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Intelligent Transportation Systems in New Mexico Winter Road Maintenance

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Acronyms

AVL  Automatic vehicle location
CAD  Computer aided dispatch
CCTV  Closed circuit television
DMS  Dynamic message sign
DOT  Department of transportation
GIS  Geographic information system
GPS  Global Positioning System
HAR  Highway advisory radio
IQP  Interactive Qualifying Project
ITD  Idaho Transportation Department
ITS  Intelligent transportation systems
MDSS  Maintenance decision support system
NMDOT  New Mexico Department of Transportation
RTMC  Regional traffic management center
RWIS  Roadside weather information system
TOC  Traffic operations center
WPI  Worcester Polytechnic Institute
Abstract

New Mexico Department of Transportation (NMDOT) seeks to improve its winter road monitoring and maintenance procedures. To support this public safety goal, we interviewed NMDOT stakeholders, companies that provide Intelligent transportation systems (ITS) services, and DOT experts from states with more winter weather experience. Our plan for New Mexico incorporates state-of-the-art ITS and current best practices. Specifically, we recommend locations for new cameras, and present our own online prototype plow tracking system. Further, we developed a plan for future groups to interview employees for feedback on proposed systems and recommend dynamic message sign locations.
Executive Summary

Effectively maintaining the safety of roads during winter weather is a complicated but critical responsibility for departments of transportation anywhere severe winter weather occurs. Some of the challenges faced by the decision-makers in charge of winter road maintenance are how to keep roads safe to drive on for as much time as possible, how to inform drivers of the safest course of action to take while traveling during harsh weather, and how to accomplish these goals in a cost-effective way.

Intelligent Transportation Systems (ITS), which refers to the use of information technology and electronic communications to improve traffic-related operations, promises to solve these problems with advanced communication systems. Departments can use Automatic Vehicle Location (AVL), an ITS technique, to track the location of snow plows in real-time. This information can be used to effectively manage plow routes, and a recent trend in the United States has local and state governments making plow locations publicly available so drivers can make informed decisions on which roads are safe to use during winter weather. States also use Dynamic Message Signs (DMSs) to inform drivers about road conditions and closings. Lastly, many roads have cameras installed nearby to inform decision-makers about conditions without requiring someone to physically drive out to a location.

Many states are already using ITS deployments to improve safety and cost efficiency. One relatively new adopter of ITS for winter road maintenance is the New Mexico Department of Transportation (NDMOT) and NMDOT’s Intelligent Transportation Systems Bureau. Recently, a WPI IQP group developed a broad set of recommendations for the ITS bureau to explore (Curtis, Jones, Picard, & Tolisano, 2015). As a continuation of this work, our group was asked to specifically develop a plan for placing new cameras, placing new DMSs, and implementing an AVL system in New Mexico’s District 5.

Our project group began by interviewing key stakeholders. We conducted several interviews our project liaison Tim Brown from the ITS department, in which we learned that the current practices of New Mexico winter road maintenance currently underutilize information technology. We spoke with representatives from Vaisala, a company that provides ITS-related products and services, to learn that advanced state-of-the-art off-the-shelf ITS solutions currently exist for AVL. Finally, we spoke with an employee of Idaho’s transportation department, which has already developed a successful ITS winter maintenance strategy that has reduced weather-related fatalities by over 50%, and found that adopting ITS is behind existing success stories of road safety in other states.

We produced several deliverables for NMDOT:

- A prototype plow tracking system consisting of an Android app that would run on a device in each plow, a back-end cloud database, and a front-end web interface for
viewing plow data in real-time

- A list of eight recommendations for locations to place additional roadside cameras
- A set of criteria for locations to place additional dynamic message signs
- An interview plan for gaining feedback from district maintenance workers

We recommend that the NMDOT adopt an AVL system for plow tracking, install cameras at the locations we found, and apply similar systematic criteria for identifying locations to add new dynamic message signs and RWIS stations.

Figure 1: All of the recommended camera locations for District 5.
1 Introduction

Road maintenance is a far-reaching public service that affects all citizens, but traditionally, it is managed with very little use of information technology except for radios, computer documents, and networking. This makes road maintenance operations less economical and road conditions less safe than they could possibly be. This situation opens the opportunity for new tools that may improve safety and efficiency in road maintenance. Intelligent Transportation Systems (ITS) refers to the tools that improve transportation productivity and safety with information and electronic technology (Barbaresso et al., 2014).

The New Mexico Department of Transportation (NMDOT) has devoted resources to investigating ITS. Currently, winter maintenance is managed in a decentralized manner, where supervisors rely on their intuition to determine when to restock on salt or sand, and plow drivers informally communicate over radio to schedule routes. The system for winter maintenance in particular has room to improve. According to Tim Brown, an engineer in NMDOT’s ITS bureau, the state sometimes has only enough resources to plow the most traveled roads first. Therefore, New Mexico needs a resource management plan that optimizes the design and coordination of snow plow routes. Public safety would be enhanced by sharing information about which roads have been cleared of snow, so drivers can be prepared for potentially unsafe road conditions.

There is already a lot of interest in ITS in New Mexico and across the country. Many states have already developed similar systems to help their winter road maintenance operations. Popular solutions across the US include automatic vehicle location (AVL) for snow plows (Marshall, 2016) and online dashboards where information on traffic conditions, weather, maintenance, and other important alerts are easily available to the public (Santa Fe Dashboard, n.d.). States also use roadside cameras to observe weather conditions and dynamic message signs to warn drivers about road work and weather conditions. A previous IQP in 2015 also explored these same ITS technologies and made key recommendations for their use in a traffic operations center in New Mexico (Curtis et al., 2015).

Despite all of the investments made in ITS, NMDOT has not yet finalized plans to implement AVL, dashboard systems, or inventory tracking systems for these purposes (New Mexico Department of Transportation, 2012). The current operations are still managed without the assistance of technology, although the ITS bureau has made progress in consolidating information in dashboard systems. The problem with adopting these new technologies is that ITS is expensive and complicated, and choosing what systems to upgrade requires careful analysis and testing, as well as feedback from employees and key individuals. Cameras and dynamic message signs exist in several New Mexico districts, but are underutilized in District 5.
Our project focuses on developing a systematic plan for improving the effectiveness and cost efficiency of NMDOT’s winter road maintenance operations using ITS. Winter road maintenance only occurs during the few months where there is snow in New Mexico, so it is an ideal candidate for a “trial run” of new technology. Our project’s goal is to plan an introduction of new systems, and to develop a means of assessing their usefulness through follow up from later projects. There’s plenty of time in between seasons to analyze the results of new systems, and canceling or substantially altering the plan down the road would not permanently impact NMDOT’s ability to keep the roads maintained.

After researching and comparing existing winter road maintenance systems, including those of New Mexico and those of states that have adopted ITS technologies, we recommended new tools and created a prototype plow tracking system to help establish ITS practices in New Mexico. Beyond that, we developed criteria and a specific list of recommendations for placing additional cameras in District 5. Finally, we produced a plan for a future group to gather feedback from maintenance workers and develop recommendations for additional message signs and weather stations.
2 Background

Responsibility for keeping the roads in Districts 1 through 6 clean and clear falls on the New Mexico Department of Transportation (NMDOT). In both the urban and rural parts of the state, cleaning up after a snowfall strains the resources of snow removal crews. This section examines the implementation of intelligent transportation systems in both Santa Fe and around the world. Then, we will examine the current operations of NMDOT and other DOTs, and also discuss the findings and recommendations from WPI Interactive Qualifying Projects that have worked with the NMDOT in the past.

Figure 2: A V-plow operator heads back to his rig on US 64 between Tierra Amarilla and Tres Piedras (Retrieved from http://dot.state.nm.us/content/dam/nmdot/Community/galleries/nmdot_vs_snow/_dsc4937.jpg)
2.1 Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) refers to uses of technology and electronic communications to improve transportation operations. Due to their potential to both increase efficiency and reduce danger in transportation, transportation departments around the world are currently exploring how they can use ITS deployments effectively. According to the United States Department of Transportation, “ITS technologies improve transportation safety and mobility, reduce environmental impacts, and enhance productivity through the integration of advanced communications-based information and electronic technologies into the transportation infrastructure and vehicles” (Barbaresco et al., 2014).

Figure 3: A blind pedestrian being assisted by ITS. (Retrieved from http://www.its.dot.gov/press/2013/dot_sxsw.htm)
2.1.1 Tools Utilized by Intelligent Transportation Systems

ITS involves combining existing technologies to form a new system. These include cameras, dynamic message signs, weather stations, and GPS technology. The majority of systems rely on some kind of wireless communication and geographic positioning system to locate and store the locations of interest, which requires hardware to transmit the locations, and software to interpret the incoming information and lay it out on a map. These geo-spatial tools are key to designing systems that provide useful data to their users.

Geographic Information Systems and Esri ArcGIS  Geographic Information Systems take geographic layers of data and overlay them on a map. These layers can contain the locations of several points of interest, or data about larger regions. Many organizations, including NMDOT, use ArcGIS, a GIS software product provided by mapping company Esri that takes data points and generates visual mappings of the data sets. (Esri, n.d.) This tool offers integration on the desktop, web client, and server platforms for different interactions of the data. ITS solutions can make use of ArcGIS’s ability to plot data sets on a relevant map. For instance, this capability could provide a way of creating a map to visualize such data as road incidents and road conditions with relation to a specific location. The NMDOT utilizes Esri’s ArcGIS to present information on their public traffic information website, NMRoads (NMRoads, n.d.).

GPS  GPS or global positioning system depends upon a network of satellites that allows a compatible device to be able to determine its position on the earth to within a few meters. It has seen huge adoption in a wide range of applications in both the public and private sector. This technology can be used to track vehicles and resources that are deployed as part of road maintenance operations.

GPS technology enables automatic tracking and efficiency analysis when applied to ITS. However, in some cities, municipal workers and unions have responded negatively to the implementation of GPS tracking because they feel it violates their privacy. Others argue that GPS tracking will lead to micromanaging, and other managerial abuses. The National Workrights Institute has released an informational document outlining the legal rights of workers relating to GPS technology, as well as analysis of practical issues that may arise from their deployment (National Workrights Institute, n.d.). Despite this report’s reluctance to assert that supervisors should be able to track their workers, many of the real world examples present within the document show positive uses of GPS technology that improve efficiency and accountability.
Roadside Weather Information Systems  Roadside Weather Information Systems (RWIS) are sensor arrays that gather weather information and send it to the DOT for analysis. These systems collect a variety of weather data, including but not limited to temperature, pressure, wind speed, and precipitation amount. State of the art RWIS installations also include sensors that can detect if there is a liquid or solid on the road pavement, and how much of it. Some DOTs allow this information to be viewed by the general public through interactive maps, or information dashboards.

Maintenance Decision Support Systems  For many departments of transportation, the decisions to use certain road treatments are based upon qualitative assessment of the road conditions by experienced workers. Someone who has been a plow operator for many years will have a good idea of how much salt or sand to put on the road for a certain amount of snowfall. Maintenance decision support systems (MDSS) are systems that consist of sensors and computer systems that help make the decision of what to put on the roads and how much of it. Based on current and future weather conditions, an MDSS will give a suggestion for what material to put on the roads and how much of it, balancing factors like time until the roads are cleared and environmental concerns. In Ontario, a field test of MDSS was done during the winter season of 2011/2012 (The Weather Network Commercial Services, 2012). The MDSS evaluations resulted in a 37 percent decrease in salt usage, which translates to an $11,100,000 savings over the entire year.

2.1.2 Existing Implementations of Intelligent Transportation Systems

ITS solutions have been deployed by numerous states around the country. The organizations responsible for each implementation have researched the practical and economical ways to use ITS in their jurisdictions. Starting with plow tracking websites and moving to more generalized systems where the user can provide valuable input, we will examine some prominent examples of ITS to understand the current state-of-the art of the field, and what the New Mexico Department of Transportation can take from it.

Track a Plow  Several states have already developed and deployed large scale ITS solutions to improve their maintenance operations and the safety of their streets. Iowa has released Track a Plow (Marshall, 2016), a website that shows the locations of all active snow plow trucks and their planned routes. The website also provides information about road conditions and the measures taken by the Department of Transportation to improve traffic safety.
Pittsburgh Snow Plow Tracker Pittsburgh provides a Snow Plow Tracker website that exemplifies using AVL to make a public interactive map of plow activity (City of Pittsburgh, 2016). Their project stands out in particular because of their plans to include sensors that detect when the plow is actively engaged. Most sites show only the location of the trucks, not their previous locations and whether they are actually plowing, so it is not possible to determine if a road is actually safe to drive on.

According to the Pittsburgh Director of Public Works, the city faced some resistance from unions over making the locations of plows publicly available (City of Pittsburgh, 2015). These concerns were resolved by not making the identities available on the public website. This sensitivity to worker perceptions about the management agendas shows that maintenance workers and those who represent them may object to certain parts of similar tracking projects, but other departments of transportation have had success gaining their approval by making compromises.

VDOT Plows In Virginia, the website VDOT Plows (VDOT Plows, 2011) provides an interactive map of all districts and the real time locations of all active VDOT trucks. These online resources provide valuable information to both residents who want to know when their road will be plowed and the DOT that needs to manage the large fleet of trucks at their disposal.

COTrip The ITS branch of the Colorado Department of Transportation also provides a web-based dashboard that shows interactive maps, route information, and travel alerts in the state. Specifically, this includes visualizations of road conditions, traffic cameras, road closures, and road work information. (COtrip, n.d.)

StreetBump The app StreetBump attempts to solve the problem of detecting potholes and other road deformities (Carrera, Guerin, & Thorp, 2013). Developed by a project team of WPI students, this app can be installed on smartphones and will detect when the user drives over a large bump, and record the location to a remote database. If enough StreetBump users experience a bump in the same location, the location will be marked as a potential pothole and the local road maintenance officials can send a team to investigate and repair it. Crowd-sourcing the sensing of road deformities presents a novel idea, and as a smartphone app, it can be deployed easily. This interactive, user-based means of gathering road conditions information may represent an attractive option to many road maintenance departments across America.

Idaho Swarm the Storm The Idaho Transportation Department (ITD) has developed a data-driven winter maintenance system named “Swarm the Storm”. This system
involves two major innovations: structured asset management and performance metrics (Western Region Road Weather Management Roundtable Web-Meeting, 2016). During a winter storm, a group of plows are mobilized to treat one area, and once done, they all move on to another area. The ITD uses performance measures such as the mobility of the roads, a ratio of ice and snow to unimpeded road throughout a storm. In tracking the mobility on a given roadway over the period of a storm, the ITD is able to clearly see how effective their plowing and other treatments were (Jensen, 2016).

2.1.3 Public Awareness and Intelligent Transportation Systems

Many projects and studies involving ITS communicate information about travel and weather to the general public. The Enterprise Project, a consortium dedicated to the advancement of ITS, maintains a large online repository of studies and projects in ITS. (ENTERPRISE Program, 2016) The projects outlined by the Enterprise Project cover a wide variety of topics including technical implementation guidelines and outlines of webinars held to inform local departments of transportation.
Traffic Safety and Traveler Information Apps  A recent Enterprise Project study analyzed the variety and usefulness of traveler information apps (Athey Creek Consultants, 2015). These apps varied from real time traffic information apps to anti-distraction apps that stopped incoming texts and calls from coming through. Since most of these apps were developed in house for specific state departments of transportation, the study included results of interviews conducted with DOT officials that outlined the role of application development. These interviews found that developing traveler information apps allows departments of transportation to further disseminate the information already hosted on a desktop website. Features that enhance functionality include real time traffic alerts and the ability for users to report new incidents or road condition changes.

Deployment Strategy for Rural Connected Vehicle Systems  Another Enterprise Project study focused on the challenges of implementing systems in rural conditions, where communications systems may be less reliable. (Cogenia Partners LLC, 2014). This paper proposed updating and broadcasting data collected over time whenever a connection is available, which users could access at communal hotspots like gas stations and truck stops. This approach could be relevant to New Mexico’s District 5, where not everyone has constant internet or cellular access. Also, since the equipment for gathering road data will be in remote areas, the amount of equipment that must be maintained must be minimized, and as much existing technology should be used as possible.

HAR Best Practices and Future Direction  As an older technology, Highway Advisory Radio dates back to the 1970s, and still has many uses, outlined in a 2014 study (Athey Creek Consultants, 2014) by the Enterprise Project. Maintained by the FCC, HAR is a radio channel where only traffic-related data may be broadcast. While not every state uses HAR, the states that do utilize it find it useful for communicating traffic accidents and conditions since every modern car has a radio capable of tuning into the HAR. Washington state in particular has used it to communicate if the roads require chained tires or not to people who live on mountains and might not have another method of long range communication.

The Next Era of Traveler Information  Instead of focusing on informing the public, in 2013 the Enterprise Project released the “Next Era of Traveler Information” (Athey Creek Consultants, 2013), a series of webinars and summary reports that informed DOTs about the cutting edge in several transportation technology categories. This program was meant to teach DOTs about the rapidly evolving methods of disseminating information to the public and inform them about commercial services that now compete with the DOT for traffic information. DOTs often underutilize social media, where a large
percentage of people get their everyday news and general information, as a means of communication. Topics also covered in the webinars included data and cost management, evolving customer needs, and performance targets for traveler information systems.

2.2 Current Transportation Operations in New Mexico

During winter, the NMDOT works to remove snow and improve road conditions so the district’s main arteries are not blocked for too long. This section details their methods. The department that handles ITS and some of the implementations they have already deployed is also discussed.

2.2.1 Winter Road Maintenance

NMDOT has six maintenance districts and each of these districts oversees multiple Maintenance Patrols. The state has 82 Maintenance Patrols. Each Maintenance Patrol is responsible for snow removal in their area (New Mexico Highway Operations Division, 2014). According to our liaison at the NMDOT, District 5 has approximately 20 patrol yards (Tim Brown, NMDOT). Each patrol yard has approximately 2-10 trucks (Tim Brown, NMDOT). Currently, the teams working during the winter do not use any advanced technology to assist in planning the maintenance responses for winter weather (see appendix C and D for current planning factors). Also according to Tim Brown, the yard supervisor often does not use a specific inventory of their materials used to treat the roads (see appendix B for a breakdown), and instead uses an estimate of whether or not they would need more, less, or have the correct amount. Beyond that the roads are serviced in order of priority. The priority for roads are determined by several factors including a calculation of average daily traffic among others. These priorities dictate in what order the workers service the roads are serviced and what is done during the period of a storm (PIARC Road Maintenance Handbook, 1982).

2.2.2 New Mexico Department of Transportation Intelligent Transportation Systems Bureau

Goals The New Mexico Department of Transportation manages a sub-department dedicated to intelligent transportation solutions for the entire state called the ITS Bureau. The Bureau’s responsibilities include outlining and implementing projects and improvements to systems that will interact with transportation throughout the state. The benefits sought by the state include information about the status of the roads, safety,
mobility, efficiency, economy, responsible funding, and preservation of the environment. The ITS bureau intends to provide information to travelers such as real time traffic information and road conditions to make sure that the public can make informed road travel decisions. In addition, the ITS Bureau utilizes ITS to reduce weather related incidents, and minimize response time and clearance time to provide safe and available roads. One particular goal tied to the New Mexico area is the idea of working to create a more environmentally friendly system for road transportation (New Mexico Department of Transportation, 2012).

Current Implementation  ITS Bureau has already taken steps towards their goals, by implementing many ITS solutions. For example, the NMDOT currently manages the District 5 Traffic Operations Center, focused on providing traffic management and information dissemination services including traffic surveillance through the use of remote closed circuit television systems, and the remote control of dynamic message road signs for the area. Generally speaking, the implementations of these systems reflect the goals outlined by the department. It can be seen that such systems may work in tandem to serve more complex goals, such as winter road services. The department collects and stores information about road conditions and weather forecasts that can be used in conjunction with the dispatch systems and information dissemination systems to
keep roads clear, and drivers informed (New Mexico Department of Transportation, 2011).

**NMRoads** NMRoads, a web app published by the ITS Bureau, displays road conditions and alerts in real-time or near real-time (NMDOT, 2015). Information displayed by NMRoads, which includes weather conditions, road conditions, traffic, and construction information, can be useful in improving the overall safety of roads in New Mexico, since drivers can use it to identify points on their routes where there may be an increased chance of danger (NMRoads, n.d.).

![Figure 6: A screenshot of the NMRoads online web app. (NMRoads, n.d.)](image)

**Santa Fe City Dashboard** The Santa Fe Dashboard (Santa Fe Dashboard, n.d.) is a centralized interface that allows residents of New Mexico and tourists to find up to date travel information. This includes weather data, safety alerts, road closings, and traffic data. We may integrate our project with the dashboard to maintain the centralized nature of this information distribution system. Additionally, this project has relevant social goals associated with it that we can use as an example of the importance making traffic and weather information easily accessible.
2.3 2015 NMDOT IQP

In 2015, a team of WPI students conducted a project sponsored by the New Mexico Department of Transportation with the goal of exploring potential ITS technologies. Motivated by the higher fatality rate of highway traffic in the state, NMDOT sponsored the project to explore technology that New Mexico could adopt in a new Traffic Operations Center (TOC) in District 5. The group identified several main ITS technologies - dashboards, Automatic Vehicle Location (AVL) systems, and NMRoads - as the most beneficial technologies for the TOC to use. Computer-Aided Dispatch (CAD) systems and video analytic were also recommended (Curtis et al., 2015).

According to the IQP group, making use of CAD in the District 5 TOC would be valuable to the state, since it would increase the speed and efficiency of law enforcement and firefighters responding to incidents. The group asserts that AVL could be integrated with CAD systems to provide dispatchers with information on emergency responders’ locations, resulting in decisions that lead to quicker response times.

The 2015 IQP group recommended internal customizable dashboards for stakeholders in the department, because they would allow decision-makers to visualize organized,
up-to-date information relevant to their organization.

Their recommendations serve as a foundation for future deployments of ITS in New Mexico. This group already did research on numerous implementations of dashboard systems, notifications and feeds, modeling tools, and communications tools and made recommendations that weighted feasibility, efficiency, and completeness in satisfying NMDOT’s problems. Our project builds on the work that the previous group of WPI students have done, and makes recommendations for new types of systems that they did not explore.
3 Methodology

This project assisted the New Mexico Department of Transportation (NMDOT) in improving the effectiveness and cost efficiency of winter road maintenance operations by applying intelligent transportation systems (ITS). The first step towards accomplishing this goal was to research how other departments of transportation are using ITS to improve operations in their districts. Using this research and an assessment of the current road maintenance operations in New Mexico, we recommended ITS implementations that would best fit NMDOT’s needs, and identified locations for additional traffic cameras. A prototype was also made to test automatic vehicle location AVL systems and demonstrate their usefulness. Our process for achieving these goals is described in Figure 8. The four main methods we used, which are described in greater detail in each section of this chapter, are:

1. Research and compare implementations of intelligent transportation systems.
2. Assess the current planning techniques used in winter road maintenance in New Mexico.
3. Design a prototype AVL system for visualizing real-time snow plow data.
4. Suggest new locations to deploy traffic cameras.

Figure 8: Project methodology
3.1 Research and Compare Existing ITS Implementations

To understand the cutting edge of ITS technology, we researched how other organizations are using ITS. Many organizations are interested in ITS, including federal and state departments of transportation, conferences on traffic safety, and independently funded projects such as the Enterprise Project. We came to an understanding of the wide variety of applications ITS has and how it works in the real world. We focused on applications of ITS that could be applied to challenges faced by NMDOT. The steps taken to complete this objective were:

1. Use online resources to find the most up to date applications of ITS
2. Find studies on ITS effectiveness to better compare ITS implementations
3. Utilize the 2015 NMDOT WPI IQP report (Curtis et al., 2015) findings to select the most applicable systems to Santa Fe

3.1.1 Utilizing Online Resources on ITS

Because ITS is closely linked with computers and technology, all of the major resources for learning about ITS and how it works can be found online. We went through many online repositories of ITS related projects and summarized key insights about the wide variety of ways intelligent systems can streamline traffic operations. Once we had gained a good understanding of what the cutting edge of ITS was, we moved on to evaluating specific implementations and their relevance to our project.

3.1.2 Comparing ITS Implementations

After compiling a wide range of research on ITS, we then narrowed down our scope to what was likely to work in Santa Fe, New Mexico. As described in Section 2.1.2, we examined implementations of ITS made by other states. The 2015 NMDOT WPI IQP group did a lot of research into what would best benefit the NMDOT in terms of technological advancements (Curtis et al., 2015). Specifically, they had outlined implementable technologies such as computer aided dispatch, which they deemed useful in District 5. Their findings influenced our decisions about which systems would be the best fit for the NMDOT.
3.2 Assess New Mexico’s Current Winter Maintenance System

We gathered information about the current state of affairs in the NMDOT. This research covered both the physical inventory of tools, materials, and vehicles, and the methods commonly used to accomplish winter maintenance tasks. We also hoped to interview road maintenance workers that will be directly affected by any implementation, but we were unable to reach any District 5 maintenance employees. The key steps towards completing this objective ended up as:

- Performing research into the rules and regulations behind NMDOT activities
- Interviewing our project liaison Tim Brown about high level operations

3.2.1 Research on Rules and Regulations

To figure out how to improve the current operations of the NMDOT, we had to first understand how things are currently done. Handbooks that dictate how maintenance is performed were sought after to find more information on the matter. An example of these documents (Appendices B, C, and D) was a handbook that detailed what chemicals are applied to the road in different conditions in addition to a rough idea of when and how to treat roads during an event. The suggestions on current road treatment was a good foundation from which to understand the changes that could and might be made to maintenance operations in District 5.

3.2.2 Stakeholder Interviews

Before we traveled to Santa Fe, we conducted an interview with Tim Brown, the district ITS engineer and our liaison for this project. He gave us valuable insight into how he conducts his business from day to day, and helped direct the project towards something that would be more useful for the NMDOT. In Santa Fe we continued to collaborate closely with our sponsor to ensure that our work was focuses on areas that would benefit NMDOT. We had planned to interview plow workers and other stakeholders to ensure that our proposed ITS solutions have their approval, however we were unable to secure interviews with plow drivers. The purpose of these planned interviews was to ensure that the plow workers who will be affected by our proposed systems are willing to collaborate on the implementation of the system.
3.3 **NMPlows: A Prototype AVL System**

We designed a prototype system called NMPlows to simulate tracking snow plows and displaying the resulting data. The prototype allowed us to better communicate our ideas and goals, as well as show a concrete piece of software for stakeholders to evaluate and comment upon. Further, it was designed such that it could be used with the NMRoads dashboard. By working with Real Time Solutions, the company that designed NMRoads, we ensured that our code could be integrated easily. We describe the system in detail and some of its technical design features in Section 5.2.

3.4 **Camera Location Recommendations**

As a part of our project, we were tasked with creating a set of recommended locations to place traffic cameras in District 5. We devised a set of criteria for useful camera locations, and applied the criteria to generate a list of suggestions. The criteria are based mainly on the insights of Tim Brown of the NMDOT, which we received while interviewing him.

3.4.1 **Camera Locations Criteria**

The existing cameras in New Mexico are primarily focused on monitoring traffic. To supplement that purpose of the cameras, our recommendations focus on where additional locations would enhance effective responses to adverse weather conditions. The locations must:

1. be flat or on a hill, not in a valley
2. have good visibility of the surrounding area
3. be in a snowy area, or an area that begins snowing before the surrounding area
4. have access to electrical lines
5. have access to internet
6. not be on tribal land

3.4.2 **Using the Criteria to Find Locations**

After generating the criteria for valid closed circuit television (CCTV) camera locations, we used them in conjunction with other available data and insights to begin generating recommendations. One such source of insight was direct input from Tim Brown. His
experience in the area and how District 5 is affected by snow was a good starting point for recommendations. Another source of data was a map of the US average snowfall from 1961 - 1990. As the locations started to fill out the map, some camera recommendations were placed to fill in the larger gaps in coverage between cameras.

However, several difficulties were encountered during this process. Without driving out to each of the recommended camera locations with a DOT maintenance technician, we could not determine if communications were easily available at each of the locations, nor whether other site-specific considerations might be apparent in the field.

3.4.3 Presenting our Recommendations

To communicate our recommendations to officials at the NMDOT, we input each proposed addition into an online map of New Mexico. The map stores the location of every recommendation, as well as the route, the mile marker, and optional notes. The map was updated in real time so that the NMDOT could see our suggestions as we made them. Our camera location suggestions are presented in Section 5.1.

3.5 Follow-up Work

Since we were not able to secure many of the interviews we planned or obtain information on road closures, there is still much more opportunity for work to be done in ITS in New Mexico winter road maintenance. We generated some materials that can be used by groups continuing our work.

3.5.1 Follow-up Interview with District 5 maintenance workers and supervisors

To accompany our recommendations we created an interview plan that can be used to get feedback for the deliverables we provided to the NMDOT. The interviews will help any groups expanding on our research to gain feedback on how a proposed system might integrate with the existing worker operations. In addition to getting feedback on a new system, the interview plan can gather feedback on the location recommendations provided, so that maintenance workers with many years of experience can express which cameras they would find most useful.
4 Findings

Our research and field work led us to a number of core findings about the state of winter road maintenance in New Mexico, and how other Intelligent Transportation Systems (ITS) implementations can serve as examples for technologies and techniques that could work here. This chapter is organized according to the following findings:

1. New Mexico winter road maintenance could benefit from increased usage of information technology.

2. States that effectively use ITS to plan maintenance see improvements in safety, and a large decrease in fatalities.

3. There are many places in District 5 that could benefit from additional cameras and message signs.

4. Many other states already publish winter maintenance data publicly.

5. A simple automatic vehicle location (AVL) system can be created easily and cheaply, and more advanced commercial products are also available.

4.1 New Mexico Could Benefit From Increased Usage of Information Technology

New Mexico has recently made large strides in the right direction when it comes to ITS infrastructure. The Regional Traffic Management Center (RTMC) is a control room located in the Mid-Region Council of Governments’ offices in Albuquerque. Here, all of the traffic data from various sources around the region including cameras, traffic sensors, and weather sensors feeds into various databases and screens on the walls. The RTMC allows the NMDOT to monitor their traffic corridors with ITS very closely.

Also, the NMDOT has created the website NMRoads.com alongside Real Time Solutions to serve as a traveler information hub. NMRoads provides real time traffic data and road closings on top of a street map. This represents a combination of ITS technologies to make the roads safer for motorists in New Mexico.

However, New Mexico’s current ITS infrastructure is much less developed compared to other states (Brown, 2016). The NMDOT has only five Roadside Weather Information System (RWIS) stations across the entire state, compared to the over 120 stations that the Idaho DOT operates (Western Region Road Weather Management Roundtable Web-Meeting, 2016). Additionally, two of the five stations are for monitoring dust storms in the southern corner of the state, and are not collecting data relevant to winter maintenance. The data being collected by the current ITS installations is also not being used by
decision makers in winter maintenance. The decision making process used by plow operators is based on their experience on the roads and where snow has piled up in the past (Brown, 2016). The lack of consideration of winter weather data when planning maintenance can cause inefficient usage of DOT resources.

We believe that the NMDOT could benefit greatly from increased usage of information technology, because as demonstrated by the Idaho Transportation Department in Section 4.2, ITS can make the roads safer for motorists.

### 4.2 ITS Usage Leads to Safety Improvements

After researching many ITS implementations, we found that ITS has a strongly positive impact on motorist safety. To substantiate this claim, interviews were conducted with both Idaho DOT officials and Vaisala, a company that offers off the shelf ITS installations.

**Figure 9:** Idaho’s mobility rating after adopting a data-driven decision-making model. (Jensen, 2016)
4.2.1 Swarm the Storm

We interviewed Dennis Jensen from the Idaho Transportation Department (ITD), along with Tim Brown of the NMDOT, to learn more about Idaho’s “Swarm the Storm” strategy for winter road maintenance. The ITD pre-treat roads and have plows travel in groups to increase efficiency. They also make heavy use of AVL and weather modeling to observe the results of their strategies and make adjustments after each storm. Further, the interview revealed insights into how the road workers had adjusted to the use of data driven decisions. The employees were initially reluctant to adopt the new systems, but as the department entered their fifth season using the new technology, they saw strong improvements due to new training programs. Swarm the Storm has resulted in approximately a 30% reduction in winter weather related traffic incidents and about a 50% reduction in winter weather related traffic fatalities (Jensen, 2016). Safety improvements that result in a 10% reduction in fatalities are considered a success, so these statistics show a remarkable improvement.

4.2.2 Vaisala, ITS Vendor

Vaisala sells RWIS products that gather, analyze, and disseminate weather information including precipitation, wind speed and direction, ambient temperature, humidity,
barometric pressure, and road temperature.

Many DOTs are using RWISs to obtain real time information about the weather in areas of interest. Not only does this information help the DOT operate more efficiently, but states with a robust network of ITS see a decrease in winter weather related accidents (DeVries & Murillo, 2016).

### 4.3 District 5 Could Benefit from Additional Cameras and Message Signs

Aside from the safety improvements ITS has provided in other states, New Mexico specifically could also benefit from increased adoption of ITS technologies for winter road maintenance. In interviews with Tim Brown of the NMDOT, he explained that since New Mexico is a state with mostly warm weather, winter maintenance related issues are a weak point for the DOT. Cameras and RWIS stations would bolster the winter maintenance system currently in place.

### 4.4 Other States Already Publish ITS Data Online

We researched the usage of ITS by other states to determine what constitutes the state of the art systems. We discovered that many other states publicize data collected by ITS devices. Examples of such systems can be found in Section 2.1.2.

In Utah, the Utah Department of Transportation (UDOT) offers a public service that tracks plows and winter maintenance through the UDOT mobile app. When we were in the field, we used this app during a snow storm and planned our travel according to where the plows had already been. This data, provided by ITS, helped us be more safe on the roads during winter weather.

### 4.5 AVL Systems are Readily Accessible

During our research, we discovered a number of vendors for ITS, such as Vaisala. Vaisala offers ready-to-install AVL sensor packages from Cirrus Navigation, which not only track the location of the plow but also gather other information such as temperature, road condition, and if the plow is engaged. According to Tim Brown of the NMDOT, the Federal Government has many programs available for states that want to purchase ITS devices for safety purposes.
5 Recommendations and Outcomes

We recommend that the NMDOT adopt an AVL system for plow tracking, install cameras at the locations we found, and apply similar systematic criteria for identifying locations to add new dynamic message signs and RWIS stations. This section describes these recommendations to improve the winter maintenance infrastructure in New Mexico, and the associated outcomes of the project, which are:

- The ITS device location plan
- A description of the AVL prototype
- Descriptions of future work

Figure 11: A CCTV camera
5.1 ITS Device Location Plan

We identified eight locations in District 5 that could benefit from an additional CCTV camera. The criteria for these locations is outlined in section 3.4.1 of our methodology. All locations are within the Department of Transportation’s District 5. Our process for choosing device locations also serves as an example that could be implemented in other districts and can be easily expanded.

5.1.1 Map of All Proposed Locations
5.1.2 Individual Proposed Locations

CCTV 1
Location: 36.779912°N 108.694335°W
Route: US 491 Northbound
Mile: 22
Notes: Power nearby, communications likely available

CCTV 2
Location: 36.334296°N 108.711971°W
Route: US 491 Northbound
Mile: 60.3
Notes: Power nearby, check for communications

CCTV 3
Location: 36.729170°N 107.793031°W
Route: US 64 Eastbound
Mile: 75.7
Notes: Power nearby, check for communications
CCTV 4
**Location:** 36.691097° N 106.558197° W
**Route:** US 84 Northbound
**Mile:** 175
**Notes:** Power nearby, check for communications

CCTV 5
**Location:** 34.657072° N 105.483273° W
**Route:** US 60 Southbound
**Mile:** 252.5
**Notes:** Power nearby, check for communications

CCTV 6
**Location:** 34.564834° N 106.134708° W
**Route:** US 60 Southbound
**Mile:** 211.5
**Notes:** Power nearby, check for communications
CCTV 7
Location: 35.770424°N 105.943915°W
Route: US 84 Southbound
Mile: 170.6
Notes: Power nearby, check for communications

CCTV 8
Location: 35.395962°N 106.160156°W
Route: US 14 Southbound
Mile: 27.8
Notes: Power nearby, near a small town, communications likely available
5.2 NMPlows: A Prototype AVL System

Imagine... Samantha wakes up to the blaring of her alarm clock. After groggily looking over and determining that it was, in fact, time to get up for work, she reluctantly gets up and turns on the coffee maker. With a yawn and a stretch, she looks over at the kitchen window. The whiteness of the snow outside is a shock to her freshly awakened eyes, but it is no surprise that there was more snow overnight. It has been snowing on and off for days now, with a few work cancellations that were well spent in front of Netflix with a tub of Chunky Monkey. Realizing that today could turn into another Unbreakable Kimmy Schmidt marathon, Samantha excitedly runs over to her computer. As she types the URL nmroads.com into the address bar and waits the seconds it takes for the page to load, she quivers with anticipation. She zooms in onto her route to work, and sees a plow just finishing up the roads that connect her home to her place of business. The lines meaning a plow has been there form a clear path to work. With a loud groan, Samantha slams her laptop closed and mopes over to the shower. “I wish I wasn’t so well informed about winter maintenance in District 5!”, she yells to no one in particular.

To help NMDOT bring this hypothetical tool closer to reality, we implemented a prototype AVL system for tracking snow plows. We recommend that the department adopt an AVL system which may or may not be directly based on our implementation. We intend that the prototype and the explanation of its design will start a discussion about adopting this type of technology in New Mexico winter road maintenance.

5.2.1 Modeling a Simple and Inexpensive System

While there are commercial off-the-shelf AVL systems available from companies like Cirrus Navigation, we designed the prototype to demonstrate the technology as cheaply as possible to incite a discussion about the use of AVL in New Mexico. The design featured three major components:

- The **Android app** representing in-plow hardware
- The **cloud-based database** to store data
- The **front-end website** to display the data

The Android app gathers data, which is sent to a database in the cloud, and then pushed to a website that displays it in real-time. (Figure 12).
5.2.2 Design Explanation

**In-plow Hardware** The plow contains an Android phone mounted somewhere in the cab. The app has a switch to turn the tracking on or off. The app, (Figure 14), sends all of the data it collects through a cellular connection to our database. This information includes latitude, longitude, speed, and bearing. Every time the app sends information to the database, it sends all of the recent locations of the plow. If cellular service is not available, the app will intelligently cache data on the phone and transmit it when the cellular service returns.

**Back-end Database** The data sent from the Android device is stored in our online cloud database. Once a user makes a connection to the database using the front-end web application, the database pushes new information to the user in real time.

**Front-end Website View** The front end consists of a website that shows a map produced using the Esri mapping software. The website connects to our database, and gets information about each plow. It then draws a plow icon for each active plow on the map, and a line showing where the plow has been recently, so users can make an informed decision about whether a road is safe to travel on. Clicking a plow reveals...
additional information, including its latitude, longitude, speed, and bearing, as shown in Figure 13.

![Figure 13: NMPlows front-end user interface](image)

5.2.3 Using the Prototype as a Tool for Research

The prototype served a second purpose by starting a discussion about the viability of such a system in New Mexico. NMPlows became a part of our discussions with stakeholders, as well as clear and defined model to reference when comparing systems in place in other states.
5.2.4 Further Implementation

From here, the main expansion that could be made to this system is to integrate into NMRoads. If our plow data was available in the system that is already in place to inform New Mexico drivers about road information, it would reach many more people. Also, since our front-end application already uses the Esri mapping software, Real Time Solutions, the company that develops NMRoads, can easily plug it into NMRoads. Both NMRoads and our AVL prototype have been designed with service-oriented architectures in mind. This means that instead of having to completely rebuild the NMRoads application, we provide a service that the engineers of the NMRoads can easily connect with. The implications of this prototype show that a possible solution could reflect this design, remain very cost effective, versatile and simple to use for all end users.

While designing the prototype, there were a number of ideas that did not make it into the final design. They could potentially be included in the deployed version of the AVL system. They include:

- Detecting if the plow is up or down and turning on and off automatically
- Showing photographs of the road near where the plow is driving
- Snapping the plows location to the nearest road

5.2.5 Deploying the AVL System to Snow Plows

To begin making plow data publicly available, the DOT should begin adding AVL devices to snow plows and training plow drivers on their operation. The device used could either be based on our prototype, or the DOT could purchase an off-the-shelf solution. If they choose to use the prototype, the front-end is designed to be easy to integrate with NMRoads.

In order for a plow tracking system to be successfully implemented in New Mexico, the ITS bureau must educate plow drivers about how to use the devices added to their snow plows. This includes teaching them how to turn on and off the tracking. Other DOT staff should also be trained to understand the data, and to use it as part of the winter maintenance decision making process.

5.3 Future Work

During our work, we discovered several promising new avenues of ITS research and development that could greatly benefit the winter maintenance infrastructure of New
Mexico. Not all of these leads were actively pursued as part of this project, however information about how to proceed is compiled here.

5.3.1 Follow-up with District 5 Employees

We planned to interview plow workers in District 5 in order to get their feedback on our prototype AVL device, as well as to gain insight from their practical experience that could be useful for constructing the ITS device plan. These interviews were not included as a part of this project because of logistical issues. However, another group could still make use of the interview plan to perform these interviews, and enhance the ITS device plan. The interview plan is as follows:

**Background Questions**

- Are you familiar with Intelligent Transportation Systems?
• Do you think Intelligent Transportation Systems could be effectively used in New Mexico?
• Based on your knowledge of the Department of Transportation’s infrastructure, what is your impression of said infrastructure?
• What is your impression of the Department of Transportation’s handling of roads in inclement weather?

Discussion of Solutions
• If NMDOT maintained a web application that provided real time data about road conditions and the locations of snow plows would you use it?
• Beyond the real time road conditions, what additional features would you like to see in such an application?
• Is there any additional information that you believe NMDOT should publicize, that would allow you to better plan for inclement weather events?

Discussion of Prototypes These questions are intended to serve as follow up after either a demonstration or discussion of a prototype AVL system.
• Did you have any difficulty understanding how to use the prototype?
• Does the prototype contain information that you find useful to you?
• Would you be likely to use a finished product with similar features and an interface to the prototype?
• Are their additional features that would make the prototype easier to use or more useful?

Discussion of Potential Worker Reservations
• Do you hold any reservation to having a GPS device mounted in your vehicle?
• Do you hold any reservation to having this GPS data made available to NMDOT officials?
• Would you object to having this GPS data made publicly available?
5.3.2 DMS Location Plan

We had initially planned to include recommendations for locations to deploy dynamic message signs in the ITS device location plan. Like the cameras, DMS recommendations are focused on providing information to help drivers respond to winter weather. Information about which roads are commonly closed is central to our criteria for placing dynamic message signs. The NMDOT ITS bureau tracks this information, however it is currently disorganized and difficult to access. In order to advance this aspect of the project, we recommend that a future group organizes this data, and uses it to apply the following criteria.

- The location must be within a reasonable distance from a decision point.
- The location must allow the DMS to be visible from a long enough distance away the drivers have time to read it.
- The location must be on flat ground, so that the vehicles used by technicians to reach the signs can anchor safely.

5.3.3 RWIS Location Plan

The NMDOT is also planning to implement RWIS stations as part of their ITS infrastructure. Based on our interview with Vaisala, we learned that RWIS devices are arranged very scientifically based on thermal measurements of streets, and environmental modeling. We recommend that another group collaborate with Vaisala or another such ITS vendor to perform these measurements, and develop a comprehensive plan to deploy RWIS stations in New Mexico.
References


Brown, T. (2016, February 3). *Interview with Tim Brown of the NMDOT* [Interview].


DeVries, M., & Murillo, B. (2016, March 30). *Interview with Vaisala* [Interview].


Jensen, D. (2016, April 12). *Interview with Dennis Jensen of the ITD* [Interview].


Appendices

A Santa Fe Climate

A lot of the work for this project relates to that of the winter road maintenance, and to further an understanding of the needs, it is appropriate to assess the average climate, including average temperature, overall average snowfall, and average snowfall by month. That said, Santa Fe is at an elevation of about 7,000 feet above sea level, so snowfall is likely during the winter (santafe.org, n.d.).

![Climate Santa Fe](image)

**Figure 15**: Average temperatures and precipitation by month in Santa Fe
A.1 Average Temperature in Santa Fe

The climate in Santa Fe is one that varies somewhat drastically throughout the year. In the winter months of December through February, the average high temperature is 45 °F. Then during the summer months the average highs are in the high 80’s (U.S. Climate Data, n.d.).

A.2 Average Snowfall in Santa Fe

In Santa Fe, the average annual snowfall is 22 inches (U.S. Climate Data, n.d.). This could make for a lot of work for the NMDOT maintenance crews. That said the average snowfall is spread over a period from October to March, and the highest average snowfall in a month is December with 8 inches (U.S. Climate Data, n.d.). So, in accordance with average snowfall data, the winter patrol yard crews are most likely to be busy during December.

B Maintenance Materials

New Mexico Department of Transportation winter guidelines outline the use of 4 main types of winter maintenance materials.

Chemical De-icers and Anti-icers They can be liquid or granular. They are used to prevent or break the bond of ice and snow to the road surface. These chemicals work similar to salt and typically work after salt becomes ineffective but not beyond 0° Fahrenheit. Additionally, chemicals can be used as a pre-wetting agent. Pre-wetting is the process of spraying deicing salt mix with a solution of liquid chemical before spreading the salt on the roadway. (New Mexico Highway Operations Division, 2014)

Salt Salt can help keep the roads clear of ice and snow by depressing the freezing point of water. Meaning that if salt is dispersed onto a road way, it will melt ice, and may prevent it from forming, depending on the air temperature. (New Mexico Highway Operations Division, 2014)

Salt Brine Salt brine is a solution of salt and water. The NMDOT mixes uses a 23% salt concentration. It is an effective tool until the temperature drops below 20° Fahrenheit. Salt bring can also be used as a pre-wetting agent which is useful as it can actually, help
to increase the effectiveness of using salt, such that the salt will then be less likely to be swept away by traffic. (New Mexico Highway Operations Division, 2014)

**Abrasives**  Abrasives often consist of cinder and sand among other materials. The main goal of abrasives are to provide traction to all traffic on the roads and are often used in conjunction with other materials such as sand or the chemical de-icers.

### C Road Priority

Each route is classified by traffic volumes and a statistic calculated to be the ”average daily traffic” and other factors. (New Mexico Highway Operations Division, 2014)

According to the guidebook, there are five route priorities. The NMDOT Winter Maintenance guide defines the route priorities as follows:

<table>
<thead>
<tr>
<th>Priority</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Routes are normally interstate and other designated high volume routes. The goal here is to provide a pavement surface that is generally free of as much ice and snow as possible.</td>
</tr>
<tr>
<td>2</td>
<td>Routes are normally roads with a moderate average daily traffic. The goal for these routes is to provide a pavement surface with one lane in each direction as free of ice and snow as possible.</td>
</tr>
<tr>
<td>3</td>
<td>Routes are normally roads with low average daily traffic. The goal for these routes is to provide a pavement service that is passable, but may still be covered in snow.</td>
</tr>
<tr>
<td>4</td>
<td>Routes are normally roads with very low average daily traffic. These are will receive maintence during normal working hours, and are patrolled as soon as possible to ensure that no one is trapped or stranded.</td>
</tr>
<tr>
<td>5</td>
<td>Routes may be closed during the winter, and are patrolled periodically.</td>
</tr>
</tbody>
</table>

### D Storm Classifications

The guide book outlines different classifications for storms, which outline the expected level of servicing and is effected by the road’s priority as well. The guidebook defines the classes as follows:
<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None or minor effect; no precipitation or too little or light for problems.</td>
</tr>
<tr>
<td>2</td>
<td>Light or localized effect; weather event which creates problems in small areas of short duration.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate or significant effect; covers most of area, moderate intensity, to 12 hours duration.</td>
</tr>
<tr>
<td>4</td>
<td>Heavy or major effect; covers most of area, heavy over 12 hours, blowing and drifting.</td>
</tr>
<tr>
<td>5</td>
<td>Severe effect; blizzard or ice storm, over 24 hours.</td>
</tr>
</tbody>
</table>