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Utilization of AVL/GPS Technology Case Study: Colorado Department of Transportation

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16. Abstract

Winter road maintenance accounts for roughly 20 percent of state DOT maintenance budgets. State and local agencies spend over $2.3 billion on winter operations annually. As such, effective winter maintenance operations incorporating smart uses of methods, techniques, technologies, equipment and materials becomes essential. Among various winter maintenance technologies, automated vehicle location (AVL) and global positioning systems (GPS) have been widely used by transportation agencies to monitor vehicle locations and equipment operational status for winter road maintenance operations.

This document is one of the six case studies conducted for the Clear Roads project entitled *Utilization of AVL/GPS Technology: Case Studies*. This case study report summarizes Colorado Department of Transportation's experiences and lessons learned in using AVL/GPS technologies for winter maintenance. The case study took a broad view, examining agencies' decision-making processes; implementation steps; difficulties and lessons learned; and documented benefits and costs for different tiers of AVL/GPS implementation.

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1. Overview of Colorado DOT Winter Maintenance Operations

This section provides an overview of this Case Study report detailing how the Colorado Department of Transportation (CDOT) has implemented Automated Vehicle Locator (AVL) / Global Positioning Systems (GPS) technologies on its winter maintenance vehicles for use in monitoring the operations of snow plow vehicles.

1.1 Case Study Background

This research project is being funded through the Clear Roads pooled fund program to develop Case Study Reports documenting how multiple State DOTs have implemented AVL/GPS technologies to support their winter maintenance programs. While the main function of the system is to provide automated vehicle location tracking for dispatchers and maintenance supervisors, AVL/GPS systems can also provide valuable information on vehicle diagnostics to maintenance supervisors. Furthermore, AVL/GPS systems can be integrated with existing vehicle components used for snow plow operations, such as spreader controllers and plow blades to provide reports to maintenance supervisors on plow usage and material applied by snow plow operators.

The purpose of the Case Study reports is to help other state DOTs make more informed decisions with respect to the implementation of AVL/GPS technology for winter maintenance activities. The case study report is intended to bring to light more nuanced issues related to the use of AVL/GPS technology for winter maintenance. The Case Study report also highlights the types of issues other state DOTs / agencies should consider prior to system procurement, provides guidance for successful implementation of the technology, and serves as a possible template for agencies to get the best value out of different levels their AVL/GPS applications.

In the spring of 2017, a survey was distributed to multiple state DOTs to gather basic, high-level information regarding each agency's level of AVL/GPS implementation, as well as detailed information on the planning, processes, steps, and results observed by agencies with their respective systems. Based on the survey responses, agencies were categorized into the following three levels of AVL/GPS implementation:

- Tier 1: Basic Location Tracking/Monitoring with or without collection of vehicle diagnostic data
- Tier 2: Medium implementation with basic location tracking, with limited additional data collection, equipment integration, and system reporting features
- Tier 3: High implementation with added, more complex data collection, integration, and reporting features

Upon a review of these survey responses, six agencies representing various tiers of implementation were selected to more in-depth interviews and for case studies. The CDOT was categorized into Tier 3 and ultimately selected for further in-depth interviews to gather more information on how their AVL/GPS system is implemented and utilized. CDOT's survey responses are also included in Appendix A of this case study report.

1.2 Agency Characteristics

CDOT is divided into five different regions as well as eight different maintenance sections as illustrated in Figures 1 and 2, respectively. On average, CDOT spends roughly $77 million on winter maintenance each season, and is also responsible for operating and maintaining the statewide heavy vehicle fleet of

snow plows and the light vehicle fleet of other maintenance vehicles including safety service patrol vehicles. The annual operational budget for the combined fleets is approximately $1 billion.

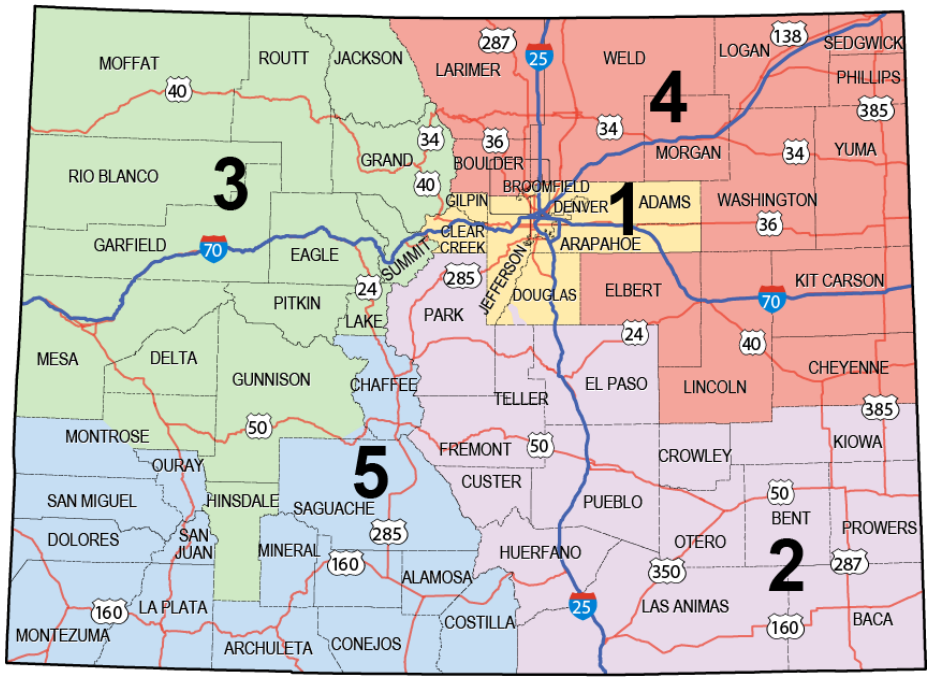

Figure 1. CDOT Regions[1]

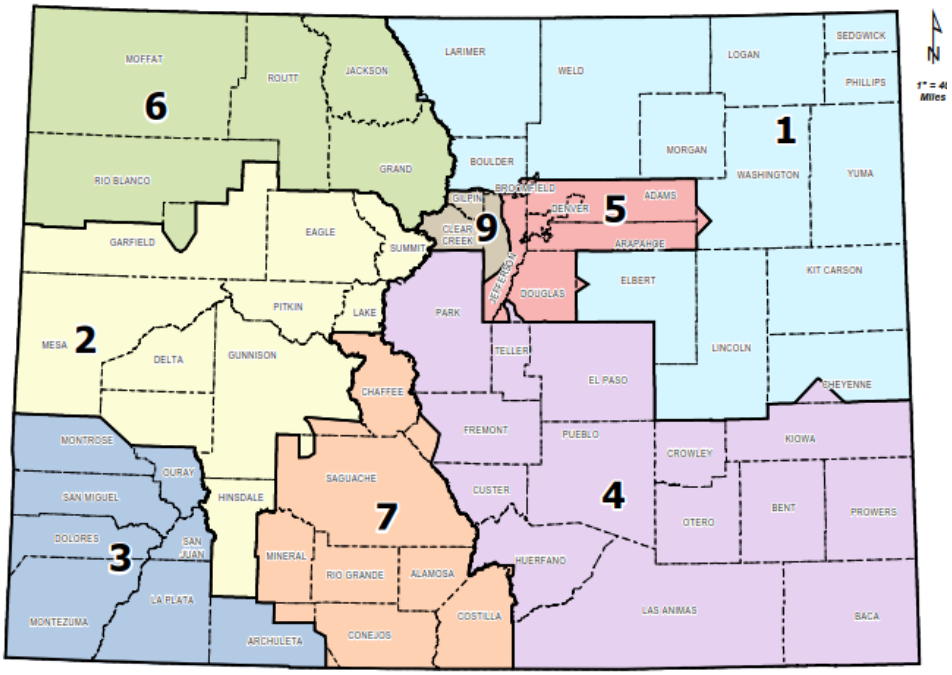

Figure 2. CDOT Maintenance Sections[2]

[1] Source: https://www.codot.gov/about/regions.html
[2] Source: http://dtdapps.coloradodot.info/staticdata/downloads/StatewideMaps/MaintSections_Small.pdf

Within each maintenance section, CDOT winter maintenance staff is structured into the following general positions:

Section Superintendent: Responsible for overseeing winter maintenance activities within the section in terms of response to winter storms. Responsible for allocating some of the section's resources to other sections of the state in the event of large winter weather storms.

Section Supervisor: Responsible for monitoring how multiple vehicle operators within the section have allocated resources to plow roads within a specific area of that section. Reports to Superintendents and communicates with vehicle operators as needed during winter events.

Vehicle Operators: Responsible for overseeing multiple snow plow drivers performing along their assigned snow plow routes within the section.

1.3 Agency Interviews

CDOT staff were interviewed over a two-day period between Jan. 9th and Jan. 10th, 2017 at CDOT offices in Denver, CO. Table 1 lists those individuals that were interviewed for the project.

Table 1. Agency Interview Dates / Times

Staff Interviewed	Date / Time	Subjects Discussed
Kyle Lester, Director of Highway Maintenance **Paul Fox,** Heavy Fleet Administrator **John Lorme,** Region 1 Superintendent **Al Martinez,** Region 1 Deputy Superintendent **David Johnson,** Winter Operations Manager **Chris Volkert,** Equipment Asset Manager **Jeff Tatkenhorst,** Region 9 Highway Maintenance Superintendent **Mike O'Neill,** Region 1 Deputy Director of Maintenance	Jan. 9th / 1:00pm	• Hardware installation • Technology issues and testing • Operations • Maintenance • Implementation and Integration Decisions • Hardware and Software Selection • Data Collection, Utilization and Management • Communications • Implementation Issues • Operations Issues • Procurement • Costs and Benefits • Recommendations and Lessons Learned
Kyle Lester, Director of Highway Maintenance **Ryan Rice,** TSM&O Division Director **John Lorme,** Region 1 Superintendent	Jan. 10th / 10:00am	• Implementation and Integration • Operations Issues • Procurement • Costs and Benefits • Decision Making Process • Data Collection Policy • Recommendations and Lessons Learned

2. Degree of AVL/GPS Implementation

This section of the report outlines the extent to which AVL/GPS technology has been deployed for CDOT winter maintenance operations.

2.1 AVL/GPS Project Background

Prior to 2014, CDOT had previously implemented an AVL/GPS system provided by Iwapi on a number of snow plow vehicles throughout the state. Each maintenance section decided on the quantity of vehicles within that section to equip with the AVL/GPS system. This resulted in some sections having more AVL-equipped vehicles than others. While the system had provided benefits with respect to increased awareness in winter maintenance operations to some maintenance sections, a statewide view of how multiple sections responding to winter storms was not possible with variant levels of implementation in different sections.

In 2014, CDOT conducted a number of AVL/GPS system demonstrations with various vendors. Through analyzing the data gathered from some of the systems, CDOT realized the opportunity to expand the use the systems for not only tracking vehicles but also improving fuel efficiency and fleet utilization and efficiency. The results caused CDOT to reconsider its priorities and determined that a system capable of assisting in fleet management and maintenance operations would be desired. Particularly, CDOT wanted to implement a system to provide the following features:

- An automated feature to reduce administrative burden for pre-trip and post-trip inspection.
- A robust vehicle diagnostic program to support vehicle health monitoring and preventive maintenance.
- A fuel management program to improve fuel efficiency and fleet utilization

Upon review of the results of the demonstrated in late 2014, Colorado DOT executive level management decided to accelerate the installation timeline of AVL/GPS and fleet management technology on CDOT snow plows. CDOT was able to leverage an existing master services agreement already in place between the City and County of Denver and a vendor to procure a system for the heavy vehicle fleet that could perform both vehicle monitoring and automated pre-trip and post-trip vehicle inspections. CDOT used a separate existing contract with another vendor to procure a system for the light vehicle fleet, which did not have the same requirements for pre-trip and post-trip reporting.

Figure 3. CDOT Snow Plow Vehicles

2.2 Size of AVL/GPS Implementation

CDOT maintains a heavy-duty vehicle fleet of approximately 1,800 vehicles, which includes about 1,200 snow plow vehicles. These vehicles are all equipped with an AVL system provided by Zonar Systems that features a ruggedized tablet within the snow plow that provides an interface for drivers to use for logging into their specific route.

CDOT also maintains a light-vehicle fleet of approximately 900 vehicles that are also equipped with a separate AVL/GPS system provided by Verizon NetworkFleet. Light duty vehicles are characterized primarily as those vehicles that do not require a commercial driver's license for vehicle operation and thus do not require pre-trip and post-trip reporting as required by federal regulations.

2.3 AVL/GPS Vendor Solution

CDOT has installed a Zonar System on their approximately 1,200 snow plows throughout the state. The Zonar system is a fleet management system that provides AVL/GPS capabilities in addition to vehicle telematics and electronic vehicle inspection reporting features. The system features an electronic process that allows drivers to complete pre-trip and post-trip reporting that is compliant with the Federal Motor Carrier Safety Administration (FMCSA) regulations.

A separate AVL system provided by Verizon known as NetworkFleet has also been installed on the CDOT light-duty vehicle fleet. Light-duty vehicles do not require the kind of same pre-trip and post-trip reporting functionality, and the Verizon NetworkFleet system meets the overall needs of the light-duty fleet and its operations.

3. Level of System Integration

3.1 Vehicle Hardware

The vehicle hardware components of the Zonar System for CDOT's snow plows include:

- A telematics control unit that captures vehicle GPS location, odometer, fuel consumption and vehicle diagnostic information.
- A ruggedized portable tablet that is capable of performing electronic vehicle inspections, providing two-way messaging, providing visual driver feedback, and integrating and communicating with other on-board technology such as spreader controller, air and temperature sensors, MDSS, etc.

CDOT drivers utilize a pre-assigned ID card and tap it to the tablet to log into the tablet to perform various functions. The tablet also performs a number of other tasks, namely electronic pre-trip and post-trip inspection reporting which has replaced paper reporting that was previously done by CDOT drivers.

Figure 4. Zonar System Tablet Installation Location and Screen

A distinguishing feature of the Zonar system is the yellow pucks that are installed on the vehicle in multiple locations. As part of the pre-trip and post-trip inspection process, CDOT snow plow drivers will physically bring the tablet to each of the areas of the truck with a yellow puck and tap the Zonar tablet to each puck. The software on the Zonar tablet then performs the electronic reporting and inspection process for the driver. All reports are sent electronically through the tablet to a central database for record keeping and identification of issues that may need maintenance on the vehicle.

Figure 5. Example Location Zonar Systems Pre-Trip and Post-Trip Reporting Puck

The Zonar system utilizes two separate antennae on CDOT snow plows as pictured in the Figure 6. The round black antenna on the left of the screen is for GPS positioning, while the other black antenna on the right is for a cellular connection to transmit data from the Zonar AVL/GPS system.

Figure 6. Zonar AVL/GPS System Antennae Locations

Equipment on the CDOT snow plows integrated with the Zonar AVL system includes:

- Plow position sensors
- Spreader controllers for material application rate and type of material
- Air and pavement temperature sensors
- Humidity sensors
- Dashcams (8 units through a pilot project)
- Engine diagnostics

CDOT's snow plows primarily equipped with spreader control systems from Cirus, Certified Power, and Force America. Force America 6100 spreader equipment within the CDOT snow plow is illustrated in Figure 7.

Figure 7. Force America Spreader Controller Location

Figure 8. Back View of CDOT Snow Plows

CDOT has installed a RoadWatch air and pavement temperature sensor near the fuel tank on the driver side of the snow plow vehicle as pictured in Figure 9.

Figure 9. Location of Air and Pavement Temperature Sensor

CDOT also uses the Iteris MDSS to assist in winter maintenance strategies. CDOT snow plow vehicles with the Zonar system receive MDSS weather forecasts and treatment recommendations. Snow plow operators can bring up the interface through a tap of the button on the right portion of the home screen. Drivers are still provided the independence to determine the level of treatment based on existing conditions and their overall judgement, given the diverse geography within the state that can make it difficult for weather forecasting services to predict the duration and intensity of winter storms for specific regions, areas or corridors.

CDOT is conducting a pilot study on using friction sensors in lieu of pavement/air temperature sensors. CDOT felt that pavement friction provides a better picture on road surface conditions. Upon successful testing, CDOT plans to integrate friction sensors with the AVL system and expand the installation statewide.

Finally, CDOT is currently conducting a project that may simplify the integration work required between in-vehicle components. The project is being conducted under CDOT's RoadX program that provides funding for new and innovative transportation projects in the state. Under the project, Verizon is partnering with two separate companies – Cradlepoint and Panasonic – to implement a system that would communicate real-time images and video from snow plow vehicles to a central office that could view roadway conditions and communicate back to the vehicle through in-vehicle equipment. Cradlepoint is providing an in-vehicle wireless communications router that is wirelessly connected to an in-vehicle dashcam provided by Panasonic, along with other in-vehicle equipment such as spreader controllers and temperature sensors.

The overall goal of the pilot project is to send and receive all data through the Cradlepoint router and improve the efficiency of in-vehicle communications. Depending on the overall success of the project, CDOT may roll it out on a larger scale in future years.

3.2 System Software and Interface

The main software interface provided by Zonar is known as Ground Traffic Control, which is used by CDOT Administrators to assign other CDOT staff different levels of access to the software interface. This includes supervisors, mechanics, and drivers as users of the software to perform various functions. Ground Traffic Control is a web-based software interface. It allows users to view real-time analytics, generate reports, and configure alert features.

3.3 Vehicle-to-Center Communications

Zonar System works exclusively with AT&T as a cellular network provider. Although different cellular providers may have better coverage in other areas of the state, CDOT noted that some areas of the state are difficult in terms of elevation and climate, which are not conducive to the use of any kind of cellular network coverage.

4. System Decision Making Processes

4.1 Level of Management Involved

Management from CDOT Division of Transportation Systems Management & Operations and Division of Highway Maintenance was supportive and engaged in the development and implementation of an AVL/GPS program for the CDOT snow plow vehicles from the beginning.

In 2014, CDOT began the preparation of a Request for Proposals (RFP) document for a statewide AVL/GPS procurement to replace the AVL/GPS system installed previously. The overall goal of the procurement was to select one vendor to supply hardware and software for both the CDOT heavy vehicle fleet and light vehicle fleet. Improving the overall efficiency of fleet management and maintenance operations was the main focus for CDOT in preparing the RFP.

CDOT executive management expressed a desire to expedite the implementation of a system that was capable of achieving CDOT's main goal of improving fleet management and utilization efficiency and fuel

efficiency. CDOT was able to leverage an existing master service agreement from the City and County of Denver to procure an AVL/GPS system for CDOT snow plow vehicles within a short period of time.

4.2 Factors Considered

The implementation of an AVL/GPS system on the entire CDOT fleet was driven by a desire to implement a system that could assist in not only winter maintenance operations but also overall fleet management. The ability to meet the vehicle inspection requirements as defined by the FMCSA and CDOT was a key decision factor for the system. CDOT's primary needs for such a system included:

- An automated feature to reduce administrative burden for pre-trip and post-trip inspection.
- A fleet management program with robust vehicle diagnostic features to support vehicle health monitoring and preventive maintenance.
- A fuel management program to improve fuel efficiency and fleet utilization
- Abilities to collect data to assist in performance monitoring and reporting.

As noted in 4.1, an accelerated implementation timeline was desired by the CDOT executive management. The ability to use existing procurement vehicles to deliver a system that would meet CDOT desired system features and functionalities was also a factor considered in the procurement process.

CDOT noted that the needs and goals for the AVL/GPS program were not clearly identified initially. CDOT staff now have a better understanding of their needs through the implementation and utilization of the system.

5. Data Collection and Management

5.1 Data Collection

Data collected by the CDOT AVL/GPS system on snow plows include:

- Plow position
- Material application rate and type of material used
- Pavement temperature and air temperature
- Humidity
- Dashcam images
- Engine diagnostics and alerts
- Inspection data

In addition to vehicle location data, the Zonar AVL/GPS system collects engine idle time, vehicle speed, vehicle health and diagnostics, inspection data and timestamps. Vehicle inspection is performed by the operator pre-trip. The operator will inspect each area of the vehicle which is marked with a yellow puck with an embedded RFID tag. The operator will scan the tag and respond to the inspection criteria using the tablet. Upon inspection, the operator will place the portable tablet into the vehicle mount where inspection information is transmitted to the software interface server via cellular transmission. Data required for the Federal Motor Carrier Safety Administration (FMCSA) compliance were retained for six months, per FMCSA requirements.

All data collected through the AVL/GPS system were stored on the Ground Traffic Control server. Data relevant to winter maintenance operations were also transmitted to and stored in Iteris MDSS. CDOT did not save any data generated from those systems on its server due to liability concerns.

5.2 Data Accuracy

CDOT staff noted that the Zonar AVL system, like many other AVL/GPS systems, is reliant on third-party mapping sites, such as Google, for integrating maps into its software interface. Inaccuracy in the mapping database may trigger false alerts. For example, speed compliance alerts are generated for snow plow vehicles traveling exceeding certain thresholds. If a snapshot of the vehicle location is taken while that vehicle is traveling 40 MPH but crossing over or under a road with a 20 MPH speed limit, a high-speed alert will be generated and sent to a superintendent. CDOT staff have learned to spot these types of errors in the system over time.

CDOT staff did not note other issues with data accuracy related to the AVL/GPS system. However, CDOT noted there were data reliability issues with the fleet management system. One of the issues noted by CDOT staff was vehicle inspection accuracy. The issue was most likely related to human interfaces with the inspection process and reporting. CDOT continues to improve the reliability of the data through training and process improvements.

5.3 Staffing and Resources

No staffing or resource issues for data collection and management were identified by CDOT.

5.4 System Data Usage

CDOT's system is a fleet management system with an AVL/GPS vehicle tracking/monitoring capability. CDOT uses the system data in four board categories:

- Vehicle health monitoring
- Automated fuel control through exception reporting
- As mobile observations for collecting winter operations data
- Snow plow location tracking

CDOT staff use the Ground Traffic Control interface to monitor and generate reports for vehicle idle time, vehicle mileage, vehicle health and error codes, etc. CDOT staff spoke highly of the automated alert features that can be generated through the Zonar software interface and sent automatically via email to CDOT superintendents. For example, automated alerts and reports on excessive vehicle idle times can be generated. The alert and reporting features helped to correct excess fuel consumption and reduce maintenance costs. In addition, vehicle diagnostic information, along with the inspection data, is used to identity recalls and faults, which improves awareness and results in more timely repairs.

Zonar system's fuel exception reports provide information on fuel purchase transactions and generate alerts for excessive transactions on fuel and other fluids such as washer fluid, motor oil, and car wash, and out of state fuel transactions, etc. Unusual activities will generate exception reports that prompt CDOT for investigation.

The system provides CDOT maintenance staff the ability to track and monitor vehicle locations and maintenance activities in real-time. CDOT uses the system data to track material usage and perform operational analysis. CDOT maintenance staff can also respond to executive management's inquiry regarding asset locations and winter maintenance responses and strategies in a timely manner.

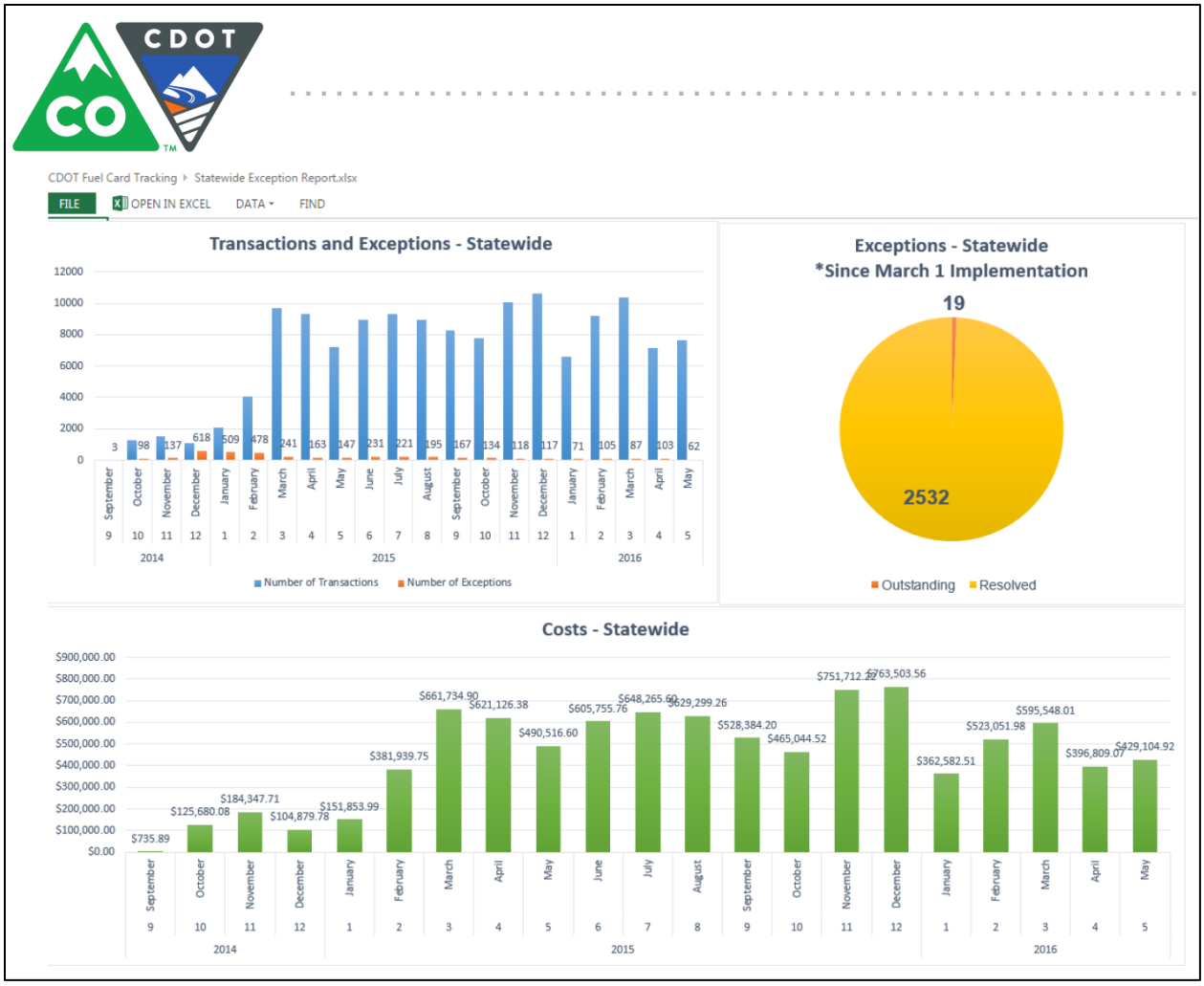

Figure 10. CDOT Fuel Exception Reporting Dashboard

Prior to 2014, CDOT procured an AVL/GPS system and the MDSS services under a single contract. Since 2014, the MDSS services have been procured by CDOT under a separate contract with Iteris. CDOT snow plows are reporting location specific weather data via the AVL/GPS system to MDSS. CDOT also has a number of fixed weather stations providing air and pavement temperatures to MDSS. Road condition information gathered via snow plows and weather stations provides near real-time information to the maintenance staff. Together with the weather forecasts from the National Weather Services and MDSS, the road condition information provides improved situational awareness to maintenance superintendents and supervisors, allowing for better resources allocation and winter maintenance strategies.

CDOT allows snow plow operators the independence to determine the level of roadway treatment based on observed conditions, their experience and inputs from supervisors. The MDSS treatment recommendations are used as general guidelines. This is due to that it is challenging for MDSS weather forecasts to accurately predict the duration and intensity of snow events given that the unique topology within the state could result in differing climates within a region or along a corridor.

As mentioned previously, CDOT is conducting a pilot study on using friction sensors in lieu of pavement/air temperature sensors. Upon successful testing, CDOT plans to integrate friction sensors

with the AVL system and expand the installation statewide. Data from friction sensor will be input into MDSS.

CDOT plans to establish a performance management program to systematically evaluate and document the benefits of the AVL/GPS and fleet management system. A performance dashboard was highly desired. CDOT noted that due to lack of sufficient data to measure improvements, cost savings and other measurable improvements have not been fully assessed. CDOT indicated likely performance measures and goals would include:

- Reduction in equipment down time
- Increase in reliability
- Reduction in repair costs
- Fuel savings
- Road surface friction

5.5 Agency Policy and Agreements for Data Sharing

CDOT has recently provided the location of snowplows on a public facing website CoTrip to increase the public transparency of winter maintenance operations. The CoTrip webpage for snowplow locations is available at: http://www.cotrip.org/snowplow.htm#/snowplow.

The locations of the snow plows are made available through the sharing of the Application Programming Interface (API) by Zonar with CDOT, so that CDOT can request latitude / longitude coordinates of vehicles and display them on a map of the state. Bread crumb trail points on where snow plows have been is also shown when clicking on a snow plow icon on the map. Snow plows would disappear from the public facing website after 15 minutes of inactivity (i.e. when the ignition is turned off). CDOT was still exploring different solutions to determine inactive vehicles.

The AVL/GPS system data is also shared with MDSS through a contract agreement with Iteris.

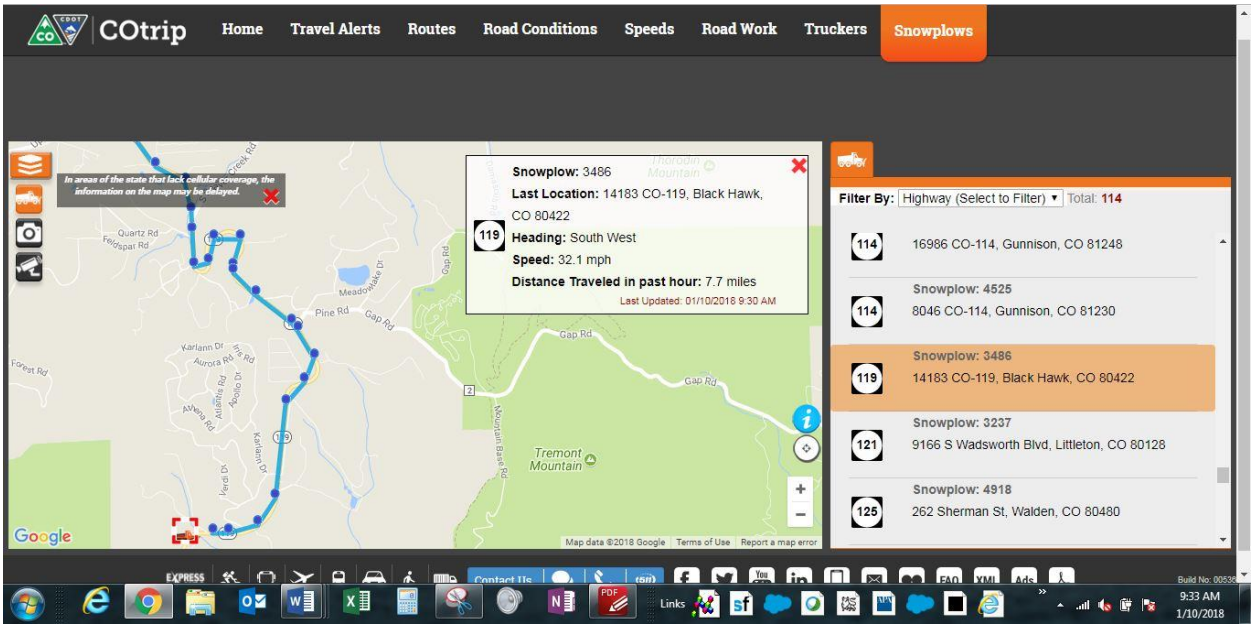

Figure 11. CDOT CoTrip Webpage for Snowplow Locations

6. System Implementation Process

6.1 Implementation Steps

CDOT began the preparation of a Request for Proposals (RFP) document for a statewide AVL/GPS procurement in 2014. The overall goal of the procurement would be to select one vendor to supply hardware and software for both the CDOT heavy vehicle fleet and light vehicle fleet. Improving the overall efficiency of fleet management and maintenance operations was the main focuses for CDOT in preparing the RFP.

Also in 2014, CDOT had been conducting a number of AVL/GPS system demonstrations with various vendors that were interested to demonstrate their system's functionalities to CDOT in advance of any future procurement. AVL vendors included Zonar and Verizon NetworkFleet among others, provided their systems for demonstration free of charge.

These demonstrations provided insight into the capabilities of the current systems and how they could achieve CDOT goals and objectives related to fleet management and winter maintenance. For example, early results from the demonstrations revealed that some vehicles had been idling with engines running for excessive periods of time, resulting in both excess fuel consumption and increased maintenance costs. The awareness of the issue resulted in the prevention of those instances in future maintenance operations, resulting in a large amount of operational savings to CDOT. This prompted CDOT to reconsider their priorities and realize an opportunity for improving fleet and fuel efficiency.

Upon review of the various systems being demonstrated in late 2014, Colorado DOT executive management decided to accelerate the installation timeline of AVL/GPS technology on CDOT snow plows beyond the previously planned timeline as part of the RFP process. Colorado state law allowed CDOT to leverage an existing master services agreement already in place between Zonar and the City and County of Denver, which enabled CDOT to procure a Zonar AVL system for the heavy vehicle fleet. CDOT used a separate existing contract with Verizon to procure a NetworkFleet system for the light vehicle fleet, which did not have the same requirements for pre-trip and post-trip reporting.

Although the procurement process resulted in two different AVL/GPS systems, CDOT was able to meet the accelerated timeline and deploy the Zonar AVL system on its heavy vehicle fleet for use in 2015.

The AVL equipment was installed by a truck building company that had existing agreement with CDOT for up-fitting CDOT vehicle chassis and other equipment. A pre-build meeting was conducted with the truck building company and Zonar to ensure installation standards. CDOT did not experience any issues with the AVL equipment installation. The truck building company was also responsible for integrating the AVL equipment with other in-vehicle equipment. CDOT encountered issues with integration of the AVL equipment and spreader controllers, and those issues are discussed in Section 8.3.2.

Zonar provided a training session at the beginning of the system rollout. Training to CDOT staff at an administrative level on the software side of the system was also provided. Upon system implementation, CDOT continues providing training to snow plow operators on the system on an annual basis. CDOT acknowledged that more training up front would better facilitate buy-in and proper use of the system. In addition to the annual training, CDOT plans to conduct traveling road shows through the state to provide additional training and raise awareness in the future. CDOT would also like to perform additional training to managers, superintendents and supervisors to help them with interpreting reports and maximizing their knowledge of the system.

6.2 Procurement Methods and Process

The City and County of Denver entered into an agreement with Zonar in 2013 to provide AVL/GPS technology in street maintenance and solid waste vehicles. As noted previously, Colorado state law allowed CDOT to leverage an existing master services agreement already in place between Zonar and the City and County of Denver, which enabled CDOT to procure a Zonar AVL system for the heavy vehicle fleet that could perform both vehicle monitoring and automated pre-trip and post-trip vehicle inspections. CDOT used a separate existing contract with Verizon to procure a NetworkFleet system for the light vehicle fleet, which did not have the same requirements for pre-trip and post-trip reporting. Although the procurement process resulted in two different AVL/GPS systems, CDOT was able to meet the accelerated timeline and deploy the Zonar AVL system on its heavy vehicle fleet for use in 2015 by using the City and County of Denver's existing agreement.

6.3 Procurement Documents

The City and County of Denver identified a list of core requirements for its AVL/GPS technology procurement. The procurement packages requested vendors to respond how their proposed solutions would meet those requirements. City's core requirements along with Zonar's responses are included in Appendix B.

7. System Benefits and Costs

7.1 Implementation Costs

Unit costs of the CDOT AVL/GPS system components for heavy vehicle fleet is provided in Table 2. The AVL/GPS package provided by Zonar included the AVL/GPS hardware for vehicle tracking and data collection, external GPS antennae, tablets, and the Ground Traffic Control software interface. Installation costs are also included in Table 2. Costs for MDSS procurement and integration are not included.

Table 2. CDOT AVL/GPS System Implementation Costs

Items	Unit Cost
Vehicle Tracking and Management Hub	$215.96
External GPS Antenna, including installation	$10.00
2020 Tablet with EVIR App and Cradle	$584.92
One-Time Activation Charge per Unit	$25.00
Vehicle Installation	$127.00
Software – Ground Traffic Control Application Initial Start Up	$24.03
Per Vehicle Total	**$986.91**

7.2 Costs for Operations and Maintenance

The annual service costs for the AVL/GPS system are summarized in Table 3. The costs include annual service, updates and customer service for the EVIR system and Group Traffic Control interface with unlimited users.

Table 3. CDOT AVL/GPS System Annual Service Costs

Items	Unit Cost
Ground Traffic Control Application	$311.88
2020 EVIR CSA Inspection System Maintenance	$84.00
2020 NAV & Messaging	$96.00
Per Vehicle Total	**$491.88**

7.3 Benefits

CDOT's AVL/GPS system implementation was a component of an overall fleet management system. CDOT performed a preliminary evaluation on return on investment of the fleet management system based on data gather through the 2015-2016 winter. As shown in Table 4, the overall savings from utilizing the system were significant. CDOT noted the savings in fleet maintenance and fuel consumption alone could cover the system implementation costs.

Table 4. Estimated Return on Investment of CDOT AVL/GPS System

Savings*	Minimum Reduction/Savings	Maximum Reduction/Savings
Fleet & Maintenance Savings	$932,577	$1,885,057
Utilization Based Savings	$262,520	$822,040
Fuel Savings	$160,938	$472,532
Compliance / Risk Management	$56,124	$78,624
Labor Based Savings	$349,716	$621,424
Total	**$1,761,875**	**$3,879,677**

** Based on 766 heavy vehicles*

Benefits identified by CDOT staff include:

- The system provides increased situational awareness to CDOT staff which helps improve winter maintenance operations.
- System generated maintenance alerts helps with proper diagnostic and repairs. This in turns saves money and promotes timely repairs.
- Alerts on long vehicle engine idle time helps reductions in idle time, fuel consumption and negative emission impacts.
- The system has abundant reporting features that help not only in situational awareness but also in improving resource management, staff management and operational efficiency.
- The system streamlines vehicle inspection process, resulting in improved maintenance process and eliminating paperwork errors.
- The system had positive impact on driver behaviors such as promoting speed compliance and minimizing improper use of the equipment.
- The system has been used to protect drivers from false/erroneous accusations by the public.

Among the greatest benefits of using the AVL/GPS and MDSS systems from field operations perspective is an increase in situational awareness. The increase situational awareness improves overall winter maintenance operations efficiency. CDOT staff also spoke highly of the automated alert features that can be generated through the Zonar software interface and sent automatically via email to CDOT superintendents. For example, automated alerts and reports on excessive vehicle idle times can be

generated. Other alerts can be generated from the Zonar system such as inspection defects; missed, incomplete and unverified inspections; last communications with GPS; excessive speeds; etc. The alert and reporting features helped to correct excess fuel consumption and reduce maintenance costs.

8. System Issues and Challenges

8.1 Institutional Issues

Although training was conducted at the beginning of the program, CDOT felt that more training up front would facilitate better buy-in and proper use of the system. Timing of conducting various levels of training was also crucial. It was noted that CDOT staff at an administrative level on the software side of the system were still learning the system at the time when supervisor and operator training sessions were carried out. CDOT staff providing the training were unable to demonstrate the smooth usage and operations of the software, which resulted in speculation in system usefulness and user resistance.

There was some reluctance among CDOT snow plow operators to accept the AVL system given concerns about the system potentially being used for disciplinary purposes. CDOT gained buy-in from operators over time as they realized that the AVL system could be used to protect them from claims of damage caused by CDOT snow plows. CDOT noted that to gain operators buy-in, support from supervisors as well as training to supervisors for proper use of the system is critical. When communicating with operators, it is essential to focus on communicating the benefits (such as for their protection from claims and personal safety) and making it clear that the system is not a tool for micro management or disciplinary actions.

8.2 Technology Issues

Zonar's previous clients included commercial vehicle fleets and other agency fleets, but they were relatively new to winter maintenance operations performed by public agencies. As such, CDOT has been working with Zonar to address specific needs and issues related to winter maintenance operations that were new to Zonar. Such issues included: integration with various spreader controllers, SAP software and dashcam, as well as development of specific reports for operations and performance management. CDOT was encouraged by the willingness of Zonar to work with CDOT to perform additional integration of their AVL system with other systems, namely vehicle spreader controllers and the SAP system CDOT uses for employee timesheets and issuing work orders on items requiring maintenance, such as roadside guardrail or other roadway assets managed by CDOT.

The integration of the Zonar system with Cirus spreader controllers was more challenging than CDOT originally expected. The integration process between Zonar and Cirus was initially hampered by the length of time required for both sides to come to an agreement on a Memorandum of Understanding (MOU) that would protect the intellectual property of both companies. The challenge was eventually resolved with the assistance from the truck building company that CDOT utilizes for up-fitting the vehicle chassis and all equipment ordered by CDOT. The truck building company brought representatives of both Zonar and Cirus together to determine how best to complete the integration process. The truck building company facilitated integration testing of the communications between the systems and accelerated completion of the integration that otherwise would not have been possible. At the moment, Cirus controllers have been integrated with Zonar on about 200 snow plow trucks.

Delays to the integration of the Zonar system with SAP arose from the length of time required to develop MOUs that were requested from legal teams of both Zonar and SAP. The MOUs were requested to protect the intellectual property developed by both companies from potentially being shared with

competitors through the exposure of those systems to each other. Although discussions had taken place between Zonar and SAP, CDOT eventually instructed Zonar not to proceed further with MOUs given the length of time it has taken to come to an agreement between both companies.

CDOT noted that these and other challenges with Zonar have caused CDOT to re-assess how they should proceed with AVL/GPS technology on both their heavy and light vehicle fleets in the future. With the current contract with Zonar expiring in 2019, a new RFP is likely to be developed in 2018 that will present a refined set of CDOT objectives with respect to AVL/GPS technology and integration with other systems for winter maintenance operations and fleet management. The RFP would likely place the responsibility of AVL/GPS system integration with other systems with a single vendor that would be accountable for the overall installation that would achieve CDOT's desired level of system integration.

It was noted that Zonar Systems works exclusively with AT&T cellular network. Although different cellular providers may have stronger coverage in other areas of the state, CDOT noted that some areas of the state have coverage gaps due to unique and challenging topology, which are not conducive to the use of any kind of cellular network coverage.

8.3 Procurement and Implementation Issues

8.3.1 Procurement Issues

CDOT did not experience issues related to the Zonar system procurement process. As noted previously, Colorado state law allowed CDOT to leverage an existing master services agreement already in place between Zonar and the City and County of Denver, which enabled CDOT to procure a Zonar AVL system for the heavy vehicle fleet within a short timeframe. This arrangement allowed CDOT to meet a desired accelerated timeline and deploy the Zonar AVL system on its heavy vehicle fleet for use in 2015.

8.3.2 Implementation Issues

The integration between the Zonar system and Cirus spreader controllers was more challenging than initially expected by CDOT, as discussed previously. Other than the integration challenges noted in Section 8.2, CDOT felt the implementation was smooth.

In terms of the Zonar AVL equipment installation, CDOT noted that a pre-build meeting was conducted with the truck building company to ensure installation standards. CDOT did not experience any issues with the AVL equipment installation.

CDOT staff noted that cellular coverage in some areas of the state still has some unacceptable gaps in coverage where snow plows do operate. CDOT has noted that this is a drawback to the reliance on cellular technology, which may cause long periods of time between updates on vehicle location and other information. CDOT has noted this on its public facing webpage so that the general public is aware of the potential delay in the update of vehicle locations.

It was noted that Zonar Systems works exclusively with AT&T as a cellular network provider. Although different cellular providers may have stronger coverage in other areas of the state, CDOT noted that some areas of the state are difficult in terms of elevation and climate, which are not conducive to the use of any kind of cellular network coverage.

8.4 Operations and Maintenance Issues

One issue that CDOT experienced in the early stage of system operations was the high frequency of alert notifications to CDOT maintenance staff. The alerts were triggered as the system identified vehicle diagnostic issues and prompted staff for maintenance actions. When an issue was detected, an email

notification was sent to maintenance supervisors and mechanics. Alerts for the same issue would be generated and sent to maintenance staff repeatedly if the issue had not been corrected. As a result, a huge amount of notifications were generated and sent to CDOT maintenance staff regardless if the issues were newly detected or previously communicated. To reduce the amount of notifications yet help users keep tracking of issues need to be resolved, CDOT worked with Zonar to reduce the alert communication frequency and create a weekly consolidation report with all vehicle diagnostic issues. Major diagnostic issues are assigned a red flag and email notifications are sent to mechanics whenever they are detected. Mechanics are required to address red flag issues, and progress of completion is tracked until completion

CDOT recognized the Zonar system has a lot of potential and capabilities. They acknowledged that CDOT has not utilized the system to its full capabilities and continued exploring its potential and capabilities. However, the lack of staff has been a key challenge that hindered CDOT's ability to explore the system capabilities within a desired timeline.

CDOT did not report any maintenance issues with the system. On rare occasions when the AVL hardware or components failed, defected items were repaired or replaced under warranty.

One of the lessons learned from superintendents and managers is for the agency to best understand what they want from the AVL system to meet their agency's needs. CDOT noted that the needs and goals for the AVL/GPS program were not clearly identified initially. CDOT staff now have a better understanding of their needs through the implementation and utilization of the system. CDOT also emphasized the importance of training and noted that properly trained personnel resulted in good results and better usage of the system.

9. Lessons Learned

The following lessons learned are offered based on the CDOT case study.

- The needs and goals of an AVL/GPS program should be identified clearly in the early stage. Clearly identified needs and goals help develop system requirements and procurement document. They also help agency establish realistic expectations for the program. Past experience and experience by other agencies with implementation and utilization of AVL/GPS systems help in needs and goals identification.
- Automatic alerting features on vehicle diagnostic issues may create burdens to maintenance staff if the alerts are communicated with higher frequency. Agencies can work with maintenance staff and vendors to identify an approach for effective communication yet ensuring timing completion of corrective actions.
- Properly trained staff results in better usage of the system. Better usage of the system produces better quality data. Training should be provided to all levels of users, including maintenance superintendents, supervisors, snow plow operators, mechanics/technicians, and system administrative staff (for software interface user management).
- Adequate training should be provided prior to system implementation. More training is beneficial and should be considered. Training not only promotes proper use of the system, it also facilitates buy-ins.
- If agency staff/trainers are utilized to provide training to system users, it is important that the trainers receive sufficient training and have adequate knowledge of the system and its operations.
- The integration between an AVL/GPS system and other technology in snow plow vehicles (such as spreader controllers and sensors) may not be straightforward. Agencies should anticipate issues and challenges, and be prepared to work with AVL/GPS vendors and other equipment manufacturers

on the integration. Performing research and gathering information from other agencies and manufacturers helps agencies to better understand potential issues and solutions. It also helps in system and procurement requirements definition.

Appendix A Survey Response

Name	Title	Agency	Phone	Email
Kyle Lester	Director of Highway Maintenance	Colorado DOT	303-512-5208	Kyle.lester@state.co.us

AVL/GPS System	
1.Are you currently using an AVL/GPS system to automatically collect data for your winter maintenance operations?	Yes
2.Does your agency have plans to implement or expand AVL/GPS technologies on your winter maintenance vehicles in future years?	Yes
If yes, please describe the anticipated implementation or expansion:	Colorado is 100% deployed. We will continue to improve the reliability of the data in Fleet operations, Highway operations, and our winter operations. Focused mostly on integrating data sets into all of our operating systems and processes. In addition we are looking at improve technology and added additional sensors.
3.Approximately how many vehicles are in your winter maintenance fleet?	1200
4.How many of your winter maintenance vehicles are equipped with AVL/GPS technology?	1200
5.Who is your contracted AVL / GPS vendor?	Zonar and Network fleet
6.What modem / GPS brand(s) does your agency utilize?	Zonar and Network fleet
7. Who performed the installation of your AVL/GPS system? Was it the system vendor or DOT agency staff?	System Vendor
8. Who is maintaining the AVL/GPS system after installation? Is there a maintenance contract with the system vendor, or is it maintained in house by DOT agency staff?	DOT Agency Staff
9.Were there any issues with the installation of your AVL/GPS system?	Yes
If yes, please describe:	Minor issues due to Regional preferences.
Integration	
10.What auxiliary equipment and sensors are installed on the vehicles and integrated with your AVL system? Please check all that may apply.	
Spreader controller	Yes
Plow controller	Yes
Plow position sensor	Yes
Mobile data terminal/computer	Yes
Pavement temperature sensor	Yes
Air temperature sensor	Yes
Humidity Sensor	Yes
Dashcam	Yes
Other (describe below)	No
If you indicated "Other" in the question above, please describe below.	Dash camera is coming. We had cameras with our previous sytem but when we changed vendors we had to work through a new solution.

Name	Title	Agency	Phone	Email
Kyle Lester	Director of Highway Maintenance	Colorado DOT	303-512-5208	Kyle.lester@state.co.us
11.Have you experienced difficulty integrating above equipment or sensors into your AVL/GPS system? If so, please describe.			Yes, cameras have been an issue due to data charges. Integrating sensors due to licensing agreements between vendors.	
12.What brand(s) of spreader controller does your agency use?			Cirus controllers.	
Data Management				
13.What types of data other than vehicle location are being captured with your AVL system? What is the data capture frequency? Please check all that may apply				
Plow position			Less than 5 min.	
Material application rate			Less than 5 min.	
Type of material applied			Less than 5 min.	
Mobile data terminal messages			Less than 5 min.	
Pavement temperature			Less than 5 min.	
Air temperature			Less than 5 min.	
Humidity			Less than 5 min.	
Surface friction			Less than 5 min.	
Dashcam			Less than 5 min.	
Engine diagnostics			Less than 5 min.	
Other, please describe below			Not captured	
If you indicated "Other" above, please describe below.				
14.Where does the AVL system data reside after it is transmitted from the vehicles?			Vendor servers.	
15.Do you use the AVL system data to perform any of the following items? Please check all that may apply.				
Vehicle location tracking / fleet monitoring			Yes	
Route/operational planning and optimization			Yes	
Material usage tracking and analysis			Yes	
Treatment recommendations			Yes	
Providing data to a maintenance decision support system (MDSS)			Yes	
Operational analysis, evaluation and performance reporting			Yes	
Collection of vehicle diagnostic data			Yes	
Sharing of vehicle location through agency traveler information webpage			Yes	
Road weather condition reporting			Yes	
Staffing analysis and management			Yes	
Other, please describe			No	
16.Does your agency share data collected through the AVL system internally with other divisions or offices within the department?			Yes	
If yes, what do those divisions/offices use the data for (e.g., operational analysis, planning, performance reporting, budgeting, etc.)?			Public Relations for location information.	

Name	Title	Agency	Phone	Email
Kyle Lester	Director of Highway Maintenance	Colorado DOT	303-512-5208	Kyle.lester@state.co.us
17.Does your agency share AVL system data externally with other public agencies?			No	
18.Does your agency share AVL system data externally with any private agencies, such as private weather service providers?			Yes	
If yes, please describe what data is being shared with these other agencies.			Iteris for MDSD and PikAlert	
19.Does your agency share AVL system data with the general public?			Yes	
If yes, please describe what AVL system data is being shared with the general public.			Location information is posted on our public facing website	
Communications				
20.What type of communications does your AVL/GPS system use to transfer data? Please check all that apply.			Cellular network, Wi-Fi	
21.How would you rate the coverage of your communications system?			Covers most of maintenance areas with unacceptable gaps	
Operational and Procurement Aspects				
22.Do you have a distributed approach to tracking vehicle locations (i.e. by district or geographic boundaries)? Or is there a centralized method of tracking all vehicles within the agency boundaries? Or do you use a mix of both approaches?			Both	
23.Is your agency's AVL system equipment provided by a single vendor or multiple vendors?			Multiple vendors	
24.Does your agency utilize a web-based interface accessible over the internet to access operational information?			Yes	
If yes, how is the data that can be extracted from the interface utilized to improve upon winter maintenance operations?			Location data, material data, road condition reporting.	
25.Does your agency extract data from the AVL / GPS system and / or web-based interface for separate analyses to improve upon winter maintenance operations after winter weather events?			Yes	
If yes, please describe how the data is utilized by your agency.			Road condition reporting for performance on a storm by storm basis.	

Name	Title	Agency	Phone	Email
Kyle Lester	Director of Highway Maintenance	Colorado DOT	303-512-5208	Kyle.lester@state.co.us
26.What was the procurement process used for your AVL/GPS system (i.e. Request for Proposals (RFP), Invitation for Bids (IFB))?			Request for Proposals (RFP)	
Was a demonstration of the system included as part of the evaluation of respondents?			Yes	
27. Does your agency move your AVL/GPS vehicle units to different trucks or equipment for use during summer maintenance operations?			No	
Costs and Benefits				
28.Do you have cost information associated with your AVL system?			Yes	
29.What cost information would you be able to provide?				
AVL equipment costs			Yes	
Installation & integration costs			Yes	
Costs associated with on-going operations (staffing, communications, software licensing, etc.)			Yes	
Maintenance costs			Yes	
Other costs, please describe				
30.Has there been any formal or informal benefits assessment or benefit-cost analysis performed on your AVL system and/or other technology for winter maintenance operations?			Yes	
Deployment Experience				
31.Please share any general lessons learned in the deployment of AVL/GPS technologies below that would assist agencies considering a future deployment of these technologies.			Be prepared that technology is dated. With the lead time to deploy and the time it takes to be accepted by the employees, by the time the system is fully operational there will be a new and improved system out on the market.	
32.May we contact you with follow-up questions about your system(s)?			Yes	

Appendix B City of Denver AVL/GPS System Core Requirements

B.2 VENDOR PROPOSED SYSTEM / EQUIPMENT SECTION:

Indicate description of proposed equivalent to the City's core requirements below. Attach and Reference additional materials as required.

Electronic Vehicle Inspection Report System (EVIR) OR EQUIVALENT		
Item	Requirement Description Provide the following:	In the fields provided below, describe your proposed Equivalent to the City requirement, you may Attach and Reference additional documentation as required.
1.	EVIR™: A Electronic (paperless)Verified Inspection Report (EVIR®) System that is DOT (Department of Transportation) Compliant.	➢ Zonar offers the only Electronic Verified Inspection Report. Our EVIR™ will revolutionize your inspection processes and make DOT compliance nearly automatic.
2.	Inspections: System shall be capable of verifying visual Pre-Trip, Abbreviated Pre-Trip, Post Trip and Periodic Maintenance inspections by requiring vehicle operators to scan a Radio Frequency Identification (RFID) tags utilizing a handheld scanner. The electronic record of the verified inspection must meet legal requirements as defined by FMCSA(Federal Motor Carrier Safety Administration) and CDOT (Colorado Department of Transportation.)	➢ Zonar's EVIR™ will visually verify pre-trip, abbreviated pre-trip, post-trip and periodic maintenance inspections. It requires that the vehicle operators scan an RFID tags utilizing our 2010 handheld scanner. The records of these inspections meet legal requirements as defined by the FMCSA and CDOT.
3.	Scanner/ RFID Tag Inspection Interface: As inspection occurs, the operator shall be prompted by scanner to inspect each area of the vehicle. As the tags are scanned, the specific inspection criteria will be communicated by the RFID tag to the scanner and displayed to the operator. The operator will document the outcome of each specific component's inspection with the scanner's push button functionality.	➢ The process of the Zonar inspections prompts the operator to inspect each area of the vehicle, which are marked with RFID tags. When the driver scans the tag, the pre-loaded inspection criteria is communicated by the RFID tag to the scanner and displayed. With push-button responses, the driver will be able to easily document the outcome of each component's inspection.

Electronic Vehicle Inspection Report System (EVIR) OR EQUIVALENT		
4.	Post Inspection: Operator will place handheld device into vehicle mount where inspection information is immediately transmitted to a secure database via cellular transmission. Ground Traffic Control™	➢ Post inspection, drivers will put the Zonar 2010 into the vehicle mount, where the inspection data will be immediately transmitted to a secure database via cellular transmission.
5.	Proximity: Handheld scanner is to be operated in close proximity (within a few inches) of each inspected component's RFID tag; thereby requiring the vehicle operator to be in the specific area to perform the visual inspection prompted by the scanner.	➢ The EVIR™ requires that drivers be in the area of the RFID tag by requiring that the handheld device be placed within 2 inches of the tag for the inspection to take place.
6.	Programming: Each RFID tag shall be able to be programmed with the following: • Installation location on vehicle • Component(s) to be inspected • Vehicle ID	➢ Our RFID tags will record the following functions: location on vehicle, components to be inspected, vehicle ID.
7.	Environmental requirement: Each RFID tag is to be weather resistant to: • Water-Rain/ Ice • Road Splash • Mud • Grease	➢ Zonar's RFID tags are made to be on the road and are weather-resistant to water, rain, ice, road splash, mud and grease.
8.	All system events shall be date and time stamped. Required: Mountain Time-Zone- Updated as required for daylight savings.	➢ All the inspections will be date and time stamped with Mountain Time Zone, updated for daylight savings.
9.	The system must be able to accommodate up to eleven (11) Radio Frequency Identification (RFID) tags per vehicle. Each tag is to be capable of being programmed to display the selected vehicle/ equipment inspection criteria identified by City's Public Works Fleet Management Division.	➢ Our system comes with 11 RFID tags per vehicle. All the tags are easy to program so that they can display the selected vehicle or equipment inspection criteria identified by the City's Public Works Fleet Management Division.

High Definition GPS System (Hub) OR EQUIVALENT (Managerial Purposes)		
Item	Requirement Description Provide the following:	In the fields provided below, describe your proposed Equivalent to the City requirement, you may Attach and Reference additional documentation as required.
10.	HD GPS System: Provide a vehicle Global Positioning System (GPS) that is reported through a web-based solution with all support provided by a sole vendor.	➢ All the information gathered from our GPS system is reported through our web-based application called Ground Traffic Control™, which we design and maintain.
11.	Sole Vendor: Vendor must be the single source of GPS hardware, GPS hardware installation, activation, in field product support, cellular / service subscription agreement, and web based hosted reporting.	➢ Zonar will be the single source of the GPS hardware, activation, support, service agreement and web-based hosting. We use a third-party, Velociti, to install the units.
12.	Inclusivity: Vendor's Service Subscription Agreement must include: • Cellular Transmission • Unlimited User/Site Access • Feature and Map Updates • Customer Support • Five (5) Year Warranty on Hardware ○ Paid all at once initially or in yearly installments-See Section C. Vendors that do not include the cost of cellular communication in their service will not be considered. Vendors requiring a separate cellular contact with a cellular provider will not be considered.	➢ Our Service Subscription Agreement includes all of these: cellular transmission, unlimited user and site access, feature and map updates, customer support, five-year warranty on our GPS hardware. With Zonar, there is no need to shop around for a third-party cellular contract. Everything's included.

High Definition GPS System (Hub) OR EQUIVALENT (Managerial Purposes)		
13.	Ground Traffic Control™ System Integration: All inspection and GPS data collected shall be downloaded via cellular GSM communication and be available on a secure web-based application: Ground Traffic Control™	➢ All inspection data and GPS data collected by Zonar's products will be securely downloaded via cellular GSM communication and will be available on a secure web-based application called Ground Traffic Control™.
14.	Communication Protocols: The system shall supports HTTPS, UDP, and TCP communication protocols.	➢ Zonar's system supports HTTPS, UDP and TCP communication protocols.
15.	IP Address Protocol: Each GPS device shall have a separate, private IP address for data security. Devices using public IP addresses will not be considered acceptable.	➢ Each of Zonar's GPS devices has a separate, private IP address for data security.
16.	Four Dimensional GPS: GPS system shall capture data in four dimensions - latitude, longitude, time and odometer.	➢ Zonar's GPS captures data in four dimensions: latitude, longitude, time and odometer.
17.	HD GPS Logging: The GPS logging shall be provided using an intelligent logging algorithm that will provide high definition data and minimize cellular data communication overhead.	➢ All GPS logging with Zonar's system uses our Intelligent Logging algorithm, which provides high-definition data and minimizes cellular data communication overhead.
18.	EVIR® System Integration: The system shall seamlessly integrate with the EVIR ® System specified above herein.	➢ Zonar's GPS system seamlessly integrates with our EVIR™ inspection system.

High Definition GPS System (Hub) OR EQUIVALENT (Managerial Purposes)		
19.	GPS System Alerts: GPS system shall provide a platform for customizable and configurable management alerts that shall have escalating capabilities with alerts including but not limited to: • activity alert • battery low voltage alert • GPS Zone alert • idle alert • input alert • inspection alert • panic stop alert • speed (max speed) alert • Other alerts Alerts shall be communicated via: ➢ Notification to logged on manager ➢ Email alert ➢ Cellular Text Message In addition, provides exception based alerting off inspection criteria.	➢ ZAlerts are Zonar's answer to providing customizable and configurable management alerts, including escalating capabilities. ZAlerts can be created around idle, low battery, GPS Zone entrance or exit, excessive idling, inputs, inspections, panic buttons (with additional hardware, costing $74.95, plus installation), speeding and more. Alerts are communicated via pop-up window within the Ground Traffic Control™ application, email and text message.
20.	The system must be capable of storing data daily for all equipment and allow for archiving and purging of historical data-90-Day Interval GPS will be powered from vehicle electrical system and provide power to the provided system's additional components-EVIR™ and Vehicle and Installed Equipment Interface.	➢ Zonar's system is capable of storing data daily for all equipment and allows for archiving and purging of historical data for up to one year. The GPS is powered from the vehicle's electrical system and provides power to other components.

Vehicle EDM (Engine Diagnostic Module)/ and Installed Equipment Interface(Modbus/ J-Bus) System OR EQUIVALENT		
Item	**Requirement Description Provide the following:**	**In the fields provided below, describe your proposed Equivalent to the City requirement, you may Attach and Reference additional documentation as required.**
21.	EDM (Engine Diagnostic Module) and Installed Equipment Interface:	➢ Our Ground Traffic Control™ service package includes an EDM and installed equipment interface.
22.	The Interface shall communicate through the HD GPS System specified herein above.	➢ Our interface communicates through our V3™ HD-GPS system.
23.	Interface General Requirements: The interface shall at a minimum be capable of reading fault codes, mileage, fuel data and engine hours from engine computer(s), idle time, brake applications, panic stops and etcetera. The data collected from the interface shall be spatially encoded, that is it shall be connected to a GPS system that affixes to the fault code information the LAT and LONG positional data. The interface shall have on-board memory for recording performance data from/during a vehicle trip. The interface device shall be field updatable; this should provide the capability of the device vendor to update the program memory in the device remotely, thus providing updated software (firmware) in the device. The interface device shall be powered from the vendor supplied GPS system.	➢ Our diagnostics interface reads fault codes, mileage, fuel data and engine hours from your engine's computer, idle time, hard-braking and more. ➢ The data collected from the diagnostics interface is spatially encoded and integrates seamlessly with our V3™ HD-GPS to provide latitude and longitude data along with diagnostic information. ➢ Our diagnostics interface has an on-board memory with the ability to store more than 40 days of performance data from vehicle trips in case of signal loss. ➢ Our interface is field updatable, meaning Zonar has the ability to update the program memory in the device remotely, providing updated software (firmware) in the device "over the air." ➢ Our diagnostics interface is powered from our V3™ HD-GPS device.

Vehicle EDM (Engine Diagnostic Module)/ and Installed Equipment Interface(Modbus/ J-Bus) System OR EQUIVALENT		
24.	Vehicle Upfit Equipment Data Tracking (Refuse Bodies, Dump Bodies, and etcetera) Must include I/O system that generates a GPS point with Lat/Lon/Time when a voltage state change has been detected across a circuit that is monitored up to 5 sensing lines. Must be able to monitor: ▪ Door: Open/Closed ▪ Plow: Up/Down ▪ Sweeper: On/Off ▪ Light: On/Off ▪ Arm: In/Out ▪ Engine Pre-heater: On/Off (Engine does not have to be running, GPS unit can be sleeping) ▪ Monitor PTO (Power Take Off) usage for Diesel fuel tax reclamation ▪ Alerting • Additional channels available for future needs. Should detect voltage of 8-30VDC for active state. Web-based software should map points or path of I/O activation.	➢ Zonar's powerful I/O capabilities generate GPS points with latitude, longitude and time information when a voltage change has been detected from activity such as: • Door opening or closing • Plow up or down • Sweeper on or off • Light on or off • Arm in or out • Engine pre-heater on or off (while vehicle is on) • Power Take Off activation • Alerts Up to 5 sensors will detect voltage of 8-30 VDC for the active state, and changes will be mapped on our web-based software. These I/O events can be shown as points or paths for activation such as sweeper and plow.
25.	This system shall use a web-based application that decodes/ converts the fault codes and additional vehicle/equipment monitoring data into human readable form.	➢ Ground Traffic Control™, our web-based application, will decode and convert the fault codes and data gathered by diagnostics into a form your employees can read easily.

	Comprehensive Web Based DATA Collection, Compiling, and Reporting System for the above OR EQUIVALENT	
Item	**Requirement Description Provide the following:**	**In the fields provided below, describe your proposed Equivalent to the City requirement, you may Attach and Reference additional documentation as required.**
26.	Ground Traffic Control ™ Provides for DATA retention, reporting and tracking for: • Managerial GPS Tracking • Vehicle Maintenance • Regulatory compliance-DOT Inspection Tracking • Operational efficiency • Information dissemination • XML Exchange	➢ Ground Traffic Control™ provides for data retention, reporting and tracking for managerial GPS tracking, vehicle maintenance, regulatory compliance such as DOT inspection tracking, operational efficiency, information dissemination, and XML exchange.
27.	The software must be capable of accommodating and processing GPS, DOT Inspection, and Vehicle/ Equipment systems data generated by a 300+ vehicle fleet of City and County of Denver Refuse and Snow removal equipment and etcetera. Software also must be able to display data as it's captured/transmitted by the GPS System in real time.	➢ Ground Traffic Control™ will accommodate and process the GPS, DOT Inspection and vehicle and equipment systems data generated by the 300+ vehicle fleet of City and County of Denver Refuse and Snow removal equipment. ➢ Ground Traffic Control™ will also display data as it's captured and transmitted by the GPS system in real time.