Aftermarket Cameras in Winter Maintenance Vehicles

Final Report

CLEAR ROADS

research for winter highway maintenance

SRF Consulting Group, Inc.

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16. Abstract

Mounting video cameras on winter maintenance vehicles can assist with operational decisions and enhance situational awareness for operators. To help agencies maximize the benefits of these systems, this project conducted a state-of-the-practice literature review, survey and interviews to identify types, uses and best practices for on-vehicle camera systems.

Among the agencies surveyed, the most common use was a rear-view device, but cameras are also used to monitor material spreaders, underbody plows and tow plows to verify operation and effectiveness.

Several best practices emerged from the research and interview process. These included:

- Cameras should be carefully positioned so they do not interfere with driver sight lines or getting into or out of the vehicle.
- Cameras should have washer systems and heated lenses, as accumulation of dirt or snow can rapidly degrade image quality.
- Cameras are often sold as packages with washer systems. Research shows that low-cost cameras can be used with washer systems, even if they are not initially packaged with them.
- In-cab displays should be carefully positioned and have driver-adjustable brightness to avoid distracting reflections on windshields.
- In general, it is not recommended to integrate the video from forward-facing cameras into in-cab displays.
- Transmitting live video from vehicles is currently poorly supported by cellular networks, particularly outside urban areas, and is not generally recommended.
- Involving operators during the planning and installation of cameras has been shown to increase effectiveness and acceptance of the system.

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Final Report

Aftermarket Cameras in Winter Maintenance Vehicles

Clear Roads Project No. 17-03

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Executive Summary

Project Overview

Clear Roads Project No. 17-03 sponsored *Aftermarket Cameras in Winter Maintenance Vehicles*, an exploration of the types and uses of cameras and video displays in winter maintenance vehicles. The project goal is to understand the value of these systems to agencies, identify issues encountered in their installation or use, and make recommendations to maximize the value of aftermarket systems.

Information for this effort was collected through a literature search, a survey with responses from 25 states, and interviews with both camera system users and manufacturers. The project also explored a unique, cost saving pilot deployment to determine its applicability to other deploying agencies.

This document is the Final Report for Clear Roads Project 17-03. The Final Report is a synthesis of the information presented in previous project reports and technical memos. This Executive Summary provides a high-level overview of the main project activities and findings.

Project Findings

Survey

A comprehensive survey of winter roadway maintenance stakeholders was conducted to understand the current state of the practice for after-market camera use on snowplows. Twenty-nine responses were received from agencies in 25 different states. Respondents were asked a variety of questions about the number and type of camera systems deployed, the uses of the system, and installation or operational issues encountered. Key findings include:

- Overall, there does not appear to be widespread information sharing about camera systems between agencies.
- Approximately 2/3 of all agencies surveyed use camera systems on vehicles.
- When selecting camera systems, the most important criteria are camera durability and image quality, with system cost being a smaller consideration.
- A large majority of systems include a display for the driver, which is consistent with findings that the most common purpose of the system is to allow drivers to monitor the vehicle systems.
- It is relatively uncommon for systems to either archive or transmit live video, although still images are gathered from forward-facing "plow cam" systems.
- Maintenances costs were generally found to be relatively low, with nearly all respondents reporting per-vehicle annual costs of less than $200, and 4 of 11 total responses indicating costs of less than $50 per vehicle per year.
- The most common operational issue was degraded video quality due to dirt and moisture accumulating on the camera. This was most often observed on spreader, rear-view and wing plow cameras.
- No correlation was observed in reported operational issues and system cost.

Interviews

Follow up interviews were conducted with three winter maintenance agencies and two manufacturers. The specific interview subjects and reasons for selection were:

- Agency Interviews
    - Minnesota Department of Transportation (MnDOT), large scale deployment (200+ vehicles)
    - South Dakota Department of Transportation (SD DOT), reported maintenance issues
    - City of Farmington Hills, MI, highest reported costs and reported installation issues
- Vendor Interviews
    - Bosch, experience working with live video transmission from moving vehicles
    - Ameritrak, MnDOT supplier and user of commercial Axis-brand cameras.

These interviews provided several insights into both the use of camera systems by agencies and vendor perspectives. Informative points included:

- There may be initial concerns from drivers about privacy and monitoring, but these tend to fade as they see the benefits of a camera system.
- Camera durability is extremely important.
- Installation issues generally do not arise from the camera unit itself, but from using "office-grade" cabling like non-locking USB connectors and video cables without sealed connectors.
- Video monitoring of material spreader devices is seen by drivers as extremely valuable.
- Care should be taken when deploying a system to ensure that the choice of camera does not create a "lock-in" condition where only one software solution can be used to view and manage video.
- Lens cleaning systems are universally recommended.
- Transmission of video from vehicles is technically possible but avoided due to poor transmission quality. Many cellular networks do not provide the performance needed to consistently deliver usable video. For this reason, some manufacturers are avoiding deployments that involve transmission.

Recommendations

A wide range of recommendations and best practices are included in this Final Report. These range from camera locations on snowplows to system planning and driver involvement. Several key recommendations are:

- Include a lens/camera washing system for each camera. Heated lenses are also recommended.
- In-cab displays should include a driver-adjustable brightness control and be carefully positioned to avoid glare on the windshield.
- In cab displays should be able to display a minimum of four camera feeds simultaneously.

- Live video transmission is not currently recommended outside of areas with high density "5G" cellular networks or 4G networks tested and known to support video applications.
- Where possible, use power-over-ethernet (POE) cameras on vehicles to simplify wiring and installation.
- Commercial camera wash systems can be used with low-cost, off-the-shelf vehicle cameras, providing they are designed for the harsh conditions of maintenance use.
- A follow-up interview found the use of a laser system mounted on each side of the cab provided operators with a visual reference while plowing, providing a viable alternative to video systems in some cases.
- Involve equipment operators in the planning and installation process. Getting their input into the system design encourages system acceptance and allows operators to get great value from the cameras.

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- Jeffery Jansen, Road Weather Technology Group Team Leader, MnDOT
- Daniel Varilek, Winter Maintenance Engineer, SD DOT
- Bryan Pickworth, Road Maintenance Supervisor, Farmington Hills, MI
- Natalie Haag, Regional Sales Manager, Bosch
- Jeff Edelstein, Chief Technology Officer, Ameritrak

List of Abbreviations

Abbreviation	Description
AVL	Automatic Vehicle Location
DOT	Department of Transportation
DNS	Domain Name Servers
DVR	Digital Video Recorder
EXIF	Exchangeable Image File Format
HDMI	High-Definition Multimedia Interface
HVR	Hybrid Video Recorder
IP	Internet Protocol
LAN	Local Area Network
LTE	Long Term Evolution
MDC	Mobile Data Computer
NVR	Network Video Recorder
TAC	Technical Advisory Committee
VDC	Volts Direct Current
VGA	Video Graphics Array

Chapter 1 - Introduction

Clear Roads is a research organization comprised of 36 agencies that pool resources to conduct research on winter roadway maintenance operations. Since its inception in 2004, the Clear Roads research program has provided forward looking guidance for implementing new practices and technologies for winter maintenance.

Video cameras have become increasingly common on a variety of agency vehicles, particularly winter maintenance plows, graders, and other heavy vehicles. In addition to "plow cam" type devices that capture images largely for public information, there are also operator assistance and supervisory systems being deployed. This project researched the variety of systems available, diversity of uses and different installation techniques employed with the goal of developing as set of best practices that could guide their use.

Several interim technical memoranda were produced for the project and are summarized in this Final Report. First, a literature review was conducted to gather information about the current types, uses of, and best practices for vehicle mounted cameras. A survey of winter maintenance agencies and organizations was conducted to determine common installation practices and issues encountered with camera use. Follow-up interviews were conducted with respondents who provided responses of interest to obtain more detailed information. Finally, a pilot deployment was examined to determine the viability of using lower cost camera systems with manufactured cleaning systems instead of more expensive integrated camera/washer packages.

Chapter 2 - Literature Review

Introduction

Based on recommendations from the project Technical Advisory Committee and sources identified using Internet searches, a list of state Department of Transportation (DOT) agencies that currently utilize aftermarket cameras on winter maintenance vehicles was assembled. The literature review explored each of the existing systems in use as well as other large-scale onboard camera surveillance systems. Specifically, first responder, transit, emergency, law enforcement, and commercial trucking were researched.

Cameras on individual maintenance vehicles does not appear to be a widely adopted practice among state DOTs. States such as Minnesota, Iowa, Michigan, and Delaware were identified as employing snowplow camera systems. These states have cameras installed on a portion of their total fleet.

State DOT Systems

MnDOT: In 2015 and 2016, the Minnesota Department of Transportation (MnDOT) installed aftermarket cameras in roughly 25% of their plow vehicle fleet. These cameras are forward-facing, capturing images of the roadway. The images from the plows were uploaded onto MnDOT's 511 website allowing the public to view them and facilitating informed travel decisions. Plow operators also had the ability to manually record videos or images and send this information to management. These images and videos were classified as: accident, general interest, or work zone. These images were not shown to the public but were used internally to identify dangerous areas and crash sites.

The cameras were connected to the mobile data computer (MDC) and the AVL units via Ethernet cable. This connection allowed the camera to obtain data and function only when the plow speed exceeded ten mph.

Iowa DOT: In 2014, Iowa DOT installed aftermarket cameras based on the iPhone 4 in roughly 50% of their snowplow fleet. These took pictures every 10 minutes and sent them back to Iowa DOT to be uploaded on Iowa DOT's 511 website to be seen by the public. Due to the high cost of the iPhone data plans and software compatibility issues, a new camera system was selected following a head-to-head comparison.

The Axis M1065 was chosen over the Dakota Micro InnoPro (DMIP-RC), Brigade DMC-1021/1025 and the Brigade MDR-494W-500 due to its ease of integration, flexibility and included software management tools. Images captured are available for public viewing on Iowa's 511 website similar to the iPhone-based system.

Michigan DOT: In 2017, the Michigan DOT (MDOT) installed aftermarket plow cameras on a portion of their snowplow fleet to allow the public viewing on the MiDrive web site.

Delaware DOT: In 2016, the Delaware DOT (DelDOT) began testing trials for an onboard camera system for roughly 1% of DelDOT's snowplow fleet. Unlike other systems, front, back, right side, and tow plow cameras are used that record video that is viewable in the cab.

Transit Systems

Surveillance camera systems are used in transit networks throughout the world including trains, buses, and transit stations. While the goals may be different from winter maintenance, installing these systems may be adapted to suit the needs of state DOTs.

A survey conducted by the International Association of Public Transportation (UITP) offered insight into the current design choices and preferences of many different transit agencies indicated that video surveillance systems are roughly 25% analogue cameras, 25% network/IP cameras, and 50% hybrid systems with both kinds of camera. While analogue cameras are common, approximately 85% of survey respondents plan on moving to IP cameras.

Apollo Video Technology manufacturers video surveillance systems used on transit vehicles. They have published several case studies offering technical insight for mobile video systems:

- Montgomery County, Maryland installed digital video recorders (DVR) on approximately 180 buses in 2007. The system recorded video on a hard drive to be later reviewed by agencies officials in the event of an incident. Additionally, police and other first responder agencies could access the video feeds on in-vehicle laptops via wireless connection from up to 900 feet away.
- Springfield, Missouri's CU Transit agency outfitted a portion of its bus fleet with a system almost identical to the Montgomery County system. In this case, each bus was equipped with seven to eight total cameras covering the interior and exterior of the vehicle.
- California Transit Agency deployed a similar system on 600 buses in 2010. This system features the ability for law enforcement to access video files from in-vehicle computers. However, the range of this feature is only 100 feet.
- The City of Gardena, California (GTrans) implemented video systems on their 55-vehicle bus fleet. The system was adapted to use the existing municipal 802.11ac network and software that provides managers and first responders with live video streams from the cameras.

Emergency Vehicles/Law Enforcement Systems

The City of Dade, Florida Police Department installed a modified version of the Apollo Video RoadRunner 4K system in fourteen police cruisers. The system features lower capacity NVRs and one onboard camera. These cameras are viewable from both the dispatch center and other police cruisers.

Manufacturers and Products

There are many suppliers of cameras designed for use in commercial trucking that could be adapted to winter maintenance vehicles. The primary difference is that commercial trucking systems generally record video to be viewed later, whereas winter maintenance video is generally viewed in real time.

Axis Communications cameras have been used in plow camera applications with success. Axis products are widely available throughout the United States.

Dakota Micro is an industrial camera supplier based in North Dakota specializing in surveillance and rear-view cameras. The EnduraCam is Dakota Micro's more specialized line of products meant for harsh environments, like those encountered by winter maintenance vehicles.

Apollo Video Technology manufactures the RoadRunner 4K recording system. This system can be configured to save or stream video. Apollo Video technology also has a variety of accessories including a mobile application that allows for live video viewing. Apollo Video Technology also offers displays ranging from 7" to 19".

Lanner Electronics offers a range of NVR options. Lanner offers the V3S, V6S, and R6S NVRs which differ in the number of video sources supported and storage capacity.

Safety Vision Products offers a variety of Hybrid Video Recorder (HVR) and NVR options. These products support from 5 to 36 cameras and 1 to 4 TB of storage space per unit. Safety Vision Products also has a variety of monitors that are compatible with their recording systems. Some monitors can connect to recorders wirelessly and others can connect to more than one video source.

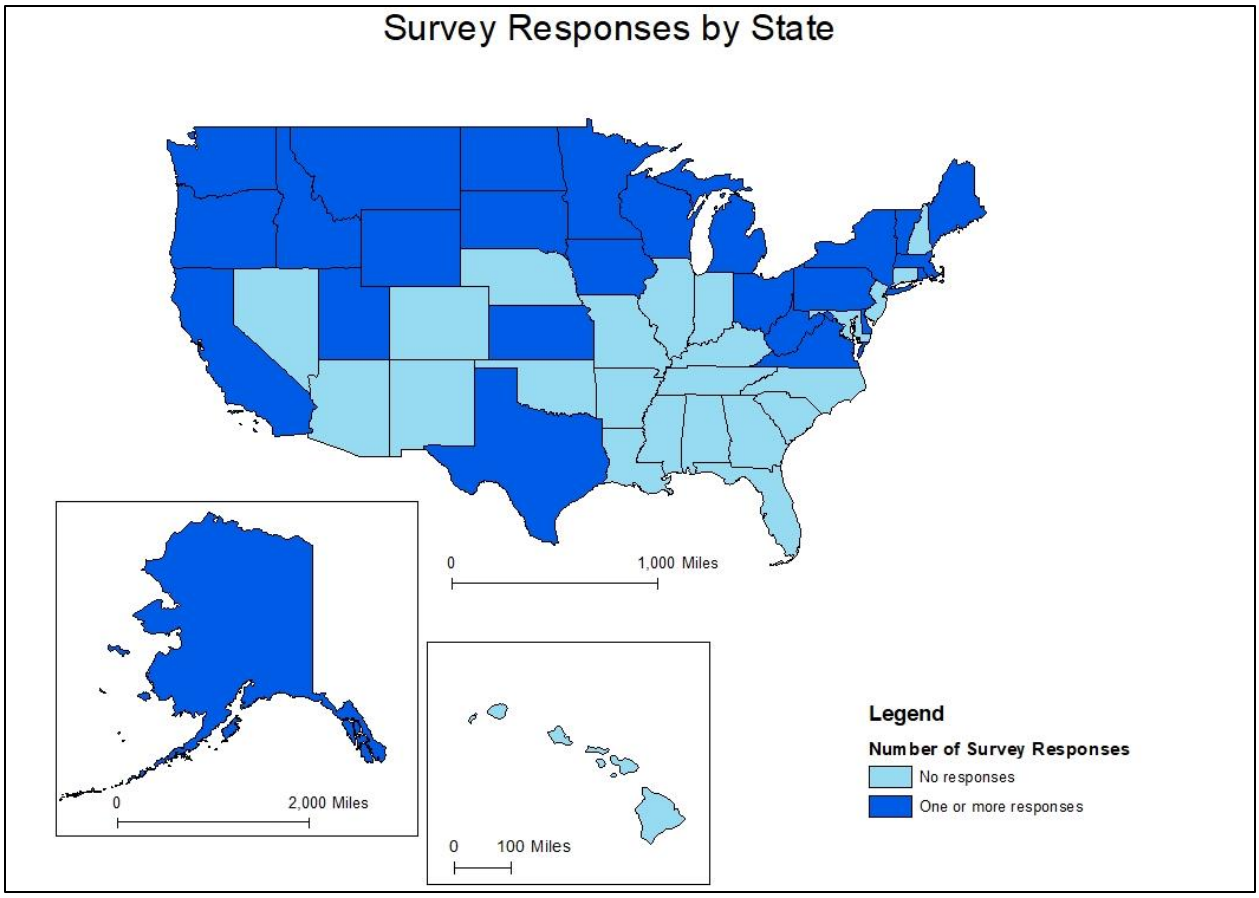
Cisco sells a video surveillance system marketed towards commercial trucking. The "6000 Series" Cisco Video Surveillance System Line comes in a variety of packages and utilizes IP cameras branded by Cisco.

Chapter 3 - Surveys

Introduction and Survey Response

The project team conducted a comprehensive survey of winter roadway maintenance stakeholders to understand the current state of the practice of after-market camera use on plows in the United States. The survey was created using the Survey Monkey on-line survey tool with questions formulated in consultation with the project TAC. Overall, the survey response was very good with 29 responses from 25 states. The following states responded to the survey.

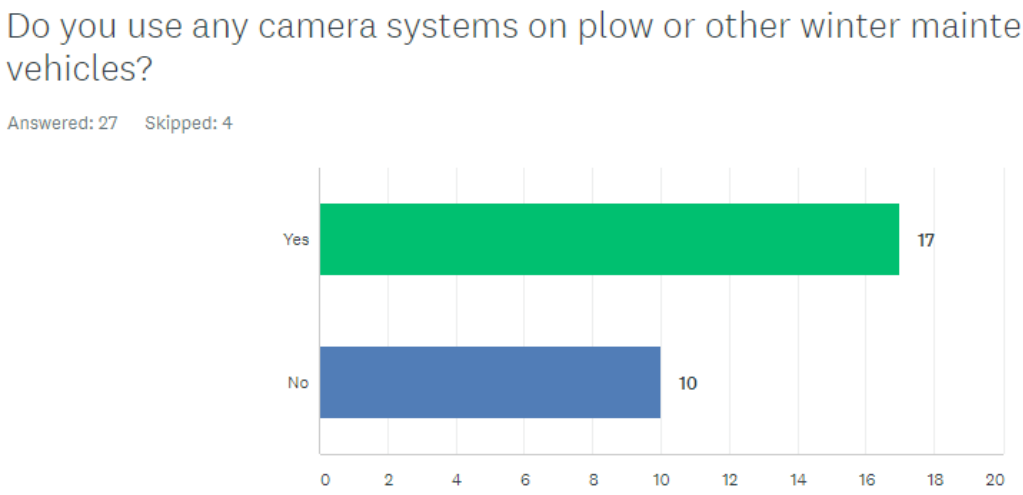
Figure 1. Survey Respondents



Survey Results and Discussion

This section highlights several survey responses. Many questions used branching logic so that follow up questions would only display when relevant. Questions that were not answered because they were not shown to respondents because of branching logic were marked as "skipped."

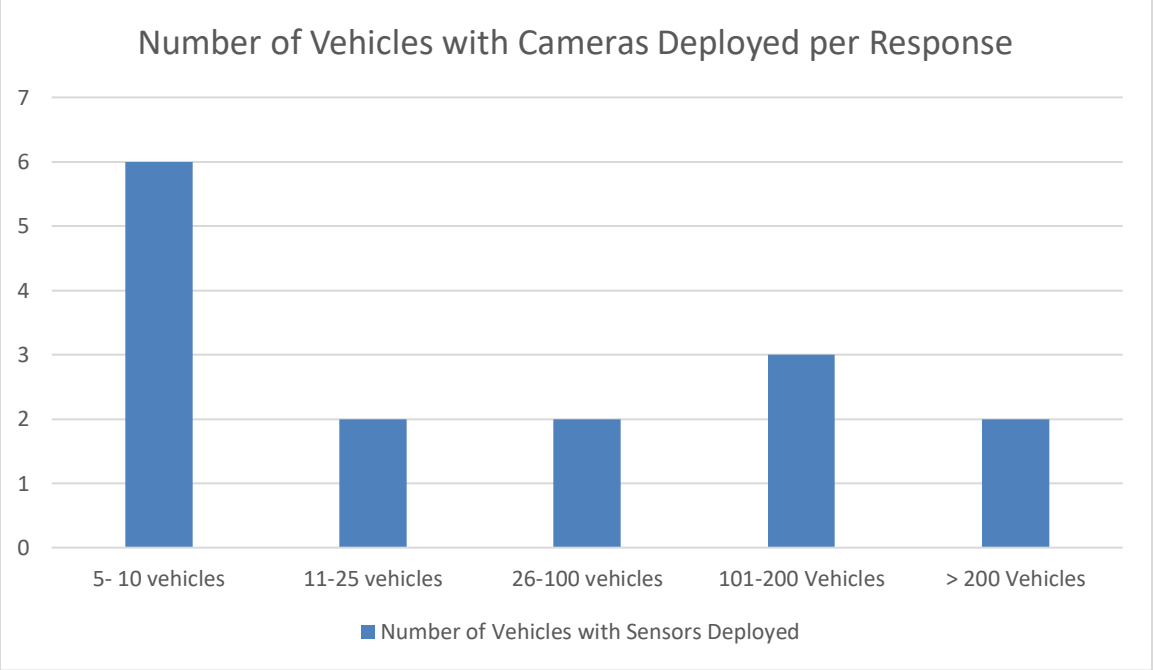
Figure 2. On-Vehicle Camera System Use



Around two thirds of agencies surveyed use some form of camera on plows or maintenance vehicles. However, even among agencies that use camera systems, very few are aware of use by other agencies.

Of respondents who had at least one camera deployed on a vehicle, most had 5-10 vehicles with cameras deployed. However, approximately half had over 100 vehicles with cameras deployed.

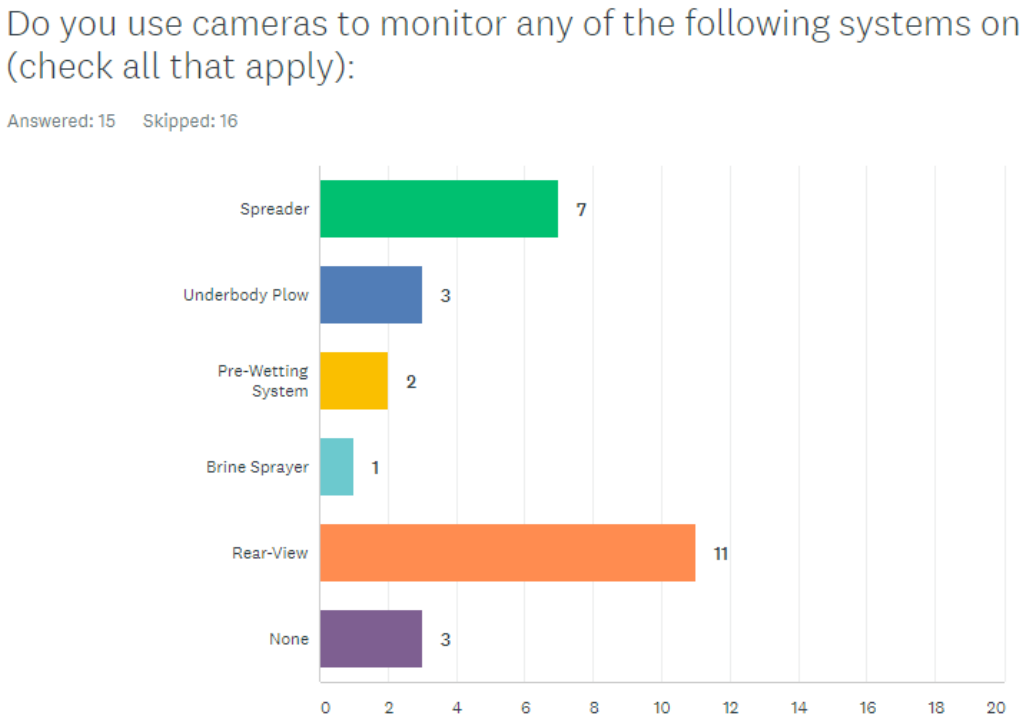
Figure 3. Number of Vehicles with Cameras Deployed per State



Nine of the respondents use forward-facing camera to monitor road conditions. Two of the respondents commented that not all trucks with cameras had forward facing camera. One respondent commented that monitoring road conditions with forward-facing cameras was their

primary focus. Two others mentioned that they were in a forward-facing camera pilot program. Manufacturers of these cameras included Live View, Logitech, Pro-Vision, and Pro-Tech.

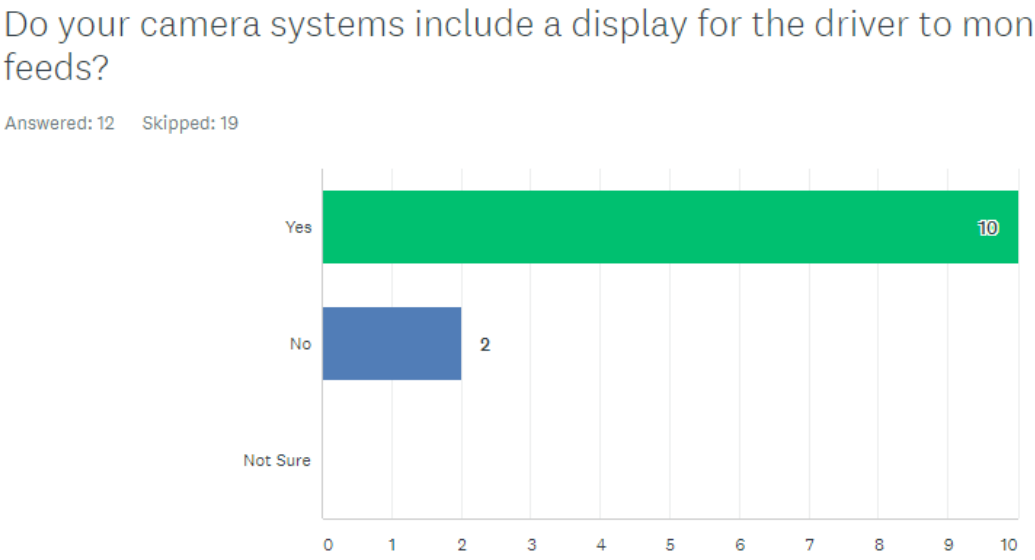
Figure 4. Monitored Areas on Vehicles



Many plow drivers use cameras to monitor the rear-view or the spreaders. In the comments, eight respondents reported they use cameras to monitor the wing plows, two mentioned monitoring the tow plow, and another two indicated use of side-view cameras. Of all the respondents who indicated using cameras on their vehicles, 80% reported using a rear-view camera, 53% reported using a camera to monitor the spreader, and 53% reported using a camera to monitor the wing plow (based on comments).

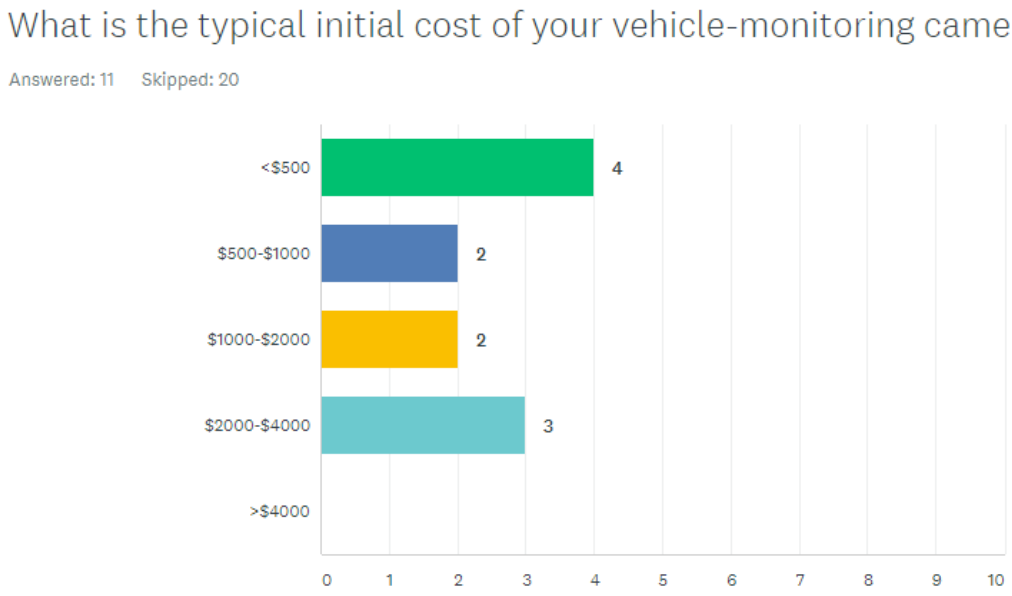
Manufacturers of these cameras included Boyo, Voyager, Dakota MFG, Delcan, MS Foster, and ProVision.

Figure 5. Driver Monitor Display



It is also common for camera systems to be used so that drivers can monitor the video feed. One agency commented that the driver can only monitor video when the vehicle is in reverse (for a rear-view camera). Another mentioned that they require displays to have dimming or off capabilities so that the drivers are not distracted in low-light conditions.

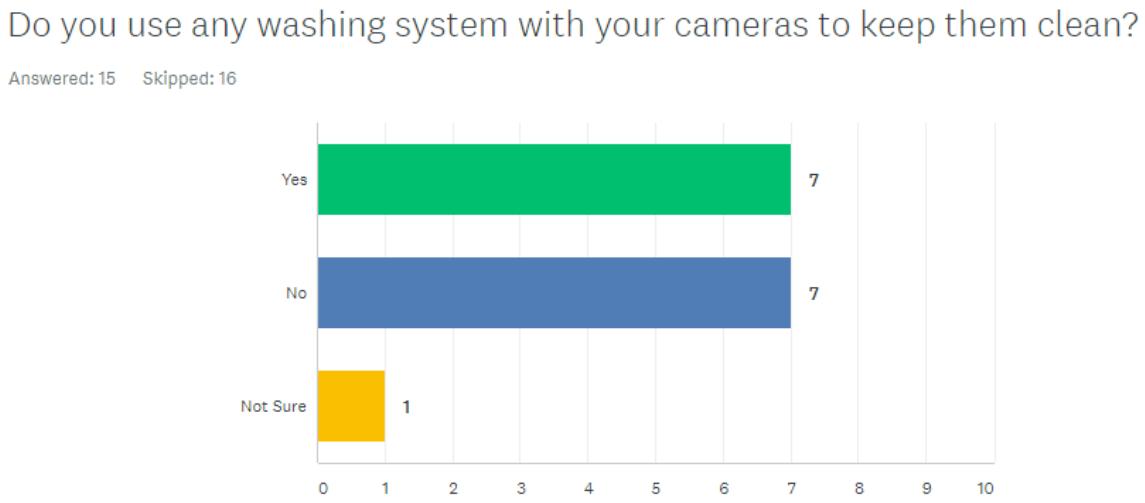
Figure 6. Vehicle-Monitoring System Cost



Vehicle-monitoring systems were reported to be more expensive than forward-facing cameras. Camera systems that cost below $500 included Delcan and ProVision. One respondent who selected "$500-$1,000" also reported using Boyo or Voyager cameras, and that the cost also included third-party installation costs. One of the respondents that reported the $1,000-$2,000 range used Dakota

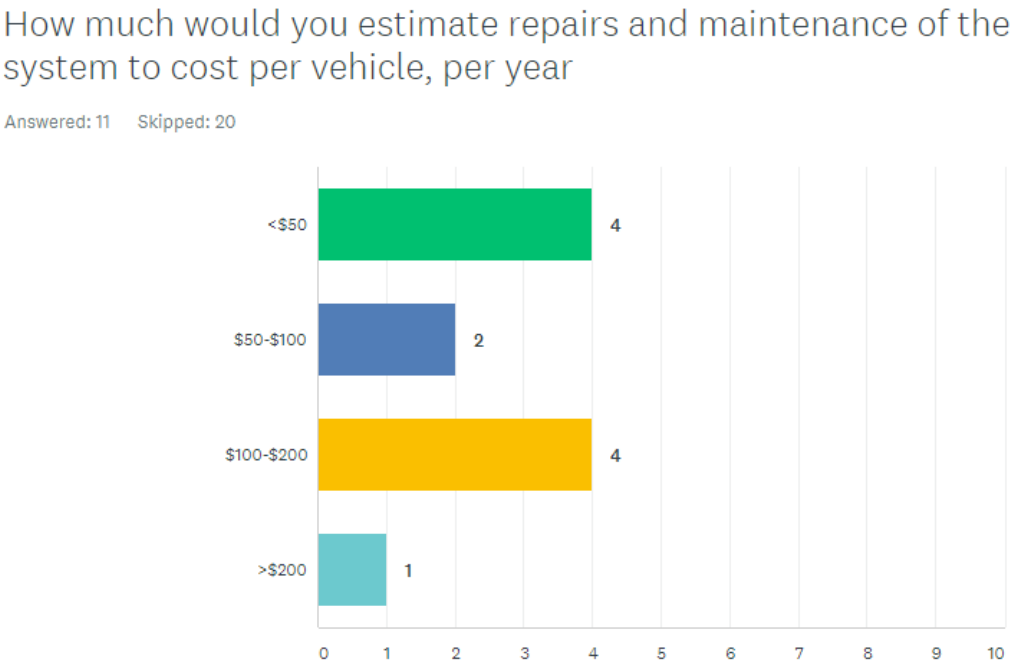
MFG. Two of the respondents who reported the system cost in the $2,000-$4,000 range used MS Foster as their manufacturer.

Figure 7. Washing Systems



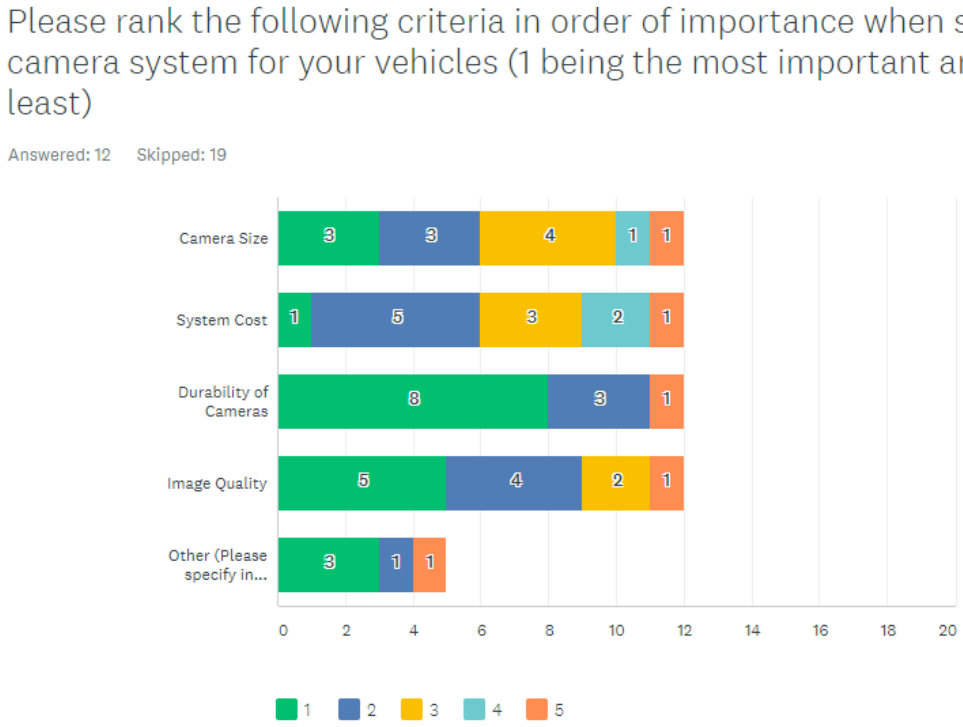
Respondents were split evenly on whether they used washing systems. Two agencies mentioned they only cleaned cameras by hand. Several agencies used fluid and air washing systems. Some were sprayed with cleaning fluid using electrical pumps.

Figure 8. Maintenance Costs



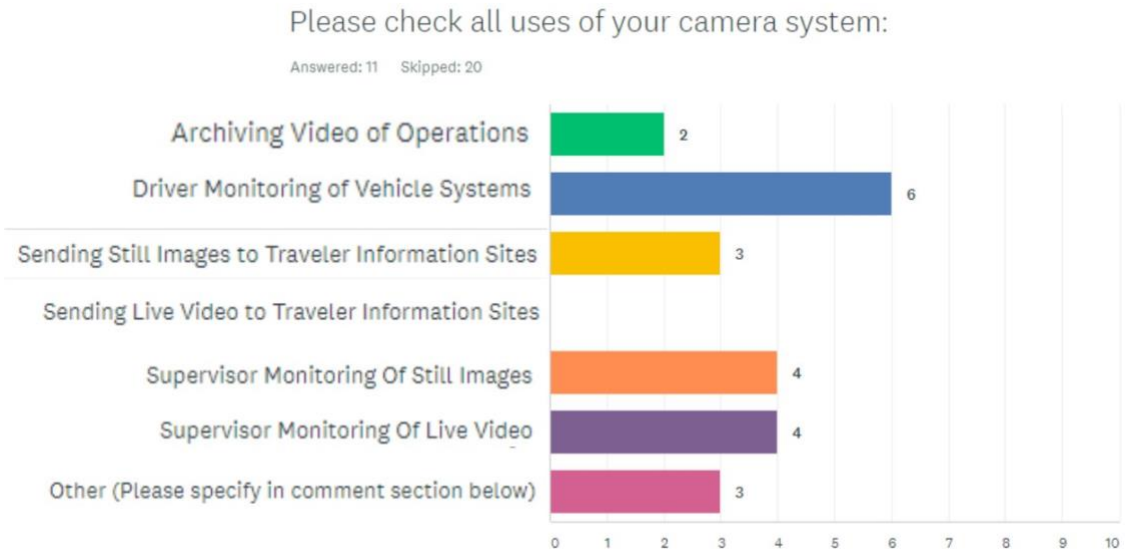
Respondents reported a wide range of maintenance costs. Several agencies mentioned that they were unsure on the cost. As several agencies just began camera use, the cost of maintenance was difficult to estimate.

Figure 9. Selection Criteria



When asked to rank the importance of certain factors when choosing a camera system, many respondents chose image quality or camera durability as the most important. The cost of the system was frequently the secondary factor. Other important factors reported by respondents included the ability to interface with their AVL system, ease of use, mounting location, and video quality in low-light conditions.

Figure 10. Camera System Use



Many respondents reported using the cameras for driver monitoring and supervisor monitoring. Several agencies responded that the cameras were used for safety purposes, especially to improve visibility when drivers were backing up.

When asked if issues were encountered with camera systems during installation or operation, respondents had a variety of comments. Two agencies reported having difficulty with snow and ice covering the lenses. The following issues were also reported:

- Camera connections becoming loose due to vibrations
- Poor placement of monitors
- Glare of monitors at night
- Potential distraction or obstruction of windshield from the monitors
- Having to install multiple cameras
- Having to use a different monitor for each system

Additional Analysis

In addition to the results above, survey analysis was done by standardizing some open-ended responses and incorporating common comments into the results. Responses were then cross tabulated to determine relationships between responses such as the common uses of cameras located on different parts of the vehicles and issues reported with cameras used for certain purposes or in certain locations.

Among the variety of issues reported in the comments, users of rear-view, spreader, and wing-plow cameras reported visibility/cleaning issues. This makes sense given the location of these cameras and indicates that washing systems may be a worthwhile investment for cameras installed in these locations. The most common uses of camera systems are monitoring the rear of the vehicle, the

wing plow, or the spreader. These areas are not visible from the driver's position in the cab and cameras allow drivers to operate equipment more safely and effectively. The potential for visibility issues with cameras installed in these locations, however, suggests that washing systems are beneficial. Table 1 and Table 2 summarize these findings.

Table 1. Reported Issues/Concerns vs. Camera Locations/System

	Spreader	Underbody Plow	Pre-Wetting System	Brine Sprayer	Rear-View	Side-View	Wing Plow	Tow Plow
Installation	1	1	0	0	1	1	1	0
Hardware Maintenance /Durability	1	0	0	0	1	0	1	1
Visibility/ Cleaning	2	0	0	0	3	0	2	0
Driver Distraction	1	0	0	0	1	0	2	0

Table 2. Camera Installation Location vs. Camera Use

	Video System Uses								
Camera View	Archiving Video of Operations	Driver Monitoring of Vehicle Systems	Driver Monitoring of Surroundings	Any Driver Use	Supervisor Monitoring of Still Images	Supervisor Monitoring of Live Video	Archive Video	In-Cab Display	Auto Washing Used
Spreader	1	4	2	4	3	2	1	6	3
Underbody Plow	1	2	1	2	1	1	0	3	2
Pre-Wetting System	1	1	0	1	1	1	0	1	0
Brine Sprayer	1	1	0	1	1	1	0	1	0
Rear-View	2	5	5	8	4	3	3	10	6
Side-View	0	1	2	2	0	0	0	1	2
Wing Plow	1	5	2	5	1	2	1	5	4
Tow Plow	1	1	0	1	1	1	1	1	2
In-Cab Display	2	5	4	7	3	3	3		4
Auto Washing	1	2	3	4	2	1	2	4	

As indicated in Table 3, the survey identified MS Foster as having more expensive systems, with two respondents rating their system cost at between $2,000 and $4,000. However, a substantial portion of respondents did not know the manufacturer.

Table 3. Camera Manufacturer vs. Initial System Cost

Initial Cost	Manufacturer							
	Boyo	Dakota MFG	Delcan	Equipment Distribution Bemidji, MN	MS Foster	Pro-Vision	Voyager	Unknown
<$500	0	0	1	0	0	1	0	1
$500-$1000	1	0	0	1	0	0	1	0
$1000-$2000	0	1	0	0	0	0	0	1
$2000-$4000	0	0	0	0	2	1	0	1

To explore if there are any common issues with cameras manufactured by these companies, a cross tabulation of camera manufacturer vs. reported issues was also performed, see Table 4. One notable finding is the frequency of issues with visibility/cleaning, which echoes some of the previous findings. Another notable finding is the report of installation issues with MS Foster cameras (reported as "Contractor Installs" by the respondent), which may indicate that these systems require more effort to install.

Table 4. Camera Manufacturer vs. Reported Issues

Reported Issues	Manufacturer							
	Boyo	Dakota MFG	Delcan	Equipment Distribution Bemidji, MN	MS Foster	Pro-Vision	Voyager	Unknown
Installation Issues	0	0	0	0	1	0	0	0
Hardware Maintenance/ Durability Issues	0	0	1	0	0	0	0	0
Visibility/ Cleaning Issues	1	1	0	0	0	0	1	1
Driver Distraction Concerns	0	1	0	0	0	0	0	0

The issues were collected from free response questions and may not completely fully represent the issues that may have been experienced.

Summary

Survey results found a wide range of after-market video camera adoption, implementation, and experiences. While most surveyed were currently using on-vehicle cameras, the methods and uses of each agency was different and very few respondents knew about other agencies' camera systems.

Despite the many differences in camera utilization, some aspects of camera use were common across agencies such as:

- Rear, wing plow and spreader views are the most common
- Displays that allow drivers to monitor in-vehicle are generally present
- Automatic video recording (as opposed to manually activated) is typically used
- Video quality, camera durability, and camera lens cleaning are important criteria
- Few users archive video

Chapter 4 - Follow-Up Interviews

Overview

Based on the analysis of the survey results, several respondents were selected for follow up interviews based on factors such as the reported deployment size, camera manufacturer and cost, location of cameras on the vehicles, and issues reported. All the follow up interviews were then conducted by telephone. The following sections describe each of these interviews, including the reason(s) for selecting that respondent, the questions that were asked and their responses, and the general findings obtained from the interview.

Interview #1

Interview Subjects

- Joseph Huneke, Transportation Program Supervisor, MnDOT
- Jeffery Jansen, Road Weather Technology Group Team Leader, MnDOT

Reasons for Selection

- Large deployment size (over 200 cameras) with no operational issue reports, but no manufacturer given.

Deployment Summary

MnDOT has over 200 plow trucks equipped with cameras. Most of these are forward-facing dash-mount cameras and installation of these cameras has now become standard for all new plow trucks. Also becoming standard during new vehicle builds is installation of rear-facing cameras near the top of the vehicle to monitor the spreader box or vehicle rear view (with the operator able to adjust the camera as they see fit). Cameras are also provided for tow plows, of which there are only about 20 in the state.

Key Information

MnDOT uses cameras manufactured by Axis (sold by Protech Design). These were selected after an initial exposure at a maintenance expo/conference, with subsequent research done as part of MnDOT's Maintenance Operations Research Program. They also have a heated lens/lens cover which is important to mitigate visibility issues.

Vehicle monitoring cameras were first installed in 2014 and dash-mounted cameras were first installed in the 2011-2012 season as part of a research project, with a full deployment starting in 2015. Most vehicles have one dash-mounted camera.

Few replacements have been needed. Most replacements have been due to manufacturer defects or upgrades. Overall satisfaction is good with the heated lens particularly important to satisfaction.

Initially there were some concerns about driver monitoring/privacy, but those have largely gone away. Driver outreach has helped considerably with this, as have filters that prevent images from being seen when drivers are on breaks and other non-maintenance activities. Drivers are very satisfied as it helps greatly with operation – it is much easier to monitor the spreader box and application rates, and drivers do not have to climb on the truck to see into the box, which is hazardous. They also help tow plow operators, which are becoming increasingly common.

Other Comments

A key factor to a successful camera deployment is durability, as vibration on the trucks is a significant issue. During trials, some cheaper cameras were tested, and had frequent failures. A cleaning system and/or heated lens is also critical, as visibility is a significant problem for vehicle monitoring cameras due to weather conditions and deicing material. MnDOT uses heated lens covers with their cameras and automatic retractable covers that cover the cameras when they are not in operation.

Software flexibility is also emphasized as important for the system. MnDOT's current system has locked them into certain camera models such that new models require additional development work, which can be expensive. They advise building more flexibility into the software to allow new cameras to be used without significant development time.

Interview #2

Interview Subject

- Daniel Varilek, Winter Maintenance Engineer, SD DOT

Reasons for Selection

- Reported maintenance and durability issues when using with a tow plow.

Deployment Summary

SD DOT plows have forward-facing cameras for viewing current road conditions in addition to rear-facing backup cameras and cameras for monitoring the wing plow and spreader box. They also have approximately 14 tow plow trucks with a dedicated camera for the tow plow. Both systems use the vehicle's Maintenance Data Collector (MDC) to monitor/collect video/images and have imagery displayed in their MDSS interface.

Key Information

Cameras are mounted on the passenger side mirror aiming at the tow plow, which provides a good field of view. The mirrors are heated which helps keep the cameras clean, in addition to a washing system with a fluid and air spray. There is a dedicated camera for the tow plow in addition to the forward-facing camera, rear-view camera, spreader, and wing plow.

The Delcan system was selected as they are also the AVL/MDC/MDSS vendor for the state.

Image quality and frame rate suffers when moving, which affects visibility, but initial installation was without incident and no cameras have been replaced. However, some forward-facing cameras (which use USB cables and non-locking connectors) have had issues with cable connections due to vibration requiring replacement or additional securing.

SDDOT is very satisfied with the system and 24 new trucks will be outfitted with cameras. Drivers are also very satisfied and have not reported any issues with distraction and only use the cameras when they need them.

Other Comments

SDDOT highly recommends a camera cleaning system and uses one with each camera attached to a separate washing fluid tank and compressed air tank. The cameras also record video that is stored for up to 24 hours. This video is reviewed to see road conditions as well as after any complaints are received. Currently there is no public distribution of any video or images, however there is a research project evaluating that possibility. New trucks have a built-in cellular modem and SDDOT will evaluate performance of the modem with other systems in the winter of 2019-2020.

Interview #3

Interview Subject

- Bryan Pickworth, Road Maintenance Supervisor, Farmington Hills, MI

Reasons for Selection

- Most expensive reported cost and reported "installation issues"

Deployment Summary

The City of Farmington Hills, MI has been installing backup cameras on plow trucks since 2014 with 14 of 18 of their large trucks outfitted with cameras. They also have one truck with a camera to monitor the wing plow. The survey response also reports using cameras for monitoring the spreader and underbody plow.

Key Information

MS Foster (system manufacturer) was selected by Truck & Trailer, a contractor who does the plow vehicle builds for the City. City staff maintain the installed camera systems and identified some issues with washer fluid leaking from the cleaning system. This is the only issue that has been experienced.

Overall, City staff and drivers are very satisfied with the system. Cameras are very beneficial from a safety standpoint. Engaging operators in the camera placement decision process and allowing them to position the cameras in the way that works best for them helps with satisfaction and acceptance.

The city is now considering installing cameras on all trucks.

Other Comments

The camera cleaning system is highly recommended. Also directly engaging the drivers in the camera installation process is recommended.

Summary

Overall, the use of cameras for monitoring vehicles is increasingly common and evolving as users learn where they provide the most benefit. Key lessons include the importance of camera durability, the use of a cleaning system, and engaging with drivers before and during the installation process and throughout operation. Conducting a thorough research effort before large-scale deployments can also help optimize the deployment. If a custom solution is used, it is important to plan how the system will interact with other systems to avoid locking the agency into a certain make or model of camera.

Chapter 5 - Vendor Contacts

Overview

The agency interviewees provided the names of several aftermarket camera manufacturers that they have either used or have seen demonstrated. These manufacturers were contacted to gain detailed information on their products and potential uses in future applications to support winter maintenance operations. The following sections contain questions asked of each vendor with their responses. A summary of each interview is provided.

Interview #1 Bosch

Interview Subject

- Natalie Haag, Regional Sales Manager, Bosch
- Bosch Application Design Department
- Bosch Pre-Sales Support

Reasons for Selection

The City of Farmington Hills, MI mentioned during their follow-up interview that Bosch had performed a demonstration of a system of 4-6 cameras on an excavator vehicle that the City is considering pursuing.

Key Information

The Bosch team was unaware of the Farmington Hills test, it was likely done by a third-party vendor. Bosch recommends the MIC 7000 camera but does not wish to pursue this application themselves due to issues they have had in the past with similar systems.

The MIC 7000 is recommended for both front- and rear-facing uses. A Bosch engineer mentioned a project he had worked on at a prior company attaching cameras to school buses for a school district in Tennessee. The engineers mentioned experiencing problems, particularly with the transfer of video off the buses due to the large amount of data needing to be moved, and the fact that the on-board equipment could only operate while the bus was turned on.

The Bosch cameras have a minimum operating temperature is -40ºC, and the minimum storage temperature is -60ºC, making them suitable for winter maintenance conditions. Recording of video is possible with the Bosch recorder model DDN 2516-212-N00. Playback is through VGA/HDMI connectors, and a smartphone app is produced by Bosch for iOS and Android for playback as well.

While cameras have defrosting and image stabilization functions, Bosch recommends against the use of their equipment for this purpose as it would require a significant design effort on their part and their engineers have experienced problems with similar systems.

Summary

Ultimately, Bosch is unwilling to pursue developing a system for this application. They have experienced significant issues when trying to implement systems like this in the past. Bosch mentioned that several manufacturers exist that specialize in mobile applications such as this, so these systems may already be on the market. Bosch identified the recording of video and the transfer of large amounts of video over wireless and cellular connections as the largest issues with implementing such a system.

Interview #2 Ameritrak

Interview Subject

- Jeff Edelstein, Chief Technology Officer, Ameritrak
- Axis Pre-Sales Support

Reasons for Selection

During follow up interviews MnDOT indicated they use Axis cameras installed by Ameritrak on their vehicles, including rear-view and for equipment monitoring purposes. Ameritrak was contacted to discuss this system; however, they were hesitant to discuss specifics of the Axis cameras they use, including model numbers. Because of this, Axis pre-sales support was also contacted to gain more information on their camera models that could be used for this application.

Key Information

Ameritrak did not provide specific camera models but mentioned that it was a mix of fixed cameras and dome cameras. Axis recommended the P3225-LVE for this application, which is a dome camera with a heated lens, but no cleaning system.

Ameritrak created custom software for MnDOT vehicle operators to view camera feeds in-cab while driving. Photos are taken at set time intervals and sent remotely to MnDOT maintenance servers and are also viewable by the public. Video is not recorded at this time and the system is not currently capable of transmitting and recording video.

The cameras should be mounted high enough (above elbow height at least) to provide a good field of vision, avoid individuals accidentally bumping them when walking around the vehicle, and to reduce the spray of salt and sand from the spreader.

Summary

Ameritrak has developed a system for viewing camera feeds in-cab and transmitting photos to remote locations from winter maintenance vehicles; however, additional development would need to be done to enable to transmission and recording of video. Ameritrak was reluctant to discuss technical details of their system before receiving detailed information about a potential pilot project.

Chapter 6 - Pilot Deployment

Overview

The Pilot Deployment (Task 8) underwent several iterations of its definition and scope throughout the course of the project. Originally envisioned as a pilot deployment of a novel technology in the area of aftermarket camera systems in winter maintenance vehicles, the task evolved into a review of recent unique deployments by MnDOT District 4 maintenance staff. The history of the task and results of the review are described in the following sections.

Task History

The results of Task 4 (Follow-Up Interviews) and Task 5 (Vendor Contact) of this project conducted in 2019 indicated that the City of Farmington Hills, MI was testing a live-video transmission system made by Bosch on one of its construction vehicles. Task 8 was to conduct a pilot project testing this system with another agency (MnDOT).

Discussions with Bosch's technology group revealed that they were unaware of this pilot in Farmington Hills, suggesting this was performed by an independent third-party. Bosch was unwilling to participate in a pilot deployment based on their previous experience with live video transmission from vehicles. Issues included prohibitively large data transfers and storage necessary to transmit video, unreliable wireless data connections, and poor video quality.

Consultation with the TAC redefined the task as a test of a camera lens washing system, which had been determined to be highly effective on maintenance vehicles. The pilot deployment would now use a commercially available camera washing system with a low-cost camera, rather than the complete camera and washier system from a single manufacturer. If successful, the pilot would demonstrate a cost-saving measure that could be used by other agencies.

After discussions with the TAC, MnDOT District 4 was selected for the pilot deployment, but the process had delayed the start until the 2020-2021 winters season. Preparations for the pilot revealed that the District 4 staff had already deployed the test configuration in the 2019-2020 season. As a result, a review of this system was determined to be desirable, and Task 8 was redefined to conduct this review.

System Review

The system review consisted of an interview with the District 4 staff and consultation with their equipment suppliers. The results of the interview are presented below, followed by conclusions drawn from the pilot deployment.

Interview

Interview Subject

Jed Schoon – MnDOT District 4 Maintenance Director

Key Information

- Each snowplow has 4 cameras and 4 MS Foster CameraWash systems, all cameras face to the rear of the vehicle. Cameras are CabCam models, which cost approximately $150 each. All District 4 snowplows use this system.
- All video feeds are displayed on an in-cab monitor visible to the operator. Operators use the video for safety purposes and to make better decisions about plowing and material applications.
- The MS Foster CameraWash system consists of cab-mounted rocker switch, fluid reservoir, pump, air solenoid, nozzle and bracket, wiring and tubing. Whenever the camera needs to be washed, the operator presses the button while driving and system pumps fluid from the reservoir to wash the camera.
- The CameraWash System is only used a couple times a day since the operators have other systems to rely upon in addition to the camera systems.
- When the wash system is not in use for a while, the water drains back to the tank and there is a delay between system activation and when the system releases the water.
- The video quality is very good in the daylight but there is a concern about low light performance without the assist of streetlights.
- The brightness of the in-cab display occasionally causes discomfort for the operators.
- Operators found the camera system most helpful after first implementation because it provided them with a greater awareness of how far the plow is from the targeted location.
- District 4 also uses a laser system to project a spot ahead of the vehicle indicating the where the plow edge will contact the pavement.
- The laser system is mounted on both sides of the cab top and projects a laser on the surface ahead of the snowplow to provides the operator with a visual reference spot in the operator's field of view. This helps the operator identify how far away there are from other objects better than through the camera system at times, particularly at night.
- The laser system was provided by the District 4 maintenance contractor (Bert's) and costs roughly $2,600 per vehicle.

Summary

Camera lens cleaning systems are highly effective and are universally recommended for use. However, integrated camera and wash system packages are expensive, particularly for vehicles equipped with multiple camera systems.

The MnDOT District 4 experience has shown that acceptable video performance can be obtained by using commercial camera wash systems with low-cost, off-the-shelf vehicle cameras, providing

they are designed for the harsh conditions of maintenance use. In this case the savings was approximately $350 per camera, or $1,400 per vehicle.

The use of forward-pointing laser reference markers also shows promise and District 4 has had positive experiences. However, there is little data on durability, and this should be further researched prior to making any recommendations.

Chapter 7 - Recommendations

Introduction

The information collected during this project makes several recommendations for aftermarket camera systems clear for agencies as they pursue deployments. These are organized into separate sections below.

System Components

This section summarizes information on common system components and criteria for equipment selection.

Number of Cameras and Camera Locations

One forward-facing camera that captures either still images or video for maintenance staff or the public are very popular. Rear view cameras are also very common, with other equipment monitoring cameras (wing plow, material spreader, etc.) also in use. These cameras allow plow operators to view video on an in-cab display and are typically not transmitted to remote locations. Rear view and tow plow cameras are recommended. Other equipment monitoring cameras may be deployed depending on operator needs.

In-Vehicle Displays

In-vehicle displays typically allow drivers to continuously monitor their vehicle's surroundings while in operation. Seven-inch display monitors are typically used, though sizes ranged up to 19-inch. When multiple cameras were installed in a vehicle, some users had one monitor for each camera feed, while others had one split-screen monitor displaying all camera feeds at once. In-vehicle displays for rear-view and equipment monitoring are recommended, but placement should be carefully considered to avoid glare on the windshield.

Transmission and Recording of Images and Video

Transmission of video to remote viewers is currently uncommon as wireless data systems in remote areas typically cannot offer the performance needed for usable video streams. Recording is also somewhat uncommon but may be advisable to provide a record of operations for incident review or training.

Transmission of video is not recommended unless the specific area of operation offers a sufficiently high-performance wireless data network. Recording may be advisable, if a manufacturer offers a recorder that can operate in the vehicle environment.

Camera Manufacturers

For the manufacturers encountered during the project (MS Foster, ProVision, Pro-Tech, Live View, and Logitech), no specific recommendation is made. Note that camera system costs vary greatly based on camera manufacturer used, number and location of cameras, and implementation of a camera washing system. Initial camera system costs observed ranged from under $500 per vehicle to a maximum of $4,000 per vehicle. No specific relationship was found between reported issues and overall satisfaction and price.

Best Practices

The following is a set of recommendations for future installations of aftermarket cameras on winter maintenance vehicles. These recommendations should be considered guidelines for agencies to consider when pursuing new installations of vehicle camera systems and provide the agency with criteria to evaluate potential camera system options. These recommendations should not be considered requirements or a set of specifications.

- Camera systems are recommended to consist of one rear-view camera, and up to three equipment monitoring cameras pointed at tow plows, wing plows, spreaders, or other equipment installed on the maintenance vehicle. Cameras shall be installed in a manner that does not interfere with normal vehicle operations and that drivers will not accidently interfere with them, particularly when entering and exiting the vehicle.
- Forward-facing cameras serve a different purpose than rear-view and equipment monitoring cameras; however, a forward-facing camera is recommended in plows with communication to remote locations to allow for the transmission of images of current road conditions. The users of these images may include maintenance supervisors and/or the public, per each agency's preference.
- No recommendation is made for a specific make or model of camera. Agencies should select cameras based on their budget, desired use cases, and other factors.
- Cameras should possess a heated lens (particularly in colder weather states) and an automatic cleaning system that can be operated while the vehicle is in motion, to always ensure visibility. Camera cleaning systems can be integrated with the camera or separate from the camera. Camera cleaning systems that are automated (such as MS Foster's optional timer in its CameraWash system) are recommended to ensure drivers do not have to divert their attention from the road to operate the camera cleaning system.
- Camera wash systems have been demonstrated to work acceptably with other manufacturers cameras. Consider whether a lower cost option is available for the cameras prior to making a purchase decision.
- In-cab displays should be able to view feeds from up to four cameras at once. Rear-view and equipment monitoring cameras should be integrated with the in-cab display. It is not necessary to integrate forward-facing cameras with the in-cab display. To avoid driver distraction and ensure driver safety, displays should be dimmable, and drivers should be able

to shut the display off when necessary. Displays should be installed in a manner that ensures that the driver's forward field of vision is not obstructed. No recommendation is made on display size; however, display size should be chosen in a manner that allows the driver to view camera feeds without difficulty and without obstructing the driver's view of the road while operating the vehicle.

- Still images should be captured periodically (per each agency's preference) from forward-facing cameras to be transmitted to maintenance offices to inform supervisors and staff of current road conditions. It is recommended that these images be provided to the public over the Internet to promote safety through informing the public of real-time road conditions. 3G and non-LTE 4G service should be avoided due to end-of-life concerns and existing systems should be upgraded to 4G LTE networks when feasible. Systems should be configured to allow for capture and transmission of images only while the vehicle is operating and in motion.
- With the current state of cellular technology and given the present needs of maintenance agencies, transmission of live video is not considered a necessity at this time. If obtaining video feeds is desired but live video is not necessary, recording video in-cab and transferring via wi-fi or USB once the vehicle has returned to the maintenance yard is recommended. Transmitting video over cellular is not recommended at this time, as compromises would have to be made on video quality and reliability of transmission. As the 5G network expands and becomes a feasible alternative to 4G LTE, transmission of live video may be more feasible.
- It is recommended that cameras that transmit images be powered by Power over Ethernet (PoE) to allow for communication to the cameras along with the ability to transmit digital videos over cellular without the use of a separate encoder. For rear-view and equipment monitoring cameras, PoE is recommended as well to allow for ease of camera communication troubleshooting. Ethernet-capable in-cab displays should be deployed in order to avoid the use of a separate video decoder. Ethernet cables should be selected that have appropriate jacket materials to resist ultraviolet light and chemical exposure.
- Drivers should be involved throughout the camera installation process, and drivers' opinions should be considered when designing camera systems. Ensuring vehicle operators are aware of the uses of these camera systems and the importance of operating them correctly is critical.

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research for winter highway maintenance

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