PILOT TEST OF AUTOMATIC VEHICLE LOCATION ON SNOW PLOWS

Technical Memorandum 2: Pre-Pilot Test Results

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GLOSSARY OF ABBREVIATIONS

AVL	Automatic Vehicle Location
CDPD	Cellular Digital Packet Data
DEQ	Department of Environmental Quality
DGPS	Differential Global Positioning System
GIS	Geographic Information System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile
MDT	Montana Department of Transportation
MMS	Maintenance Management System
NOVA	Northern Virginia
RVL	Remote Vehicle Location
SEMSIM	Southeast Michigan Snow and Ice Management

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EXECUTIVE SUMMARY

This memorandum summarizes the findings regarding the performance of AVL in pre-pilot tests on vehicles engaged in weed spraying and snowplow operations. AVL units were applied to weed spraying equipment in Bozeman and snowplows in Helena and Boulder. In addition, Remote Vehicle Location (RVL) units were installed on snowplows stationed at MacDonald Pass and Butte; however, limited use of these systems did not allow for a detailed evaluation to be made as part of this work. To determine how AVL performed during the pre-pilot tests, researchers at the Western Transportation Institute (WTI) solicited feedback from those who worked directly with the systems, namely maintenance superintendents/managers and vehicle operators, through personal interviews. This provided an overview of the issues that must be addressed and upgrades that might be desired in order to ensure a successful deployment on a broader vehicle fleet.

Results of the AVL weed sprayer application were mixed. The system was set up to record vehicle location, speed (via GPS) and application rates (these rates being manually entered by the operator). It did not send data back to a central location in real time, which prevented an assessment of the effectiveness of such transmission in a weed spraying application. Data were downloaded via a memory stick at the end of the day but could not be easily examined, as no viewing software had been provided with the system.

Limited guidance was provided to the operators concerning the use of the system, so much of its use was “self taught” by the operators themselves. The application of the system to the vehicle was presented to operators at the onset as something which was being used to enhance safety and efficiency, not to monitor their activities. This resulted in operator buy-in and acceptance. The operators’ general consensus was that this system would have usefulness in the broader MDT fleet for tort claims and reducing or streamlining paperwork; however, a cautious approach to applying it should be taken.

From a management standpoint, AVL on weed sprayers was viewed as a system that would assist in record keeping and improve programming activities. The system has the potential to save time and money in terms of identifying instances of overapplication, addressing tort claims, and streamlining and eliminating errors in paperwork. Managers did not view the provision of AVL data in real time or improved communications as essential enhancements. Improved communications would only make sense in a weed spraying application if the infrastructure were in place for other applications and its use deemed cost effective.

The AVL systems on snowplows experienced some problems in terms of communications, primarily loss of cellular coverage in isolated areas. The system did continue to record data in chronological order when cellular communications were lost. The use of real time data in managing storm activities was not pursued; rather, the data were examined mainly to verify that the AVL system was actually working and sending in acceptable location data. To this end, the data did appear to be accurate. Interviewed personnel acknowledged that the data being received would have both real time and historical usefulness if or when AVL is deployed to a broader fleet. The critical element to the success of the system when applied to snowplows was viewed to be integration with as many sensors as possible. This would provide a full picture of the plowing operation, subsequently allowing for inefficiencies to be identified and corrected. It would also allow managers to develop alternative treatment strategies, which could be employed and analyzed.

From an operator perspective, AVL was viewed to be a useful technology to include on plows. One view commonly expressed was that much of the data it could provide (when integrated with sensors) could be used to automatically update dispatchers, storm managers and RWIS systems, rather than relying on radio communications. Overall, the view of operators was that AVL was a system which should be applied to a broader fleet of MDT vehicles based on their experiences using the system.

The view of managers overseeing the snow plow AVL systems was that it has the potential for quantifying and documenting the potential savings from different treatment alternatives, as well as determining what the most effective maintenance strategies are. In addition, AVL could reduce operator workload and tort claims. Finally, AVL was viewed to be a tool which could improve operator safety by identifying vehicles which had not moved for extended periods of time or which could not be contacted via radio.

Should the pilot test proceed, a number of recommendations should be taken into consideration based on the feedback provided by operators and managers. A systems engineering approach should be utilized to ensure a successful planning, design and deployment of a wider scale AVL system. User buy-in, both at the operator and management level, will be critical for ensuring the successful acceptance and utilization of the AVL system starting at deployment. Software issues must be addressed both in terms of the level of detail available to users, as well as functionality. Interchangeability of AVL units between vehicles remains to be examined; this is an area that could provide significant cost savings to MDT should it be proven feasible.

Consideration should be made towards conformity between the AVL system architecture and the architectures of other complementary ITS elements throughout the state. AVL systems should also be taken into consideration when future vehicle procurements are being considered. Such procurements should specify vehicles be equipped with sensors that are compatible with a number of different AVL makes/models.

Institutional issues remain to be addressed for subsequent pilot testing. Namely, issues such as the specification of what data will be collected by the AVL, who will use that data and when, as well as how the data will be used both in a real time and archived manner. Similarly, training issues must be addressed with operators, dispatchers, management and whoever else will be working in some way with the AVL units and/or data. This training does not need to be extensive; rather, it should familiarize users with the systems and software associated with AVL.

Finally, any pilot test pursued by MDT in the future should track and quantify the benefits and costs associated with the AVL system in terms of dollars. This will allow for a determination of the effectiveness of the system in meeting MDT goals, objectives and expectations. It would also provide a means by which benefits and costs for the system could be extrapolated on a statewide basis. The tracking of the financial aspects of AVL would also allow for a benefit-cost analysis to be made. Such an analysis would provide a solid justification for MDT regarding whether a statewide deployment should be pursued or not.

1. INTRODUCTION

To preserve mobility for motorists, many transportation agencies spend a significant amount of resources on winter maintenance operations. These operations are critical for protecting traveler safety and ensuring efficient flow of people and goods in and through the state. As noted by one author, however, winter maintenance operations are continually being challenged toward "simultaneously increasing productivity, quality, and environmental sensitivity while maintaining a constant or improved level of service on roads." (1) In addition, improvements in traveler information through 511 and the Internet in recent years have enhanced public expectations on the quality, accuracy and timeliness of information.

Into this environment, automatic vehicle location (AVL) has emerged as a technology with significant promise for meeting the previously cited challenges. Already in widespread use in the transit, trucking and emergency response communities, AVL has been recently been applied to winter maintenance applications, with such goals as improving agency efficiency and enhancing traveler information.

1.1 MDT Interest

The Montana Department of Transportation's (MDT) Maintenance Division has expressed interest in adopting AVL on a statewide basis. Recognizing that other states and agencies have used AVL for similar applications, MDT was interested in proceeding with implementation by learning from the experience of other agencies. A previous Technical Memorandum, "Recommendations for Pilot Test", served as a guide for MDT in this regard (2). The document provided an overview of AVL systems, reviewed various applications of the technology by other agencies, established MDT's needs with respect to AVL systems and provided recommendations for pre-pilot and pilot tests.

To fully understand the costs, benefits, challenges and issues which would result from the use of a new technology, pre-pilot and pilot tests on a small scale are necessary to demonstrate whether AVL would work satisfactorily. Pre-pilot tests are those which involve a small-scale application of AVL to a limited number of vehicles in specific MDT sections. The pilot test, which will occur in the future, will involve application of AVL to a majority of vehicles in a section. If successful, AVL could then be expanded statewide as funding and technology allows.

1.2 Overview of Report

The purpose of this memorandum is to summarize the findings made with respect to the performance of AVL in pre-pilot tests. These tests involved the application of AVL systems to vehicles engaged in weed spraying and snowplow operations. The results of these small-scale AVL applications are intended to serve as a guide for MDT in the implementation of the pilot test. To this end, feedback was obtained from those who worked directly with the systems, namely maintenance superintendents/managers and vehicle operators. The feedback obtained provides an overview of the issues which must be addressed and upgrades which might be desired in order to ensure a successful deployment on a broader vehicle fleet.

The organization of this technical memorandum is as follows: Chapter 2 provides background on AVL, the architecture of such systems, and previous use of AVL in supporting winter maintenance operations. Chapter 3 provides a technical background on the specific AVL systems selected for the pre-pilot test, as well as a brief review of their features. Chapter 4 is an overview of the evaluation plan used to assess the performance of the AVL during testing. Chapter 5 summarizes the evaluation results for AVL units applied to both weed spraying equipment (Bozeman) and snowplows (Helena and Boulder). In addition, this chapter will present a brief overview and findings related to Remote Vehicle Location (RVL) units which have been installed on snowplows stationed at MacDonald Pass and Butte. Finally, Chapter 6 presents conclusions and recommendations for the pilot test based on the results of the evaluation presented in Chapter 5.

2. BACKGROUND

This chapter provides background on automatic vehicle location (AVL) as a technology. It will briefly describe how the system works, how it is represented in the National ITS Architecture and provide examples of applications. Case studies regarding transportation agency experience with using AVL in winter maintenance applications are also reviewed.

2.1 Definition of AVL

Automatic vehicle location (AVL) is a computer-based system that collects and transmits information on a vehicle's actual location and other characteristics. The location may be determined through several means, but is generally determined through the use of global positioning systems (GPS), which can provide accuracy of ± 3-5 meters. GPS technology uses signals transmitted from a network of satellites orbiting the earth and received by a GPS antenna placed on the roof of each vehicle. A GPS receiver calculates the vehicle position by measuring the travel time of radio signals from at least three satellites (3). AVL uses location information, communication technologies, geographic information system (GIS) technologies, route planning technologies, and the Internet to allow real-time tracking of vehicles from a computer with access to the World Wide Web. The process consists of a vehicle calculating its position from data transmitted by satellites. These data, along with other data from the vehicle, are transmitted to a computer via radio, cellular communications, or satellite uplink. The computer then takes the information to plot a symbol on a map which is made available on a web site.

AVL meets the need for data communication between a center and maintenance vehicles in the field, particularly with respect to the location of a vehicle. Traditionally, this communication has occurred via radio, requiring significant manual efforts, while also being quite time-consuming. One potential for AVL is to streamline this cumbersome communications process through automation. To this end, a number of agencies (state, municipal) have deployed the technology in pilot projects using AVL for winter maintenance. These will be reviewed in subsequent sections of this chapter.

2.2 System Architecture

In the National ITS Architecture, the basic AVL functionality is represented by the Vehicle Location Determination equipment package. Under this equipment package, technology inside the vehicle receives information regarding its absolute or relative location. This location information is then transmitted from the vehicle to a dispatch center. The basic data transmission consists of a timestamp, which is associated with a specific location as identified through GPS. This transmission may be supplemented with other data, depending upon the application.

Figure 2-1 shows how the National ITS Architecture represents an example AVL application, in this case tracking of emergency vehicle location. The Location Data Source would represent a determination of the vehicle's location (i.e. through GPS). The vehicle's location would be contained in a vehicle-based system. The vehicle would send this information to a dispatch center on a real-time basis; the dispatch center would respond with information on suggested routing. Communication between vehicles and dispatch centers has previously occurred without

AVL technology through the use of voice (radio) communications. Once a channel has been opened for real-time data communications between the vehicle and the dispatch center, additional data may be added as well, within the limitations of communications bandwidth and coverage.

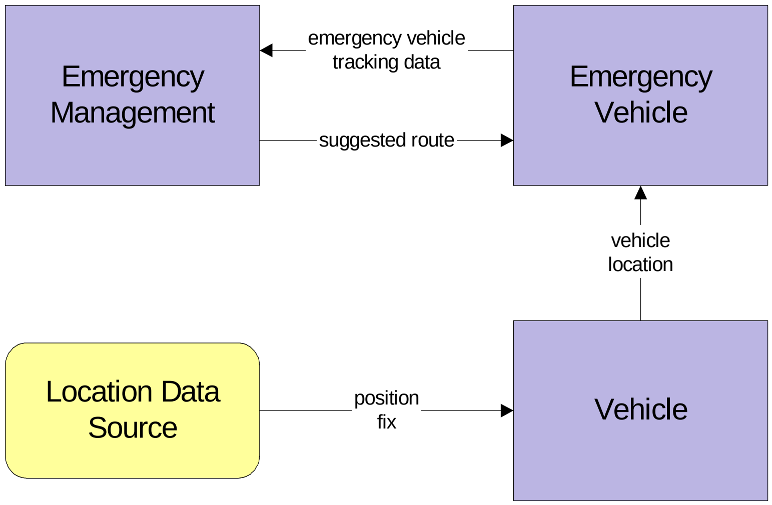

Figure 2-1: Example AVL Schematic from National ITS Architecture

Once the information is received at a dispatch center or central location, it can be parsed and used in a variety of ways. For example, data may be passively displayed on a Web page to allow travelers to view the progress and activity of vehicles. Data may be archived and stored for monitoring and management purposes to assist in analysis of events.

Vehicle location capabilities are included in the National ITS Architecture for commercial vehicle, emergency response, transit and maintenance applications. The market packages and equipment packages in the National ITS Architecture that include AVL are shown in Table 2-1.

Table 2-1: Vehicle Location in National ITS Architecture

Application Area	Market Package	Equipment Package
Commercial Vehicles	• Fleet Administration • HAZMAT Management	• On-Board Cargo Monitoring • On-Board Trip Monitoring • Vehicle Location Determination
Emergency Response	• Autonomous Route Guidance • Emergency Routing • Roadway Service Patrols	• On-Board Emergency Vehicle En Route Support • Vehicle Location Determination
Transit	• Autonomous Route Guidance • Transit Vehicle Tracking	• On-Board Transit Trip Monitoring • Vehicle Location Determination
Maintenance and Construction	• Maintenance and Construction Vehicle (MCV) and Equipment Tracking • Roadway Maintenance and Construction • Winter Maintenance	• MCV Roadway Maintenance and Construction • MCV Vehicle Location Tracking • MCV Winter Maintenance • Vehicle Location Determination

2.3 Example Applications

Public transit has been one major application area of AVL technology, where it has been used for monitoring of location of transit vehicles to improve vehicle routing, assist in transit security, and provide real-time traveler information. A review of national ITS deployment experience published in 2001 judged the use of AVL in public transit to be "successful" (3). According to recent statistics from 2006, 58 metropolitan area transit agencies have deployed AVL on their fixed-route buses, with over 26,000 vehicles using the technology (4). As an example of the types of benefits transit agencies may receive through AVL, the Denver Regional Transportation District (RTD) decreased the number of early-arriving vehicles by 12 percent over a five-year period, and decreased the number of passengers per vehicle who arrived at their stops late by 21 percent. The number of passenger assaults per 100,000 passengers decreased by 33 percent in the same period (5).

The emergency response community has found benefits in having AVL capabilities on their vehicles, as it can allow dispatchers to locate the closest available unit to respond to a call, evaluate the efficiency of various emergency routes, and adjust route decisions based on traffic (6). Recent national statistics show 72 agencies in 41 metropolitan areas having deployed AVL on over 2,800 fire and rescue vehicles, while 105 agencies in 59 metropolitan areas have deployed AVL on over 11,000 law enforcement vehicles (4).

Commercial vehicle fleets have also been major users of AVL, to provide real-time shipment tracking and routing for carriers operating over longer distances (7).

2.4 Experience with AVL in Winter Maintenance

According to the 2006 Intelligent Transportation Systems (ITS) deployment survey, twelve states (excluding Montana) reported using or pilot testing AVL for winter maintenance operations: Alaska, California, Colorado, Kentucky, Iowa, Michigan, Minnesota, North Dakota, Oregon, South Dakota, Washington and Wisconsin (8). Other transportation agencies have adopted pilot projects with AVL in winter maintenance: McHenry County (Illinois); and the cities of Columbus, Ohio and West Des Moines, Iowa. This suggests that AVL is gaining national acceptance as an important tool in improving winter maintenance operations. However, documented results of evaluations of AVL deployments are somewhat limited, and they offer a mixed picture, as the following sections illustrate.

2.4.1 Northern Virginia (9, 10)

A pilot AVL program was initiated in the Virginia Department of Transportation's Northern Virginia (NOVA) District in 1996. AVL was tested for three consecutive winters, from 1997-98 to 1999-2000, on 80 trucks to help manage operations and communications during storm events, when the NOVA District relies heavily on contractor support. Because of its early deployment, the system relied on components such as Differential GPS (DGPS), cellular digital packet data (CDPD) transmission, and three networked desktop computers, which have been superseded in more recent deployments. An in-vehicle unit recorded binary information on the plow position, chemical spreader and vehicle engine at two-second intervals, and transmitted it every ten seconds. It supported customized messaging from the base station to the vehicle operator, and 30 pre-written messages that the operator could send to the base station. Maps were displayed on vendor-provided software that could be updated at varying scales and showed real-time displays of vehicle location, route traces, and color-coding based on vehicle activity.

While the pilot test performed reasonably well in mapping vehicle location, it revealed several areas for potential improvement. Short update speeds provided more information than could be processed by dispatchers and resulted in significant delays in receiving information. The color-coded maps and the specification for lane-specific DGPS precision were also more information than was required. The use of temporary installations of the in-vehicle units resulted in a higher-than-expected failure rate. Moreover, milder-than-normal winters were experienced through the duration of the pilot test. The pilot test was terminated in 2000 due to sensor failures, obsolescence of the in-vehicle units, and cost.

NOVA District resuscitated AVL in 2003 using GPS cell phones in conjunction with an Internet map and reporting system. The customized system was far less expensive than the earlier system, and maintenance managers were pleased with its performance. However, no benefit-cost information is available.

2.4.2 Aurora, Colorado (11, 12)

The City of Aurora started implementation of AVL on 20 snowplows in 1998. The system collected vehicle position information every two seconds, and transmitted this information to a base computer every 20 seconds. Aurora's experience is somewhat unusual in that they have successfully migrated between vendors and communications systems since the project's inception. The system originally used CDPD for communications, but later switched to General Packet Radio Service (GPRS) Global System for Mobile (GSM) communications, because CDPD was to be deactivated. The city switched vendors because the original in-vehicle unit was no longer being supported, and the city desired greater functionality.

City officials estimate that the tracking capabilities afforded by their AVL system have reduced treatment costs by 15 percent and improved productivity by 12 percent. The system has also given maintenance managers better ability to answer citizen queries on when a specific street will be plowed.

2.4.3 Wayne County, Michigan (13, 14)

In 1997, Wayne County, where Detroit is located, recognized the difficulty in supervising and managing snow clearance operations, which could involve 160 trucks on 130 routes at any given time. There was a desire to improve coordination of trucks based on the dispatcher having a clearer understanding of how current road clearing operations were progressing. A public-private partnership was formed to install AVL in one Wayne County district, provide the district with intelligent routing software, and determine the efficiency increase that resulted from the dispatcher having a color-coded map that indicated what portion of the district's roads were salted or plowed. The in-vehicle unit collected information on plow position, amount of salt being dispersed, and vehicle location every three seconds, and an assessment of snow conditions every three to five minutes. The system used CDPD to transmit information.

The primary benefit of this project is that it spawned interest in SEMSIM (see next section), which included Wayne County. The study found that there was a 3-4 percent reduction in "deadhead" miles (i.e. the distance where the vehicle is not actively treating the road) on freeway routes, with more improvement expected on non-freeway primary roads. The study also reported reduced salt consumption, reduced operational costs for snow removal, quicker response time, and reduced fatigue for dispatchers and drivers during peak operations.

2.4.4 Southeast Michigan Snow and Ice Management System (SEMSIM) (9)

The SEMSIM project was initiated in the spring of 1999, and an evaluation report was completed after the 2003-04 winter. SEMSIM's total cost, through September 2004, was nearly $8.2 million, which was required to equip nearly 400 vehicles with sensors and communications infrastructure. Three types of sensors are used: spread rate, blade position and temperature. The system cost included design, development, and installation of the equipment onto the vehicles. The scale of this project is significant not only for the number of equipped vehicles, but also because it integrates four transportation agencies.

Several improvements were made to the system during the course of the project, based on interim evaluations. These improvements included migrating the center software application to a Web-based application, adopting a mercury switch to detect plow position, upgrades in the in-vehicle unit, and modifications to the cabling and connections to improve environmental durability. The SEMSIM evaluation considered it early to expect observable cost benefits from the system, but maintenance supervisors were optimistic that the system would improve material usage and supervisor efficiency.

2.4.5 Howard County, Maryland (15, 16)

In Howard County, Maryland, the Bureau of Highways implemented AVL on their snowplow fleet starting in 2000-2001 to track and balance progress in three operational zones. The Bureau's goals included being able to send a replacement truck to a specific area when a truck breaks down, manage the maintenance of the roadways based on the time since the road was last maintained, and increase public trust through improved service. Howard County estimated they could recover the costs of the system in less than three years if it helped them reduce the number of trucks required by one.

The Bureau of Highways considered the AVL system to be a success. The county had several snow events over the winter that allowed the Bureau to track its snowplow operations. Managers were able to watch the location of plows and plowed routes from their office in real-time, allowing them to send plows to areas with greater snowfall and re-deploy snowplows if one became unusable. Call volume was decreased to the Bureau concerning road conditions due to real-time information that was made available to the public through a Web site. Another benefit was the ability of the 911 dispatchers to route emergency vehicles based on the information provided by the Web site. If there wasn't a cleared route to the location of an emergency, the dispatcher could request that the nearest plow on the map be sent to clear a path for the emergency vehicle. It was not known, however, whether the Bureau was able to recoup the costs as they had expected.

2.4.6 Vaughan, Ontario (17)

AVL was implemented in Vaughan's winter maintenance operations in 2001-2002 due to population growth and increasing complaints from residents and council members regarding the level of service on their streets. These complaints included missed streets, missed sidewalks, and poor timing of driveway clearance operations.

The installation of the system involved two power wires, two quick connectors for GPS and communications, and a magnetic mount antenna on top of the vehicle. Computerized salt spreaders were also connected to the system to relay the rate and location of salt application. Information is sent via wireless text messaging to a vendor-owned server. Equipment operations can be monitored on any computer connected to the Internet. Equipment can be tracked in real-time or past activities replayed in order to determine the location at any point in time. Vehicle summaries are also provided, including information on the amount of salt used and the distance covered by the vehicle.

The city found several benefits to this system, including accurate information on storm costs, an assessment of whether minimum maintenance standards mandated by the province and council have been met, and a reduction in paper timesheets and progress reports. Implementation of AVL resulted in a significant decrease in complaints, better coordination, better information for city council members and residents, and better management of in-house and contracted services.

2.4.7 Other Reports

The SEMSIM evaluation report included capsule evaluations of several other AVL deployments, which were based on interviews with project managers of the implementing agencies; these provide some additional documentation of other agencies' experience with AVL (9).

Iowa DOT. Iowa DOT conducted a pilot test in 1998 on a limited number of its winter maintenance vehicles. Maintenance managers were using the system primarily for archived information, not real-time applications. While users were reportedly satisfied with the system and its information, funding was not available to continue the project and so the AVL units were removed from the vehicles. DOT management speculated that the cost of AVL could be justified only based on year-round use, not just for winter maintenance.

City of Baltimore. The City of Baltimore installed AVL on its snowplow fleet in 2001. Managers report the system has been fairly reliable, but they have difficulty in compatibility between the radio system and the vendor's software. At the time of publication of the SEMSIM report, the City was looking to upgrade the entire system because the vendor no longer supported that product. They were interested in migrating AVL to non-winter applications.

City of Waukesha (Wisconsin). The City of Waukesha (Wisconsin) ran a test deployment of AVL on six vehicles starting in March 2003. The system worked well initially, but server problems resulted in significant delays in polling updates. The City removed the units in September 2003, and has no plans to expand AVL to other snowplows.

2.5 Summary

AVL integrates location information with other information from the vehicle to provide temporally and spatially referenced information on a vehicle's activities. It can assist in storm response through vehicle tracking and dispatching capabilities. It can also guide storm event planning by providing previous storm event histories. AVL can simplify tracking and reporting requirements for agencies, thus decreasing the paperwork and time required to manage winter maintenance activities.

There is a sizable body of documented experience on lessons learned and best practices for use of AVL in winter maintenance operations. Through several years of demonstration and evaluation, many of the problems which plagued earlier AVL deployments, such as sensor protection, communications availability, and GPS accuracy, have been addressed. The level of support from the vendor community has improved as AVL vendors have become flexible, adapting and customizing systems to fit specific customer requirements. AVL users generally plan to sustain or increase their use of the technology, and there are a number of transportation agencies performing AVL pilot projects to further the use of AVL in winter maintenance activities.

3. AVL CHARACTERISTICS AND SPECIFICATIONS

The following sections provide a brief overview of the specific makes and models of AVL (and RVL) equipment installed by MDT on the weed sprayer and snowplows for the pre-pilot test. When available, information specific to the installation is provided (e.g. hard drive memory). In addition, a brief narrative on how the AVL systems were set up to operate is supplied.

3.1 Weed Sprayer

MDT selected Farm Works to serve as the vendor for the AVL system installed on the Bozeman weed sprayer. The delivered system was less sophisticated technologically than that installed on the Helena and Boulder plows, as will be seen. Rather than feature extensive integration of on-board sensors, the weed sprayer AVL simply recorded positional information, as well as spraying data entered manually by an operator. The delivered Farm Works system consisted of:

- Farm Works CF GPS Receiver;
- HP iPAQ 2010 pocket PC (PDA);
- Powered iPAQ RAM-Mount (docking station).

The Farm Works GPS receiver works by simply plugging it in to the card slot on the PDA through the use of an adaptor. Once plugged in, the GPS data are recorded to the appropriate file. The system was not set up nor designed to transmit data in real time. Instead, the data were saved on the PDA and downloaded at the end of a workday, as will be detailed in Chapter 5. However, no software was provided for viewing the data recorded by the PDA, creating a problem for Bozeman users.

3.2 Snowplows

MDT selected Iwapi Inc. as the vendor for the AVL systems installed on the snowplows in Helena and Boulder. Helena was selected due to the availability of good existing wireless communications, while Boulder was selected to test the system's capability for "Store and Forward" transmission. Iwapi does not produce a catalog of AVL models; rather, such systems are built to purchaser specifications. According to the vendor, the basic AVL package can include fully programmable in-vehicle hardware, a minimum of 2 gigabytes of internal memory, PCMCIA/CF slots, various ports, a GPS puck, an optional camera, store and forward capabilities, interchangeable connection cards and software to support cellular transmission via AirCard, database setup, XML interfaces and flexible map options and access (18). Features specified by MDT for the AVL units delivered by Iwapi included:

- Appropriate AVL software and database setup
- Hardened SMD (Smart Model Device) with vehicle configuration
  - 2 gigabyte hard drive
  - 1 gigahertz processor
  - 256k of RAM
- Garmin GPS
- External antenna

- Configuration and setup with MDSS software
- 7 inch TFT-LCD Color Digital Touch Screen Monitor
- Verizon-Sierra Wireless 595 AirCard
  - Support 14.4 kilobytes per second data transfer
  - Available bandwidth of 824-849 MHz.

The systems delivered to MDT integrated a number of sensors on the Helena plow, while the Boulder plow is awaiting integration with newer controls, to be installed following the 2006-2007 season. The specific sensors integrated on the Helena plow will be expanded upon in Chapter 5. The Verizon-Sierra Wireless AirCard facilitated data transmissions made every 15 minutes, although there may have been more frequent updates occurring, as evidenced by the experience of Helena personnel.

3.3 Remote Vehicle Location

In addition to the AVL units installed on vehicles in Bozeman, Boulder and Helena, MDT has also installed Remote Vehicle Location (RVL) units on two snowplows; one stationed at MacDonald Pass and one in Butte. RVL is similar to AVL in that it tracks a vehicle's location, as well as application rates, miles traveled and plow status, among other items. Unlike AVL systems (excluding the Farm Works system previously covered), the potential to transmit these data back to a central location in real time is not available. Rather, an onboard computer records and stores the data for download at a later time/location. This download can be accomplished via a wireless bridge and access points (located, for example, at vehicle fueling pads) or via a medium such as a memory stick.

The RVL units installed by MDT were manufactured by Cirus Controls. Vehicle location information was obtained from a GPS unit which was integrated with a spreader control system. This system was set up to record not only vehicle location, but also the application rates of wet and dry materials being applied while in motion. The system was comprised of a SpreadSmart Spreader Control System and a Garmin GPS.

As stated, the system was designed such that data could be downloaded once a vehicle had arrived back at base. The SpreadSmart systems delivered to MDT were equipped with ports which allowed for the plug in of memory sticks through which data could be downloaded. As will be discussed in Chapter 5, efforts to download and examine data from these systems have been limited.

4. EVALUATION PLAN

In order to determine their applicability in statewide usage, each pre-pilot test application was evaluated. This was accomplished through interviews and surveys with MDT managers and operators, with questions designed to gain feedback on how well the system was meeting the intended goals, objectives and measures of effectiveness. A common evaluation plan was developed for each application and submitted to MDT for review and approval before implementation. Data were subsequently collected and analyzed over the duration of the pre-pilot test. Data collection for the pre-pilot evaluation of the weed sprayer application occurred in September 2006, while snowplow data were collected in March and April 2007.

For the evaluation of each application, researchers traveled to and coordinated teleconferences with the maintenance sections where the vehicles and operators were located (weed sprayer – Bozeman; snowplows – Helena, Boulder). The interviews consisted of a series of questions intended to obtain feedback with respect to the various aspects of the AVL application. These included details on the installation of the system, the extent to which it was applied to vehicles, driver involvement and perspective, the extent to which monitoring occurred, the nature of communications used by the system, the functionality of the equipment, the functionality of remote monitoring/tracking, and the project monitor's perspectives of the system. The evaluation questions posed to MDT personnel are presented in Appendix A.

Guidance for the evaluation questions were derived from the table of "Proposed Measures of Effectiveness and Data Sources for AVL Evaluation" found in Technical Memorandum 1: Recommendations for Pilot Test (2). This table is reproduced and presented here as Table 4-1. The majority of the data required for the evaluation of the pre-pilot test was collected through interviews of MDT personnel at various levels. For example, it was thought that vehicle operators could provide a ground-level assessment of whether the technology is easy-to-use or in any way interfered with maintenance operations. Section supervisors would have familiarity with maintenance challenges, as well as the potential utility of the data. Additional MDT staff would provide valuable insight regarding how well the technology could integrate into existing MDT processes and databases.

In developing the evaluation plan, it was clear that the vast majority of data would be subjective, relying on the judgments of personnel at various levels within MDT. This was appropriate for the pre-pilot test for a couple of reasons. First, a full benefit-cost scenario of AVL would be practical only when MDT personnel have developed an understanding of the potential benefits of AVL and have exhausted its capabilities; this would be unlikely to occur in a short duration pilot test. Second, the department has expressed the belief that the benefits of AVL will outweigh its costs and are planning to proceed with statewide implementation provided the pilot test is successful and funding is available. Therefore, the evaluation needs only to provide information that would help MDT to confirm that the technology is reasonably worthwhile, and to help "tweak" the system to make it better on a statewide implementation.

Table 4-1: Proposed Measures of Effectiveness and Data Sources for AVL Evaluation

Objective	Measure of Effectiveness	Data Source
Provide accurate and reliable data that can improve traveler information	The data regarding pavement conditions is accurate, timely and reliable	Interviews of MDT staff in pilot test area
	The interface for traveler information integrates with MDT's existing web page	Interviews of MDT staff in pilot test area
	The interface for traveler information is easy-to-use	Interviews of MDT staff in pilot test area
	The data regarding maintenance vehicle activity is accurate, timely and reliable	Interviews of MDT section supervisors
	Data is timestamped and stored according to MDT requirements	Interview with MDT information technology (IT) personnel
Archive data that could be used for risk management or tort liability	Data is stored in an easy-to-access format	Interview with MDT IT and/or risk management personnel
	Data has sufficient accuracy and reliability to be defensible in tort claims	Interview with MDT risk management personnel
Improve the efficiency of winter maintenance operations	The AVL system does not create a significant additional workload on vehicle operators	Surveys of vehicle operators
	Section supervisors find value in the new information available through AVL	Interviews of MDT section supervisors
	The AVL system offers opportunities to streamline data collection (e.g. pavement conditions)	Interviews of MDT section supervisors
	The AVL system offers valuable opportunities to expand data collection capabilities	Surveys of vehicle operators and interviews of MDT section supervisors
	The AVL technology is reliable and relatively maintenance-free	Surveys of vehicle operators and interviews of MDT section supervisors
	The sensors are reliable and relatively maintenance-free	Surveys of vehicle operators and interviews of MDT section supervisors
Provide a reasonable approach for statewide implementation	Communication speed is acceptable in "good" and "bad" wireless environments	Comparison of transmission and receipt timestamps Interviews of MDT section supervisors
	Vendor technical support has been acceptable.	Interviews of MDT section supervisors
	Software and database formats are compatible with other MDT applications	Interview with MDT IT personnel

5. EVALUATION RESULTS

As MDT considers the implementation of a broader pilot test of AVL, evaluation is a critical component. The intention of evaluation is to provide MDT with a means to objectively assess the extent to which the technology has been beneficial or not, in what areas the technology has or has not met expectations, and what modifications would be necessary or desirable before broader deployment. The evaluation activities of the pre-pilot test will help ensure that all data relevant to MDT in making the decision to proceed with wider AVL implementation are available. The following sections present the results of this pre-pilot evaluation of AVL.

In summarizing the results of the interviews with MDT personnel, specific responses to each question will not be provided verbatim. Rather, responses have been condensed into a format that provides an overall picture of the system and the knowledge and experiences gained from its use. In this respect, the text combines the experiences of MDT personnel from various capacities (operators, management, etc.) in order to provide the reader with a picture of how the experiences of these personnel intertwine.

5.1 Weed Sprayer Evaluation

5.1.1 Background

Weed spraying operations encompass all activities involving the application of chemicals to control or prevent the growth of vegetation, such as noxious weeds and brush (19). Among the objectives for controlling weeds are to inhibit the growth of vegetation around structures such as signs and guardrails, improve aesthetics, improve sight distance, reduce fire hazards, reduce snow drifting and help with drainage problems in areas where mowing is not practical (19). Weed spraying operations may be handled by either MDT personnel or outside contractors, depending on the nature of the work.

Weed spraying operations may take on two forms: truck spraying or hand spraying. Truck spraying is accomplished through the use of truck-mounted boom sprayers. Typically, these boom sprayers are used to control weeds that are within Zone 1, or the area that reaches out approximately 20 feet from the roadway edge. Hand spraying, as the name implies, is performed by an operator walking through an area with a spray wand, manually applying the sterilant. Such an operation is performed to control weeds which are present in Zone 2, or the area beyond the 20-foot limit of Zone 1 up to the edge of the right of way. In addition, hand spraying may be required in areas closer to the roadway that may not be adequately covered by a boom sprayer (such as hillsides).

5.1.2 Vehicle and Installation Detail

In conjunction with the AVL pre-pilot evaluation on weed sprayers, the Bozeman section took delivery of a new weed spraying truck in the spring of 2006. This truck and the AVL unit are pictured in Figures 5.1 and 5.2. This truck, a 1994 Ford Elgin, was formerly a street sweeper. During its modification to a weed sprayer, it was equipped with the AVL technology described in Chapter 3. The unit was mounted in the center of the cab, between the driver and passenger seats. A Personal Digital Assistant (PDA) to record data was mounted to a bracket which was hung from the windshield of the vehicle.

Figure 5-1: The Bozeman Weed Spraying Vehicle

Figure 5-2: Bozeman In-Vehicle AVL Equipment

As the AVL was intended for use only on the weed sprayer (the only such vehicle in the Bozeman Office's fleet), no attempts were made to move the system between vehicles. The system itself has not had any hardware or software upgrades since the truck was placed into service. The only changes to the device were those made by the operators, such as the data inputs specific to a work site (gallons per acre being used, etc.).

The vehicle was delivered with a limited number of sensors for different applications, most notably, a ground sensor for detecting vehicle speed. In speaking with the two MDT operators who worked with the vehicle, each expressed some question as to whether the information from this sensor was being recorded with the AVL data. The operators' concern stemmed from the inability to examine the data being recorded and downloaded from the PDA because of a lack of complementary software. Further investigation into the Farm Works system confirmed that the ground speed sensor was not integrated with the AVL system. Rather, the speeds being recorded by the system were derived from GPS readings. During the course of its use, no additional sensors have been added to the vehicle, so no integration issues were encountered.

5.1.3 Vehicle Usage

Once in use, the weed sprayer was used an average of six hours per day. Some days had higher usage than others, depending on the nature of that day's programmed activities. The mileage the vehicle covered per day also varied, depending on the programmed activities for the day. An example cited by an operator was that one day he or she might go two miles out of town and spend the entire day in one location hand spraying. The next day, the operator might cover fifty miles of roadside using the boom sprayer. As the vehicle is solely equipped to serve as a weed sprayer, it is limited to that duty.

It was difficult for those who worked with the weed sprayer to definitively say if use of the vehicle changed (increased, decreased or static) with the addition of the AVL, because the vehicle came equipped with the technology. As such, there is no frame of reference on the same vehicle for a before and after comparison. This stems, in part, from the fact that prior to delivery of the new vehicle, the personnel in Bozeman were equipped with older, less efficient equipment. The AVL vehicle as a whole was an upgrade and improved their productivity tenfold. However, it is difficult to establish what, if any impact the presence of the AVL itself had on vehicle usage, because the improvements present throughout the vehicle changed the way weed spraying operations were conducted. In terms of the technology influencing vehicle usage decisions, the viewpoint was that right now it's just a learning process given the newness of the system. As a result, the presence of AVL has not had an influence on how the vehicle will be used (albeit in its already one-dimensional activity).

As stated in the previous section, only a limited number of sensors were present on the vehicle, most notably, the ground speed sensor which was not integrated with the AVL, given the nature of the Farm Works system itself. As a result, no vehicle activities were automatically recorded. Rather, the operator had to manually create a job file in the PDA. Following this, they would begin recording the AVL data. If they forgot to stop or start the tracking, the data would still be recorded, regardless of activity. This did not create a problem, however. For example, if hand spraying was being performed and the operator walked in a loop to reach a remote area or avoid an obstacle, the AVL would record the vehicle making a small loop, even though it is stationary.

With respect to vehicle activities being recorded by sensors, the operators participating in the interview felt that, when combined with AVL, the vehicle could do much more if all systems on the vehicle (sensors, AVL, etc.) were integrated. One operator stated that he had overseen contractor vehicles that did not have an AVL system but did have a computer that read a number of different data elements. In a weed spraying context, this might include the fluid flow, chemical usage, and the acreages covered. On MDT's AVL weed sprayer, the operator has to program the acreages being covered into the PDA. This is in contrast to the vehicles used by some contractors, which have a computer onboard that already contains the programs and formulas. If the MDT vehicle were so equipped, the flow rate and speed could automatically be read into the computer which, if coupled with the AVL, would be able to adjust chemical usage according to vehicle speed and position.

5.1.4 Operator Involvement

As stated previously, only two drivers operated the vehicle. Each operator had extensive experience with various types of equipment and could be classified as very experienced personnel. However, their experience with the AVL equipped weed sprayer was limited to the time using the vehicle in the Bozeman office's fleet.

In terms of training with respect to the AVL technology, the operators received limited guidance when they took delivery of the vehicle in Helena. This guidance mainly pertained to starting the system. Aside from this, the operators trained themselves in the use of the AVL system. However, the system was straightforward, so an operator could learn it in about thirty minutes. The manual that came with the system was particularly useful in this aspect. Based on their usage thus far, the operators believe there is more potential to the system than is presently recognized, but the limitations of the system have also not yet been identified. This once again stems from the lack of software to allow personnel to work with the downloaded PDA data.

As the vehicle was modified by MDT personnel in Helena, the Bozeman operators did not assist in the AVL installation. Since being placed into service, the system has not required any maintenance, so the opportunity for operators to assist in system maintenance never arose. Some non AVL improvements were to be made to the vehicle over the winter of 2006-07 unrelated to the AVL. These improvements would be made by the shop forces in Bozeman without the assistance of operators.

5.1.5 Extent of Monitoring

The AVL system onboard the weed spraying vehicle is not capable of remotely transmitting data back to a base (in this case Bozeman) via cellular telephone or satellite transmission for the purpose of real time monitoring. As such, monitoring was not performed during the pre-pilot test. As a result, the effectiveness of web-based real time monitoring of weed spraying operations was not assessed. Rather, the AVL data were downloaded at the end of the day or once every few days and maintained as an archive should the data be requested by other MDT offices. The data were not used as a replacement to any form of communication (e.g. radio); rather, they served to enhance recording and compliance activities, particularly in terms of historical recordkeeping.

The purpose of the historical monitoring was to record locations of spraying activities and their respective application rates in a more streamlined manner. Under normal practice, such information is recorded in paper files by the operator. These files serve to comply with Department of Environmental Quality (DEQ) requirements, and also to provide a record of what locations have been treated, at what rate and with what chemical, should questions arise.

In speaking with the operators, they viewed these records (aside from being required by the DEQ) as advantageous not only from a historical standpoint, but also for public relations. Occasionally the office will receive calls from the public questioning if staff has treated an area. The operators know whether they have treated the area in question, but providing a paper record to confirm this is not the same as having the ability to provide a map of coverage, which is what the AVL system has the potential of producing. However, until the appropriate software is provided to the Bozeman section, this remains a possibility rather than a reality. If the software provides personnel the ability to map activities by milepost, then it should be straightforward to report what has been sprayed, when the operation took place, what chemical was used, its rate of use, and the acreage covered. Subsequently, this would serve as a corollary to DEQ records, although it would not replace them entirely (paper logs are required by the DEQ and will continue to be into the future).

5.1.6 Nature of Communication

As stated in the previous section, the AVL system was not reporting information back to a base in real time. The result is that elements related to real-time reporting, such as bandwidth issues and updating frequency, still need to be assessed in the weed spraying operation (provided a different AVL system were utilized).

5.1.7 Functionality of In-Vehicle Equipment

With respect to getting the AVL equipment to work when the vehicle was entered into service, those who had operated the weed sprayer stated that, aside from the self training that was required initially, the system itself never presented any significant problems. No difficulties were encountered in integrating the AVL system with other sensors on the vehicle since few sensors were present and no attempt was made to do so.

Once in operation, there were limited occasions where the system did stop working in the field. In one particular instance, the weed sprayer was operating in a canyon and the GPS signal was lost. Generally, the system reacquires the signal on its own, but there have also been instances when it would have to be shut off and restarted in order to reset. Additionally, there have been cases in which the PDA would lock up when trying to open or close a particular job file. The PDA also appears to lock up when its data storage becomes full as a result of not performing daily data downloads. Overall, the view was that these were normal computer glitches and infrequent occurrences.

While in service, the AVL system required no maintenance, aside from having to reboot the system on occasion. In daily operation, there was no discernable interference with other communication systems on the vehicle. However, the operators pointed out that, aside from the radio, there were no systems on the truck with which the system could interfere. Similarly, the system did not have any effect on the rest of the vehicle's operations. Essentially, the AVL operated in the background; the only way the system could interfere with vehicle operations would be if it were mounted in an improper location and became an obstruction to the operator.

Regarding the consistency of operation of the AVL system, operators noted that its recording is very sensitive. One operator observed that when the chemical calibrations were entered into the computer, it automatically computed required flow rates for traveling at five miles per hour versus ten miles per hour. Essentially, the GPS and computer were determining that an application rate of 40 versus 30 gallons per acre should be applied. However, if speeds varied slightly, for example the vehicle was moving eleven miles per hour, then the computer would determine that 26 gallons per acre should be the application rate, which would be incorrect. The slight speed difference being computed from the GPS data caused a dramatic miscalculation, which was subsequently recorded. If either the operators or managers were to go back and look at the downloaded data in the future, it is likely they would observe an incorrect application rate in examples such as these. As a result, there might be some question by management as to why so much product was being applied. In reality, the vehicle was likely using less product, but the sensitivity of the system to small changes in speed has led to some discrepancies which need to be addressed.

As for the user interface with the AVL, those who had operated it felt that it was easy to use. One operator likened the system to using Microsoft Windows™, relative to how they started the unit, opened and closed different files, and so forth. However, the operators were careful to note that its use would not be straightforward for everyone; indeed, those with little to no computer experience would struggle initially with its use. For such personnel, more detailed training would be required.

When asked what aspects of the interface worked best, the operators felt that it was difficult to conclusively answer aside from the fact that the system was user friendly to those who were familiar with computers. Similarly, no definitive answer to the most challenging aspect of the user interface was provided, aside from the caution that those unfamiliar with computers or Windows would struggle with the system.

5.1.8 Functionality of Remote Tracking/Monitoring

As stated throughout previous sections, remote, real time monitoring did not occur as part of the weed sprayer pre-pilot test. However, this section will still provide an overview of the aspects pertaining to the tracking/monitoring functionality aspects which are still relevant.

The data that were recorded and capable of being remotely monitored included location, speed (via GPS readings) and application rate (gallons per minute, as specified by the operator). The AVL system is set up to determine how many gallons of product per acre are required, which the operator mechanically injects into the water for the spraying operation itself. As long as the system is tracking the gallons per acre being used, no other tasks or assistance are required from the operator.

In terms of information that the system is not providing but would be useful to track, the operators stated that the type and amount of chemical being used per acre would be advantageous. Currently, the system does not record if a switch has been made between sterilant; rather, this is something the operator must manually enter. This limitation is directly related to sensors and their integration with the AVL system. If sensors were equipped on each of the sterilant injection systems, then a switch could be recorded automatically.

The accuracy of location information from the vehicle could not conclusively be determined due to the lack of software to comprehensively examine the data. At the time of the interview, downloaded data were loaded into ArcView, with personnel checking particular points to see if GPS location, speed, and application rate were recorded. In some cases, it has been noted that the GPS coordinates are not matching up with the locations that have been treated; however, this may be a function of the software being used to view the data rather than the data itself.

The data showed where the AVL had been turned on and off, along with the GPS coordinates in between; however, the precision of the location information (on a highway versus a frontage road) also could not be assessed. When the AVL is turned on, the operators enter the date and the mile marker where their work begins. When the work was completed, the ending mile marker would be entered. The expectation is that future software will take this information and automatically be able to map it over the roadway, allowing for a definitive answer as to whether the locational information being obtained is truly precise.

Improving the accuracy and precision of the locational data recorded was seen as potentially beneficial in certain cases. For instance, pinpoint accuracy would be helpful when Zone 1 spraying is being performed. However, for pinpoint accuracy in Zone 2 spraying, an additional GPS unit would have to be integrated with the hand spaying wand. If this were not done, the GPS would show the vehicle sitting in one spot for a given length of time while the operator was moving alongside the truck with the spray wand. Even if such an application were made (GPS equipped on the hand wand), the coverage could potentially be sketchy, depending on the number of GPS readings being taken over a period of time. As a result, the data could show that only a small area was covered. Currently, such an activity is recorded on paper as being Zone 2 spraying to the edge of the right of way.

At present, it is unclear how the Zone 2 spraying appears in the data. In particular, it is not evident whether the system is recording the correct application rates when it is stationary. For example, the system may be reporting that based on speed, an application of 115 gallons per acre occurred, when in reality, the hand spraying operation applied 50 gallons per acre. Without the assistance of appropriate software, it is unclear what (and how) the system is tracking such data.

In terms of communications breakdowns, as mentioned previously, there were instances where the GPS signal was lost while working in canyon areas. In cases where a signal had been lost while a project was ongoing, it did not appear that any data (aside from the GPS locations) were lost. If there was no signal obtained before a project had been started, the system was not used. As a result, it is unclear how data would have been recorded in such a situation. The question remains as to whether the PDA would have recorded the current application rates while intermittently recording GPS signals in their correct sequence or whether the data would have been mixed up.

In another observation regarding communications, operators noted that there is some signal drift when the vehicle is stationary for an extended period of time. Depending on the number of satellites that are within view during a given time of day, the GPS may show some movement. In examining the data in ArcView, it appears that the vehicle might be moving in a circle of approximately 20 feet diameter. This is an issue that can be better confirmed once the data is examined in the appropriate software package. Aside from this, when the vehicle was moving, the system seemed to perform without such issues arising.

5.1.9 Driver Perspective

When asked if this technology could be useful to MDT drivers and how so, the two operators interviewed felt that it could be very useful. They believed that having a record of where the vehicle was at a specific time would be useful for tort claims. Such a record would be an excellent defense not only against vehicular damage claims (broken windshields) but also against claims that plants on private property were accidentally killed as a result of operations. Of course, the AVL does not record items such as wind speed, direction and temperature, which also influence such an event. However, being able to show a vehicle was or was not in the area at a specific time would help in defending such cases.

Aside from the legal aspects, the potential for the system to keep records of not only location, speed and application rate, but also additional data which could be added in the future offers a good deal of potential usefulness. For example, the system could evolve into one that records the amount of chemical used, which is of critical importance (and interest) from a management standpoint. At present, this sort of precision in record keeping simply is not available with the paper filing system.

When asked if the technology interferes with other tasks they performed, the operators felt that, in its present configuration, the system does not affect their work. The system allows them to simply set up a new project and then go about their work while the system records its data in the background. The operators stressed, however, that if they were continually required to input data (updating items such as the chemicals being used, etc.), then the system could become an interference.

The technology itself has essentially enhanced the work that operators perform. AVL is currently providing additional documentation while not directly increasing workloads. This added documentation serves as a layer of redundancy to back up paper records. In addition, the system provides the potential for mapping activities which, at present, are not performed but would enhance their activities.

When asked their views on utilizing the capability of transmitting the data back on a real-time basis to a base location, the operators felt that it would be useful, but not entirely necessary. From a safety standpoint it would be useful, particularly in cases of Zone 2 spraying where the operator may be off of the truck and out of sight from the roadway. Such a capability would also be useful in situations where an operator is needed for another activity; remote monitoring would allow for their location to be quickly identified, allowing for their reassignment if it is convenient to do so.

Aspects of the technology which seem to work well were primarily the nature of the system being very user friendly to those familiar with computers. Aside from this, the system required very little operator interaction, so it was difficult for operators to determine any additional aspects of the technology that worked well.

In terms of improvements required on the system, the drivers felt that the system should record more detailed information with respect to the spraying activities being performed. Each operator had overseen contractors whose equipment was equipped with a multitude of sensors, far beyond what the present weed spraying vehicle contains. In particular, it would be beneficial for the truck to be equipped so that it could calculate and produce an equal amount of sterilant and water mixture regardless of vehicle speed. Right now, the computer on the MDT vehicle is too basic to perform such an activity.

When asked if they felt the AVL technology was ready for broader use in MDT's fleet, the operators felt a cautious approach was warranted. Each would like to see specific applications, such as AVL on snowplows, tested before wider implementation. In particular, tests integrating other sensors, such as the amount of material being put down, would be particularly useful.

In terms of the usefulness of the technology to maintenance managers, the operators felt that the technology would indeed be useful. In particular, past application rates, chemical usage and similar data would be available for managers to reference electronically as questions arise in the future. In addition, one operator suggested that the system would keep honest people honest and identify those who might not be. However, each operator recognized the technology was first and foremost in place to enhance efficiency and safety rather than monitor driver behavior and performance. The operators had not received any feedback from management in the Bozeman section with respect to the technology and its usefulness.

5.1.10 Monitor Perspective

The weed sprayer operation is overseen by management at the local level; for this pilot, management in the Bozeman office monitored the AVL deployment. From the perspective of the monitor, the addition of AVL to the vehicle is useful. In particular, the monitor believes that it is a tool that can assist in record keeping and improve programming activities. It serves as a form of redundancy and something which can be consulted when questions arise, particularly with respect to application rates.

Receiving AVL data (e.g. application rate) in real time is not necessarily critical from a management standpoint. As stated previously, the data are being downloaded at the end of each day, and that seems to be adequate for their needs. It would be useful to be able to monitor vehicle location in real time once the technology is more proven, in particular to identify areas where spraying had been performed and those that were missed. It is difficult to say how much time per day would have to be spent doing such monitoring to make it worthwhile. If the software provided by MDT could download the data automatically, then monitoring activities would require minimal time. The need for real time monitoring is not the same for weed spraying as it is for a snowplow operation, either. For weed spraying, it is far more critical from a documentation aspect, which does not require real time monitoring.

The monitor views the AVL system as being able to save time and money in several different ways. It could save money by identifying and addressing possible over applications. It could also save money when dealing with tort litigation, which was discussed in previous sections, because a thorough log could serve as a legal support document. From a time standpoint, the system could support operators when filling out paperwork. In this respect, the operators could draw their information off the system data once the technology is in established use. It could eliminate the human errors which might occur (e.g. math errors). Finally, the system would be useful from a time and financial standpoint in that it thoroughly records operator activities from day to day, eliminating some guesswork.

In terms of the aspects of the technology that worked well, management reiterated the operators' observation that the system did not interfere with the other activities the operator was completing. In terms of the aspects of the technology that did not work well, the lack of software to use the data in a meaningful way was the biggest problem. Aside from this, the operators were the personnel most familiar with using the system on an everyday basis, so they are most familiar with its problems.

From the perspective of the monitor, a broader use of the technology in MDT's fleet was dependent on its performance in other applications (e.g. snowplows). In essence, a wait and see approach is advisable. The technology itself would be useful to drivers throughout the fleet primarily from a record keeping standpoint. As stated previously, the data coming from the AVL adds another dimension to their records, as well as some redundancy in terms of the data being provided. Secondly, it allows for a new level of safety to exist, should real time communications be implemented. Vehicle progress can be monitored, allowing potential incidents to be identified in a timely manner.

In terms of the technology protecting the safety of roadway users, AVL on weed sprayers holds less promise than it does on similarly equipped snowplows. The technology should help them improve maintenance activities, so as a result it should also help to improve the overall safety of the roadway environment. It was stressed that this would be in a limited capacity from a weed spraying standpoint. Aside from the maintenance aspects, the technology could potentially identify a case where an operator was improperly operating the vehicle. With respect to being able to provide the public with traveler information, the project monitor did not believe AVL on a weed sprayer would be useful in the same way the system would be on a snowplow.

In terms of the benefits of having real time location and activity information on their vehicles, there is not a great benefit from a weed spraying perspective. It would let managers and dispatchers know where their trucks were at and allow the base to contact a truck if needed. It would also identify vehicles which may have been stationary for a long period of time, which might be an indication that something has happened to the operator. In such an instance, the decision could be quickly made on whether someone needs to be sent out to check on the driver.

The primary view expressed was that real time information would be more useful on vehicles performing different activities, such as snowplows. For example, it would be a useful tool in dispatching the nearest plow in cases where the office gets a call of a high concentration of accidents in an area. At present, a section supervisor might radio three or four operators before finding one in the vicinity to go put sand down. The AVL allows the supervisor to know who is nearest to the site, thus saving time.

The use of satellites to ensure uninterrupted communications service for sharing real time was briefly discussed. In the monitor's opinion, if the technology were being cost effectively applied to another operation (e.g. snowplows) with the infrastructure in place, it would make sense to use it for all AVL operations, including weed spraying. However, it would not be worth significant added cost to use satellite communication for weed spraying alone.

Feedback from the operators with respect to the technology had not been possible at the time of the interview because of the inability to examine the data in an appropriate software package. However, the operators have stated that the system appears to be user friendly, once it has been worked with for a period of time.

5.1.11 Additional Feedback

Interview participants provided feedback on several additional issues. There was a consensus that the AVL could not be perceived as a tool to monitor operators. It is critical that MDT continues to be upfront with the weed sprayer pre-pilot test operators, and emphasize that this equipment is going in to improve efficiency and safety, as well as reduce paperwork, among other benefits. In doing so, the buy-in of operators will be obtained, rather than having them suspicious about the technology. Participants stressed the point that as long as the operators were doing their job, they had nothing to worry about. In reality, the equipment would help them do their jobs more effectively and efficiently. Millions of dollars are potentially going to be spent on the technology over the long term to improve public safety. It would be a waste of time and money to use the system to simply watch and monitor each truck to observe the driver's behavior and activities.

Perhaps the greatest benefit of the system will be in its ability to record and condense vast amounts of information into a useful format. This is particularly helpful when maintenance staff members go before the Legislature and request more resources for their activities. AVL can provide documentation to support their requests by showing what MDT is doing on maps and in tabulations. These documents would serve as a justification for their funding requests and hopefully help secure greater support.

5.1.12 Conclusions

The overall conclusion that can be drawn from speaking with operators and management regarding the AVL application on weed sprayers is that the system has tremendous potential, but a good deal of work remains to take full advantage of it. Specifically, software must be developed that will allow users to view and work with the data provided by the AVL. Until this is available, the accuracy of the data cannot be determined and the potential of the system will remain unrecognized.

As for the AVL system itself, it was viewed to be user friendly. Minimal time was required to learn the use of the system, and it seemed to work in the background with minimal difficulties. When problems did arise, they could be addressed through resetting the system, rather than a costly repair. It was unclear to the operators what information was being recorded by the AVL, as they lacked the essential software to view the downloaded data.

In terms of real time monitoring, the consensus was that it was not essential to weed spraying operations. While it would be useful from a safety standpoint, it is not critical from an operational aspect. The present procedure, in which data is downloaded from the PDA at the end of the day, is adequate.

5.1.13 System Needs

Despite the optimism about the potential of the AVL system in weed spraying operations, the system still has several issues that need to be addressed. First and foremost is the issue of software, which arose repeatedly throughout the interviews. This issue is being addressed by MDT, but as of the time of the interview, a package had not been provided to the Bozeman office. Once the appropriate software is available, the question of the data's accuracy and usefulness can begin to be answered.

In speaking with the operators, the interest in integrating additional sensors to automate procedures was repeatedly expressed. Integration would improve the accuracy of items such as the chemical mixtures being produced and the application rates being applied as speed varies. It was believed that if such capabilities were added to the vehicle and combined with AVL, the benefits would be tremendous.

At present, the data collected by the AVL system is saved to a PDA and downloaded in the office at the end of the day. As such, no assessment has been made as to the transmission of data in real time by cellular communications. This is one of the attractive capabilities of the AVL system that will require assessment as it applies specifically to the weed spraying vehicle.

Finally, as mentioned by the operators, while the system is user friendly and straightforward to those who are familiar with Windows, the system would present challenges to those who are less computer literate. This suggests that training materials and sessions may need to be developed to familiarize users with the system and its use.

5.2 Snowplow Evaluation

5.2.1 Background

Winter maintenance operations encompass all activities involving the application of abrasives and chemicals as well as the removal of ice and snow from roadways to improve driving conditions (19). Among the primary objectives for winter maintenance are to keep roadways open and safe for the traveling public. Winter maintenance activities are confined to MDT maintained routes, unless a Memorandum of Understanding exists with other agencies or individuals (19).

Winter maintenance typically includes preventative winter maintenance, plowing and removal, as well as patrolling activities. Preventative maintenance entails the application of anti-icing chemicals before or during the early stages of a winter storm (19). Plowing and removal activities include clearing the roadway of snow and ice, as well as treating the surface with abrasives and/or chemicals. Patrolling entails the inspection of roadways and reporting of conditions (19).

To expand on the activities outlined above, the winter maintenance crews who were interviewed were asked to briefly describe their activities during an average winter storm, as well as those on a day when no storm was anticipated. During a typical winter storm, the plow crews get called out early and work up to 12 hour shifts. Plows patrol all state-maintained roadways. The strategy is to go wherever the snow is, focusing on major roadways first and addressing secondary routes after these. During a normal winter day when there is no storm, most plows do not leave the maintenance yards. Plows that leave the yard primarily check the roads for ice and blowing snow. If temperatures allow, work/repairs are performed on guardrails and signs.

5.2.2 Vehicle and Installation Detail

To facilitate evaluation of AVL on snowplowing equipment, the Helena Maintenance Section installed units on two vehicles: one stationed in Helena and one stationed in Boulder. The Helena plow (Figure 5-3) is a 1995 Ford L-9000 set up to be a dedicated FreezGard truck[1]. The Boulder plow is a 2001 International equipped with a wing[2] and has the capability to spread sand, liquid, or a combination of both. Each vehicle was equipped with an Iwapi AVL unit mounted in the center of the cab, between the driver and passenger seats. The installations occurred in the spring of 2006.

No attempts were made to move the AVL units at either location to other vehicles. Neither vehicle had hardware upgrades during the course of the evaluation period; the Boulder plow did receive software modifications, however. These modifications were in response to problems experienced with the AVL unit not properly restarting when the vehicle itself had been shut down and restarted in a short period of time. In essence, the AVL unit was in the process of shutting down at the same time it would normally be booting up (vehicle restart), resulting in the system freezing up and having to be manually reset. Iwapi provided a software patch to address this, and, following its installation, the problem has not reoccurred.

[1] A dedicated FreezGard truck is a vehicle which is equipped solely with a plow and a FreezGard applicator. FreezGard is liquid magnesium chloride produced from naturally-occurring minerals in the Great Salt Lake. When temperatures are below 15° F, the truck does not leave the section because the FreezGard tank is mounted such that it cannot be easily removed to facilitate sanding applications.

[2] A wing is a side-mounted plow which increases snow removal capacity.

Figure 5-3: The Helena Snowplow (Note: plow is removed for summer)

Figure 5-4: Helena Snowplow AVL In-Cab Equipment

Each plow was equipped with a number of onboard sensors that monitored a number of different applications. These included plow position, vehicle speed, mileage, atmospheric temperature, and a flow meter/application rate (on the Helena FreezGard truck). At the end of the 2005-06 winter plowing season, the sensors present on the Helena plow were integrated with the AVL unit. To date, the sensors on the Boulder plow have not been integrated. This was due, in part, to the incompatibility of the AVL unit with the sanding controls that are currently on the vehicle. New controls that are AVL compatible are planned for installation in the near future. When this occurs, integration of other vehicle sensors can also begin.

5.2.3 Vehicle Usage

Given the nature of winter weather, each plow had a tendency to see sporadic use throughout the pre-pilot evaluation period. The Helena plow, because of its status as a dedicated FreezGard truck, could only operate during storms in which the temperature was above 15° F. The Boulder plow was far more flexible, as it could operate during any storm, regardless of temperature. Each plow had the potential for being used 24 hours a day if a storm justified it. More typical usage would range from 16 to 20 hours of use per day. The estimated mileage plowed by each truck during a 12 hour shift varied between the sections: Helena's truck covered an average of 160 miles, while Boulder's covered between 200 and 250.

In the case of both vehicles, the special equipment associated with them (a liquid tank [Helena] and a wing plow [Boulder]) prevented their use for other maintenance activities during the winter months. During the summer, the Helena truck has been used to haul water, while the Boulder truck has been used for hauling miscellaneous materials to worksites.

During the course of the pre-pilot test, neither plow saw a change in its usage (i.e. it remained constant when compared to before the AVL installation). The technology itself also had no impact on vehicle usage decisions. However, the consensus between both sections was that it has the potential for influencing decisions in the future. One example cited was that an AVL system could determine that a plow should work a certain critical segment of roadway, so that the electronic data transmitted could be used to update road condition reports in a more efficient manner than using radio.

As stated previously, only the Helena plow had any integration of on-board vehicle sensors made with the AVL unit. The information being recorded along with location was vehicle mileage, speed, plow positions and FreezGard application rates. The recording of data from these sensors was performed automatically once the vehicle was started; at no time was the operator required to specify what would be recorded. At present, the Boulder plow only records and transmits locational data, with sensor integration planned for the future.

5.2.4 Operator Involvement

The number of operators using the plows stationed at each test location differed significantly. The Helena plow was operated by approximately 14 operators, while the Boulder plow was run by only two. The reason for this difference stems mainly from the accessory equipment on the Boulder plow. Several operators stationed at Boulder were not comfortable using the AVL-equipped plow because of the wing attachment on the vehicle, which limited the number of operators who tested the plows. In terms of overall years of experience in plowing operations of those using the AVL equipped plows, the staff at each location was comparable. Helena operators had an average of eight years experience, while the Boulder staff had five years of experience (the discrepancy coming mainly from the limited number of operators using the Boulder plow).

Personnel at each location received only a limited amount of training on the AVL equipment. This training mainly consisted of an explanation of where the AVL unit's power switch was and showing the operator that the unit itself turned on when the vehicle was started. In addition to this, the personnel were shown where to access the AVL locational data (i.e. the rudimentary website which had been developed). Aside from these points however, no additional training was provided, nor did the plow operators attempt any further "self training" through experimentation with the AVL unit.

In the case of each plow, no staff from Helena or Boulder assisted in the installation of the AVL units. Additionally, operators have not participated in the limited maintenance activities specific to the AVL itself. For Helena, the extent of maintenance on the unit was repairing the touch screen pad which had detached from its mounting. Maintenance to the Boulder unit consisted solely of the software update mentioned earlier.

5.2.5 Extent of Monitoring

Unlike the AVL unit on the Bozeman weed sprayer, both the Helena and Boulder plows transmitted their data back to their respective sections in real time. The transmission of data occurred in such a manner that locations were collected every few seconds and transmitted every 15 minutes. The Helena section confirmed this rate of collection by acknowledging that they had actually observed the point locations on the website moving when their plow was being brought from the back of their shop out to the front. However, this also suggests that the transmission rate may have been set to a shorter span than the 15 minutes specified upon installation. While the effectiveness of real time monitoring of plowing operations during storms was not something either section assessed, their experiences with the data have led them to believe that, going into the future, such monitoring will prove beneficial to them.

Both maintenance supervisors and plow operators monitored the data display webpages at each location. Each site believed that personnel at MDT's Helena headquarters had also monitored the websites on occasion. Aside from these locations, none of the personnel interviewed believed any other sections throughout the state had monitored that data. Helena personnel reported checking the website data numerous times during a storm, or at least once in the morning when no storm event was occurring. The Boulder personnel typically examined the data after a storm event (typically a couple of days later), mainly because other activities consumed their time during a storm.

Both the Helena and Boulder personnel monitored the AVL data primarily to verify that the system itself was working. Helena personnel also worked with the data for familiarization purposes, as well as to determine where the plow had worked when the supervisor was absent during a storm. The AVL system was not used to supplement any existing communications (i.e. radio); rather, it operated in the background with the other systems on the vehicle. Going into the future, however, personnel at each location saw the potential for the system to be used by a storm manager to view what has been plowed and shift equipment accordingly, without having to tie up the radio channel to obtain such information. Typically, performing this task via radio is time consuming, so there is the potential for time savings and efficiency gains in this area.

To date, the AVL data are only being used in a limited capacity in real time (namely to verify that the AVL system is working). Both Helena and Boulder personnel confirmed that they also foresee the data having historical uses as well. Aside from providing a historical record of where a plow has been and at what time, the AVL data, when integrated with other sensor data, provide the potential for analyzing a plow's activities, allowing for flaws (ex. inefficient route coverage) to be identified and corrected. Historical data would also allow for experimentation in terms of the rates which materials are applied at to address various roadway conditions. This would allow maintenance personnel to develop a greater understanding of what strategies are working best and which are not, ultimately allowing for an optimization of treatments and a more efficient use of resources.

5.2.6 Nature of Communications

Cellular communications via an AirCard were utilized to transmit AVL data. There has also been some discussion about the creation and use of towers and other locations as "hotspots" to allow for drive-by downloading of data as a plow passes. Interviewed personnel had no knowledge of the bandwidth available or used by the cellular communications. However, in examining the product literature related to the Sierra Wireless 595 AirCard utilized for the AVL deployments, the available bandwidth was stated as being 1.8 Mb per second at an operating frequency of 824-849 MHz. Based on observations, communications problems stemmed more from certain areas lacking cellular coverage rather than issues such as bandwidth. When communications were established, the locational data appearing on the AVL website was being transmitted from the vehicle at 15 minute intervals, as specified by MDT headquarters staff. However, Helena personnel stated that they were able to observe the locational points moving on the screen when their plow was moved within the maintenance yard in real time. This would suggest that the updating rate on this vehicle may have been set to a time span shorter than 15 minutes.

5.2.7 Functionality of In-Vehicle Equipment

As the AVL equipment on the plows was set up to turn on when the vehicle itself was started, both the Helena and Boulder personnel had no difficulties in getting the equipment to operate (aside from Boulder's issues with the AVL unit freezing up on restarts). In the case of the Helena plow, the vehicle was delivered with sensor integration already completed and operational, so the maintenance personnel were not aware of any difficulties in terms of integrating the AVL with onboard sensors.

Once the plow was operating in the field, neither Helena nor Boulder personnel were aware of instances in which the AVL unit stopped working, aside from those already cited in previous sections. As a result, operators did not make any attempts to manually restart the AVL system. While in service, only limited maintenance was required on the AVL units. This included the repair of the monitor which had detached from its mounting (Helena) and the software patch (Boulder). Along those same lines, the system did not have any effect on the rest of the vehicle's communications or operations. Regarding the consistency of operation of the AVL system, there was a consensus that it did operate in a consistent manner. When communications were lost, the data continued to be recorded chronologically and transmitted in the correct sequence once restored.

Operators found the AVL interface easy to use, with the touch screen being the most useful feature. Helena personnel added that with a medium level of training, anyone should be able to work between the AVL menu screens. However, if an operator is not using the AVL plow frequently, there may be a tendency to forget how the system works. The Helena section has an operations manual for its plows which serves as a reference for operators to look through when operating the vehicle, getting up to speed quickly on the operation of specific systems. In their experience, the AVL system would be better understood once instructions for its use have been added to the manual. The goal of this would be for inexperienced operators to get in the truck, have access to the manual and let them go through it step by step depending on the situation they encounter.

While the interface itself was easy to use, both Helena and Boulder personnel could not conclusively state any specific aspects of it that did or did not work well. This stemmed from the nature of the AVL system operating in the background with other plow systems during the pre-pilot testing period. Since it was a background system that ran itself, operators only used it in a limited capacity (such as familiarizing themselves with the menu items on the touch screen). Boulder personnel stated that, while the user interface is easy to use, one downside to it is that it required the operator's attention, which can be a distraction. They suggested a voice-activated interface could be used to allow the operator to speak out the instruction to the interface while still being able to concentrate on the road.

5.2.8 Functionality of Remote Tracking/Monitoring

As stated in previous sections, there were differences between what the AVL unit at each location was recording and transmitting. In Helena, the AVL unit sent back not only locational information, but also additional data, which included vehicle speed, ambient temperature, plow position and application rates. The Boulder plow only transmitted locational information. While the differences in the data being transmitted do limit the ability to accurately assess how well the overall AVL system is working in terms of integration with other on-board sensors, it does at least provide some preliminary evidence suggesting that limited integrations have been successful.

In terms of additional sensor information and additional features that would be beneficial, each section provided a number of different ideas. Helena staff members stated that they would like to see some form of data transmission or docking station (where data could be transferred from the AVL or a PDA) to their Maintenance Management System (MMS). Boulder personnel understandably stated that basic sensor information such as speed, mileage, plow position, ambient temperature and application rates are items that would be beneficial to receive. Additionally, each section stated, to some extent, the need for an improved map interface. The present map makes it difficult to know where the vehicle is unless you have some idea of what the travel times from the section garage are under certain conditions. Instead, it would be beneficial to have a map that shows roadways at the block or milepost level of detail. If possible, it would also be useful to have the ability to "zoom in" on the point location of a particular vehicle and see in detail what work/applications they have performed for the last mile.

Despite the perceived level of detail problems with the existing map interface, personnel at each location believed that the location information being presented was accurate. However, it was pointed out that with the present map, you have to know the roadway network well in order to recognize where the plow is at. Two different views were expressed when asked if it was possible to differentiate whether the vehicle was traveling along a highway as opposed to a parallel frontage road. Helena personnel were able to differentiate, based on their personal familiarity with the roadways, whether the plow was on a highway or a frontage road. In fact, the level of detail already had allowed them to determine when the plow was moving too fast (typical operating speed is approximately five miles per hour). In contrast, Boulder personnel were not able to make such a determination, primarily because the size of the points showing the vehicle location were too large to allow for any determination of detail at the roadway level. Their viewpoint was that the resolution of the locational points would have to be adjusted before they would be able to assess whether the difference between a highway and its frontage road could be identified.

When asked whether improving the accuracy and precision of locational information would enhance the usefulness of the AVL technology, personnel from both sections agreed that it would be. Helena personnel stated that while the accuracy at present already appears to be quite good, further improvements would be welcomed. Boulder personnel seconded this view, but also cautioned that too fine a level of accuracy was not necessary.

With respect to communications breakdowns, the only example reported by each location was loss of cellular communications. Boulder specifically stated that, once cellular coverage was lost, it did not reestablish itself. No actions were taken to address this problem in the field, as plowing operations were the primary concern at the time. Helena personnel stated that when they had communications problems, MDT headquarters notified them, with the truck being taken in to the main garage in Helena for repairs to address the problem. As stated in previous sections, when communications were lost, it appeared that the AVL data continued to be saved chronologically and transmitted accordingly when communications were restored.

5.2.9 Driver Perspective

When plow drivers were asked whether AVL technology was a useful technology for them, both Helena and Boulder operators verified that yes, it is and will continue to be. Helena personnel found the system useful in that it was providing them with information such as application rates and where product was put down, among other items. In their opinion, the more data that were cataloged on their part, the better off they would be as drivers, particularly with respect to tort claims. Additionally, personnel at both locations believed that much of this data could be used in updating dispatchers and RWIS going into the future, allowing operators to just press a button and send their report. Aside from these potentially useful additions, operators believe the system provides them with more responsibility and leadership opportunities. In this respect, operators could get on the AVL website and see what they've done and, for example, identify locations that may have been over-serviced. In this sense, the system would be useful to operators in their future decision-making.

When asked if the technology interferes with other tasks they performed, the operators felt that, in its present configuration, the system does not affect their work. Often, the plow operators are so busy with their other tasks that, at present, the AVL is the least of their concerns. Going into the future, the system is viewed by operators as being something which has the potential for reducing their task load. This reduction would occur if the sensors are eventually integrated with the AVL units on plows, eliminating the need for operators to manually enter information at frequent intervals.

From an operator standpoint, the unobtrusive nature of the technology itself, as well as the ease of use with respect to the menu touch screen, are the elements that work best. In terms of improvements from an operator standpoint, the primary response was that voice activation of the system would be welcomed. Any improvements that would minimize the work load of an operator would have long term benefits. Additionally, it was suggested that the installation be made such that the AVL system was interchangeable between vehicles. This would allow for fleet flexibility (use a unit on a mower in the summer and place it on a plow in the winter) and provide cost efficiencies.

When asked if the AVL system was ready for broader use in MDT's fleet, operators in both Helena and Boulder were in agreement that it was ready for such usage. The belief was that AVL systems have a much broader fleet potential beyond plowing operations. Indeed, one operator believed that no vehicle (trucks, pickups, sweepers, other major wheeled vehicles) should leave the maintenance shop or be delivered without an AVL system installed in it. The reasoning behind this broad application is that it would ultimately pay for itself through reduced paperwork and manpower when addressing tort claims. It would provide documented proof of where work was done and when, along with other pertinent information (such as the materials being applied in the case of plows).

In terms of the usefulness of the technology to maintenance managers, the operators felt that the technology would indeed be useful. In particular, they believed that the system would provide managers with better data with which to make decisions. The operators had not received any specific feedback from management with respect to the technology and its usefulness, but their overall impression was that it was a system that their maintenance managers were in favor of.

5.2.10 Monitor Perspective

From a project monitor/maintenance manager perspective, the addition of AVL to plows is viewed as having potential. For example, the system could be used to quantify/document the potential savings from the usage of a particular material compared to another in certain situations. Provided the operation of the system itself is flawless, it will let operators focus on plowing rather than having to be burdened with entering data. This in turn would make plowing operations safer and less stressful for the operator.

Maintenance managers viewed the provision of AVL data in real time as something that is worthwhile. In spite of not extensively utilizing real time data during the pilot test, managers saw its value, particularly when the system is integrated with onboard sensors. The data being transmitted back during the pre-pilot test was in near real time (collected every few seconds and transmitted every few minutes), and this was found to be adequate for meeting management needs.

In order for the AVL system to be successfully utilized in winter maintenance operations, MDT personnel will need to spend time working with the data being transmitted to them. When asked how much time per day would need to be spent monitoring and utilizing the AVL data to make the system worthwhile, responses from managers varied. Helena managers stated if the system was on all plows, then they would spend at least a half an hour on the day of a storm performing management tasks with the data (examining patterns, application rates, and such). During the time when no storm was occurring, they would work with the data on an as needed basis. Boulder personnel stated that, at least initially, they would need to spend quite a bit of time working with the data both during a storm, as well as after the event. It was expected that the amount of checking during a storm would not drop off, while the amount of time spent working after a storm would diminish as they became more familiar with the data. Post-storm analysis was envisioned to include examining application rates and locations in order to determine how to better program plows for similar events/situations in the future.

In terms of the potential areas of time and cost savings from a maintenance management perspective, tort claim reductions as well as improved operations/practices were listed as the primary areas where such benefits would be accrued. Tort claim savings would consist of both time and financial savings, as it takes a great deal of labor to manually search through paperwork to determine where a plow was and what it was doing at the time in question. AVL data have the potential to not only streamline this aspect of tort claims (and subsequently produce cost savings by utilizing personnel for more productive activities), but also prove whether or not a state vehicle was in the vicinity at the time in question, possibly eliminating the cost of paying the claim itself. An added benefit tied to tort claims is that the electronic records provided by the AVL system could potentially cut down on the number of paper records that would need to be kept.

With respect to improved operations/practices, managers would be able to examine elements such as application rates and prevailing weather conditions to determine more optimal use of treatments. Determining the most effective strategies for a given set of conditions was envisioned to ultimately produce cost savings. In addition to these areas of time and cost savings, the system also has the potential for streamlining the answering of calls from the Montana Highway Patrol concerning what roadways have been plowed and at what time the work was completed. Instead of having to contact plow operators via the radio, real time data from the AVL system could be consulted. Finally, the system could also produce savings by identifying when idle time had occurred (i.e. the truck was not plowing, but rather, stationary but still running, allowing for the AVL to continue to send positional information). This would allow managers to contact operators and let them know that the plow should be shut down to conserve fuel.

With respect to what aspects of the technology worked well, management reiterated the views previously expressed by operators. Namely, the user interface is straightforward and easy to use. Aside from this, there was some concern expressed about keeping the other sensors and systems on the plow separate from the AVL in the sense that, if the AVL broke down, it would not result in the entire truck being rendered inoperable. Managers reiterated that the aspects of the technology that did not work well, at least sporadically during the pre-pilot test, were the cellular communications. Coverage problems were acknowledged as the main cause for this, and, provided the system is able to effectively reestablish communications once coverage is restored, this problem would be considered insignificant.

When asked whether the technology was ready for a broader application in MDT’s fleet, managers in both Helena and Boulder agreed that it was. It has great potential for streamlining and improving operations/practices, reducing tort claims, and minimizing the workload of plow operators. The efficiency and cost effectiveness of the program itself would be enhanced if the AVL units were interchangeable between equipment. This would allow for units to be moved between dedicated seasonal equipment (mowers to plows), thus spreading the costs of the units out. One manager made the additional suggestion to first conduct a broader pilot test using all vehicles from one section while quantifying the costs and benefits associated with this deployment.

With respect to protecting operators’ safety, managers agreed that AVL would be a useful tool. It would be helpful for a dispatcher in cases where the radio on a plow is accidentally shut off and the operator cannot be reached. Rather than not knowing if there had been an accident, the dispatcher would be able to look for the plow on the map interface and verify whether or not it was moving. If there was an accident, there would be accurate information as to where the vehicle was, eliminating the need for a dispatcher to guess the approximate mile marker location of a plow.

Just as the technology has the potential for improving the safety of operators, it was also viewed as having benefits to the general public through improved traveler information. If the AVL data from plows were tied together with RWIS information, the status of specific roadways could be updated in a more timely manner. At present, such information is being updated by dispatchers based on the information coming in from plow operators via radio. However, the primary concern of the operator is clearing the roadway of snow, so sometimes the information provided to dispatchers, and subsequently the traveling public, suffers as a result. Access to AVL data would provide the dispatcher with pertinent information in real time and alleviate this problem. In addition, the present procedure is to present the worst observed conditions for an entire roadway segment; however, the finer detail available through AVL would allow for more accurate information to be provided for shorter segment intervals.

Managers saw value in moving to satellite as a means for obtaining greater communications reliability. Specifically, communications are critical in plowing operations as different storms produce different conditions out on the roadways. Having the capability of constant monitoring would be beneficial as it would eliminate the gaps that at present occur when the plow enters an area with poor cellular coverage. The present rate at which information is updated (every few seconds) is viewed as being adequate, and would continue to be viewed as such if the switch to satellite communications was made.

Managers in both Helena and Boulder initially perceived some reluctance from their operators with respect to the AVL system, as it was viewed as something going into the vehicle to monitor their actions. At both locations, it was explained that the system was not being used for this purpose; rather, it is being installed to help make their job easier through reduced paperwork and additional protection when tort claims arise. Once the operators understood this, their acceptance and enthusiasm about the system grew.

5.2.11 Additional Feedback

In addition to the feedback received from operators and management presented in the previous sections, further thoughts were expressed by those who were interviewed. The common thought expressed between personnel in both Helena and Boulder was that the AVL system is one which has a great deal of promise, but there was concern that wider deployment would not move forward because of cost issues. As mentioned throughout the previous sections, those working in the maintenance sections where the pre-pilot tests occurred had identified a number of potential areas where cost savings could be accrued. The view expressed by many was that these savings would pay for the AVL systems placed into vehicles many times over.

In both sections, interview participants stressed that they had only used the AVL system and its data to a limited extent. This was in part due to the limited period in which the AVL system itself was active and operational. While they viewed the information received as being accurate and that the system was working as it was intended to, the conclusions which they have drawn with respect to AVL are only based on their limited experiences and understanding.

5.2.12 Conclusions

The primary conclusion to be drawn with respect to the application of AVL on plows is that the technology holds a great deal of promise in the area of winter maintenance. When integrated with other onboard sensors (speed, temperature, application rates), it creates a tool that has the potential for providing a number of benefits. Foremost among these is the potential for cost savings through a more efficient use of treatment materials, reduced tort claims and less paperwork. The view of many who were interviewed was that these potential savings alone justified the application of the system to a wider range of vehicles.

The AVL system was viewed to be user friendly and straightforward to use. Indeed, those who operated the system essentially taught themselves how to use it. Some communications problems occurred throughout the pre-pilot test, namely the loss of cellular coverage. When coverage was restored, the system on the Helena-based plow appeared to restore itself and send data in chronological order. The Boulder-based plow did not self-restore communications once cellular coverage was lost, which is a point of concern. Aside from this, the AVL unit in Boulder exhibited some software problems, preventing the unit from restarting properly if the vehicle had been shut off for a short time. This problem was corrected during the course of the pre-pilot test.

The data being provided by the system with respect to vehicle location appeared to be accurate. The nature of the map interface provided with the system prevented users from forming a definitive conclusion regarding locational accuracy. The ability to monitor vehicles in real time was something that was appreciated, as it had the potential to minimize radio traffic and confirm vehicle status when such communication had been lost.

Plow operators responded favorably to the system for its potential to record their activities automatically. The view toward this was that it would allow them to focus on their plowing activities rather than having to update dispatchers about what they had done or were in the process of doing. Managers also had a favorable view of the system not only for the wealth of data it has the potential to provide, but also for its ability to streamline tasks both for the operator as well as maintenance personnel in general (reduced time for looking up archived information).

5.2.13 System Needs

In spite of the optimism about the potential that AVL has for plowing operations in the wider MDT fleet, the system still has a number of needs that must be addressed to ensure a successful deployment, should the decision be made to do so. Foremost is the need for reliable communications. While it is expected that cellular coverage will be lost occasionally (assuming that this will continue to be the preferred media in the future), the reliability of the AVL system itself to reestablish those communications is essential. While the Helena-based unit appeared to successfully accomplish this, the Boulder-based unit did not. For a successful deployment, all units must behave in a consistent manner, regardless of location or communications availability.

In addition to communications reliability, it is also essential for the AVL unit to be integrated with as many onboard sensors as possible. This integration would allow for more benefits to be accrued from the system by providing managers with a full picture of the plowing operation. The information provided would allow for an optimization of procedures, subsequently producing cost savings through a more careful use of materials and equipment.

Numerous personnel members stated AVL system would be more cost-effective if the units were interchangeable among vehicles. In this manner, equipment dedicated to winter or summer operations (i.e. plows and mowers) could share AVL units, cutting down on the total number required for purchase. The interchange of AVL units between vehicles was not attempted during the pre-pilot test, but it is something that should be examined carefully before electing to proceed with deployment to the broader MDT fleet.

A common complaint shared between Helena and Boulder personnel was that the web-based map interface used to display AVL data was not acceptable. The level of detail was poor, which made it a challenge to determine where the vehicle was at on the roadway network. A new map interface would be necessary for a broader AVL deployment, ideally one which displayed a level of detail at block or milepost intervals. This interface should be capable of allowing the user to zoom in and out on the roadway network, allowing them to view either the entire fleet in operation at the time or a specific vehicle of interest.

While not critical given the ease of use which operators had with the system, some form of training with respect to the overall operations of the AVL system should be considered if the decision is made for deployment to a broader fleet. This training would not only familiarize operators with the functions of the system (overall operation, menu selections, etc.) but also provide them with a better understanding of what the system is really being used for. Both Helena and Boulder personnel were initially concerned about the presence of the AVL units, but once their operations and the data they were providing were explained, each location saw increased acceptance. As with any new system, education is critical, and this is a component that should not be overlooked if the decision is made to move forward.

One final improvement suggested for the system was to provide maintenance managers with a laptop, so that when they were out in the field during a storm, they would still have the ability to monitor vehicle locations. While the communications aspects of this would need to be worked out (utilize wireless hotspots, cellular communications, other), such a capability would provide managers with the ability to control operations when away from base.

5.3 Remote Vehicle Location (RVL)

As presented in Chapter 3, MDT has also installed Remote Vehicle Location (RVL) units on snowplows stationed at MacDonald Pass and Butte. To date, the data collected by these units have not been utilized. The MacDonald Pass truck has experienced a number of mechanical issues, preventing its use (and subsequent collection of data) during the winter of 2006-2007. In talking with Butte personnel, they are aware that the system is present on their plow, but have not been instructed in how to use it or download the data. As a result of these field experiences, a thorough evaluation similar to that presented in the prior sections of this chapter was not possible.

The extent of knowledge and experience with respect to the RVL units lies with MDT staff in the Helena headquarters. The units have been installed on two Monroe snowplows, with the stored data downloaded via memory sticks. Data recorded by the system included location, plow position, speed, air and roadway temperature, and spreader actions. On-site visits were made by personnel from headquarters to collect the data from the Cirrus system, with a large quantity of data being acquired. The system is capable of saving up to 30 days worth of data, and upon examination, the data saved over the course of the 2006-2007 season was found to be very accurate. The level of accuracy observed was illustrated by the ability to visually determine via Cirrus software when a plow had changed lanes.

To facilitate data acquisition in the future, the existing Cirrus systems will be equipped with an 802 antenna to enable automated download at hotspots (envisioned to be at fueling pads). However, this will raise networking issues; namely, the need for a server to be present at the download site to transmit the data to the appropriate locations. Such issues will need to be addressed when deciding how to move forward with the RVL project as a whole.

5.4 Conclusion

This chapter has presented the results of interviews conducted with MDT personnel who have worked with equipment equipped with AVL (a weed sprayer in Bozeman, and snowplows in Helena and Boulder). The overall conclusion that can be drawn from these interviews is that there is a great deal of potential in AVL; however, this potential will not be fully realized without correcting the shortcomings of the system itself prior to wide scale deployment. RVL units have been installed on plows at MacDonald Pass and Butte, but to date, none of the data which they have collected have been downloaded from the vehicle systems. As a result, management and operator experiences from this method of vehicle monitoring could not be evaluated.

6. CONCLUSIONS AND RECOMMENDATIONS

WTI researchers conducted a series of interviews with MDT staff to evaluate the experiences of those who had worked with the AVL systems installed on one weed spraying truck and two snowplows. To this end, several useful conclusions and recommendations were obtained. The following sections provide a summary of the key items of feedback provided by operators and management who had worked with the system on a frequent basis.

6.1 Weed Sprayer Conclusions

An AVL system was installed on the lone weed spraying truck stationed in Bozeman. The system was set up to record vehicle location, speed (via GPS) and application rates (these rates being manually entered by the operator). No attempts were made to move the AVL system between vehicles; it was solely dedicated to the weed sprayer. Limited guidance was provided to the operators concerning the use of the system, but much of its use was "self taught" by the operators themselves. The application of the system to the vehicle was presented to operators at the onset as something that was being used to enhance safety and efficiency, not to monitor their activities. This resulted in operator buy-in and acceptance.

The system itself did not send data back to a central location in real time. This prevented an assessment of the effectiveness of such transmission in a weed spraying application. Instead, data were downloaded via a memory stick at the end of the day. This system was found to be acceptable, as real time weed spraying information is not of critical importance. The data received could not be easily examined, as no viewing software had been provided with the system. Rather, MDT personnel utilized ArcView GIS to view the data. This package allowed for the data to be viewed as points, but in the absence of specific software, it was difficult to closely examine and evaluate that data. This resulted in some questions on the part of personnel as to whether the onboard sensors were actually recording additional data beyond location (e.g. ground sensor speed, application rates). In addition, it prevented conclusive determinations from being made with respect to the precision of locational information (e.g. highway versus frontage road).

The system itself was viewed to be beneficial from the standpoint that it provided electronic records of what had been done and at what location. This provides MDT with good redundancy for the paper records that are presently required by DEQ for weed spraying operations. Future integration of additional sensors and equipment with an on-board computer/AVL system was viewed by personnel as something that would be of further benefit to MDT.

From an operator viewpoint, the system was easy to use once familiarized with it. One operator likened this ease to using Microsoft Windows™. The AVL system did not interfere with other equipment and systems on the vehicle and was viewed in general as being "hands off". Operators did observe instances where the AVL system stopped working in the field (due to losing view of GPS satellites), but generally it reestablished operations without operator intervention. The system also showed some sensitivity with respect to computing application rates for a respective vehicle speed (e.g. miscalculations). Finally, some signal drift was observed to occur when the vehicle was stationary for an extended period of time (observed when examining the data in ArcView).

The view of operators was that this system would have usefulness in the broader MDT fleet for tort claims and reducing or streamlining paperwork; however, a cautious approach to applying it should be taken. Operators expressed that it should be used in specific applications (e.g. snowplows) rather than applied haphazardly. In a weed spraying application, improvements are necessary, including recording of additional sensor inputs such as type and amount of chemical being applied. At present, operators must manually enter such information into the system, but these are functions that could easily be automated. Cellular or satellite communications for real time data transmission were viewed to be something that would be useful, but not entirely necessary. Locational accuracy (if it were ultimately determined to be too low when examining data in appropriate software) is the primary area where improvement might be beneficial, as it would show exactly what had been done and where for a particular work site.

From a management standpoint, AVL was viewed as a system that would assist in record keeping and improve programming activities. The system has the potential to save time and money in terms of identifying instances of overapplication, addressing tort claims, and streamlining and eliminating errors in paperwork. Broader use in MDT's fleet should be dictated by performance in specific applications (e.g. snowplows), where the system holds the most promise. The provision of AVL data in real time was not viewed as being essential, nor were improved communications. Improved communications would only make sense in a weed spraying application if the infrastructure were in place for other applications and its use deemed cost effective.

Based on the feedback obtained in interviews with MDT personnel associated with the Bozeman weed sprayer, four distinctive needs were identified that should be addressed in future pilot tests:

- First, software with which to view and work with the data collected by the AVL system itself is necessary. At present, personnel are using ArcView GIS to view the data, but this package is not suitable for working with and exploiting the potential of the data itself.
- In its current configuration, the AVL system does not fully integrate all of the available sensors present on the vehicle. The addition of these would provide more robust data specific to weed spraying, while reducing the workload of operators.
- While not viewed as being essential to weed spraying operations, the application of cellular communications for providing real time data transfer in spraying operations remains to be assessed.
- Finally, while the system was viewed to be easy to operate, training materials should be drawn up to better familiarize operators with the AVL system and its functions.

6.2 Snowplow Conclusions

Two AVL systems were equipped on snowplows: one in Helena and one in Boulder. The Helena system was integrated with other onboard sensors, including plow position, vehicle speed, mileage, atmospheric temperature, and flow meter/application rate. No sensors were integrated on the Boulder plow, as that vehicle is awaiting upgrades to AVL-compatible controls. No attempts were made by personnel in either section to switch the AVL units to other vehicles.

The systems experienced some problems in terms of communications, primarily loss of cellular coverage in isolated areas. Additionally, the Boulder AVL unit experienced problems restarting when the vehicle had been shut off for a brief period. The system would not fully shut down, and, as a result, froze up, preventing a proper restart. This problem was addressed with software patches, but it is a glitch which needs to be considered (and possibly something that will need to be addressed again) in future applications.

The Helena section checked the data being sent from their plow periodically during a storm, while Boulder checked data in the days following an event. As a result, the use of real time data in managing storm activities was not pursued by either section. Rather, the data were examined mainly to verify that the AVL system was actually working and sending in acceptable location (and in Helena, sensor) data. To this end, the data did appear to be accurate. Each section acknowledged that the data being received would have both real time and historical usefulness if or when AVL is deployed to a broader fleet.

The critical element to the success of the system was viewed to be integration with as many sensors as possible. This would provide a full picture of the plowing operation, subsequently allowing for inefficiencies to be identified and corrected. It would also allow managers to develop alternative treatment strategies which could be employed and analyzed.

Communications problems did occur during the course of the snowplow pilot test. These were primarily the result of cellular coverage issues, rather than an equipment failure specific to the AVL. The AVL system itself did not appear to stop working at any time in the field; rather, the system operated consistently and continued to record data in chronological order when cellular communications were lost. Mixed results were found in terms of communications being restored automatically when an area of coverage was entered. Helena reported that their communications were restored in such a manner, while Boulder stated that communications often did not automatically restore themselves once lost. This is an element which must be addressed in future pilot testing.

The overall user interface of the AVL system was viewed to be easy to use, requiring a medium level of training in order to use it. In general, the system ran in the background and did not interfere with any of the other equipment onboard the vehicle. Evidence from the Helena sensor integration indicated that this aspect of the pre-pilot test was also successful.

From an operator perspective, AVL was viewed to be a useful technology to include on vehicles. One view commonly expressed was that much of the data it could provide (when integrated with sensors) could be used to automatically update dispatchers, storm managers and RWIS systems, rather than relying on radio communications. Items such as this underscored the recognition of the potential for the system to reduce operator taskloads during plowing operations. A few operators expressed the belief that the system would pay for itself through reduced paperwork, more efficient use of personnel/equipment and reduced tort claims. Overall, the view of operators was that AVL was a system that should be applied to a broader fleet of MDT vehicles based on their experiences using the system.

The view of managers overseeing the AVL systems at each section was that the system has the potential for quantifying and documenting the potential savings from different treatment alternatives, as well as determining what the most effective maintenance strategies are. In addition, AVL could reduce operator workload and tort claims (including a streamlining of the process for looking up data to address them). Finally, AVL was viewed to be a tool that could improve operator safety by identifying vehicles that had not moved for extended periods of time or that could not be contacted via radio.

Overall, the user interface was viewed to be easy to use, although some training materials should be drawn up for it. The system as a whole was viewed to be ready for application on a broader fleet of vehicles. However, managers believed that a more cost-effective use of the system could be achieved if it were interchangeable between vehicles. It was stressed that operators must be briefed on the system and its intended uses at the onset to ensure their buy-in. In moving forward on a pilot test, it was suggested that such a program be pursued by equipping all vehicles located in a selected section. This would allow for a manageable evaluation of the true costs and benefits of a broader fleet deployment to occur.

Based on the feedback obtained in interviews with MDT personnel associated with the AVL equipped snowplows, a number of distinctive needs should be addressed before moving on to a broader pilot test program. Foremost among these is the need for reliable communications. This does not necessarily mean that a continuous communication link needs to be present; rather, the system will need to operate in a consistent manner. When cellular coverage is reestablished, the system needs to reestablish its communication link. This was something that did not occur with the Boulder AVL system, and an item which need to be addressed and solved prior to any pilot test.

Several of those interviewed stated that, if the AVL units were interchangeable between vehicles, cost savings could be recognized. No attempts were made during the pre-pilot test to switch the AVL units between plows (or other fleet vehicles), so this remains an area to be examined in the future.

Aside from this, several improvements specific to the system are suggested. First, the integration of sensors on the vehicle is essential to maximize the utility of the system as a whole. An improved map interface is also necessary. In its present state, the map does not show great detail in terms of the roadway network, which limits the ability of managers and operators to fully exploit the AVL data being displayed. Subsequently, a map interface with greater detail and functionality should be developed for future AVL deployments. In addition, some flexibility in the system itself, in order to transfer AVL data to maintenance management systems, would be beneficial.

Aside from these primary items, other suggested improvements included the provision of training materials, a laptop for maintenance managers to use to observe vehicle locations when working out in the field, and the development of a voice recognition command system. Training materials would quickly familiarize an operator with the functions of the system such that they could get into the plow with no experience and become comfortable with operating the AVL in a short period of time. The remote access laptop would allow maintenance managers to keep track of vehicles and operations while they are away from the section base. Finally, voice recognition would allow the AVL system and the menu selections associated with it to become hands-free for operators. Operators would simply state the command they wish to complete and the system would carry it out.

6.3 Recommendations

Based on the experiences, feedback and conclusions provided by interviews conducted with MDT personnel who had worked in some manner with the AVL units during the pre-pilot test, a number of recommendations can be provided. These recommendations are intended to serve as a blueprint for addressing the issues that were experienced during the pre-pilot test, as well as present other aspects that will need consideration when moving forward with a larger pilot test. Many of these recommendation also take into account the past experiences and lessons learned from AVL deployments in other jurisdictions.

Use a Systems Engineering Approach. The systems engineering approach is foundational for the successful planning and design of an AVL system. While such an approach may not have been entirely necessary for the small-scale pre-pilot test, any larger deployment pursued in the future should consider the use of this approach. It is an iterative process that seeks to build the true user needs and requirements into the final product to minimize the need for costly modifications later. Key aspects of this approach include the following:

- Development of a concept of operations – e.g. how AVL will be used and by whom;
- Identification of requirements – the functionality that is necessary for the concept of operations to be realized;
- Development of a system design that follows the requirements.

The pre-pilot test has provided considerable input from vehicle operators and maintenance managers with respect to the performance of their respective AVL systems, as well as what their needs and desires for the system are moving into the future. As a result, much of the foundation for following the systems engineering approach for a larger pilot test is already completed.

Obtain Buy-In. As stated repeatedly during the course of interviews by both managers and operators, buy-in at multiple levels is essential to the success of any AVL deployment pursued by MDT. The initial views of operators toward the AVL systems installed were that it was a “Big Brother” device. The fear was that AVL would be used to monitor what operators were doing – i.e. an intrusive device to micromanage vehicle operators. Once managers explained that the system was not being used for this purpose, but rather to reduce and simplify their workload, the reluctance toward the system was minimized. Perhaps the greatest selling point to operators was that AVL would be able to provide conclusive data to support them when tort claims arise.

Aside from “Big Brother” issues, AVL has the potential to introduce changes in how winter maintenance operations are performed. Depending on its use, AVL could simply provide better historical information for maintenance managers, or it could involve a virtual re-invention of how snowplow routes are executed. As a result, there may be staff reluctance to learn the new technology, and there may need to be reassignment of staffing resources to better align with the capabilities of AVL.

Software. Another common problem cited during the course of interviews with MDT personnel was related to software. The Bozeman weed sprayer did not come with any software support for viewing the collected AVL data, while the web site provided for viewing the Helena and Boulder plow data was rudimentary and lacked the level of detail which managers and operators felt necessary to fully exploit the potential of the system. In all of these cases, improvements will be necessary when moving forward with a pilot test. AVL is sufficiently advanced that there are a variety of commercial, off-the-shelf packages that could meet the needs in fully utilizing MDT's AVL data. These packages can also be modified to meet agency needs; however, the tradeoffs between costly redevelopment and the needs/goals related to the use of AVL data will need to be considered. Using a commercial off-the-shelf AVL software package could the avoid problems of customization, but it might not provide the agency with their desired functionality.

Interchangeability. One means by which cost savings might be accrued in future deployments is to purchase AVL units that support exchange between vehicles. In this sense, a unit that may be equipped on a snowplow during the winter could be shifted to a vehicle, such as a mower, which only sees summer usage. In this sense, the number of units required for purchase is minimized while maximizing the use of them over the course of a year. No attempts were made to interchange AVL units between vehicles as part of the pre-pilot test; future pilot testing should investigate such strategies.

Revisit ITS Architecture Conformity. As a technology that uses other technologies to exchange information between maintenance vehicles and maintenance centers, AVL may be a candidate for inclusion into a region's ITS architecture. The inclusion of AVL into Montana's architecture has occurred, primarily through market packages related to maintenance and construction, including AVL (MC01) and Winter Maintenance (MC06) (20). However, the inclusion of AVL into other market packages should also be investigated. For example, the archival nature of AVL data suggests a logical tie in to packages such as the ITS Virtual Data Warehouse (AD2) or Interactive Traveler Information (ATIS02). These linkages remain to be explored and defined as they relate to the Montana architecture.

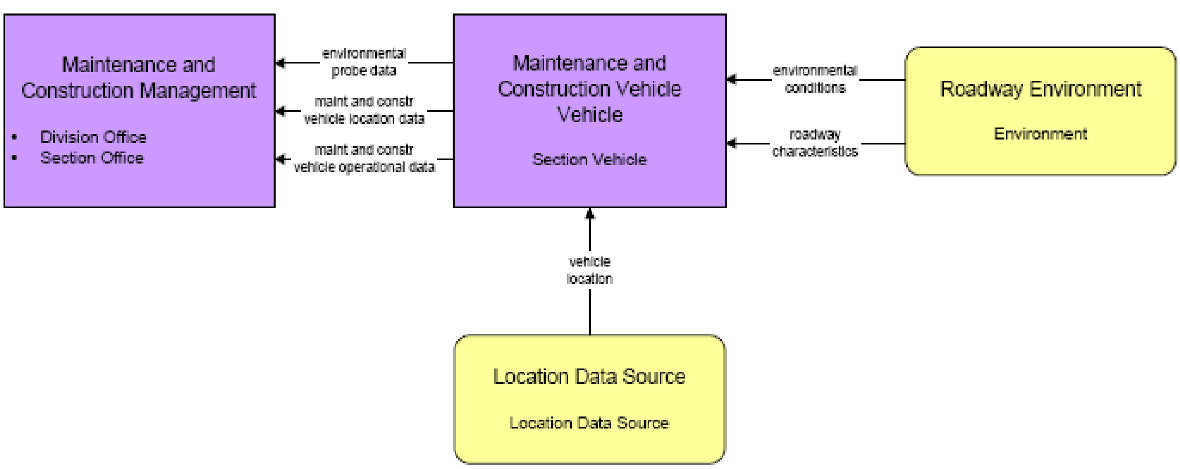

Figure 6-1: Market Package MC01 – AVL (20)

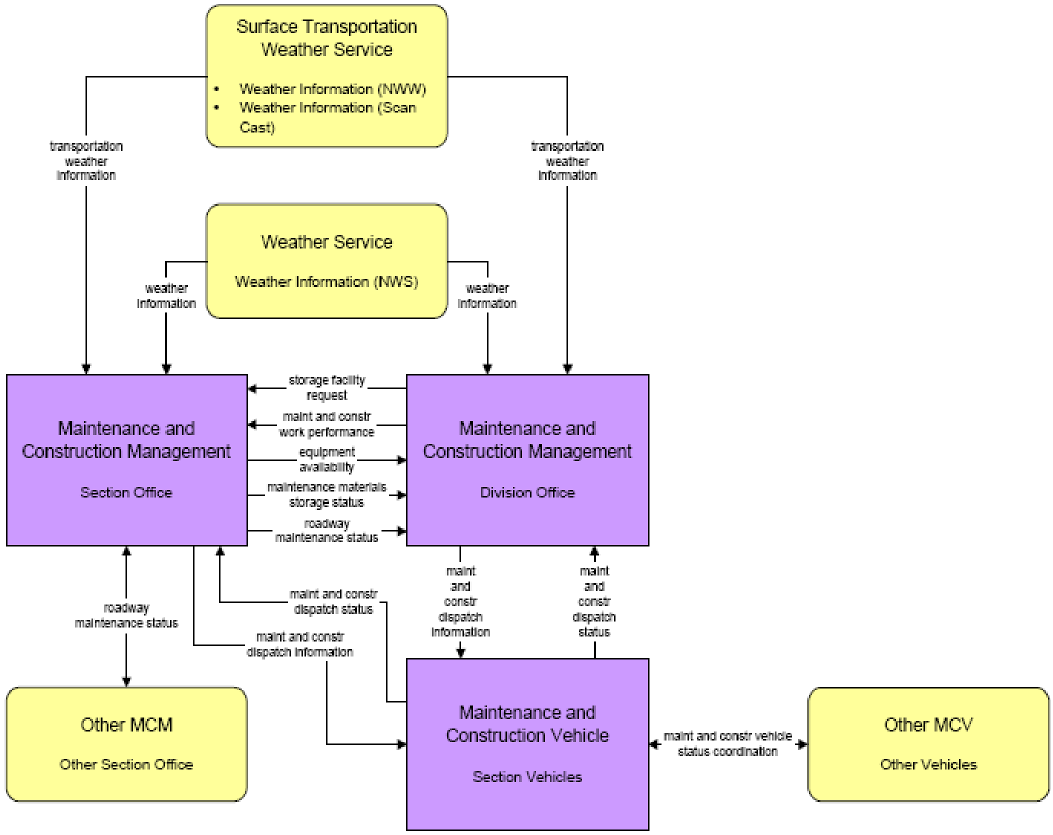

Figure 6-2: Market Package MC06 – Winter Maintenance (20)

Incorporate AVL into Vehicle Procurement Decisions. Since AVL is a vehicle-based system, the use of it may affect vehicle procurement decisions, particularly for vehicles being acquired for use in the location(s) where the pilot test will occur. Specifying that a vehicle be equipped with AVL can ensure that any on-board integration issues – for example, with spreader controllers – are addressed at the outset. It would be advisable that all vehicle specifications state that sensors be compatible with more than one AVL vendor.

Address Remaining Issues before Pilot Test. While AVL is gaining recognition as a technology that can improve winter highway maintenance efficiency, and while the technology has become more robust and failure-resistant over time, a slower approach toward full deployment is still advisable. Should MDT choose to follow the pre-pilot test with a pilot test, institutional and operations issues remain to be addressed, including:

- Who are the personnel who would act on AVL information on a real-time basis? (e.g. section supervisors?) What will those actions entail?
- What will be the use of the data beyond storm events? (e.g. development of alternative treatment strategies, addressing tort claims)
- What suite of sensors should be integrated with the AVL unit?
- What is the optimum frequency of updating vehicle status information?

- What software/modifications are necessary to meet vehicle operator and dispatcher expectations?
- Who will monitor the progress of the pilot test, and what metrics will be used to measure its success?
- Will the AVL data be integrated with traveler information to update that system?
- Are improvements necessary with respect to communications (different cellular provider to improve coverage, satellite)?

Training. Proper usage of any new technology is often dependent on the training that is provided to users of the technology. With respect to AVL, there are two groups of people who will interact with the technology: vehicle operators and dispatchers/maintenance managers. The training needs for each will vary based on how MDT chooses to proceed with the use of AVL.

> *Vehicle Operators* While the managers and operators who were interviewed indicated that the actual use of the AVL system was straightforward, it would be advisable to develop a brief manual detailing the functions and operations required when using the system. The operators who were interviewed were briefly shown limited features of the system by those who installed it and taught themselves how to use the system during the pre-pilot tests. However, if applying AVL to a broader fleet of vehicles with multiple uses and functions, it would be advisable to provide training materials which quickly familiarize the operator with the system. These might take the form of a brief manual which can serve as a quick tutorial on the system, as well as a troubleshooting guide.

> *Dispatchers/Maintenance Managers* There have been significant improvements in the usability of information gathered through AVL, so that familiarity with a Web browser may be all that is required of maintenance managers to view and use the data. However, if the software being used to work with the AVL data has special features, such as the ability to generate reports, it would be advisable to provide guidance to those who will be working with the data in how to utilize such features. The training and expertise required may also need to focus on interpretation of the data rather than actual use of the system.

Benefit/Cost Analysis. In justifying the application of AVL beyond a pilot test, the benefits and costs of such a system will need to be weighed and compared to one another. Since it provides limited geographical coverage, often times not covering all types of winter maintenance strategies within a given region, a pilot test will not give a comprehensive picture of the potential efficiency benefits of AVL related to dispatching and fleet management. However, the pilot test can provide at least a sense of what could be expected in terms of the benefits and costs of a broader scale deployment. A full benefit-cost analysis of AVL would be practical once MDT personnel have developed a broader understanding of the benefits of AVL and have exhausted its capabilities, as well as what the initial and ongoing costs associated with the system are.

6.4 Summary

Interviews with MDT personnel who had worked with the AVL systems on trucks in Bozeman, Boulder and Helena indicated that the technology is viewed as beneficial to both operators and managers. There are some issues with the systems which need to be resolved, specifically, software, communications, and sensor integration. However, the consensus of those who were interviewed was that the deployment of AVL on a broader fleet of MDT vehicles should be pursued.

Based on the results of the pre-pilot test evaluation, it would be advisable to proceed with a pilot test of AVL on a larger fleet of vehicles. The approach that should be considered in accomplishing this test would be to install AVL on a majority or all vehicles in one section. This would allow for a manageable deployment that could be closely observed in order to quantify the specific costs and benefits accrued from the AVL system.

Should the pilot test proceed, a number of recommendations should be taken into consideration. A systems engineering approach should be utilized to ensure a successful planning, design and deployment of a wider scale AVL system. User buy-in, both at the operator and management level, will be critical for ensuring the successful acceptance and utilization of the AVL system starting at deployment. Software issues must be addressed both in terms of the level of detail available to users, as well as functionality. Interchangeability of AVL units between vehicles remains to be examined; this is an area which could provide significant cost savings to MDT should it be proven feasible.

Consideration should be made towards conformity between the AVL system architecture and the architectures of other complementary ITS elements throughout the state. AVL systems should also be taken into consideration when future vehicle procurements are being considered. Such procurements should specify vehicles be equipped with sensors that are compatible with a number of different AVL makes/models.

Institutional issues remain to be addressed for subsequent pilot testing. Namely, issues such as the specification of what data will be collected by the AVL, who will use that data and when, as well as how the data will be used both in a real time and archived manner. Similarly, training issues must be addressed with operators, dispatchers, management and whoever else will be working in some way with the AVL units and/or data. This training does not need to be extensive; rather, it should familiarize users with the systems and software associated with AVL.

Finally, any pilot test pursued by MDT in the future should track and quantify the benefits and costs associated with the AVL system in terms of dollars. This will allow for a determination of the effectiveness of the system in meeting MDT goals, objectives and expectations. It would also provide a means by which benefits and costs for the system could be extrapolated on a statewide basis. The tracking of the financial aspects of AVL would also allow for a benefit-cost analysis to be made. Such an analysis would provide a solid justification for MDT regarding whether a statewide deployment should be pursued.

APPENDIX A: EVALUATION QUESTIONS

A. Installation Detail

1. How many vehicles was the equipment put on?
2. What is the make/model of the vehicle?
3. Where/how was equipment installed on the vehicle?
4. Was any effort made to switch the equipment between vehicles? If so, was it successful?
5. What existing vehicle sensors were integrated with the equipment?
6. Were new sensors added to the vehicle and integrated with the equipment?
7. Was the system upgraded or changed in response to MDT request during the pre-pilot test?

B. Extent of Vehicle Usage

8. How many hours per day on average was the vehicle used?
9. How many miles per day on average was the vehicle used?
10. How did vehicle usage change during the pilot test – increase, decrease, or stay the same?
11. Did having the technology influence vehicle usage decisions?
12. What were typical vehicle activities?
13. Of typical vehicle activities, which ones were automatically recorded by sensors, and which were defined by user input?

C. Extent of Driver Involvement

14. How many drivers used the vehicle with the equipment?
15. How would these drivers' length of experience in MDT maintenance vehicles compare with other MDT personnel – more, less, the same?
16. How much training did drivers receive on the technology?
17. Did drivers help with system installation?
18. Did drivers help with system maintenance (if any)?

D. Extent of Monitoring

19. Who monitored the web page regarding vehicle location?
20. What locations was it monitored from?
21. How often was the vehicle monitored (times per day)?
22. What was the purpose of monitoring?
23. Was the monitoring used to supplement or replace other communication (e.g. radio, cellular phone)?
24. Was the monitoring used for real-time information, historical information, or both?

E. Nature of Communication

25. What media was used for communication between the in-vehicle unit and remote monitoring capabilities?
26. What was the available bandwidth on this medium?
27. What was the updating frequency?

F. Functionality of In-Vehicle Equipment

28. Were there any difficulties experienced in getting the equipment working at the outset?
29. Were there any difficulties integrating the in-vehicle equipment with on-board sensors?
30. Did the equipment stop working at any time in the field? Did it automatically re-start? If not, did the driver attempt to manually re-start it?
31. Were there any maintenance or repair needs for the in-vehicle equipment during the field test?
32. Did the technology's communication system interfere with other vehicle communication systems?
33. Did the equipment have any adverse effects on the rest of the vehicle's operations?
34. Did the equipment operate consistently? (for example, did a lack of cellular communications impact the user interface?)
35. Was the user interface easy-to-use?
36. What parts of the user interface worked best?
37. What parts of the user interface were most challenging?

G. Functionality of Remote Monitoring/Tracking

38. What information was provided through the remote monitoring/tracking interface?
39. What information was not provided but would have been helpful to receive?
40. Did vehicle location information seem to be accurate?
41. Was the vehicle location information precise (for example, highway versus frontage road, which lane of a multi-lane highway)?
42. Would improving the accuracy and precision of location information significantly enhance the usefulness of the technology?
43. Were any breakdowns in communications experienced? If so, what seemed to be the cause, how was it remedied, and how long did it take to resolve the problem?
44. Did the technology receive historic data in proper sequence after communication was restored?
45. Was the user interface easy-to-use?

H. Driver Perspective

46. Do you think this technology could be useful to drivers? If so, how?

47. Do you think this technology interferes with the other tasks you have as a driver? If so, how?
48. Are there ways in which the technology makes your job as a driver easier?
49. The equipment supports transmitting a variety of information back to a remote location. What types of information would it be helpful to send to maintenance managers on a real-time basis?
50. What parts of the technology work well from a driver perspective?
51. What parts of the technology could be improved?
52. Do you think this technology is ready for broader usage on MDT's fleet? If not, why not?
53. Do you think this technology could be useful to maintenance managers? If so, how?
54. Have you received feedback about the technology (positive or negative) from maintenance managers?

I. Monitor Perspective

55. Do you think this technology could be useful to maintenance managers? If so, how?
56. The equipment supports transmitting a variety of information back to a remote location. What types of information would it be helpful to receive from vehicles on a real-time basis?
57. Is it worthwhile to monitor vehicles on a real-time basis?
58. How much time per day do you think would need to be spent monitoring vehicles to make the technology worthwhile?
59. How do you think this technology could save time or money from a maintenance management perspective?
60. What parts of the technology work well from your perspective?
61. What parts of the technology don't work well?
62. Do you think this technology is ready for broader usage on MDT's fleet? If not, why not?
63. Do you think this technology could be useful to drivers in doing their jobs? If so, how?
64. Do you think this technology could help protect driver safety? If so, how?
65. Do you think this technology could be useful in providing traveler information? If so, how?
66. What benefits do you see in having real-time location and activity information on your vehicles?
67. If there were communication breakdowns, how valuable would it be to spend extra money and use satellite communications?
68. How often was location/activity information updated? Is this about right, too frequent, or too infrequent?
69. What types of information would it be helpful to receive from vehicles for archival purposes?
70. Do you think this technology could be helpful in defending against or resolving tort claims? If so, how?

71. What benefits do you see in having archived location and activity information on your vehicles?
72. Have you received feedback about the technology (positive or negative) from drivers?

J. Additional Questions

73. Does the user interface require too much attention from the vehicle operator?
74. Does the in-vehicle unit have any special maintenance requirements?
75. How well does the in-vehicle unit integrate with MDT's in-vehicle sensors and equipment?
76. What benefits do maintenance managers see in having real-time location and activity information on their vehicles?
77. What benefits do maintenance managers see in having archived location and activity information on their vehicles?

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