

NDOT Research Report

Report No. 163-11-803



**Maintenance Decision Support System: Pilot
Study and Cost-Benefit Analysis (Phase 2)**



July 2014

**Nevada Department of Transportation
1263 South Stewart Street
Carson City, NV 89712**



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**MAINTENANCE DECISION SUPPORT SYSTEM:
PILOT STUDY AND COST-BENEFIT ANALYSIS
(PHASE 2 & 2.5)**

PROJECTS P163-11-803 & P202-11-803

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1. EXECUTIVE SUMMARY

This project focused on several tasks: development of in-vehicle hardware that permits implementation of an MDSS, development of software to collect and process road and weather data, a cost-benefit study, and pilot-scale implementation.

Two Automatic Vehicle Location (AVL) systems were developed at UNR for NDOT: one for rural Nevada and one for urban environments where cellular phone data is available. For rural areas a system was developed that relies on the statewide Enhanced Digital Access Communications Systems (EDACS) radio system for sending/receiving data. The system developed for urban areas currently use a Droid cell phone to transmit data. No driver interaction is needed in either system, which avoids distracted driving concerns. Both systems communicate with a central server located at UNR. Using both snow plows and light duty trucks, a total of 37 vehicle installations were completed (not including two installations at UNR).

A survey of other DOT's experiences with MDSS and interviews with 3 MDSS service providers was also completed. Most DOTs have one of two goals for their MDSS: 1) to increase the level of service while using the same resources or 2) maintaining the same level of service using fewer resources. Our conclusion is that if Nevada DOT were to aim for maintaining the same level of service it can expect to see substantial savings if they chose to implement MDSS. With an annual salt/sand budget of about \$2.6 million, NDOT can expect to save between \$520k to \$1 million annually.

Our research has also identified several potential impediments to implementing an MDSS in Nevada. The most pressing issue is related to data communication in rural Nevada. It is envisioned that two types of AVL systems will be needed, one that makes use of the Statewide radio network and another that uses mobile (cellular) data. An AVL system that seamlessly switches between modes would be desirable. Both systems will need to safely provide snowplow drivers with updated treatment plans without distracting the operator. The pilot-scale systems developed can serve as templates for eventual vendor RFPs.

The second issue that could hinder implementation of an MDSS is Nevada's Material Management System (MMS). Because it is currently difficult for NDOT personnel to accurately report *where* along the route material is being used, it would be difficult to determine where MDSS benefits/losses are being realized.

Thirdly, building trust by NDOT personnel in MDSS recommendations may be difficult. Nevada's many microclimates in the northern region of the state are attributed to making it difficult for making accurate weather predictions. If the MDSS has inaccurate weather forecasts, then the treatment recommendations it provides will not engender any trust in the supervisors consulting the system.

Finally, the MDSS community, which includes many state DOTs and private vendors, have to deal with intellectual property (patent) issues. Our analysis indicates that NDOT/UNR is not infringing on any of the claims in any of the seven patents reviewed. However, the group of patents issued to Concaten and Iwapi remains a concern for all DOTs using an MDSS and all providers of MDSS solutions. Nevada cannot proceed to implement an MDSS without developing a plan to address the intellectual property issues.

2. PROJECT GOALS

The long-term goal of this project is to develop recommendations and formulate an implementation plan for a Maintenance Decision Support System (MDSS) for the Nevada Department of Transportation (NDOT). An MDSS is a decision-making tool that gathers and interprets reliable road and weather information and facilitates use of these data to help operations managers maximize their winter maintenance resources. Several states' DOTs currently employ an MDSS and the consensus is that the primary benefits of an MDSS are increased mobility, safety, level of service, and cost savings. Implementation of an MDSS by NDOT has the potential of reducing winter material costs by an estimated 20-40% (over \$500k per year). This report describes the progress made during phases 2 and 2.5 of the projected 3 phase project (phase 2.5 was implemented only because a 6 month no-cost extension of phase 2 was not processed in a timely manner by UNR).

3. BACKGROUND

3.1 MDSS Systems

A Maintenance Decision Support System (MDSS) is a software and hardware package that is typically provided through a private sector vendor, intended to assist DOTs in using their winter maintenance resources more efficiently. These packages can vary between vendors as well as from the type of contract that is made between the vendor and the DOT. A typical MDSS package contains a GPS-based Automatic Vehicle Location (AVL) device and a Mobile Data Computer (MDC). Some vendors also include installation and maintenance of Road Weather Information System (RWIS) stations.

MDSS software uses weather forecasting models to predict storm events and, when combined with a road weather model, changing roadway conditions on routes that are selected by the DOT. Most MDSS software includes a Graphical User Interface (GUI), as well as the backend software which refers to rules and guidelines on chemical applications and makes recommendations to snow plow drivers or the Maintenance Supervisor (shown in [Figure 1](#)). What is displayed and controlled through the GUI depends on the MDSS provider. Typically, the display will show predicted storm activity and road conditions over a certain time period (e.g. 24 or 48 hours) and recommended route treatment schedules. Some systems will allow for entry of actual driver treatments, a selection of the different forecast models, and display a comparative 24 hour "what-if" scenario for when no treatment is applied.

As shown in [Figure 2](#), the DOT data (snowplow and RWIS data) is combined with both local and national weather observations and forecasts. These data are then input into a road weather forecast system (RWFS) that predicts the road conditions. Based on these forecasts a road treatment is determined and sent back to the DOTs computer (either directly to the driver in the snow plow (MDC) or in a supervisor accessible shed).

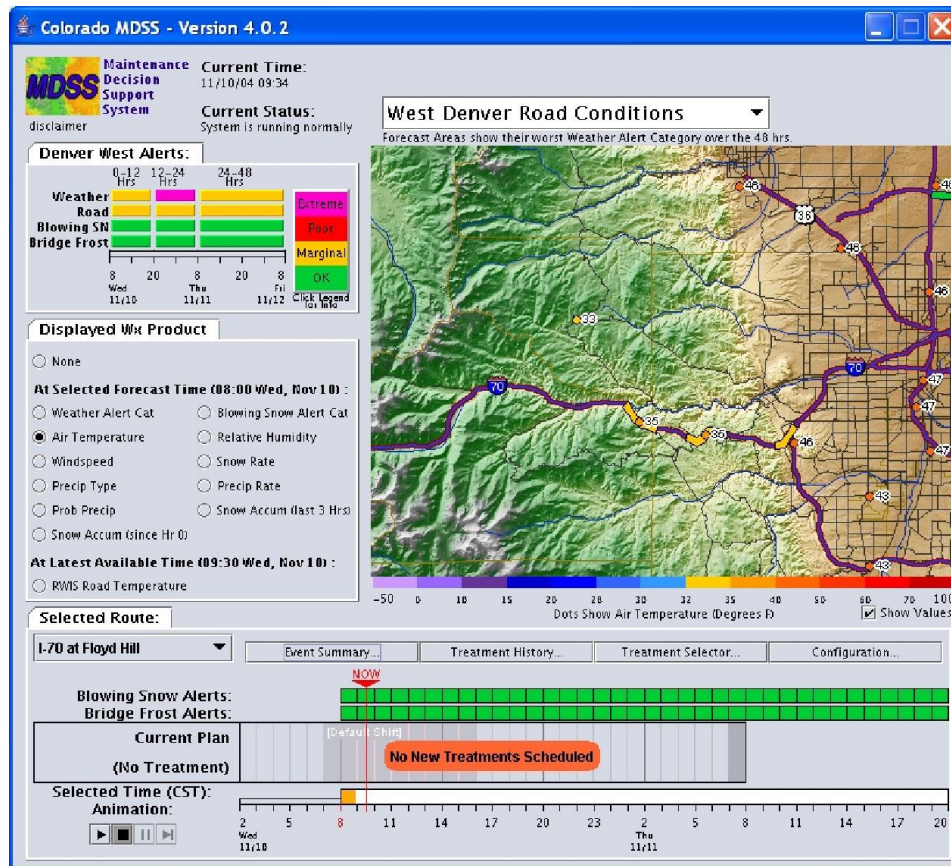


Figure 1. MDSS GUI depicting road conditions and application types and times *courtesy of NCAR* (https://www.ral.ucar.edu/lar/2005/surface_transp.php).

The goal of an MDSS package is to improve how effective a DOT is at using de-icing and anti-icing materials. The DOT should be providing a baseline level of service with a given amount of available resources without the use of MDSS. With an MDSS package there are two implementation schemes that can be pursued by the DOT: 1) increasing the level of service while using the same resources or 2) maintaining the same level of service using fewer resources. In the first scenario, if the state is satisfied with the current amount of resources (material and labor) being used in winter road maintenance, they can continue using the same amount. However, because MDSS improves how efficiently these materials are used, the level of service on the state's routes is expected to improve. Alternatively, the second scenario can be implemented where the state DOT can attempt to maintain a baseline level of service and subsequently reduce the amount of winter maintenance materials used. Figure 3 illustrates these two implementation schemes.

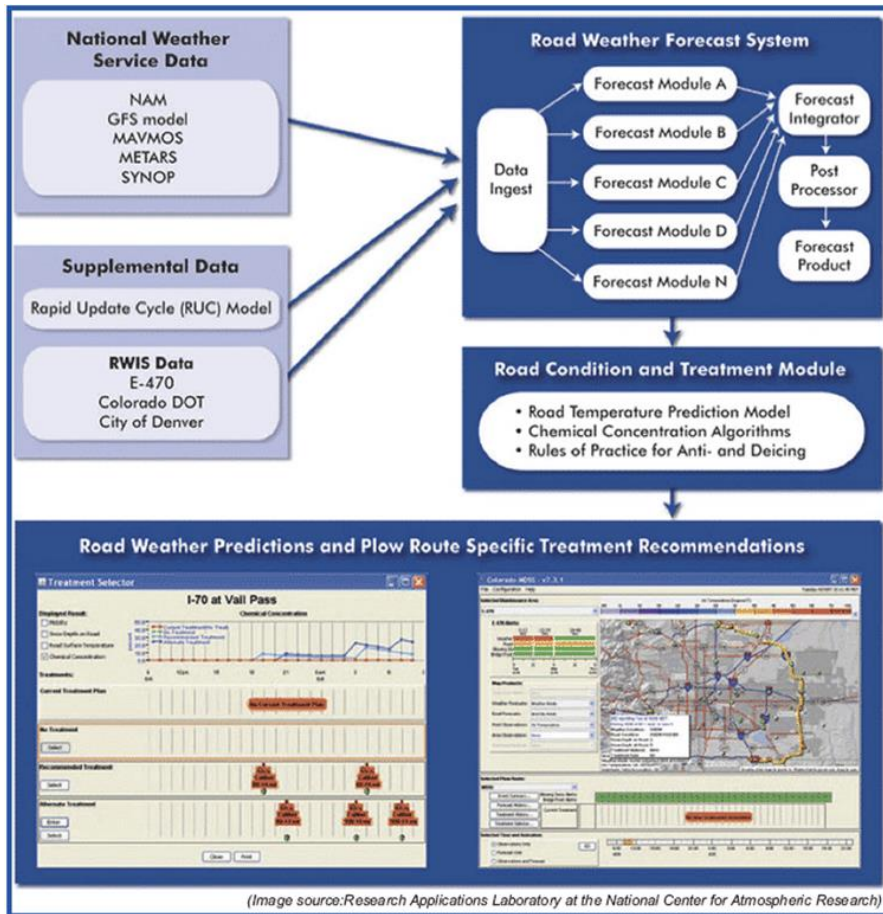


Figure 2. Overview of a typical MDSS system - for Denver/ Colorado [1].

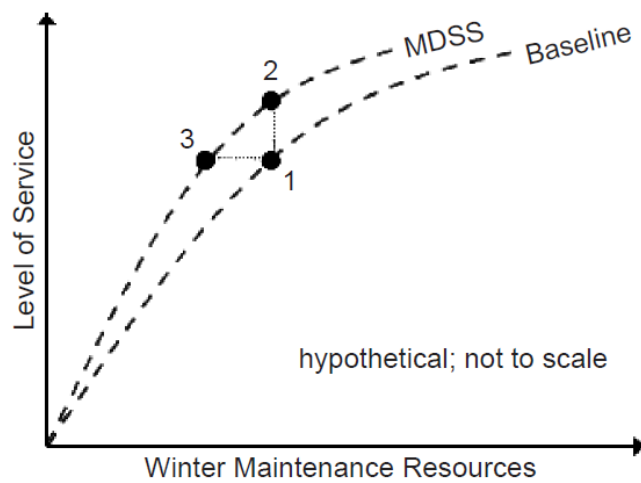


Figure 1. Potential Saving Cases Available with MDSS package [2]. From a baseline case (point 1), the DOT can either keep the resources used fixed (point 2) or maintain the current level of service provided to the roads (point 3).

Another useful tool that is available with an MDSS package is the *what-if scenario* treatment selector. A supervisor can use this as a tool to simulate how road conditions might change over a 24-48 hour period with user-defined treatment times, chemical types and application rates [2]. These simulations tend to create a level of confidence in the MDSS package's predictions and recommendations, facilitating a stronger level of trust in the system for supervisors.

There is also an enhanced MDSS option (EMDSS) for DOTs that is in development by the FHWA. These services include outfitting a number of vehicles on predetermined routes with sensors to gather mobile weather and road condition data along the road. This mobile data is transmitted to the MDSS server and used to supplement RWIS (and other non-mobile) weather data. The benefit of including mobile data is more measurements of the route's conditions, which in turn results in better accuracy from the system's weather and road forecast models. Rather than interpolating between RWIS stations to estimate conditions, physical measurements of the weather and road between the stations are made. EMDSS is still in the development stages but is expected to result in more accurate weather predictions from their MDSS (two separately funded projects, Nevada Intelligent Mobile Observations (NIMO)-1 and NIMO-2, are dealing specifically with EMDSS).

3.2 History of MDSS

Winter weather events lead to motorist hazards and damage to state roads, resulting in large costs to state Departments of Transportation (DOTs). Damage done by winter weather have led to state and local agencies spending more than \$2.5 billion each year on snow and ice operations, as well as more than \$5 billion in the infrastructure repairs needed from snow and ice events [3]. While not directly affecting state DOT costs, hazards to motorists have a negative economic impact through delays experienced by the general public as well as commercial freight.

To handle the issues associated with winter weather, DOTs typically have Maintenance Supervisors on staff. These supervisors are responsible for minimizing the impact of these winter storms (the level of service applied to a road) while working within a tight budget. While Maintenance Supervisors are generally very experienced in terms of guidelines and regulations regarding chemical applications and their associated environmental impacts, tools that can help them perform their duties more efficiently are of interest to DOTs and the supervisors themselves.

The Federal Highway Administration (FHWA) sought to improve the types of information available to state DOTs and their Maintenance Supervisors in the late 1990's with a "*Manual of Practice for an Effective Anti-icing program*" [4]. This manual gave guidance to supervisors on developing a systematic and effective way to maximize the level of service provided to roadways during winter storms. This manual did not provide explicit recommendations on when to implement these treatments. There was a need to bridge this gap between the appropriate road treatment and when to make that treatment. This is what led the FHWA to begin designing the Maintenance Decision Support System. A program was initiated in 2001 by the FHWA to develop a MDSS Functional Prototype with the assistance of the following five national research centers [5]:

- Army Cold Regions Research and Engineering Laboratory (CRREL)
- National Center of Atmospheric Research (NCAR)

- Massachusetts Institute of Technology – Lincoln Laboratory (MIT/LL)
- NOAA National Severe Storms Laboratory (NSLL)
- NOAA Forecast Systems Laboratory (FSL)

According to NCAR’s Maintenance Decision Support System webpage [6], the MDSS project goal was to develop a prototype that was capable of:

- Capitalizing on existing road and weather data sources
- Augmenting data sources where they are weak or where improved accuracy could significantly improve the decision-making task
- Fusing data to make an open, integrated and understandable presentation of current environmental and road conditions
- Processing data to generate diagnostic and prognostic maps of road conditions along road corridors, with emphasis on the 1-to 48-hour horizon
- Providing a display capability on the state of the atmosphere and roadway
- Providing a decision support tool, which provides recommendations on road maintenance courses of action
- Providing all of the above on a single platform, with simple and intuitive operating requirements, and does so in a readily comprehensible display of results and recommended courses of action, together with anticipated consequences of action or inaction

The goal of the FHWA MDSS Federal Prototype (FP-MDSS) was not to develop a fully functioning product that would work for all DOTs, but rather to provide an open source MDSS platform that could be improved upon by private-sector vendors based on the needs of their individual clients. This prototype is still available as an open source package to DOTs that want to adapt it for their state’s personal needs. The FP-MDSS prototype is currently the only open source MDSS available to DOTs.

The pooled fund study (PFS-MDSS), which began in late 2002, help bridge the gap between the Federal Prototype and an MDSS product that state DOTs would find useful. The PFS-MDSS project started with five states (the lead state being South Dakota) and involvement from the private sector vendor Meridian Environmental Technologies (which recently was acquired by Iteris) [7]. Since its inception, the PFS-MDSS project has increased to involvement from 19 states. A timeline of when these states made yearly commitments (and their total contributions to date) to the PFS-MDSS project is shown in [Table 1](#). The 19 states that have made financial commitments to the PFS-MDSS project, as of March 2014 are shown in [Figure 4](#) [8].

Table 1. Timeline of the Participating State's Monetary Commitments to the PFS-MDSS project. As of March 2014, the total contributions from all 19 states amount to \$5,120,903.00 [8].

State	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total Commitment
South Dakota													\$ 799,949.00
Indiana													\$ 300,000.00
Iowa													\$ 170,000.00
Minnesota													\$ 325,000.00
North Dakota													\$ 325,000.00
Colorado													\$ 175,000.00
Wyoming													\$ 200,000.00
California													\$ 150,000.00
Kansas													\$ 375,000.00
New Hampshire													\$ 260,586.00
New York													\$ 1,122,857.00
Kentucky													\$ 100,000.00
Nebraska													\$ 250,000.00
Virginia													\$ 225,000.00
Idaho													\$ 75,000.00
Pennsylvania													\$ 50,000.00
Wisconsin													\$ 25,000.00
Maryland													\$ 82,511.00
Michigan													\$ 110,000.00
													\$ 5,120,903.00

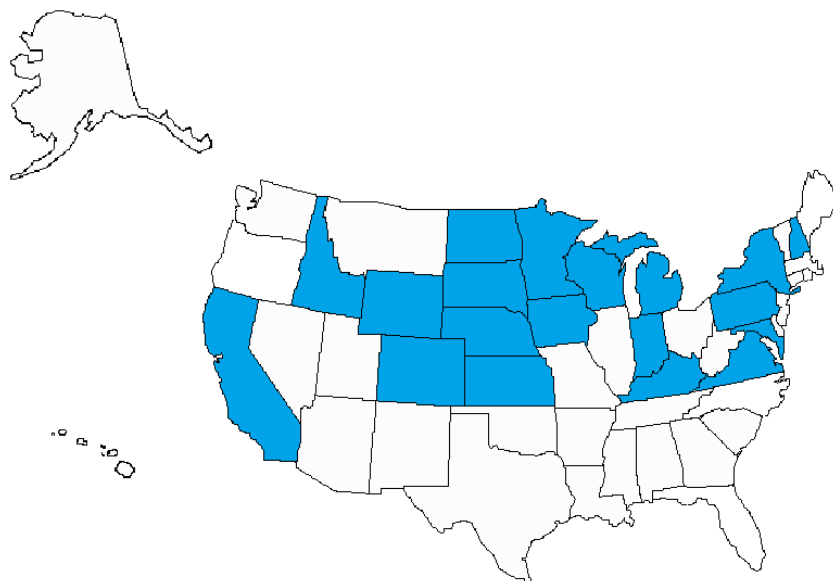


Figure 2. States that have made Financial Commitments to the Pooled Fund MDSS (PF-MDSS) study

Some states (New Jersey and Maine) chose to circumvent use of vendor-derived products from the pooled fund study (PF-MDSS) and instead took the federal prototype MDSS and customized it (themselves) to their states' needs. Users of the federal prototype (FP-MDSS) do not benefit from the experience gained in multiple states from the more extensive pooled fund study, and Meridian's commercial MDSS package. Despite the need for states to start from near the beginning with the FP-MDSS option, New Jersey and Maine have successfully created working MDSS products [5,9].

4. RESULTS AND FINDINGS

Phase I of this project was conducted under Task 3 of the Winter Maintenance Improvements program in 2009 (project 02-09). This first phase focused on performing preliminary evaluations of several different approaches to data transmission from remote areas (a particular issue in Nevada). Whereas most other states with working MDSS systems use cellular phone based systems, this is not viable in wide areas of Nevada, which has little or no cellular network coverage. To circumvent this potential problem, we evaluated and tested the use of NDOT's existing Enhanced Digital Access Communications Systems (EDACS) radio systems, which have data transmission capabilities. Some of NDOT's RWIS data is currently transmitted via the EDACS system using propriety hardware and software developed for NDOT by a consultant (Robert Moore of IDIC Research & Consulting). During Phase I of the project a new Windows-based system was prototyped that demonstrated the existing EDACS system is a viable means for transmitting the most critical elements of vehicle and road condition data, which is a necessary starting point for an MDSS system.

The results and findings from Phase 2 of this 3-phase project are described below. Phase 2.5 was implemented only because a 6 month no-cost extension of phase 2 was not processed in a timely manner by UNR and a new contract had to be issued. The narrative below does distinguish between phase 2 and phase 2.5 activities.

4.1 Hardware Developed

Phase 2 of this project overlapped with the later part of Nevada Intelligent Mobile Observations (NIMO)-1 and the first half of NIMO-2. As such, two different hardware systems were developed: one for rural locations without cellular phone coverage (NIMO-1) and separate system for urban areas where cellular data is reliable (NIMO-2).

The NIMO-1 system consisted of a rugged, PC-104 single board computer (SBC) to serve as the "brain" of the system and developed custom client software that runs on the PC-104 and collects the data from the instruments, logs the data, processes and aggregates it, and then transmits it using an on-board EDACS radio through the EDACS radio network to a central server ([Figure 5](#)).

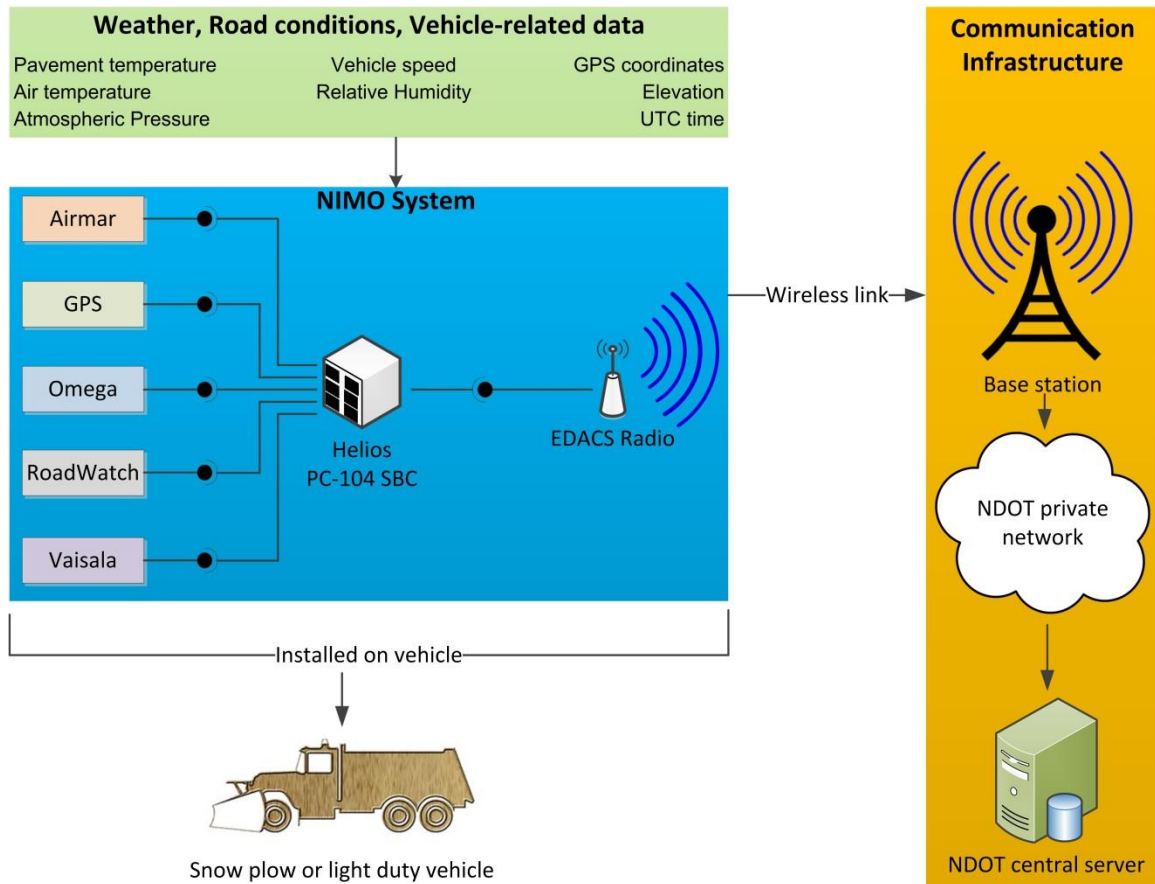


Figure 5. NIMO-1 data collection and delivery to central server (CANbus not shown).

In addition to the PC-104 computer and EDACS radio, the other major system components of the NIMO-1 hardware included the instrumentation used to perform temperature, humidity, pressure, vehicle speed, location and CANbus measurements: i.e., the Aimar, RoadWatch, Vaisala, OBD Scan Tool, and Netway instruments.

The NIMO-2 hardware developed (for urban areas of Nevada) uses a Motorola Droid handheld device in the test vehicle (Figure 6) running a data logger application called NIMO-2-Telemetry. The Droid is installed underneath the dash or passenger seat, along with a multiplexer device, and no driver interaction is needed. When power is applied through the ignition switch activation, the application is launched and data is transmitted to the backend server. The application may also be launched manually when vehicle ignition is off, through the graphical user interface (GUI) on the phone for testing and debugging purposes.

Multiplexer Device

Our Arduino-based Multiplexer device (MUX), reads sensor data from a Roadwatch-SS over an RS-232 serial interface, from our custom weather sensor, from our custom windshield wiper frequency sensor, and from our custom spreader motor sensor. It multiplexes the signals and writes an NMEA-format sentence to the Droid every 10 seconds.

Roadwatch Subsystem

The Roadwatch-SS with its RS-232 adapter provides air and surface (road) temperature readings. It was used in the previous version of our system with NIMO-1. The only difference here with NIMO-2 is that it is directly read by the MUX device rather than by the central processor (Droid) because the phone does not have any RS-232 ports.

Configuration

The system can be configured in the field by editing text files on the phone, through the NIMO-2-Telemetry app GUI by selecting “Sticky” Run States (Start, Stop, or Auto), or remotely by editing each phone’s corresponding configuration files on the backend server. Updated configuration files on the server are automatically downloaded by the Droid and changes are applied.

Data Logging

Applications running on the Droid phone and on the optional Raspberry-Pi power watchdog write log messages to files that are stored on the Droid’s SD-card. These log files are then uploaded to the backend server automatically. Whether and what to log, as well as whether to upload the logs or only store them on the SD-card, is user-configurable.

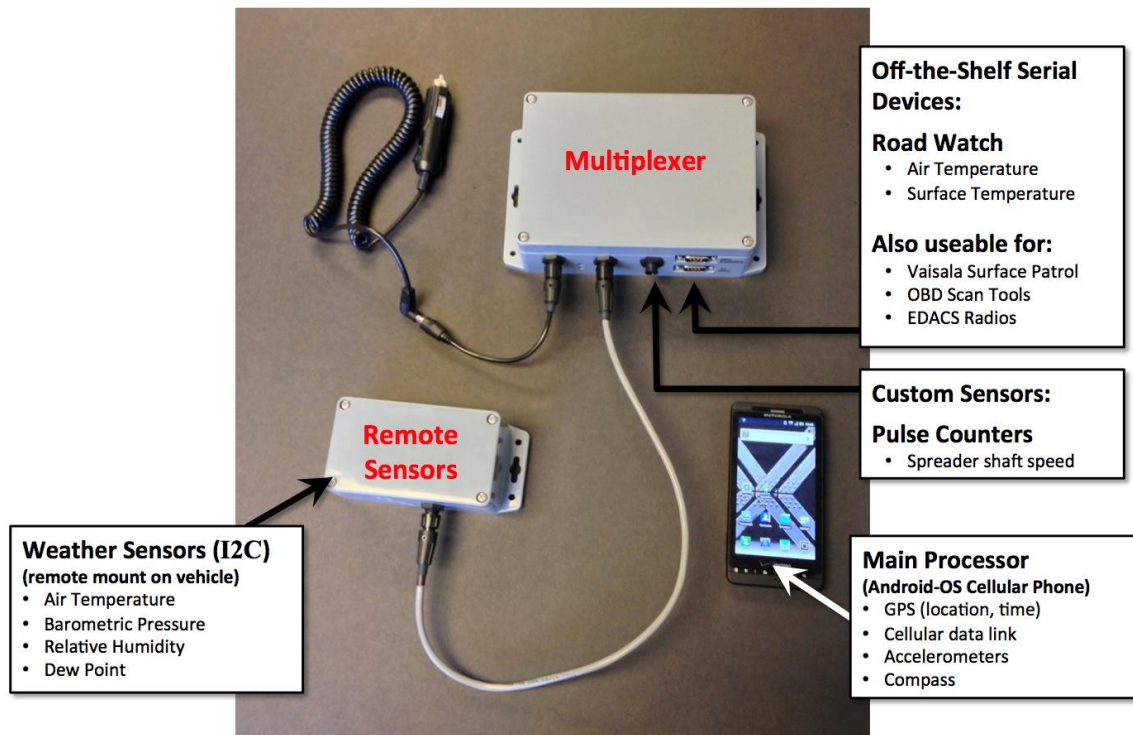


Figure 6. The Droid NIMO-2.0 System

4.2 Data Transmission

For the NIMO-1 hardware, in order to limit the burden on the statewide EDACS radio system, the minimum transmission interval for any given vehicle was set to 5 minutes. Each data packet is also

limited to approximately 500 bytes (a limitation of the EDACS system). Because the amount of data collected far exceeded the maximum packet size, only a subset of collected (logged onboard the vehicle) data was transmitted. The transmitted subset is adjustable and consists of high-priority data. It is a representative sampling of the collected data, and provides enough information for meaningful near-real-time analysis by NCAR and end-users at NDOT to gauge road conditions and make road maintenance decisions. [Table 2](#) summarizes the current 500 byte transmitted data packages used in the snow plow and light duty vehicles.

The superset of collected data is available (after manual retrieval from the vehicles) to NCAR analysis and possible assimilation into road weather models and applications. The storing of this data was accomplished using an internal solid state drive that is part of the NIMO-1 hardware. Additionally, we opted for mirroring the data to an external USB flash disk that is easily periodically swapped and delivered to UNR by the NDOT vehicle maintenance crews. We then post the data from the flash disks to a website from which NCAR downloads the data for study.

Table 2. Typical transmitted 500 byte data packages (for the two basic vehicle types) for NIMO-1 systems.

Parameter	Number of Measurements per 5-min Data Package	
	Snow Plow	Light Duty
Air Temperature (Vaisala, Omega, Airmar)	5	5
Air Temperature (Road Watch)	5	5
Air Temperature (CANBus)	5	5
Road Surface Temperature (Road Watch, Vaisala)	30	30
Air Pressure (Omega, Airmar)	5	5
Air Pressure (CANBus)	5	5
Relative Humidity (Vaisala, Omega, Airmar)	5	5
Location, Time, & Vehicle Speed (GPS)	30	30
Vehicle Speed (CANBus)	5	5
CANBUS/OBD Trouble Codes	0	1

For the NIMO-2 systems, the sensor suite is comprised of a Droid internal GPS receiver, and a Bluetooth network interface to an external multiplexer device that reads ambient and surface temperature, humidity, dewpoint, windshield wiper frequency, and spreader motor frequency. Data is collected and transmitted every 10 seconds.

Due to cost, accuracy, and licensing constraints, we chose not to read OBD data in the current version of the system. We also do not use the Airmar or Vaisala weather sensors. Instead we developed a custom, low-cost Arduino-based multiplexer device (MUX), which the phone interfaces with over Bluetooth. The MUX uses RS-232 serial and i2c to collect data from a Roadwatch device, our custom weather sensor (WX), a custom spreader count device, and a custom windshield wiper counter. [Table 3](#) lists the various sensor devices and the data streams they provide. The MUX device streams our custom "\$MUX" sentences which are an extension of the NMEA protocol over Bluetooth to the Droid X2, with which it is paired.

Table 3. NIMO-2 Sensor Devices and Provided Data. Data is collected every 10 seconds.

Device	Data Stream Provided
Droid X2	NMEA GPS sentences (latitude, longitude, elevation, speed, number of satellites, UTC timestamp)
UNR-WX	Air Temperature, Dewpoint, Relative Humidity
Roadwatch	Air Temperature, Surface (road) Temperature
Spreader	Spreader Frequency
Wiper	Windshield Wiper Frequency

4.3 Vehicle Installations

The original proposal only indicated that a few vehicles would be instrumented as part of a pilot-scale proof-of-concept. However, because of the overlap with the NIMO-1 and NIMO-2 projects, a total of 37 NDOT vehicle installations have been completed (3 more are planned as the NIMO-2 project has not yet ended).

The NIMO-1 systems have been deployed in 21 DOT-owned vehicles. All of the NIMO-1 vehicles are currently using the statewide 800 MHz EDACS radio system to transmit data back to the central server that currently resides at UNR (Figure 7). As described in section 4.2 above, bandwidth limitations require that a representative subset of the data collected be transmitted with the entire data set being logged onboard for periodic retrieval. Currently, vehicles each transmit ~500 bytes every 5 minutes.

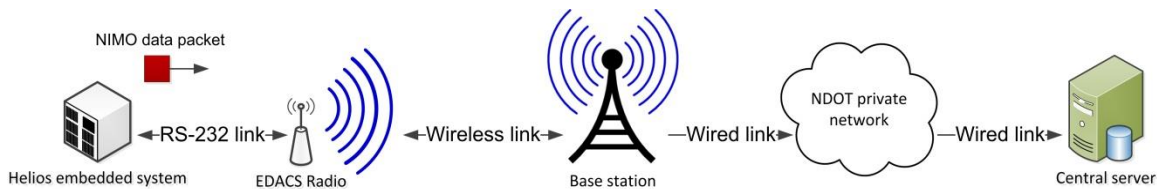


Figure 7. Helios embedded system-to-central server communication links.

The NIMO-2 systems have been deployed in 16 DOT-owned vehicles. All of the NIMO-2 vehicles are currently using a Droid cell phone to transmit data back to the same central server used by the NIMO-1 system resides at UNR (Figure 8).

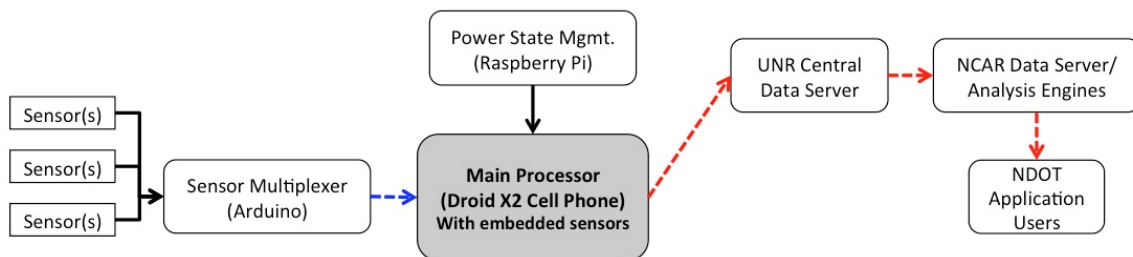


Figure 8. Cellphone system-to-central server communication links.

4.4 Data Storage and Display

Persistent LabVIEW applications, as well as on-demand PHP web applications on the backend NIMO server (located at UNR), provide tools for visualizing and tracking incoming observations and telemetry. LabVIEW applications include a Web-accessible Table of incoming data by vehicle for NIMO-1 and NIMO-2 vehicles, with date-time of last transmission received (Figure 9). Vehicles that have not transmitted in longer than a week are marked in red. There is a LabVIEW “Control Panel” for monitoring what set of observations are being reported by NIMO-1 vehicles.

Vehicle	Home Location	Date*	Time*	Speed [m/s]		Road Temp [°C]		Air Temp [°C]				Pressure [kPa]			
				GPS / Airmar	Canbus	Roadwatch / Vaisala	Airmar	Roadwatch / Vaisala	Canbus	Omega	UNR WX	Airmar	Canbus	Omega	UNR WX
Android Suburban	UNR	06/24/2014	15:39:04	0.0	N/A	32.2	N/A	29.4 [RW]	N/A	N/A	Err	N/A	N/A	N/A	86
Android 1750	Carson City	06/27/2014	23:20:51	5.4484	N/A	52.8	N/A	24.6 [RW]	N/A	N/A	24.1	N/A	N/A	N/A	86
Android 1026	Reno	06/26/2014	23:44:17	30.8914	N/A	36.7	N/A	26.2 [RW]	N/A	N/A	25.5	N/A	N/A	N/A	85
Android 1025	Reno	01/29/2014	16:57:46	0.0	N/A	Err	N/A	Err [RW]	N/A	N/A	12.0	N/A	N/A	N/A	86
Android 2274	Reno	06/12/2014	19:45:33	0.7196	N/A	55.6	N/A	30.1 [RW]	N/A	N/A	30.7	N/A	N/A	N/A	85
Android 1250	Reno	10/25/2013	03:37:09	21.4338	N/A	Err	N/A	Err [RW]	N/A	N/A	22.3	N/A	N/A	N/A	74
Android 0219	Carson City	06/27/2014	19:08:49	7.5558	N/A	52.8	N/A	27.6 [RW]	N/A	N/A	30.4	N/A	N/A	N/A	85
Android 0323	Reno	06/18/2014	18:41:38	0.0	N/A	27.8	N/A	22.4 [RW]	N/A	N/A	22.8	N/A	N/A	N/A	86
Android 1186	Reno	06/27/2014	20:43:49	3.0326	N/A	55.0	N/A	28.7 [RW]	N/A	N/A	28.7	N/A	N/A	N/A	86
Android 2272	Reno	01/15/2014	21:21:30	0.0	N/A	15.6	N/A	15.7 [RW]	N/A	N/A	18.0	N/A	N/A	N/A	87
Android 1187	Reno	06/25/2014	22:35:53	0.0	N/A	52.8	N/A	31.8 [RW]	N/A	N/A	31.3	N/A	N/A	N/A	81
Android 3200	Reno	06/02/2014	23:06:44	0.0	N/A	35.6	N/A	24.2 [RW]	N/A	N/A	25.8	N/A	N/A	N/A	85
Android 1206	Reno	06/11/2014	00:18:49	0.5654	N/A	39.4	N/A	32.4 [RW]	N/A	N/A	31.7	N/A	N/A	N/A	83
Android 2275	Carson City	06/04/2014	18:57:56	0.0	N/A	Err	N/A	Err [RW]	N/A	N/A	28.6	N/A	N/A	N/A	81
Android 0763	Carson City	02/27/2014	11:07:10	0.0	N/A	Err	N/A	Err [RW]	N/A	N/A	0.7	N/A	N/A	N/A	78

Figure 9. User display – Data Grid.

There are also LabVIEW and PHP web applications using the Google Maps API to plot NIMO-1 and NIMO-2 vehicle locations throughout the state (Figure 10). Users can also monitor a single vehicle. Markers on the map display UTC timestamp and weather observations for each GPS waypoint – humidity, dew-point, pressure, air and surface temperature where available (Figure 11).



Figure 10. User display – statewide location of all vehicles.

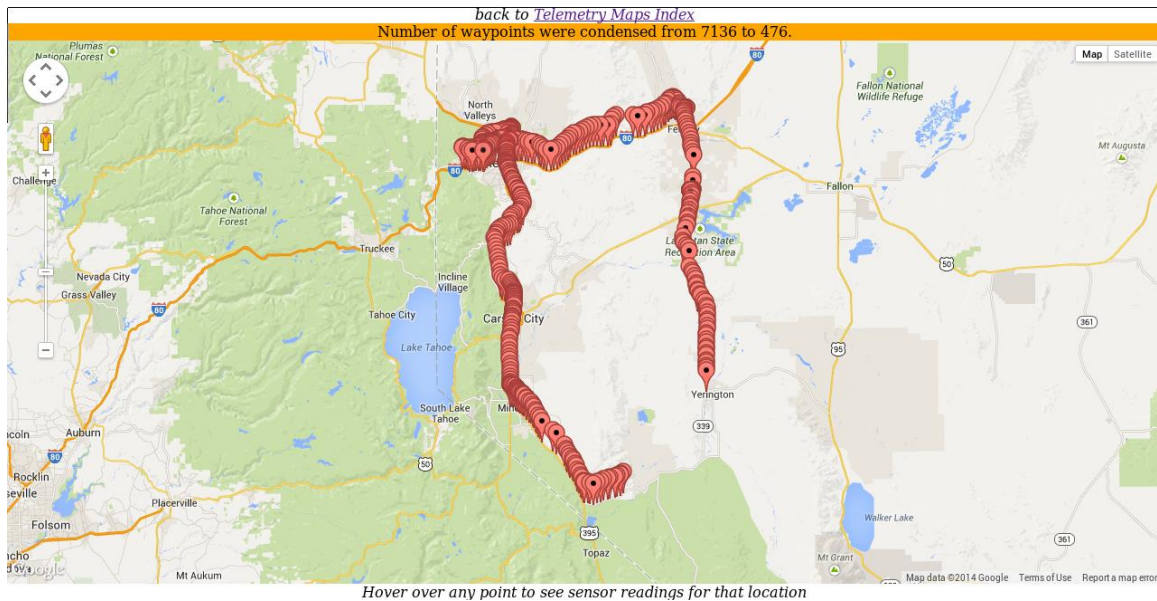


Figure 11. User display – track for a single vehicle. Clicking on any track point will display the time, location, humidity, dew-point, pressure, air and surface temperature data.

4.5 Survey of other State’s MDSS Experiences

Although MDSS has not yet been explored in Nevada, several other states have participated in either the Pooled Fund Study or have made personal adaptations of the Federal Prototype. For over a decade now, more than 20 state DOTs have been working to get a successful implementation of MDSS. Some of the experiences by these states have been reported and can provide insight on the benefits and shortcomings of MDSS expressed by other DOTs [9,10]. These experiences were expressed in the 2009 Western Transportation Institute final report [10], unless otherwise noted.

Colorado

ColoradoDOT has varying levels of deployment of MDSS, stating that one of six DOT regions have MDSS with AVL and MDC in all fleet trucks, while the remaining five regions only have limited MDSS deployment. An interest in progressing to all vehicles in the state having an MDC with GUI was expressed. MDSS is mostly used on major roadways. ColoradoDOT expressed that their use of MDSS was as a year round tool for winter maintenance objectives. Drivers who have the maximum amount of real-time information available to them found MDSS to be most effective. This data could be presented either directly in the trucks or over 24-hour dispatch.

ColoradoDOT, in general, trusts MDSS recommendations. These recommendations would be considered, but not always followed. MDSS was typically seen as guidance, but some user saw the potential for MDSS to progress to the level of a directive. Not all participants shared this view, however.

The city and county of Denver in Colorado have also reported on their experiences with an MDSS package [11]. From their report, they managed to save an average of around \$95,000 a year in 2007

and 2008 while spending an average of about \$71,000 on MDSS services annually from 2007 – 2009. These savings experienced by Denver were largely due to the supervisor’s ability to confidently deploy maintenance crews. Because of their increased awareness of the length and severity of storm events, they were able to avoid calling in extra shifts, thus saving around \$30,000 per shift [11]. These results suggest that Denver trusted MDSS as a weather forecast tool, but not for its treatment recommendations.

Indiana

IndianaDOT regularly uses MDSS largely on priority roads in two districts and three sub-districts. Trucks rarely have an AVL and MDC, most need to have road conditions and application rates reported to them via radio. There is an interest in improving the MDC availability for these trucks, including GUI. During storm events, the MDSS forecasts are referred to several times throughout.

IndianaDOT reports that MDSS application suggestions are primarily used as a reliable tool, mostly as a reference point for those lacking in experience. At the time of the report, the state didn’t have extensive use of the system due to weather. MDSS suggestions are typically considered but not always followed. Other supervisors would follow the recommendations around 80% of the time. The use of MDSS as a tool seems to be considered its best use, rather than using MDSS as a directive. The weather forecasting component of MDSS appeared to be the favorite feature for IndianaDOT. Overall, most involved from IndianaDOT believe that MDSS has increased road safety and decreased cost, meeting their expectations.

Iowa

IowaDOT has a moderate level of MDSS deployment across the state, each garage having about 10 routes. They have MDC capabilities and use computers in sheds in all interstate garages. They generally would like to move towards having AVL incorporated, but not a GUI for the trucks. MDSS routes are typically on primary roadways across the state.

The level of use of MDSS was primarily during storms, where it was looked at several times for each storm event. These observations were limited to times when observers were at the shed (most garages only having one computer). The recommendations that MDSS made to IowaDOT were used as guidance, being referred to as a tool. The possibility of developing a “snow desk” to take MDSS forecasts and recommendations and broadcast them to drivers is being considered, although still far from implementation. The likelihood of MDSS being a directive does not seem likely for IowaDOT.

MDSS event predictions were the most useful aspect for IowaDOT, not the treatment recommendations. In general, users did not trust what MDSS recommended as treatment plans. They might consider these recommendations, and some have followed them about 5% of the time. The event forecasting was the strongest aspect of MDSS for IowaDOT, being comparable or better than alternate weather forecasting options that are available. There is a lack of trust in MDSS, but IowaDOT still believed they learned from their experiences with the system.

Kansas

KansasDOT has different levels of implementation for MDSS across the state. There is MDC available in Dodge City and Topeka, but Dodge City has a user interface for each truck. There is a

desire to improve the whole state to GUI, but the cost for such an upgrade is an issue. Kansas has 400-450 trucks, and each installation would cost about \$1,100, plus the additional \$30 / month cellular fee. There are about 10-15 MDSS routes in Kansas, focusing on the two highest level priority roads.

The amount of use that KansasDOT gets out of MDSS is high, with personnel from the entire management chain looking at the system every storm, several times during the event. They usually use the system as a guide or tool, not as a directive. Treatment recommendations provided by MDSS are widely trusted, and generally implemented in the Dodge City area. These treatments are always considered, and implemented if the forecast is accurate. The forecasting is considered by KansasDOT to be the best that is commercially available, although it can be incorrect. They believe MDSS has improved the decision making process, meeting their expectations. The system allows the department to be more confident in their decisions, and some believe MDSS has also reduced resource usage.

Minnesota

MinnesotaDOT is aggressively increasing their involvement with MDSS. As of 2009, the state had a total of seven MDSS trucks and 30 computers statewide. These trucks service differing priority level roads and cover at least two routes per truck. The levels of AVL and GUI installed in each truck varied, but the state intended on increasing these numbers. By 2011 the test sections for MDSS had increased to 240 throughout the state [12]. Trucks with AVL had increased to 78, but MinnesotaDOT expected this number to increase to over 400 by 2013 [12].

MDSS was used as a tool more than a directive in 2009. Treatment recommendations are viewed as guidance, being observed several times a day when storm activity is occurring. These recommendations would be considered if they were reasonable, but often they would be too high or the weather activity would be inaccurate. The level of trust in the system varies for upper management compared to the operators. The system's use as a time management tool for storms was a major benefit seen by MinnesotaDOT.

New Hampshire

New Hampshire Department of Transportation (NHDOT) had a low level of experience with MDSS in 2009 due to it being their first year of use. They had MDC, but nothing was mounted in the trucks. Two MDSS routes covered a portion of a two-lane highway in. These routes were handled with three computers, two located at the shed and one on a supervisor's personal laptop. There were also unspecified start-up problems that NHDOT had with MDSS for the year.

The trust that NHDOT has with MDSS is low. Participants stated that they did not have experience with the system and they felt the prescribed treatments were not trustworthy. Some users, however, did feel like they trusted these recommendations and even followed them. MDSS was used on a per storm basis, sometimes multiple times during the storms. Respondents claimed that MDSS was used more for guidance than as a directive, stating that it will probably never be a directive. The idea of transmitting information directly to drivers through a GUI was split between favorable to distracting. One respondent did claim that salt usage was down due to MDSS, which was the organizations goal.

North Dakota

The North Dakota Department of Transportation (NDDOT) has participated in the PFS-MDSS project since its inception, and has a relatively large level of deployment. There is MDSS on 4-5 state headquarters computers, and also computers at all district headquarters. Fargo County has MDSS on 7-10 sections and has computers in every shed. Grand Forks County MDSS is on four high priority roadways with no interaction in the trucks, but has a computer in a shed. Dickerson County has MDSS on all 11 sections, 15 computers and even have interaction in four trucks. Overall, there are about 80 MDSS computers statewide. There is even MDC with AVL in eight units. There is strong interest in having transmission to trucks, as respondents felt that the system would be best used in this manner.

The response that NDDOT has to MDSS is generally positive, with only minor concerns. All respondents felt that MDSS has met expectations, helping increase road safety and mobility, as well as reducing agency costs. MDSS users claimed differing levels of trust, with some users following recommendations 50% of the time while other users saying that not everyone trusts the system.

NDDOT's MDSS level of use is typical. Respondents claimed that they use the system on a per storm basis, sometimes multiple times for these storms. For the survey, all users felt that MDSS recommendations were followed as guidance. Respondents were split on whether they felt that these recommendations would eventually be a directive rather than a suggestion. Treatment recommendations were typically considered but not always followed. NDDOT feels that MDSS is a tool.

South Dakota

The South Dakota Department of Transportation (SDDOT) has two sheds with MDSS on about six actual roads (10 MDSS routes). These roads are all major farm to market roads. MDSS is on computers in each of these sheds, but SDDOT reported problems with these computers being too slow. Getting MDC with GUI in trucks is an area of interest for SDDOT. In the 2009 report, the state expected to have four trucks with GUI with live forecast and radar by the end of the season. All respondents felt that GUI would improve the value of MDSS.

The level of trust that SDDOT has in MDSS is low, but respondents claim that time could increase this trust. Some operators stated that they would not even consider MDSS treatment recommendations that didn't match their gut feeling, while other users followed these recommendations 100% of the time for a single truck to compare results. Whether or not MDSS has met user's recommendations varies from respondents, some claiming that it has help reduce product use, save money and increase road safety. MDSS is used on a per storm basis, and is treated like a tool. Reasons for the system not being viewed as a directive are liability and cost, estimating about \$20,000 for a single truck with GUI with radar and forecast services.

Wyoming

WyomingDOT has MDSS deployed on three segments of interstate, totaling five MDSS routes. There are two sheds that have MDSS computers in them, as well as a couple of personal computers

that have the system. In 2009, WyomingDOT made the transition into MDC in all trucks at Evanston and Cheyenne (five trucks each).

Most respondents from Wyoming felt that MDSS met their expectations. Only one participant stated that he did not trust MDSS prescribed treatments. All respondents would consider the MDSS suggestions, and about half would then implement these prescribed treatment plans. Users, in general, felt that the system helped improve road safety and reduce cost, one respondent even saying that MDSS has good event timing.

WyomingDOT uses MDSS as a tool more than a directive. MDSS is looked at on a per storm basis, often multiple times during storms. Users view the systems recommendations as guidance, and do not foresee a time when they will be treated as a directive. The inclusion of GUI in trucks is generally seen as beneficial. One respondent, however, thinks this may not be true based on driver's experience and capability.

Maine

Maine's overall experience with MDSS was, according to MaineDOT, a beneficial one [9]. In 2006-2007, MaineDOT used MDSS mostly as a weather forecasting tool. Maine acknowledges the variety of needs for different states, and suggests that the level of MDSS deployment be determined on a per state basis. Maine expressed that the MDSS recommendations could have a greater level of use if they were viewed as more accurate by the MDSS users [9]. Maine felt that MDSS recommendations should be customized on an individual state level to account for different climate, geographical, and operational needs.

There were several lessons learned by MaineDOT (and expressed by other states) that can help bring realistic expectations to MDSS users in other states [9]:

- If an MDSS offers accurate and consistent forecast and treatment recommendations, users will be more likely to trust the system.
- Training the maintenance crews before MDSS introduction, as well as offering additional training and support afterwards will help improve maintenance decision making.
- It will take time for management and maintenance crews to adopt and accept MDSS into their standard operations.
- Selecting alert topics and timings that are helpful for a state's specific roads without being too general and abundant will allow MDSS to be more helpful than distracting.
- A mechanism for MDSS to incorporate decisions made by DOTs will help improve its effectiveness later in storms.
- MDSS should be treated as a valuable tool available to DOT's winter maintenance crews.

4.6 Survey of Existing MDSS Vendors

Because there are multiple vendors who provide MDSS to state DOTs, UNR and NDOT decided to inquire from some of these vendors directly about their services. This process has given NDOT the opportunity to determine what differences in products exists. These talks also gave a very rough estimate of how much an MDSS package might cost NDOT. Three vendors (Iteris, Schneider Electric and Vaisala) spoke with interested personnel from NDOT and UNR over a two month period. Summaries of these meetings are provided in the following pages.

Iteris (01/30/2014)

Iteris (formerly Meridian) has been active since 1993. They have served as the prime contractor for states involved in the pooled fund study. According to Iteris, they have worked with about 14 states MDSS programs. They have worked in Nevada in the past, using MDSS on the I-80 Donner Pass.

Highlights from the Iteris discussion:

- Grid based forecasting system (10 km² section) for atmosphere and road conditions
- Recommendations provided either directly to driver or to supervisor
- Pavement forecast takes in past/current data to predict future behavior, material phase changes and mass loss
- Software can display cross section view of road conditions
- Route configuration options include
 - Level of service
 - Hours of operation
 - Agency policies and procedures
 - Available materials
 - Roadway construction and surrounding environment
- Forecasts are constrained to selected routes only
- Future enhancements will include web based MDSS with Mobile apps (iPhone and Android)
- Weather comes from RWIS/airports/MesoWest stations/etc.
- Mobile data is not necessary for MDSS, but it is useful
 - They have worked with Colorado using mobile data
 - Resolution is not important (can transmit as fast or as slow as the DOT wants)
- Route by route automated alerts available (High wind alerts, NWS watches and warnings, etc.)
- Potential non-winter uses
 - Vegetation management (wind patterns)
 - Crack sealing projects
- Costs include
 - Weather forecasting cost
 - Per route cost
 - Monthly treatment/pavement forecast cost
 - Application access cost
 - User defined costs
- Customer Service
 - 24/7 consultation
 - Video briefing services offered once a week
 - Help with route set up

Schneider Electric (02/11/2014)

Schneider Electric is a multinational corporation that is primarily involved electricity distribution, automation management and energy management. They are based out of Paris, France and have

been providing MDSS packages since the 2005-2006 winter season. They are the weather forecasting contractor for Nevada, as of spring 2014. They have worked with about 33 state DOTs and provinces, as well as with thousands of cities and counties. Their Basic MDSS package is available to NDOT with their weather forecasting services.

Highlights from the Schneider discussions:

- Basic MDSS package available with weather forecasting services
 - RWIS station point based system
 - Only gives forecasts for these RWIS locations
 - Provides both atmospheric and pavement forecasts
 - Truck icons that give recommended treatment plans
 - Will not tell you optimal application times
 - Provided treatment recommendations for before, during and after storm events
- Intelligent MDSS package also available
 - Was developed two years ago
 - Provides recommendations for routes, not single points
 - Intelligent timing for recommended application rates
 - Uses Metro pavement model that compares predictions to RWIS readings for model improvements
 - Has ‘no treatment’ option for “what-if” comparison with recommendations
 - Provides 36 hour animations of road conditions/ temperatures etc. to identify locations of importance
 - Actual treatments are not used as inputs into their models
 - Potential for mobile access with smartphones, etc.
- Claim around 90% accuracy of predictions on good months, average about 85%.
- Can be used for summer maintenance as well, such as mowing, spraying, striping or road repairs.
- Has lightning storm predictions, as well as flood warning features.
- No mobile data incorporation for their models, but research and development is being done.
- No estimate for a typical system cost, but could be potentially as little as \$10,000 a month.
- Costs include:
 - Weather forecasting cost.
 - Per route cost.
 - Groups adding treatment plans raises price.
 - On sight visit expenses.
 - Training expenses.
- Schneider can also be the prime contractor for RWIS station installations and maintenance, or they will work with third party contractors.

Vaisala (03/24/2014)

Vaisala is a Finnish based company that specializes in environmental and industrial measurement equipment. They have been focusing research and development on uses and applications of the data that their instruments measure.

Highlights from the Vaisala discussion:

- MDSS system is based off of the Federal Prototype
- Four levels of display for system:
 - Advisor: a site by site display of real-time RWIS station condition. Useful for novice MDSS users
 - Observer: a map showing real-time RWIS stations in the area. These stations can be examined closer to show the same information as the Advisor display
 - Navigator: same map as Observer display, but with archived historical data as well as real-time data. Users can examine past readings made by RWIS stations
 - Manager: The only true MDSS display. Same features as the navigator display, but Manager also contains a maintenance tab that will give treatment recommendations
- Contains IceBreak surface condition forecast software
 - Forecasts surface temperatures for any location though-out the world
 - Uses mesoscale forecast data, location specific information and sensor data as model inputs
 - Uses RWIS data to make 24 hour site specific predictions
 - Does not include mobile data as input yet
- System is capable of keeping track of materials applied
 - Needs manual updates after drivers perform maintenance tasks
 - Has potential to use AVL and spreader control to remove manual uploads, but Vaisala is waiting on IWAPI patent resolution
- Worked with Idaho on Storm Performance Index to quantify DOT performance
 - Developed over four winters, available to Vaisala MDSS users
 - Goal is to reduce ice-up time during storms and improve grip
 - Uses a combination surface temperature, maximum wind speed, precipitation rates to calculate a performance index
- Performing forecast verifications by comparing model predictions with actual measurements
 - Only possible at RWIS stations, but there is potential to include mobile data comparisons
- Vaisala does not perform their own weather forecasting, will need third party provider
- Not their own hardware for the MDSS package. AVL options would also require other providers
- RWIS readings have been used for painting and herbicide usage in summer
- Vaisala wants to reduce the number of treatments while keeping the level of service high
- Web interface with cloud-based storage. iPad application is available
- Future improvements and developments would not cost extra money
- Costs include:
 - Setup fee
 - Per RWIS station fees. Desired routes require at least one station for MDSS to work
 - Training costs
 - Webinar or classroom
 - Vaisala recommends annual training

4.7 Potential NDOT Winter Maintenance Benefits from MDSS

Maintenance Decision Support Systems have helped several other states realize savings in winter maintenance, and can potentially help Nevada experience similar benefits. The amount of savings seen by these states depends on the size of their winter maintenance costs and how large scale they implement the MDSS. For example, in Indiana there was an increase in scope for their MDSS program in FY2009. The amount of savings experienced statewide when compared to the previous year was over \$12 million in salt usage alone [7]. When compared to a normalized year, these savings are just under \$10 million [9]. Nevada would not experience this much in salt savings, due to a three-year average salt budget of \$2.6 million [13-15]. However, this may still be comparable to other state budgets. Colorado's salt/sand mixture cost in 2006 was about \$4.7 million, while their total winter material costs (shown in full in Table 4) were about \$11.9 million [10]. These cases demonstrate how a successful integration of MDSS into a DOT can vastly decrease winter maintenance costs.

Table 4. Material costs for Colorado during the Winter of 2006-2007 [10].

Product	Amount Used	Unit	Cost
Ice Slicer RS	28,875.7	Ton	\$2, 194, 243
Salt	492.0	Ton	\$14,570
Salt/Sand Mix	192,815.3	Ton	\$4, 718, 464
Sand Slicer - ton	7,145.0	Ton	\$155,272
APEX (Liquid Deicer)	1,250,694.0	Gallon	\$849,830
Liquid Deicer	7,270,127.0	Gallon	\$2, 733, 995
Liquid Deicer Special (Liquid + Salt/Sand)	2,417.0	Ton	\$53,196
Caliber 1000	1,870,393.0	Gallon	\$1, 160, 517
Abrasives non-mixed	457.0	Ton	\$12,502
Total			\$11, 892, 589

Simulated cost-benefit analyses have been done by Ye et. al. on New Hampshire, Minnesota and Colorado [10]. Their benefits are shown in Table 5. These cost-benefit simulations compare the material usage recommended by an MDSS package to a baseline level of service for the state. Savings were split into those experienced only by the DOT (e.g. salt usage) and those experienced by the public (e.g. delay costs). Any reductions in these costs that are observed by the MDSS simulation are considered to be benefits. The studies takes into account the amount of trust that DOTs have in using the MDSS recommendations for material treatment plans. This adjustment varies between states, from 30% of recommendations followed in New Hampshire to 75% in Colorado [10]. In all of these studies, the benefit-to-cost ratios were favorable to the DOT. The most beneficial simulation saw over eight times the cost of MDSS in savings, while the least beneficial simulation reduced costs by 1.33 times the MDSS costs [10].

Table 5. Benefits seen by New Hampshire, Minnesota and Colorado are above \$1 million for each state, with benefit-cost ratios ranging from 1.33 to 8.67 [10]. The same condition option and same resources option were both simulated for all three states.

Case State	Scenario	Benefits	Percent of User Savings (%)	Percent of Agency Savings (%)	Costs	B-C Ratio
New Hampshire	Same Condition	\$2,367,409	50	50	\$332,879	7.11
	Same Resources	\$2,884,904	99	1		8.67
Minnesota	Same Condition	\$3,179,828	51	49	\$496,952	6.40
	Same Resources	\$1,369,035	187	-87		2.75
Colorado	Same Condition	\$3,367,810	49	51	\$1,497,985	2.25
	Same Resources	\$1,985,069	90	10		1.33

Nevada can expect to see substantial savings if they chose to implement MDSS. With an annual salt/sand budget of about \$2.6 million, these saving will not be as large as other states have reported, but still significant. Indiana reported a reduction in their use of salt/sand by about 40%. If these reductions were realized in Nevada, this would save NDOT about \$1 million annually. While a 40% reduction is not an average level of savings, other states typically can see above a 20% reduction in material usage. At these levels, Nevada would still save about \$520,000.

4.8 MDSS Implementation Challenges & Concerns for Nevada

If NDOT decides to pursue implementation of an MDSS package, there could be impediments that could hinder the uses of the system. Some of these issues are unique to the state, while others have been experienced by other MDSS active states. It will be necessary for Nevada to address these challenges in order to maximize the potential value that Nevada can achieve through an MDSS implementation.

One of the most notable impediments to implementing an MDSS package in Nevada is related to data communication. Most states in the United States have adequate cell phone coverage, allowing information to be transmitted to and from MDSS outfitted snow plows with ease. Nevada has, however, significant areas of poor to no coverage (shown in [Figure 12](#)). This means that when using cell phone communications to transmit data to and from vehicles, there will be routes that cannot be included in the treatment recommendations made by the MDSS. I.e., without sufficient communications bandwidth, treatment recommendations will not reach the driver in a timely manner.

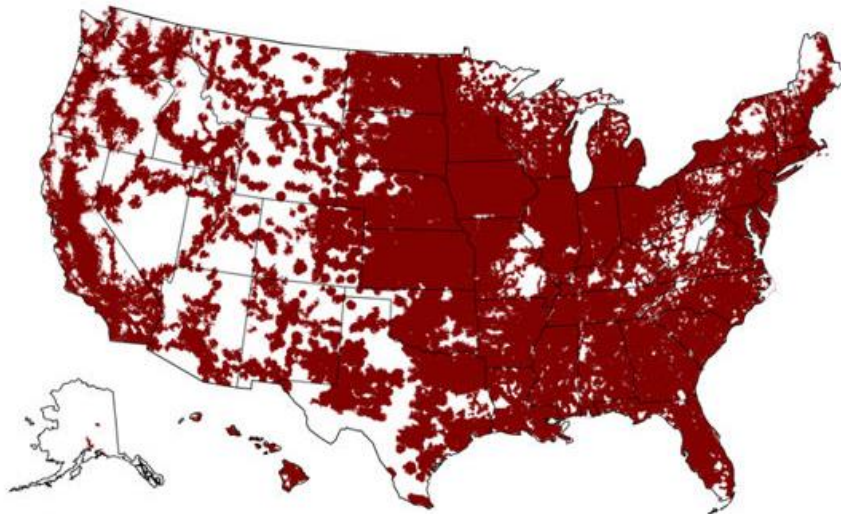


Figure 12. Verizon Data Coverage (per Verizon website). Major cellular service providers don't cover large areas of Nevada, leading to routes where MDSS recommendations cannot reach plow drivers.

A way to circumvent the issue of poor cell phone data coverage in Nevada is through use of the state's Enhanced Digital Access Communications Systems (EDACS) radio network. The coverage provided by the already-present EDACS network in Nevada is much more wide-spread than cell phone coverage, but significantly more limited in bandwidth capabilities. Vehicles outfitted with EDACS equipment from the first phase of the Nevada Intelligent Mobile Operations project (NIMO 1.0) have demonstrated consistent data transmissions from autonomous weather measurement systems since 2012. Additionally, bench tests have been done to prove the capability for 2-way communication between a mobile observations vehicle and the server it reports to, so treatment recommendations can also be sent to drivers when necessary. A hybrid system using both EDACS (or any trunked radio system) and cell phone data services may be desired for the coverage provided by radio and the bandwidth capabilities of a cell phone data plan. This issue will need to be solved through cooperation with whichever MDSS vendor is chosen to work with NDOT. We note briefly here that the transmission of treatment recommendations to vehicles may also have intellectual property issues, which will be discussed below and more extensively in an appendix to this report.

Transmitting weather data over Nevada's radio network has been demonstrated feasible through the NIMO 1.0 project, but the EDACS radio network that was used for this project is being phased out for a different suite of standards. Nevada will be implementing a Project 25 (P25) radio network across the state. This new radio network will use a different communication protocol (most likely TC/PIP) than the EDACS network used in the NIMO 1.0 project. Ultimately, this change in radio could potentially lead to a higher available bandwidth, an easier communication protocol to work with, and better coverage. This transition needs to be taken into consideration in regards to any MDSS plans for NDOT.

Another issue that could cause problems in effectively using an MDSS system is the Nevada's Material Management System (MMS). Currently, there are records for how much de-icing and anti-icing materials are being used by snowplows as they drive their routes. The problem is that

there is no way for NDOT personnel to accurately report *where* along the route material is being used. Without having a good understanding of how segments of a road are being treated, there is no effective way of determining where MDSS benefits or losses are being experienced. The second phase of the NIMO program (NIMO-2) includes (as a low priority task) the development of a method to track materials used by location, but it was not fully implemented or tested.

While MDSS may have proven to be useful for other agencies, getting NDOT personnel to trust the recommendations that the system provides may require time and training (based on experiences from other states). From anecdotal examples provided by NDOT employees in District III, the current weather forecasts that the state's contractor provides (which do not incorporate mobile observations) can have very poor accuracy. These forecasts were reportedly inaccurate more often than when measurements observed 24 hours before were assumed to be the current conditions. Nevada's many microclimates in the northern region of the state are attributed to making it difficult for making accurate weather predictions (according to several providers of weather forecasting services). If the MDSS has inaccurate weather forecasts, then the treatment recommendations it provides will not engender any trust in the supervisors consulting the system.

Safely providing snowplow drivers with updated treatment plans may be another issue that NDOT has with MDSS. States have been heading in the direction of using a mobile display (MDC) to receive transmissions of the treatment plans that their MDSS recommends to snowplow drivers, but this might not work well with Nevada. NDOT is very concerned with making sure that their drivers are not distracted while operating vehicles, and installing an MDC into a snow plow may be considered as an unwanted distraction.

The hardware requirements of getting snow plows to both transmit and receive data is also difficult, as this requires two radios. This would increase the cost needed to implement MDSS. The state's upgrade to the P25 radio network could potentially solve this problem. Additionally, these treatment update broadcasts will require a supervisor (most likely) to personally inform the driver. NDOT is understaffed and increasing the duties of its employees may have negative results.

The MDSS community, which includes many state DOTs and private vendors, have been contacted by IWAPI's legal department concerning the development and/or implementation of an MDSS system that may infringe upon one or more of Concaten/IWAPI's patents. The PI team conducted an analysis of the following Concaten/IWAPI United States patents:

- 7,355,509 (the '509 patent): Smart Modem Device for Vehicular and Roadside Applications.
- 7,714,705 (the '705 patent): Maintenance Decision Support System and Method.
- 8,120,473 (the '473 patent): Smart Modem Device for Vehicular and Roadside Applications.
- 8,231,270 (the '270 patent): Integrated Rail Efficiency and Safety Support System.
- 8,275,522 (the '522 patent): Information Delivery and Maintenance System for Dynamically Generated and Updated Data Pertaining to Road Maintenance Vehicles and Other Related Information.

- 8,284,037 (the '037 patent): Maintenance Decision Support System and Method for Vehicular and Roadside Applications.
- 8,497,769 (the '769 patent): Maintenance Decision Support System and Method for Vehicular and Roadside Applications.

The analysis indicates that NDOT/UNR is not infringing on any of the claims in any of the seven patents reviewed. However, the group of patents issued to Concaten & IWAPI remains a concern for all DOTs using an MDSS and all providers of MDSS solutions. Nevada cannot proceed to implement an MDSS without developing a plan to address the intellectual property issues. A detailed claim-by-claim analysis is included in [Appendix 1](#).

5. CONCLUSIONS AND RECOMMENDATIONS

A Maintenance Decision Support System has the potential to be very beneficial to the Nevada Department of Transportation. Lessons learned from other states can help ensure that NDOT implements a useful MDSS package without unnecessary difficulty. There are still issues that need to be addressed by Nevada before MDSS should be attempted.

The Concaten/IWAPI patents have caused much upset in the MDSS community. If NDOT plans on implementing an MDSS, if the patents are not to be challenged, or if an agreement cannot be otherwise be reached, licensing from Concaten/IWAPI may need to be done or else find an alternative method for transmitting the necessary data to and from snow plows will need to be investigated. Radio network transmissions are a potential solution to this issue, but will result in an entirely different problem set. Bandwidth limitations, equipment costs and areas lacking coverage need to be accounted for in determining how NDOT will transmit and receive data. The transition from EDACS to P25 should also be considered.

Methods for evaluating how well MDSS is improving the level of service on routes are an important step in getting the most out of the system. Automation of NDOTs MMS for material usage is recommended. If snow plows can record and transmit where and when salt/sand is being used along their routes (through the use of a spread rate sensor), an even more accurate understanding of material usage can be had. NDOT should use this information, as well as other measurements, to quantitatively represent how well they are treating roads. Formulating a performance index can either be done entirely in the department, or other state's performance indices can be referenced.

The performance of MDSS (both in forecasting and treatment recommendations) needs to be trustworthy. Nevada has had weather and road condition forecasting in the state and it doesn't always perform well. Although MDSS has proven accurate in other areas, this may not be the case for Nevada. If the forecasts that MDSS provides and uses as a model input are poor, the treatments plans it recommends will also be poor. If MDSS performs as a reliable tool, there will also be a reduction in resistance that crews could potentially exhibit to the systems implementation.

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APPENDIX 1: ANALYSIS OF CONCATEN & IWAPI PATENTS

The MDSS community, which includes many state DOTs and private vendors, have been contacted by IWAPI's legal department concerning the development and/or implementation of an MDSS system that may infringe upon one or more of Concaten/IWAPI's patents. The PI team conducted an analysis of the following Concaten/IWAPI patents:

- 7,355,509 (the '509 patent): Smart Modem Device for Vehicular and Roadside Applications.
- 7,714,705 (the '705 patent): Maintenance Decision Support System and Method.
- 8,120,473 (the '473 patent): Smart Modem Device for Vehicular and Roadside Applications.
- 8,231,270 (the '270 patent): Integrated Rail Efficiency and Safety Support System.
- 8,275,522 (the '522 patent): Information Delivery and Maintenance System for Dynamically Generated and Updated Data Pertaining to Road Maintenance Vehicles and Other Related Information.
- 8,284,037 (the '037 patent): Maintenance Decision Support System and Method for Vehicular and Roadside Applications.
- 8,497,769 (the '769 patent): Maintenance Decision Support System and Method for Vehicular and Roadside Applications.

This analysis was not conducted by lawyers and in no way should be considered legal advice.

This analysis does not represent a legal opinion by any of the investigator team members.

The '509, '705, '473, '037 and '769 patents all make a distinction between a "smart modem device" and "clients," such as a PC or laptop, and "servers." The computing platforms used by NDOT, the PC104 and Raspberry pi, are both PCs that fall under the category of "client" rather than "smart modem device" because they do not have a removable network card of any kind.

A smart phone is not a smart modem device (SMD) either. As described in all the patents, the SMD includes a slot that can accept a network card. The WiFi capability of a smart phone is not enabled by a slot that accepts a network card and thus does not constitute a SMD.

The SIM card in a smart phone has some attributes of a wireless network card (as described in the patents). However, one attribute of a SMD is that the removable network card enables "quick change to an entirely different network or even to a fixed connection such as fiber, network, or wireless Ethernet." A SIM card does not permit this level of flexibility. At the very most, it will permit users to change carriers (but even this is not possible with the vast majority of smart phones sold in the US).

Analysis of the '509 patent:

Claim 1: The NDOT system is not infringing this claim because neither an EDACS radio nor a smart phone have a network card slot. An EDACS radio does not qualify as a smart modem device because it cannot be easily reconfigured to use a different network carrier. A smart phone does not qualify as a smart modem device because it lacks a slot to receive a network card.

Claims 2-9 are dependent to claim 1 and, thus, are not of concern since NDOT is not infringing claim 1.

Claim 10: The method used by NDOT is not infringing this claim because neither an EDACS radio

nor a smart phone have a network card slot. An EDACS radio does not qualify as a smart modem device because it cannot be easily reconfigured to use a different network carrier. A smart phone does not qualify as a smart modem device because it lacks a slot to receive a network card.

Claims 11-18 are dependent to claim 10 and, thus, are not of concern since NDOT is not infringing claim 10.

Claim 19: The NDOT system is not infringing this claim because neither an EDACS radio nor a smart phone have a network card slot. An EDACS radio does not qualify as a smart modem device because it cannot be easily reconfigured to use a different network carrier. A smart phone does not qualify as a smart modem device because it lacks a slot to receive a network card.

Claims 20-21 are dependent to claim 19 and, thus, are not of concern since NDOT is not infringing claim 19.

Analysis of the '705 patent:

Claim 1: The method used by NDOT is not infringing this claim because neither claims 1(b) nor 1(c) are infringed (both would have to be infringed in order to infringe on claim 1).

1(b): NDOT is not infringing at this point because the server receiving the mobile data is not providing instructions to the vehicle operator.

1(c): NDOT is not providing any visual maps to the vehicle operator. Use of a non-touch screen interface would be an easy method to avoid infringement of claim 1 in the future.

Claims 2-12 are dependent to claim 1 and, thus, are not of concern since NDOT is not infringing claim 1.

Claim 13: The method use by NDOT is not infringing this claim because claims 13(b), 13(c) and 13(d) are not infringed upon (all 3 would have to be infringed in order to infringe on claim 13).

13(b): NDOT is not providing any visual maps or operator instructions to the vehicle operator (note: the claim requires that both a map and operator instructions be sent).

13(c): NDOT is not using a touchscreen monitor. Use of a non-touch screen interface would be an easy method to avoid infringement of claim 13 in the future.

13(d): NDOT is not providing any operator instructions to the vehicle operator.

Claims 14-25 are dependent to claim 13 and, thus, are not of concern since NDOT is not infringing claim 13.

Claim 26: The method used by NDOT is not infringing this claim because claims 26(b) and 26(f) are not infringed upon (both would have to be infringed in order to infringe on claim 26).

Claim 26(a): NDOT is not using a touchscreen monitor. Neither is NDOT having the operator indicate any information (weather, road condition, etc.). Use of a non-touch screen interface would be an easy method to avoid infringement of claim 26 in the future.

Claim 26(f): NDOT is not sending any treatment commands or recommendations to the vehicle operator.

Claims 27-33 are dependent to claim 26 and, thus, are not of concern since NDOT is not infringing claim 26.

Claim 34: NDOT is not using a touchscreen monitor. Neither is NDOT having the operator indicate any information (weather, road condition, etc.). Use of a non-touch screen interface would be an easy method to avoid infringement of claim 34 in the future.

Claims 35-41 are dependent to claim 34 and, thus, are not of concern since NDOT is not infringing claim 34

Claim 42: This claim appears to be targeting FHWA or private MDSS vendor that may operate a server that communicates to snow plows from more than one DOT. NDOT is not infringing this

claim because claim 42(a) is not infringed upon.

Claim 42(a): In order for an NDOT server to infringe on this part of the claim, all five (i through v) functions must be present on the server. The snow plows that the NDOT server communicates with are not operated by a plurality (2 or more) different government agencies. Additionally, the server at NDOT is not sending any dispatch commands or recommendations to the vehicle operator.

Claims 43-50 are dependent to claim 42 and, thus, are not of concern since NDOT is not infringing claim 42.

Analysis of the '473 patent:

Unlike the '705 patent, the '473 patent is not limited to the use of a touchscreen device in the vehicle.

Claim 1: The method used by NDOT is not infringing this claim because neither claims 1(b) nor 1(c) are infringed (both would have to be infringed in order to infringe on claim 1).\

1(b): NDOT is not infringing at this point because the server receiving the mobile data is not determining any instructions for the vehicle operator.

1(c): NDOT is not providing any visual maps or instructions to the vehicle operator.

Claims 2-12 are dependent to claim 1 and, thus, are not of concern since NDOT is not infringing claim 1.

Claim 13: The method used by NDOT is not infringing this claim because claims 13(b), 13(c) and 13(d) are not infringed upon (all 3 would have to be infringed in order to infringe on claim 13).

13(b): NDOT is not providing any visual maps or operator instructions to the vehicle operator (note: the claim requires that both a map and operator instructions be sent over a cellular network).

13(c): NDOT is not providing any visual maps to the vehicle operator.

13(d): NDOT is not providing any operator instructions to the vehicle operator.

Claims 14-25 are dependent to claim 13 and, thus, are not of concern since NDOT is not infringing claim 13.

Claim 26: The method used by NDOT is not infringing this claim because claim 26(f) is not infringed upon.

Claim 26(f): NDOT is not sending any treatment instructions or recommendations to the vehicle operator based on the mobile data collected.

Claims 27-33 are dependent to claim 26 and, thus, are not of concern since NDOT is not infringing claim 26.

Claim 34: The NDOT system is not infringing this claim because claim 34(f) is not infringed upon.

Claim 34(f): NDOT is not sending any treatment instructions or recommendations to the vehicle operator based on the mobile data collected.

Claims 35-41 are dependent to claim 34 and, thus, are not of concern since NDOT is not infringing claim 34

Claim 42: The method used by NDOT is not infringing this claim because claim 42(b) is not infringed upon.

Claim 42(b): NDOT does not employ a method to delay processor shut down as described. The systems using either the PC104 or Rasberry Pi PC formats do not delay shut down when the vehicle is powered off. For the systems that use a smart phone, the phone's battery, charge control circuit and processor are not the same as a DC voltage regulator and sequencer.

Claim 43 is dependent to claim 42 and, thus, are not of concern since NDOT is not infringing claim 42.

Claim 44: The NDOT system does not employ a method to delay processor power-on or shut down as described. The systems using either the PC104 or Raspberry Pi PC formats do not delay start-up or shut down when the vehicle is powered on or off. For the systems that use a smart phone, the phone's battery, charge control circuit and processor are not the same as a DC voltage regulator and sequencer.

Claim 45 is dependent to claim 44 and, thus, are not of concern since NDOT is not infringing claim 44.

Claim 46: The NDOT system is not infringing this claim because claims 46(b), 46(c) and 46(d) are not infringed upon (all 3 would have to be infringed in order to infringe on claim 13).

46(b): NDOT is not providing any visual maps or operator instructions to the vehicle operator (note: the claim requires that both a map and operator instructions be sent over the cellular network).

46(c): NDOT is not providing any visual maps to the vehicle operator.

46(d): NDOT is not providing any operator instructions to the vehicle operator.

Claims 47-57 are dependent to claim 46 and, thus, are not of concern since NDOT is not infringing claim 46.

Claim 58: This claim appears to be targeting FHWA or private MDSS vendor that may operate a server that communicates to snow plows from more than one DOT. NDOT is not infringing this claim because claim 58(a) is not infringed upon.

Claim 58(a): In order for an NDOT server to infringe on this part of the claim, all five (i through v) functions must be present on the server. The snow plows that the NDOT server communicates with are not operated by a plurality (2 or more) different independent agencies. Additionally, the server at NDOT is not sending any dispatch commands or recommendations to the vehicle operator.

Claims 59-68 are dependent to claim 58 and, thus, are not of concern since NDOT is not infringing claim 58.

Claim 69: This claim appears to be targeting FHWA or private MDSS vendor that may operate a server that communicates to snow plows from more than one DOT. In order for an NDOT server to infringe on this part of the claim, all five steps of the method must be employed. The snow plows that the NDOT server communicates with are not operated by a plurality (2 or more) different independent agencies. Additionally, the server at NDOT is not sending any dispatch commands or recommendations to the vehicle operator.

Claims 70-79 are dependent to claim 69 and, thus, are not of concern since NDOT is not infringing claim 69.

Claim 80: NDOT is not infringing this claim because claims 80(b) and 80(c) are not infringed upon (both would have to be infringed in order to infringe on claim 80).

80(b): NDOT server does not develop a map and instructions for the vehicle operator. It does currently produce a map, but not instructions.

80(c): NDOT server is providing neither a visual map nor instructions to the vehicle operator.

Claims 81-91 are dependent to claim 80 and, thus, are not of concern since NDOT is not infringing claim 80.

Analysis of the '270 patent:

All of the claims of the '270 patent relate to rail vehicles and, thus, are not of concern to NDOT.

Analysis of the '522 patent:

Claim 1: The NDOT system does not infringe this claim because it does not determine instructions to send the snow plows and does not include a display inside the snow plow.

Claims 2-11 are dependent to claim 1 and, thus, are not of concern since NDOT is not infringing claim 1.

Claim 12: The method used by NDOT does not infringe this claim because it does not determine instructions to send the snow plows and does not include a display inside the snow plow.

Claims 13-22 are dependent to claim 12 and, thus, are not of concern since NDOT is not infringing claim 12.

Claim 23: The NDOT system does not infringe this claim because it does not determine instructions to send the snow plows and does not send a map to the snow plow or display it on a touch screen display.

Claim 24: The method used by NDOT does not infringe this claim because it does not determine instructions to send the snow plows and does not send a map to the snow plow or display it on a touch screen display

Analysis of the '037 patent:

Claim 1: The method used by NDOT is not infringing this claim because claim 1(c) is not infringed.

1(c): NDOT is not infringing at this point because the server receiving the mobile data is not sending any maps, instructions or weather forecasts to the maintenance vehicle.

Claims 2-9 are dependent to claim 1 and, thus, are not of concern since NDOT is not infringing claim 1.

Claim 10: The NDOT system is not infringing this claim because claim 10(c) is not infringed.

10(c): NDOT is not infringing at this point because the server receiving the mobile data is not sending any maps, instructions or weather forecasts to the maintenance vehicle.

Claims 11-18 are dependent to claim 10 and, thus, are not of concern since NDOT is not infringing claim 10.

Analysis of the '769 patent:

Claim 1: The method used by NDOT is not infringing this claim because claims 1(b) and 1(c) are not infringed upon (both would have to be infringed in order to infringe on claim 1).

1(b): The NDOT server is not determining any operator instructions.

1(c): NDOT is not providing any visual maps or instructions to the vehicle operator.

Claims 2-10 are dependent to claim 1 and, thus, are not of concern since NDOT is not infringing claim 1.

Claim 11: The NDOT system is not infringing this claim because claims 11(b) and 11(c) are not infringed upon (both would have to be infringed in order to infringe on claim 11).

11(b): The NDOT server is not determining any operator instructions.

11(c): NDOT is not providing any visual maps or instructions to the vehicle operator.

Claims 12-20 are dependent to claim 11 and, thus, are not of concern since NDOT is not infringing claim 11.



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