports via their ATIS interfaces (see Table 11-1). The traveling public now has access to RWIS information, camera imagery, road condition reports, traffic speeds and volumes, road closures, construction, and potential detours or delays related to highway maintenance or repair. States/provinces that are not providing all of this information are in the process of restructuring their processing to assure that this data gets to motorists and commercial drivers.

The dissemination of these resources to the public and the level of exposure that results are being addressed by a number of states through the introduction of performance based data management agreements. The increase in the level of quality and reliability of RWIS data makes the data more valuable in the maintenance decision-making support process and will positively impact meteorological support and MDSS.

Table 11-1: Advanced Traveler Information Systems

TRAVELER INFORMATION

AGENCY	ATIS			
	511	RWIS	CAM	RCR
Alaska	◆	◆	◆	◆
Alberta	◆	◆	◆	◆
Colorado	◆	◆	◆	◆
Idaho	◆	◆	◆	◆
Indiana	◆	◆	◆	◆
Iowa	◆	◆	◆	◆
Kansas	◆	◆	◆	◆
Michigan		◆	◆	
Minnesota	◆	◆	◆	◆
Montana	◆	◆	◆	◆
Nebraska	◆	◆	◆	◆
Nevada	◆	◆	◆	O
New York	◆		◆	◆
North Dakota	◆	◆	◆	◆
Ohio	◆	◆		
Ontario	◆		◆	◆
Pennsylvania	◆		◆	◆
South Dakota	◆		◆	◆
Utah	◆	◆	◆	◆
Washington	◆	◆	◆	
Wisconsin	◆	O	O	

LEGEND

Cell filler	Advanced Traveler Info Svc
◆ – many	511 – 511 service?
O – few	RWIS – RWIS to ATIS?
	CAM – ESS images to ATIS?
	RCR – road conds to ATIS?

During the *Clarus* Demonstration project one of the use case scenarios evaluated the feasibility of providing forecasted road conditions. Current 511 and DOT traveler information services have provided forecast conditions for specific segments of highway but not potential road conditions. The ability to determine potential road conditions based upon the forecasted weather and execution of best practice maintenance actions is already done to support the DOTs. It is likely that this capability will be added to traveler information services in the near future once the legal issues have been adequately addressed. Once end users accept that information resource as an acceptable tool, it is anticipated that travel time estimates (as impacted by the projected road conditions over the period of travel) will be introduced as a traveler information service.

The other big change that DOTs anticipate is the introduction of Connected Vehicle data into the ATIS data set. Connected Vehicle data has the potential to deslineate local changes in weather and road conditions that current analysis techniques cannot resolve. There are numerous quality control issues but ongoing research is addressing these issues and developing techniques to eliminate or reduce their impact. The FHWA WxDE program plans to commence integrating CV data in an operational test in the near future. The WxDE will acquire, process, store, and disseminate the data for use by research organizations and weather service providers interested in integrating the CV data into traveler support services.

NOTABLE TREND: RWIS information and road condition reports are displayed through nearly all 511 programs or from links available on the 511 web site.

12. DOT PROGRAMS USING RWIS-RELATED INFORMATION

A review of the Background section suggests that the direction of RWIS and road weather support can change directions significantly due to changes in the environment that support RWIS or based on end user needs that take on added importance over time and subsequently affect the direction or emphasis within the existing road weather support program. There are two factors that may have considerable influence on the direction of the RWIS program in the near future.

12.1. PERFORMANCE MEASURES

Performance measures are a keystone of the Moving Ahead for Progress in the 21st Century (MAP-21) Act signed into law by President Obama on July 6, 2012. States have initiated programs to develop performance measures to objectively evaluate winter maintenance practices. Two distinct programs have surfaced to measure maintenance level of service using specific measurement criteria. One approach is the creation of a repeatable method to determine regain-time. The approach uses RWIS precipitation information to define the start and end of a winter-storm event and traffic speed information to determine the time to regain normal driving conditions. Traffic speed as a criterion for regain-time is a reasonable measure as long as traffic speed is not impacted by congestion or some traffic situation unrelated to winter weather conditions. The determination of the beginning and ending time for precipitation requires more extensive logic than the speed variable. Specific criteria are needed to define when a precipitation sensor accurately defines the beginning and end of an event. The end of an event may require a period with no measurable accumulation of precipitation and the specific time will need to be determined in retrospect. The criterion for cessation of an event must receive considerable review and agreement between transportation officials. This approach will require the use of a high-resolution precipitation sensor and the requirement is likely to impact procurement specifications in the future.

The second approach is the use of a non-invasive sensor to accurately determine the percentage of snow, ice, and water and transform these conditions into an equivalent grip value or coefficient of friction. The non-invasive IR sensors are currently the only sensors that can make fairly accurate assessments of grip values. Idaho has opted to pursue this approach and has made a commitment to procure non-invasive sensors for all its ESS locations.

NOTABLE TREND: Performance measures to assess level of service, degree of maintenance performance, or time to return roadways to 'normal' winter driving conditions are adding value to RWIS data and affecting the instrumentation requirements at ESS sites.

12.2. SUMMER MAINTENANCE ACTIVITIES

RWIS operates all year round and there is a growing need to justify its value as part of a summer support program as well as a winter maintenance support system. State DOTs are investigating innovative techniques to be able to use RWIS for non-winter situations that add value to the entire RWIS investment. MnDOT's use of RWIS to guide mowing around noxious weed patches is a good example. More programs such as this are likely to surface and help to justify the use of RWIS throughout the year.

12.3. BEST PRACTICES IN RWIS-RELATED SUPPORT PROGRAMS

- DOTs have commenced integrating traffic monitoring devices into RWIS to evaluate the level of service status of their maintenance practice or determine post-storm performance metrics.
  Traffic speeds and to some extent traffic volume serve as a measure of the effectiveness of maintenance efforts during inclement weather. Adverse weather conditions tend to reduce traffic speeds and the amount of the reduction is related to the condition of the driving surface. Thus traffic speeds can be used as an estimate of the level of service. This factor becomes particularly important

at the end of a storm to assess the time it takes to implement the necessary maintenance actions to restore roadways to bare pavement or normal driving conditions.

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APPENDIX A

See attached document.