Collision Avoidance Systems for Snowplows: An Overview of Strategies and Research

Prepared for
Clear Roads Pooled Fund Study

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Snowplows are often forced to operate in dangerous, low-visibility conditions that can lead to collisions with other vehicles, guardrails and objects on roadways, such as mailbox posts. These conditions are hazardous to the safety of snowplow drivers as well as the traveling public, and create a considerable liability for state DOTs. As the lead state for the Clear Roads winter maintenance pooled fund, Wisconsin DOT asked us to investigate collision avoidance systems and strategies for snowplows.

Summary

This report documents various strategies for preventing snowplow collisions. These strategies are organized into two key categories: **Driver Assistive Systems** to increase snowplow operator safety, and measures that improve the visibility of the snowplow so motorists can better judge the snowplow's speed and position to avoid rear-end collisions.

These strategies vary in cost, benefit and availability, but all have potential to ameliorate the safety and liability issues associated with snowplow collisions.

This report reviews two initiatives in driver assistive technology: Minnesota's **Intelligent Vehicle Lab Snowplow Driver Assistive System** and California's **Advanced Snowplow Driver Assistance System**, or **RoadView**. The two systems have been tested extensively, but deployment is not widespread. In fact, in California, the system was recently retired because of cost and maintenance issues. In Minnesota, use of the technology in snowplows has stagnated. Still, driver assistive systems are viable in some state DOTs. The Alaska Department of Transportation & Public Facilities, for example, has integrated components of Minnesota's driver assistive system in several plows and blowers. In addition to these initiatives, this report addresses the emerging use of **laser technology in driver assistive systems**.

This report also reviews how measures such as lights, reflectors, vanes and deflectors can enhance **Snowplow Visibility** to increase highway safety for other drivers and reduce the occurrence of collisions, particularly with passing vehicles.

Strategies

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Driver Assistive Systems

Driver assistive systems use a combination of technologies, including differential global positioning systems, real-time kinetics, radar, geospatial databases, magnetic guidance technology and laser sensors to help snowplow drivers navigate in low-visibility or whiteout conditions. While these systems have the potential to significantly improve drivers' abilities to avoid collisions, none has been deployed widely, in part because of cost, maintenance and lack of user-friendliness.

In 1998, Minnesota, California and U.S. DOT created the U.S. DOT Intelligent Vehicle Initiative Specialty Vehicle pooled fund. Two major initiatives in driver assistive technology are:

- Minnesota Intelligent Vehicle Lab Snowplow Driver Assistive System
- California Advanced Snowplow Driver Assistance System, or RoadView

The partnerships in these states developed technologies that would aid drivers and maintenance engineers with snow removal in difficult, low-visibility conditions. Each partner focused on technologies appropriate to its environmental and geographical conditions: in Minnesota, light, dry, drifting snow; and in California, large amounts of wet, heavy snow.

The two systems have been tested extensively, but deployment is not widespread. In fact, in California, the system was recently retired because of cost and maintenance issues. In Minnesota, use of the technology in snowplows has stagnated. Still, driver assistive systems are viable in some state DOTs. Alaska DOT&PF, for example, is currently using a repackaged Minnesota system in several plows and blowers.

Minnesota: Intelligent Vehicle Lab Snowplow Driver Assistive System

This system uses high-accuracy, dual-frequency, carrier-phase differential GPS; radar; digital maps; and a conformal, augmented graphical display to provide snowplow drivers with a virtual view of the road and obstacles ahead when atmospheric conditions would otherwise preclude driving. The graphical display is augmented with an active, tactile seat that complements the visual system by providing vibrational cues to a driver that a lane departure is imminent.

System testing in two areas of Minnesota—St. Louis County and Polk County—resulted in very different operational benefits. In St. Louis County, where low visibility was uncommon, testing operators found few benefits. However, in Polk County, where the topology is flat with few trees and high winds, blowing snow frequently reduces visibility. Testing operators found the system useful. According to Bryan Newstrom, an engineer at the University of Minnesota, two plows equipped with the technology are in use in Crookston, Polk County, and the system is installed in some public buses in Minnesota. John Scharffbillig of Mn/DOT said that the technology never caught on statewide partly due to the bulkiness of the system and its head-up display. Research in this area continues in Minnesota, but Scharffbillig does not foresee new technologies entering the market in the near future.

However, Alaska DOT&PF has realized considerable benefits from the system, including reduced accident rates as well as reduced sign and guardrail damage, an improved ability to keep roads open and clear, and decreased stress and fatigue for plow drivers. After the system was tested during the winter of 2001-2002, Alaska DOT&PF procured two units for testing and operational deployment. Alaska DOT&PF now has three vehicles equipped with the system and had plans to equip an aircraft rescue and firefighting vehicle. Alaska DOT&PF previously used snowplows equipped with magnetic lateral guidance technology (which is used in California's RoadView system).

The University of Minnesota and Mn/DOT developed this technology to address the challenge posed by dry, drifting snow that results from high winds. This system is designed to work best in those conditions. A Minnesota newsletter (see below) reported that the cost of the driver assistive system was approximately $46,000 per truck (not including labor) for the equipment and GPS. Also, in a technology nomination to AASHTO (also listed below), Alaska DOT&PF cited equipment costs of $40,000 per vehicle, $5,000 for labor to install the equipment, and $20,000 for the GPS equipment.

Four Mn/DOT research reports describe the development and deployment of the system:

"Driver Assistive Systems for Rural Applications: A Path to Deployment, Volume 1," August 2005.
http://www.lrrb.org/pdf/200530.pdf
"Driver Assistive Systems for Rural Applications: Digital Mapping of Roads for Lane Departure Warnings, Volume 2," August 2005.
http://www.lrrb.org/pdf/200531.pdf
Mn/DOT deployed a driver assistive system in two Minnesota counties to gauge demand and functionality. Volume 1 summarizes the experience in these counties. Volume 2 describes a system designed to collect and process geospatial data used by the driver assistive system, along with the costs and time associated with collecting map data and creating a map from that data.

"Driver Assistive Systems for Snowplows: Part of the Intelligent Vehicle Initiative," March 2003.
http://www.lrrb.org/pdf/200313.pdf
This report addresses four areas of research—driver assistive displays, the integration of a geospatial database for improved radar processing, snowplow dynamics under slippery road conditions, and gang plowing—and their effects on the performance and reliability of driver assistive systems.

"The Effectiveness of Auditory Side- and Forward-Collision Warnings in Winter Driving Conditions," June 2003.
http://www.lrrb.org/pdf/200314.pdf
In this study, researchers conducted a driving simulation and a field test with snowplow operators to investigate the usefulness of auditory signals as side- and forward-collision avoidance warnings.

This page describes the Minnesota Specialty Vehicle Initiative:

"Human Centered Technology for Handling Low Visibility: Vision Enhancement and other Driver Assistive Technologies," March 2002.
http://www.its.umn.edu/Research/IVfieldtest/index.html
This project is evaluating new technologies for specialty vehicles, such as snowplows and other vehicles used for road maintenance, that enhance the operator's ability to see the road and other vehicles while performing necessary functions to keep the roads clear and open for others.

Two Minnesota newsletter articles summarize the initiative:

"Deploying a Driver-Assistive System for Rural Snowplows," Center for Transportation Studies Research E-News, November 2005.
http://www.cts.umn.edu/Publications/ResearchENews/2005/11/index.html#das_snowplows

"Using GPS Technology in Snowplows," Minnesota Local Technical Assistance Program *Technology Exchange* newsletter, Summer 2004.
http://www.mnltap.umn.edu/Publications/Exchange/2004-3/2004-3-5-1.html

Two documents reference Alaska's experience with Minnesota's system:

Intelligent Specialty Vehicle System Pilot Program Report, March 26, 2007, Alaska DOT&PF.
http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/14370.htm
This report describes Alaska's experience testing Minnesota's snowplow driver assistive system as part of its Intelligent Specialty Vehicle System. Alaska found that the system is cost-effective, improves safety and increases productivity in the transportation system.

AASHTO Technology Implementation Group, Nomination of Technology Ready for Implementation, September 2007, submitted by Alaska DOT&PF.
http://www.transportation1.org/tig_solicitation/uploads/AASHTO%20TIG%202007%20Nomination%20AK%20ISVS.doc
Based on the department's positive experience with the Intelligent Specialty Vehicle System, Alaska DOT&PF nominated the system for its ability to allow snowplow drivers to operate in zero or near-zero visibility conditions.

In 2001, the technology was evaluated by TRB's Ideas Deserving Exploratory Analysis program:

"Phase II Evaluation Trunk Highway 19 Snowplow Demonstration Project," Minnesota DOT Intelligent Vehicle Initiative, Winter 1999-2000, Final Report for ITS-IDEA Project 80, October 2001.
http://onlinepubs.trb.org/onlinepubs/sp/its-idea_80.pdf

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California: Advanced Snowplow Driver Assistance System (RoadView)

RoadView uses a magnetic guidance system to help snowplow operators drive a plow even under total whiteout conditions by providing a visual display inside the cab of the plow's position relative to the sides of the road and to potential obstacles. A conventional snowplow (International Paystar 5000 10-yard sander truck with front blade and wing plow) was modified to include:

- computer data acquisition and information processing unit sensors for measuring steering angle and vehicle movements
- sensors that detect the vehicle's location on the roadway
- radar sensors for obstacle detection
- a human-machine interface

Roadway characteristics are obtained through position updates from the magnetic guidance system, and the current and projected positions of the vehicle are processed using the lateral position measurements. Potential obstacles, as well as relative vehicle spacing, are obtained from the radar system and conveyed to the driver through the human-machine interface.

The California team also developed an advanced rotary plow, a blower that uses magnetic guidance technology and automatic steering. It follows the plow to pick up excess snow.

The RoadView system was tested heavily in California and Arizona for several winters and at additional sites in Montana, Idaho, North Dakota and Wyoming for a 2004 cost-benefit analysis. California abandoned the technology because of the maintenance-intensive nature of the magnetic guidance markers and because the system was also cost-prohibitive, according to Brian Carlson, area superintendent for the Kingvale, Calif., test site. Kin Yen, hardware engineer and manager for the RoadView project at the Advanced Highway Maintenance and Construction Technology Research Center, said the magnetic guidance components for the lateral guidance system proved commercially infeasible and prevented full deployment of the product. Caltrans and its partners are now looking into differential GPS systems, which the Minnesota system uses.

Two reports detail the development of the Advance Snowplow system for Caltrans by AHMCT Research Center at the University of California–Davis:

> **"Advanced Snowplow Development and Demonstration: Phase I: Driver Assistance," June 1999.**
> http://www.ahmct.ucdavis.edu/images/99063003.pdf
> This report documents phase I of the Advanced Snowplow system project, developed to enhance the safety and efficiency of snow removal. The technology includes lane position indication and lane departure warning systems along with a forward collision warning application.
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> **"Development of an Advanced Snowplow Driver Assistance System (ASP-II)," June 2000.**
> http://www.ahmct.ucdavis.edu/images/00063002.pdf
> This report describes improvements made to the Advanced Snowplow system project based on findings from Phase I research.

The utility and cost-effectiveness of the RoadView system were analyzed in this paper presented at the June 2004 Sixth International Symposium on Snow Removal and Ice Control Technology:

> **"Needs Assessment and Cost-Benefit Analysis of RoadView Advanced Snowplow Technology System,"** David Kack and Eli Cuelho, Montana State University–Bozeman, *Transportation Research Circular*, June 2004.
> See Appendix A; the full PDF is 26MB, available at http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf (pages 332 to 347).
> Researchers found that the most common methods used by snowplow operators to maintain their lane position are visual. Operators had a high perceived usefulness of technology that would assist in detecting obstacles and provide lane position information. RoadView would be most cost-effective on roadways with high traffic volumes associated with significant road closures caused by winter weather conditions.

More information on the system is available online:

> **California Partners for Advanced Transit and Highways Web site**
> Advanced Snowplow Vehicle Control
> http://www.path.berkeley.edu/PATH/Research/snowplow/
>
> Advanced Rotary Plow Vehicle Control
> http://www.path.berkeley.edu/PATH/Research/blower/
>
> RoadView Snowplow
> http://www.ahmct.ucdavis.edu/index.php?title=SnowAndIce

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Emerging Strategies
According to Kin Yen, hardware engineer and RoadView project manager at AHMCT, using lasers in snowplow driver assistive systems is an emerging technology. These systems aim to provide an extra

margin of safety and reduce collisions with guardrails, mailbox posts and other obstacles near the shoulder of the road. Mn/DOT tested the use of lasers on wing plows in 2007:

Laser Guides for Wing Plows
"Mankato/District 7: Road Tests Evaluate Laser Guide for Wing Plow Operations," Mn/DOT Newsline employee newsletter, January 3, 2007.
http://www.newsline.dot.state.mn.us/archive/07/jan/3.html
In 2007, Mn/DOT tested a laser guidance system for wing plows in which a sensor in the laser system tracks the wing plow's location on the roadway relative to the direction of the plow. As the sensor tracks the wing, the laser emits a beam that places a green dot on the roadway, indicating the path the driver should follow to ensure adequate clearance for the wing plow.

Mn/DOT also sponsored a research project on differential GPS that builds on the driver assistive work done under the Specialty Vehicle Initiative pooled fund project:

Differential GPS for Gang Plowing
"DGPS-Based Gang Plowing," Lee Alexander, Alec Gorjestani and Craig Shankwitz, University of Minnesota, April 2005.
http://www.lrrb.org/pdf/200518.pdf
University of Minnesota researchers developed a differential GPS-based gang-plowing system that allows a trailing snowplow to follow the lead snowplow at a user-specified lateral and longitudinal offset, improving safety and productivity. This driver assistive system combines tactile steering feedback with throttle and brake actuators to help the driver of the following vehicle maintain the proper distance and lane position behind the lead vehicle. A side scanning laser sensor and a "virtual mirror" are also used to detect rogue motorists trying to violate the gang formation.

Enhancing Snowplow Visibility

Another approach to reducing rear-end collisions with snowplows is to enhance the snowplow's visibility to other drivers.

Lighting treatments that make snowplows more visible are widely available and often less expensive than intelligent driver assistive systems. Considerations for lighting systems are intensity, color and visibility.

Vehicles

Factors that influence vehicle visibility are:

- **Markings.** Reflective markings on the snowplow and blades can help motorists accurately judge the position, size and speed of the snowplow, improving drivers' judgment when trying to pass snowplows. Products like the Edge-O-Lite reflector can illuminate the outer edge of snowplow blades, making them easily visible to passing motorists.
- **Vanes and Deflectors.** Vanes and deflectors added to the front, sides or rear of plows can increase the visibility of plows and their lights by reducing snow accumulation and snow cloud formation. Curved vanes and straight-edged deflectors mounted on the rear of the sides of the snowplow were especially effective in reducing snow cloud formation. Iowa DOT identified a deflector with a scoop design as particularly effective at preventing snow accumulation on the vehicle.
- **Color.** A 2006 study by the University of Minnesota could determine no optimal paint color for making snowplows more visible. Colors used vary from state to state.

Research into this technology includes:

"Improving the Ability of Drivers to Avoid Collisions with Snowplows in Fog and Snow," Albert Yonas and Lee Zimmerman, University of Minnesota, July 2006.
http://www.lrrb.org/pdf/200629.pdf
This research found that low-contrast lighting and flashing lights may substantially decrease crash avoidance. The optimum color to paint snowplows so that they are less susceptible to rear-end collisions could not be determined.

"Synthesis of Best Practice for Increasing Protection and Visibility of Highway Maintenance Vehicles," Center for Transportation Research and Education, Iowa State University, August 2002.
http://publications.iowa.gov/2559/1/visibility.pdf
This research reviews current practices to protect and enhance visibility of highway maintenance vehicles, including warning lights, retroreflective tape, shadow vehicles, truck-mounted attenuators and advanced vehicle control systems.

Three articles describe the lighting systems and their effects on snowplowing operations:

"Improved Visibility for Snowplowing Operations," NCHRP Research Results Digest No. 250, November 2000.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rrd_250.pdf
Recommendations from this research included modifications to front and wing plow operations and lighting to improve visibility for snowplowing operations.

"Lighting on Snowplows: An Accident Countermeasure?" John D. Bullough, American Public Works Association *Reporter*, October 2001.
http://www.apwa.net/publications/reporter/reporteronline/index.asp?DISPLAY=ISSUE&ISSUE_DATE=102001&ARTICLE_NUMBER=287
Lighting system design on snowplows can alert motorists that a plow is on the roadway, increasing safety significantly. Steady-burning lights are far more effective than flashing or strobing lights.

"Rear Lighting Configurations for Winter Maintenance Vehicles," J.D. Bullough et al., Rensselaer Polytechnic Institute, August 2001.
http://www.lrc.rpi.edu/resources/pdf/iesna01a.pdf
A prototype steady-burning light bar with light-emitting diodes was developed and tested on a snowplow also equipped with conventional flashing lights. The steady-burning light bar was more visible to other drivers than conventional flashing lights, increasing their confidence for judging speed and distance.

Needs Assessment and Cost–Benefit Analysis of RoadView™ Advanced Snowplow Technology System

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The RoadView™ system was originally developed to determine the feasibility of implementing an advanced snowplow control system to improve the safety and efficiency of snow removal operations. As follow-on research, this evaluation was designed to determine the magnitude of the challenges faced by snowplow operators, particularly during low-visibility conditions. Both a needs assessment and a cost–benefit analysis (BCA) of the RoadView system are provided.

The analyses focused on data gathered primarily from four western states: Idaho, Montana, North Dakota, and Wyoming. The three main factors to be considered in the needs assessment and potential BCA were safety, mobility, and operational issues. Both quantitative and qualitative data were collected from participating departments of transportation, including a survey distributed to snowplow operators in the four designated states. The survey was designed to gain further insight into perceived problems with limited-visibility snow removal operations and to examine current methods being used by snowplow operators to improve their spatial and situational awareness during low-visibility conditions.

Results indicated the three methods most used by snowplow operators to maintain their lane position are visual. Operators had a high perceived usefulness of technology that would assist in detecting obstacles and provide lane position information. The BCA indicated that RoadView would be most beneficial on roadways with high traffic volumes associated with significant road closures due to winter weather conditions.

INTRODUCTION

Keeping roads open and passable in the winter is a fundamental public safety task, the importance of which is emphasized by newspaper articles with headlines such as “Storm Paralyzes Upper Midwest.” The details of this particular article describe the magnitude of the problem. “Minnesota snowplow crews parked their rigs Tuesday because they couldn’t keep up with blowing, drifting snow that closed schools for thousands of youngsters from the Plains to the upper Great Lakes” (*1*).

In addition to being an inconvenience to travelers, a major snowstorm can have a significant economic impact. A study conducted for the Salt Institute estimated that impassible roadways in a 12-state Midwest region would cost $526.4 million per day in federal, state, and local taxes. In addition, it was estimated that such a storm would cost $1.4 billion per day in unearned wages and $600 million per day in lost retail sales (*2*).

Further, a major snowstorm has the potential to increase the number and severity of motor vehicle accidents. Researchers have explored the relationship between adverse weather and safety and found a significant decrease in crash rates after snow removal and deicing activities (*3*). Studies also have found that the number and rate of highway fatalities and injuries increase on snowy days (*4*).

Recent projects have focused on utilizing and evaluating technology to allow snowplow operators to continue to work in reduced-visibility situations (*5, 6, 7, 8, 9, 10*). By utilizing a variety of technologies, it is hoped that snowplow operators will be able to continue clearing roads in low visibility conditions ands thereby keep roadways open and reduce the economic impact of a storm. The RoadView™ system was initiated in response to these concerns as a means to facilitate snowplow operations in inclement weather.

PURPOSE OF THE STUDY

The purpose of this research project was to determine the need for the RoadView system and to perform a benefit–cost analysis (BCA) of the technology. Previous demonstrations have shown the potential success of RoadView deployments, although such demonstrations are limited in terms of the number of advanced technology-equipped vehicles and the amount of time these vehicles have been in operation. Theoretically, the technology utilized in the RoadView project is expected to increase safety by reducing erratic snowplow movements, run-off-the-road incidents and lane departures, snowplow accidents, damage to other vehicles and the infrastructure, and injuries to snowplow operators or other vehicle occupants. Increasing the speed or efficiency of snow removal tasks may potentially reduce road closures and travel delays and thereby improve both the operational aspects of snow removal activities and the mobility of motorists during adverse winter weather.

The needs assessment portion of this project discusses possible measures of effectiveness for the RoadView system and potential benefits that may be realized from more extensive implementation and deployment of the technology. Data for the study were gathered primarily from four states: Idaho, Montana, North Dakota, and Wyoming. Additional data collected as part of a RoadView evaluation in the Donner Pass area of California were included as supplemental information.

Quantitative data on winter weather-related accidents, as well as on the frequency and duration of winter road closures, were collected for descriptive purposes and to enhance the needs assessment. The qualitative data collected via the snowplow operator survey were used to determine equipment and route characteristics, perceived problems with limited-visibility snow removal operations, and current methods used to position the snowplow on the roadway during typical snowplow operations and particularly during periods of limited visibility.

The next section presents the needs assessment portion of the project, and the third section presents the BCA. The final section of this paper presents the conclusions of the research.

NEEDS ASSESSMENT

A needs assessment represents an attempt to identify and quantify, if possible, the potential benefits of a given accident countermeasure or safety improvement. This task often provides the justification for funding decisions and as such is a valuable tool for departments of transportation.

Based on previous research, RoadView and similar advanced snowplow technologies have been found to assist snowplow operators in determining their lane position as well as in providing a warning of objects and obstacles in front of and behind the vehicle (*5, 6, 7, 8, 9, 10*). Research in Minnesota (*5, 7*) focused on accidents and the related costs as the basis for continuing research efforts on this topic, and two studies conducted in Iowa focused on the operational aspects of plowing snow (*6, 8*). The present study was designed to combine these two approaches in order to provide a detailed investigation into various issues associated with snowplow operations in low-visibility situations and to consider variables that might be used to measure system effectiveness and assess possible benefits associated with the technology.

Analytical Considerations and Limitations

Identification of the potential benefits of the RoadView system focused on data related to snowplow-related accidents and run-off-the-road incidents, delays to motorists, and perceptions and opinions of snowplow operators.

Data on accidents and incidents involving snowplows, as well as information on winter road closures, were used to describe the magnitude of problems that might be mitigated with the implementation of the RoadView system. Quantitative data confirmed the incidence of snowplow-related accidents, both with and without the involvement of other vehicles, on those roadways selected as study sites and statewide. Roadway closures due to severe winter weather and resulting in unspecified delays to travelers also were documented. Intuitively, any technology assumed capable of reducing accident-related costs or injuries would be perceived as beneficial. Furthermore, technology that has the potential to shorten or eliminate road closures would have appeal. As emphasized elsewhere throughout this document, the ability of the RoadView system to reduce accidents or road closures remains undetermined at this point.

In assessing whether a need exists for advanced snowplow technology, it was difficult to determine an appropriate threshold for each of the factors described above. In other words, at what point does each measure of effectiveness become a meaningful indication of need? How many snowplow-related accidents per year, for example, would have to be reported in order to establish a need for advanced technology? how many winter road closures? how many hours of delay due to road closures? Does the fact that snowplow operators perceive the proposed technology to be highly useful validate a need? There are no objective criteria for determining appropriate thresholds, and, often answers to these kinds of questions, by themselves, cannot establish whether the system is needed. Information concerning benefits to be accrued must be compared with the costs associated with the system in order to calculate the net value of the technology. Only then can a safety improvement program or technology be judged relative to other budgeted or proposed projects to establish funding priorities. Wider-scale deployment and field testing of the RoadView technology are necessary in order to collect empirical data to assess the system's effectiveness and quantify its benefits so that objective decisions can be made regarding the need for and cost-effectiveness of the system.

Given that empirical data were not available to evaluate system effectiveness as part of this research, it was necessary to incorporate other, more subjective, information into the needs assessment. Responses to the snowplow operator survey were used to more broadly define the potential need for the advanced snowplow technology. For example, operators were asked to assess the potential usefulness of technology that would assist them in various aspects of snowplow operations. The survey responses regarding the perceived usefulness of the system became surrogate measures of the technology's potential benefits. It was not possible, however, to meaningfully assign monetary values to these potential benefits, which were based on hypothetical examples of the system's technological capabilities.

Survey Results

The results of the operator survey highlighted several issues that may have implications regarding the need for advanced snowplow technology. One of the RoadView system's two primary purposes is to provide lane-positioning information to snowplow operators. When asked what methods operators currently use to maintain their position on the roadway, their three highest-ranked choices involved judging their distance from the following roadside features: guardrails, mileposts and delineators, and the centerline. In fact, 8 of the 15 most commonly used methods for maintaining lane position involved visual cues. By definition, these methods all rely on the operator's ability to see out of the vehicle, which may be severely hampered by a number of factors as discussed below.

Weather conditions, as expected, were ranked highest in terms of factors that contribute to poor visibility. In addition, certain driving conditions (e.g., meeting or being passed by other vehicles) can exacerbate the situation. Whereas these things cannot be controlled, there were other factors that might be addressed through design modifications or routine maintenance and repair. Specifically, three different placements of the vehicle's lights were believed to create visibility problems, and numerous comments on the survey described problems caused by wipers and defrosters that did not function properly.

The importance of maintaining their lane position was ranked fourth out of five factors related to safe snowplow operation, although the mean rankings were extremely close for all five choices. Operators acknowledged that road configuration and traffic volume determine to a large extent the risks involved with crossing into another lane of travel. Similarly, run-off-the-road incidents increase during low-visibility conditions; the incidents potentially can cause damage to the snowplow or the infrastructure, as well as injury to the snowplow operator. Survey responses described the magnitude of this problem, as well as provided information regarding what, if any, objects were struck when the snowplow left the road.

Operators were asked to rank the usefulness of technologies that would assist with four specific tasks, the first of which was providing lane position information. The remaining three tasks dealt with detecting obstacles to the front, rear, and side of the vehicle, respectively. It should be reemphasized that the operators had only a general written description of each technology (e.g., "If the technology existed that could tell you your lane position while plowing, how useful would it be to you?"). The operators indicated that technology with the ability to detect obstacles in front of their vehicle would be most useful, followed closely by technology to assist with lane position awareness.

Lastly, the frequency and duration of loss-of-visibility events may be considered relevant to the needs assessment. During an average snowstorm, operators estimated they typically lost sight of the roadway once every two hours, with each occurrence lasting four seconds or less. This finding was similar to results obtained by McGehee and Raby (*6*) when they surveyed snowplow operators in Iowa and Minnesota. Loss-of-sight occurrences did not happen frequently or for extended periods of time, but these events can cause stress for snowplow operators, as can snow removal activities, in general. Perhaps more importantly, such instances can affect the efficiency of snowplow operations. During reduced visibility conditions, operators may have to reduce significantly their speed or stop their vehicle altogether. Either action potentially affects the mobility of travelers and could have safety implications for both the snowplow operators and other motorists on the roadway.

Conclusions and Implications—Needs Assessment

This research identified ways in which advanced snowplow technologies may benefit snowplow operations, but operational testing on a wider scale and for extended periods of time are needed to establish the effectiveness of the system. To date, advanced snowplow technologies have been utilized predominantly in proof-of-concept or proof-of-technology research. Minnesota and California have had early successes in demonstrating that certain technologies can provide lane position and obstacle detection warnings to snowplow operators. Ultimately, however, deployment of the technology in real-world situations will be necessary to provide quantifiable data on system benefits associated with reductions in accidents or delays.

There is evidence to support the continued research on and operational testing of advanced snowplow technologies. Historical data confirm snowplow-only and snowplow versus motor vehicle accidents on designated roadways in this research effort. Reductions in mobility caused by winter road closures also were documented. The ability of an advanced snowplow system to impact these factors directly has not been determined but should be investigated.

The results of the snowplow operator survey revealed the extent to which operators rely on their ability to see obstacles and vehicles in front of the snowplows and to utilize visual cues to maintain their lane position. Given the variety of circumstances in which visibility is severely restricted, advanced technology to assist operators by providing lane position information and obstacle warnings has obvious utility. The added potential benefit of reducing operator workload and stress was not addressed specifically in this study but should be examined in future research efforts.

As stated previously, in order to determine the feasibility of widespread use of RoadView or other advanced snowplow technologies, it is important to consider the costs, as well as the potential benefits, of the system. A discussion of variables that could be used in a BCA of RoadView is included in the next chapter, along with cost–benefit scenarios using the five designated study sites.

BENEFIT–COST ANALYSIS

For the BCA, an attempt was made to quantify the benefits of the RoadView system in terms of safety and mobility. For purposes of this analysis, the economic benefits associated with improved safety were related strictly to reductions in the number of snowplow-only accidents. Benefits associated with increased mobility were related solely to decreases in the time associated with road closures due to winter weather. Other benefits of the advanced technology may be related to increased effectiveness and efficiency of snowplow operations, which in turn may increase both mobility and safety. No attempt was made to quantify these variables for use in the calculations.

Quantification of the system's potential benefits was problematic because of a lack of empirical data. Advanced snowplow technologies have been used in demonstrations or proof-of-concept research but have not been deployed in sufficient numbers or for a sufficient length of time to enable a rigorous evaluation of the system's effectiveness. Thus, estimates of reductions in the frequency of snowplow-related accidents and the occurrence and duration of road closures were arbitrary. As discussed elsewhere in this report, previous demonstrations have concluded that the technology was useful in terms of providing snowplow operators with greater lane–roadway awareness during low-visibility plowing operations (*9*), but estimates of the accident-reduction capabilities of the system or the system's effect on road closures are unavailable. Thus, the results of the BCA should be interpreted with caution.

Overview of Analytical Technique

To perform the BCA, an equation was used to calculate the annualized benefits and costs associated with full deployment of the RoadView system and produce a benefit–cost ratio.

The costs associated with the advanced technology system include both in-vehicle and in-road elements. The in-vehicle costs of the RoadView system include the sensors, monitors, and support systems that allow the technology to provide lane positioning information and obstacle detection to the snowplow operator. The in-road costs are those associated with placing magnets in the roadway which, when read by sensors in the vehicle, provide lane position information.

The total system cost can be calculated by adding the in-road costs with the in-vehicle costs. The resulting total can then be divided by the expected useful life of the system to provide an annualized system cost. Finally, annual maintenance costs are added to calculate the total annual cost for the RoadView system.

It is hypothesized that full implementation of the RoadView system will produce certain benefits. Possible benefits include a reduction in the duration of road closures and a reduction in the frequency or severity of snowplow-only accidents. The monetary savings associated with these benefits also are annualized. Finally, the annualized benefits can be divided by the annualized costs to calculate a benefit–cost ratio. If the ratio is greater than 1.0, the RoadView system will be considered cost-effective.

A simplified summary of the calculations used to produce the benefit–cost ratios is provided below:

Costs	
In-road costs	$ IR
In-vehicle costs	+ $ IV
Total RoadView system initial purchase costs	$ Tot Cost
Annualized cost (Total cost/N yrs. + maintenance)	$ COST
Benefits	
Reduction of road closure duration (annual hours gained)	$ CD
Reduction of snowplow-only accidents (annual number)	+ $ SP
Annualized benefits from the RoadView system	$ BENE
Annual gain (loss)	$ COST – BENEFIT
Benefit–cost ratio	BENEFIT–COST

To illustrate the potential costs and benefits associated with implementing the RoadView system, five scenarios were analyzed. These scenarios pertain to the five areas that were targeted for data collection. The roadways represented in the scenarios have individual characteristics that distinguish them from one another, including variations in traffic volume, the number of lanes, road grade, and the frequency of road closures due to winter weather conditions. From a review of the scenarios, the factors that influence the benefit cost–ratio can be examined more fully.

Parameters Used in the Analysis

As previously discussed, the expected benefits of the RoadView system include increased safety and mobility. It is assumed that implementation of the RoadView technology will reduce the number and duration of road closures, as well as reduce the number of snowplow-only accidents. Operational benefits are anticipated, as well, but measures of the efficiency of plowing operations were not included in the analysis.

To calculate the economic benefits associated with the implementation of the RoadView system, the following data were used in each scenario: snowplow-only accident statistics, average annual daily traffic (AADT) and average daily truck traffic (ADTT), and the aggregate duration of road closures. The data used in Scenarios 1 through 4 were collected as part of this study, while the data utilized in Scenario 5 were collected by Ravani et al. (*9*).

The benefits of the RoadView system were quantified using the following factors:

- Travel delay cost for automobiles of $12.20 per hour (*11*),
- Travel delay cost for commercial vehicles of $25.30 per hour (*11*), and
- Cost of damage to snowplows per accident of $2,450 (*7*).

The costs associated with the RoadView system pertain to placing magnets in the roadway (in-road costs), as well as outfitting the snowplow with the necessary radars, sensors, and control units (in-vehicle costs). Correspondence with Mr. Kin Yen, University of California–Davis, and Stephen Owen, Arizona Department of Transportation (unpublished data), identified the following costs associated with the RoadView project:

In-vehicle costs	= $30,000/snowplow (includes installation),
In-road costs	= $18,000/lane mi (includes installation),
Maintenance costs	= $500/year/snowplow, and
In-vehicle and in-road equipment life expectancy	= 5 years.

The scenarios and the formula used constant dollars (not adjusted for inflation) and were rounded to the nearest $10. It was assumed that the number of hours associated with road closures due to winter weather would be reduced by 5%. An average of 4 h per closure was used for the purposes of the scenarios. It was further assumed that snowplow-only accidents would be reduced by 15%. Finally, the number of snowplows to be equipped with the RoadView system for deployment on each roadway was established on the basis of the number of miles and lane miles to be plowed. Because of the cost associated with equipping the plows, it was assumed that a minimal number of plows would be equipped for each area and used primarily for that specific roadway. Because plows are often part of a gang-plowing operation, two plows were used for all but one of the scenarios. Four plows were used in the Idaho scenario because of the high number of lane miles for this example.

SCENARIO 1: US-12 IN IDAHO (BETWEEN LOLO PASS AND LOWELL, IDAHO)

The section of US-12 used in this analysis (Figure 1) begins at the Lolo Pass, located on the Montana–Idaho border, and flows to the southwest to the town of Lowell, Idaho. The majority of this section of roadway follows along the Lochsa River. This roadway segment consists of 76 mi of two-lane highway.

In-road costs (152 lane miles)	$ 2,736,000
In-vehicle costs (4 snowplows)	120,000
Total RoadView system initial purchase costs	$ 2,856,000
Annualized cost (including maintenance)	$ 573,200
Reduction of road closure duration (Assumption 1)	$ 0
Reduction of snowplow-only accidents (Assumption 2)	3,310
Annualized benefits from the RoadView system	$ 3,310
Annual gain (loss)	($ 569,890)
Benefit–cost ratio	0.006

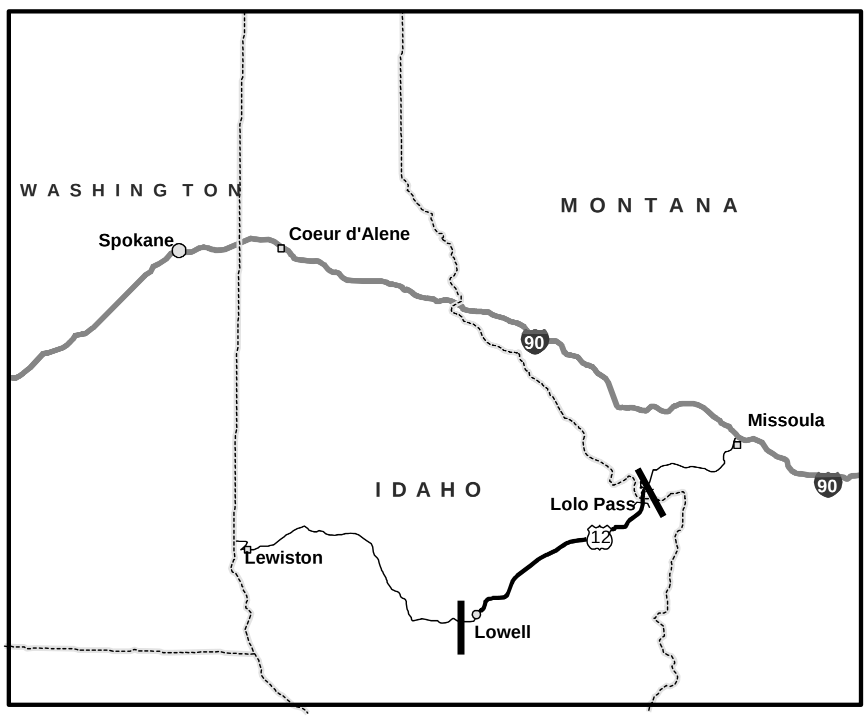

FIGURE 1 Idaho (US-12) scenario site.

The Scenario 1 assumptions follow.

1. Although Lolo Pass was closed during the 5-year timeframe examined in this study, the closures were due to forest fires and avalanche conditions, factors that would not be affected by RoadView technology. Thus, there could be no reduction in this variable.
2. Snowplow-only accidents would be reduced from 9 to 7.65 (15% reduction).

SCENARIO 2: HOMESTAKE PASS ON I-90 NEAR BUTTE, MONTANA

Homestake Pass is located on I-90 approximately 7 mi southeast of Butte, Montana (Figure 2). I-90 is a major east-west road connecting the West Coast to the Midwest. The area considered in this analysis consists of 14 mi of four-lane Interstate highway.

In-road costs (56 lane miles)	$ 1,008,000
In-vehicle costs (2 snowplows)	60,000
Total RoadView system initial purchase costs	$ 1,068,000
Annualized cost (including maintenance)	$ 214,600
Reduction of road closure duration (Assumption 1)	$ 1,780
Reduction of snowplow-only accidents (Assumption 2)	1,470
Annualized benefits from the RoadView system	$ 3,250
Annual gain (loss)	($ 211,350)
Benefit–cost ratio	0.015

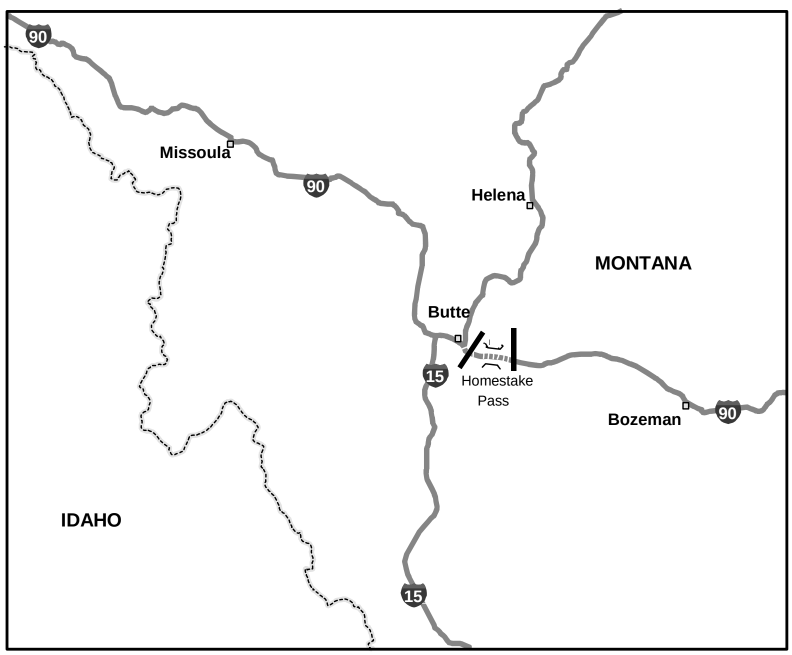

FIGURE 2 Montana (I-90) scenario site.

The Scenario 2 assumptions follow.

1. Reduction in closures equals 0.4 h per year (5% reduction).
2. Snowplow-only accidents would be reduced from 4 to 3.4 (15% reduction).

SCENARIO 3: I-94 IN NORTH DAKOTA NEAR BISMARCK

I-94 runs the entire length of North Dakota, approximately 360 mi. I-94 enters the state in the east at Fargo (the largest city in the state) and continues west through Bismarck (the capital) and then into Montana. The targeted 31-mi section of I-94 consists of a four-lane Interstate highway between Bismarck and Driscoll, North Dakota (Figure 3).

In-road costs (124 lane miles)	$ 2,232,000
In-vehicle costs (2 snowplows)	60,000
Total RoadView system initial purchase costs	$ 2,292,000
Annualized cost (including maintenance)	$ 459,400
Reduction of road closure duration (Assumption 1)	$ 2,230
Reduction of snowplow-only accidents (Assumption 2)	1,100
Annualized benefits from the RoadView system	$ 3,330
Annual gain (loss)	($ 456,070)
Benefit–cost ratio	0.007

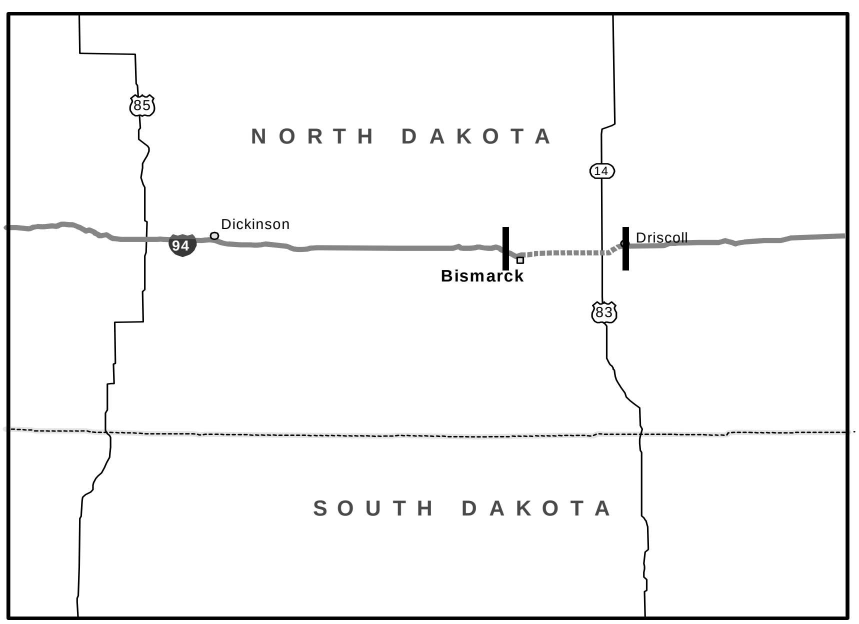

FIGURE 3 North Dakota (I-94) scenario site.

The Scenario 3 assumptions follow.

1. Reduction in closures equals 0.5 h per year (5% reduction).
2. Snowplow-only accidents would be reduced from 3 to 2.55 per year (15% reduction).

SCENARIO 4: I-80 IN WYOMING NEAR LARAMIE

I-80 runs the entire length of the state of Wyoming, approximately 400 mi. I-80 enters the state in the east near Cheyenne (the Capital and largest city in the state) and continues west into Utah. The targeted 12-mi section of I-80 consists of a four-lane Interstate highway, near Laramie, Wyoming, extending eastward to milepost 329 (Figure 4).

In-road costs (48 lane miles)	$ 864,000
In-vehicle costs (2 snowplows)	60,000
Total RoadView system initial purchase costs	$ 924,000
Annualized cost (including maintenance)	$ 185,800
Reduction of road closure duration (Assumption 1)	$ 11,370
Reduction of snowplow-only accidents (Assumption 2)	1,470
Annualized benefits from the RoadView system	$ 12,840
Annual gain (loss)	($172,960)
Benefit–cost ratio	0.069

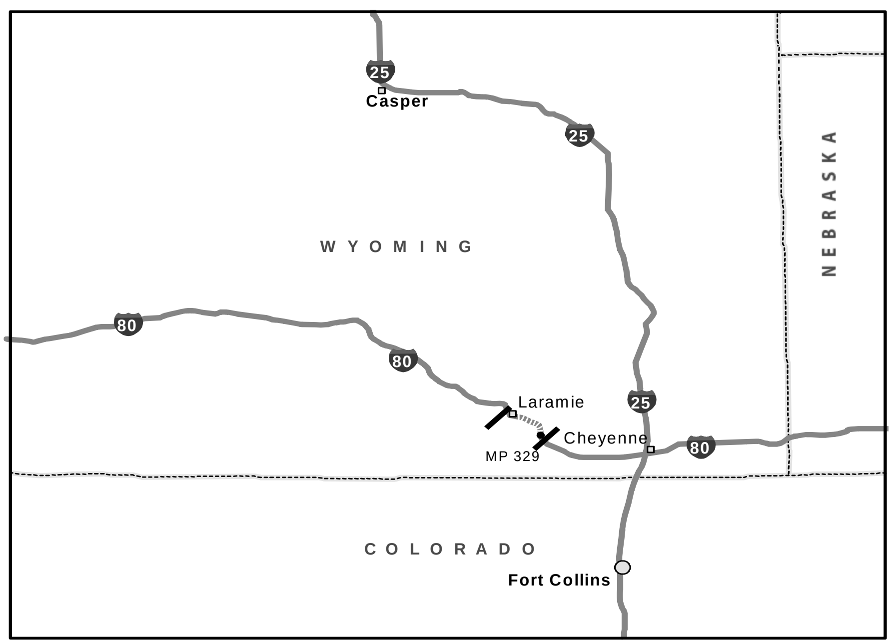

FIGURE 4 Wyoming (I-80) scenario site.

The Scenario 4 assumptions follow.

1. Reduction in closures equals 1.7 h per year (5% reduction).
2. Snowplow-only accidents would be reduced from 4 to 3.4 per year (15% reduction).

SCENARIO 5: DONNER PASS, CALIFORNIA

Donner Pass is located on I-80, to the west and southwest of Reno, Nevada. Although magnets were placed in just one lane for previous research (*9*), it was assumed that all lanes would receive magnets for purposes of this scenario. The targeted section includes approximately 4 mi of Interstate highway, part two-lane and part three-lane in configuration (Figure 5).

In-road costs (20 lane miles)	$ 360,000
In-vehicle costs (2 snowplows)	60,000
Total RoadView system initial purchase costs	$ 420,000
Annualized cost (including maintenance)	$ 85,000
Reduction of road closure duration (Assumption 1)	$ 106,740
Reduction of snowplow-only accidents (Assumption 2)	6,250
Annualized benefits from the RoadView system	$ 112,990
Annual gain (loss)	$ 27,990
Benefit–cost ratio	1.33

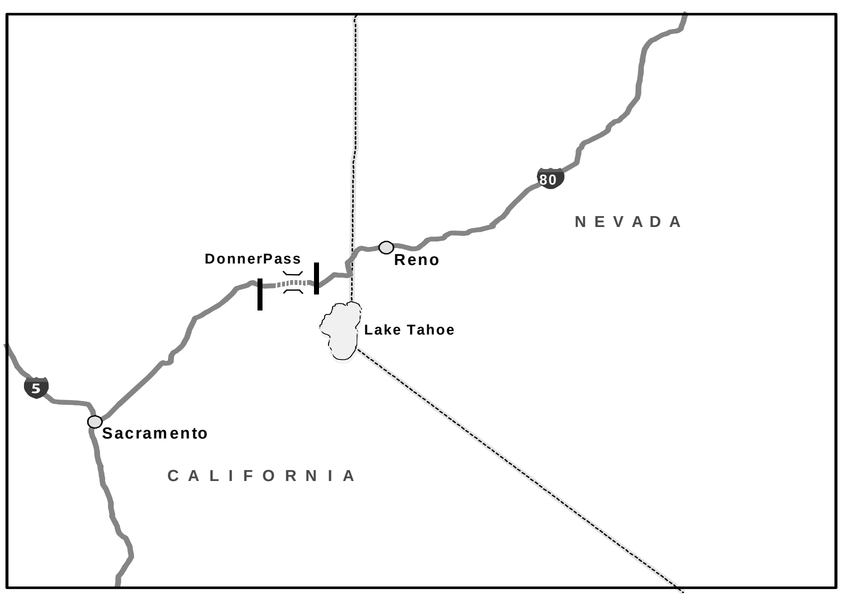

FIGURE 5 California (I-80) scenario site.

The Scenario 5 assumptions follow.

1. Reduction in closures equals 4.4 h per year (5% reduction).
2. Snowplow-only accidents would be reduced from 17 to 14.45 per year (15% reduction).

CONCLUSIONS AND IMPLICATIONS: BENEFIT–COST ANALYSIS

The RoadView system was found to be cost-effective in only one of the five scenarios: the Donner Pass area in California. Several characteristics that distinguished this site from the other locations should be highlighted. First, this location experienced the highest frequency of snowplow-related accidents among the study sites, as well as the highest 4-year average of winter road closures. In fact, road closures at this site were 6 to 10 times more frequent than at the other four locations. The AADT at Donner Pass was approximately six times greater than at the remaining sites, with ADTT figures ranking second only behind the designated roadway in Wyoming. Thus, it appears that the RoadView system may have the greatest impact on roadways that have a history of numerous winter road closures, with high volumes of automobile and truck traffic. Roadways with high accident experience (i.e., crashes involving only snowplows or snowplows compares with other motor vehicles) also should be considered for deployment of vehicles equipped with advanced snowplow technologies in order to maximize the opportunity to detect and measure the system's effect on snowplow-related crash and injury rates.

To further illustrate the impact that road closures, traffic volume, and the length of road have on the benefit–cost ratio, a break-even curve was created for each scenario (Figure 6). The break-even curve is defined as having a benefit–cost ratio of 1.0 at any point along its length. Points lying to the right of the curve have a benefit–cost ratio of greater than 1.0, while points to

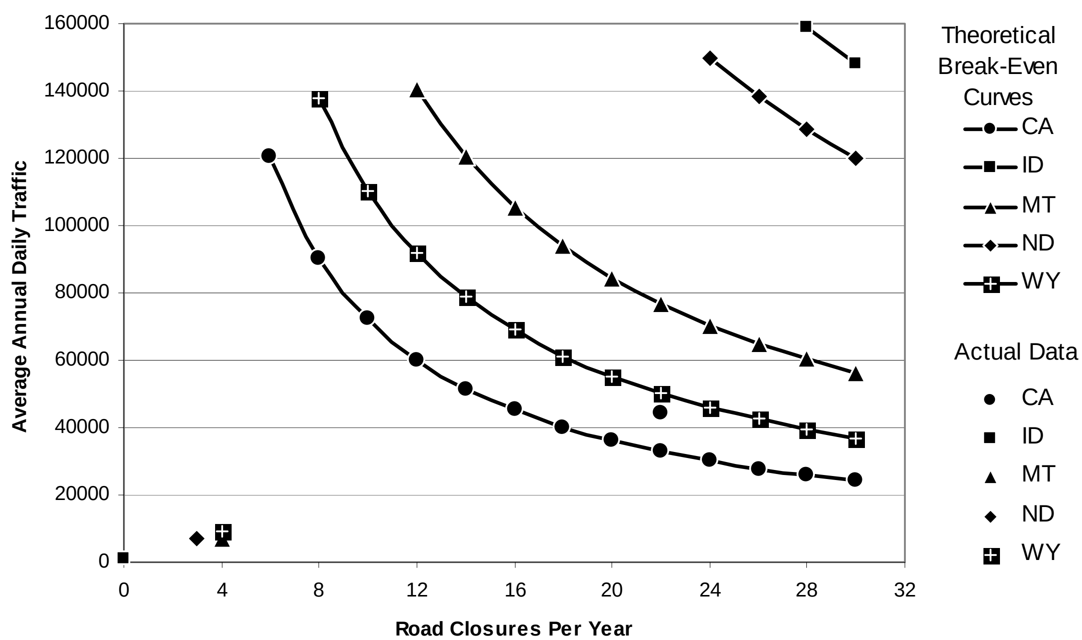

FIGURE 6 Break-even analysis of the RoadView system.

the left of the curve have a benefit–cost ratio of less than 1.0. Break-even curves were individually calculated for each of the five scenarios. It is important to note that the data point for each scenario should be compared against only its respective break-even curve.

From the analysis, it was found that the length of the roadway to be instrumented, the number of closures, and AADT are the three most significant factors in determining whether the RoadView system would be cost-effective in a particular area. The number of snowplow-only accidents had less effect on the analysis because of the relatively small cost of these incidents. Therefore, benefits realized from deployment are realized mostly through delay savings to the traveling public and, to a much lesser extent, snowplow only accidents. Bear in mind that this analysis was based on assumed estimates of benefits to be derived from the RoadView system.

At this stage of development, the costs associated with the RoadView system are extensive. Further testing or system modifications may reduce costs as well as could wholesale manufacture and product distribution. Correspondence with Yen discussed the equipment costs being reduced by up to 20% in a full-scale production and deployment scenario. The useful life of the in-road portion of the system (i.e., the magnets) is estimated to be at least 5 years; however, this estimate depends largely on the frequency of resurfacing activities on any given roadway. Extending the useful life of the RoadView components would increase the benefit–cost ratio, because the system costs could be amortized over a longer period of time. Assuming the estimates of system benefits used in the scenarios were reasonable, the costs currently associated with the advanced snowplow technology would have to be reduced significantly in order to make the system cost-effective. Once again, however, these results must be interpreted with caution because of the arbitrary estimates of system effectiveness used in the calculations.

SUMMARY

The goal of this project was to determine the feasibility of implementing an advanced snowplow guidance and warning system to improve the safety and efficiency of snow removal operations and to assess potential costs and benefits associated with combining conventional snowplow operations with intelligent vehicle technologies. The study was designed to determine the magnitude of the challenges faced by snowplow operators while they attempt to clear roadways of snow and ice, particularly during low visibility conditions. A needs assessment and a discussion of variables that could be used in a BCA of the RoadView system were provided, along with a detailed analysis of responses to a survey administered to snowplow operators. This study was not intended as an effectiveness evaluation of the system.

The quantitative and qualitative data that were collected for subsequent analyses were related to safety, mobility, and operational issues. Previous demonstrations have shown the potential success of RoadView deployments, although such demonstrations were limited in terms of the number of vehicles equipped with the advanced technology and the amount of time these vehicles had been in operation. Theoretically, the technology used in the RoadView project is expected to increase safety by reducing erratic snowplow movements, run-off-the-road incidents and lane departures, snowplow accidents, damage to other vehicles and the infrastructure, and injuries to snowplow operators or other vehicle occupants. Increasing the speed or efficiency of snow removal tasks may reduce road closures and travel delays and thereby improve both the operational aspects of snow removal activities and the mobility of motorists during adverse winter weather.

Historical data confirmed the incidence of snowplow-related accidents, both with and without the involvement of other vehicles, along those roadways selected as study sites. Roadway closures due to severe winter weather and resulting in unspecified delays to travelers also were documented. Presumably, any technology capable of reducing accident-related costs or injuries would be perceived as beneficial. Furthermore, technology that has the potential to shorten or eliminate road closures would have intuitive appeal. The task of determining the need for advanced technology without the benefit of empirical data was problematic. Therefore, subjective assessments of the perceived usefulness and potential benefits of the system, based on the responses to the snowplow operator survey, were used as additional measures or indications of the need for the technology.

The survey also provided information regarding difficulties encountered by snowplow operators while conducting operations in low-visibility conditions, current practices, and operational concerns, and the receptivity of operators to the advanced technology. During an average snowstorm, for example, snowplow operators estimated they typically lost sight of the roadway between one and six times for roughly 4 to 5 s per event. In terms of current operations, the three visual cues that snowplow operators relied on most frequently to maintain their position on the roadway included judging their distance from guardrails, mileposts and delineators, and centerlines. When asked to assess the potential usefulness of various advanced technologies, operators gave the highest ratings to those that would provide lane position information, followed by those that would provide obstacle detection capabilities. Despite these high ranking of potential usefulness, operators felt that there would be weather conditions in which snowplow operations should be suspended, regardless of the availability of advanced snowplow technology.

As with the needs assessment, the BCA was limited by the lack of empirical data to measure system benefits. Five scenarios that corresponded to the designated study sites were used to illustrate how benefit–cost ratios for the RoadView system could be calculated. It must be emphasized that until sufficient data have been collected to quantify the benefits of the advanced snowplow technology such hypothetical examples should not be considered statistical estimates of system effectiveness and should be interpreted with caution. In response to these concerns, what were believed to be conservative estimates of potential benefits associated with the RoadView system were used in the calculations. In comparison, Parsons Brinkerhoff Quade & Douglas, Inc. (*7*) utilized benefit levels of 10%, 20%, and 30% for reducing the number of snowplow crashes with other motor vehicles and fixed objects, reducing delays to commercial vehicles, and increasing the productivity of snowplow operations.

Of the five scenarios, only one produced a benefit–cost ratio greater than 1.0 (i.e., signifying benefits that outweighed the costs of the system). Overall, it appears that the potential cost-effectiveness of the RoadView system would be increased in areas with high traffic volumes and high probabilities of road closures due to winter weather and to a lesser extent in areas that have experienced a large number of snowplow-related accidents in the past.

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