Evaluation of the Minnesota Department of Transportation’s Intelligent Vehicle Initiative Snowplow Demonstration Project on Trunk Highway 19 Winter 1998-1999

Prepared by:

BOOZ-ALLEN & HAMILTON INC.

McLean, VA

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EXECUTIVE SUMMARY

Maintaining roadways in snowbelt states during the winter is very challenging, particularly in rural areas. Snow, combined with strong wind, frigid temperatures, fog, obstacles and vehicles hidden by snow, can make driving conditions nearly impossible. Studies indicate that the economic impact of road closures due to winter storms is significant. It is estimated that $1.4 billion per day would be lost in unearned wages and if all roads were closed in twelve snowbelt states studied (Billion$ at Risk…). The intelligent vehicle initiatives (IVI) technologies currently being tested on winter maintenance vehicles in several states may lead to improved winter maintenance of roadways, which in turn would lead to safer roadways and widespread cost savings.

The Minnesota Department of Transportation (Mn/ DOT) IVI Snowplow Demonstration Project (SDP) is a bold step to test how technology can be used to assist state maintenance workers in clearing roadways during winter storms. The project showcases both lateral guidance and collision warning technologies. Phase I of the IVI Snowplow Demonstration was conducted during the 1998-1999 winter. The overall goal of Phase I was to train the snowplow operators on the use of the selected technologies and to conduct test runs of the snowplow using the lateral guidance and collision warning systems during limited snowplow runs. Phase II will be conducted during the 1999-2000 winter and will focus on full-scale testing of the technology and snowplow operators' acceptance of it. Specifically, it is designed to assess the benefits of IVI technology application in the areas of safety improvements, time savings, traffic
flow improvement, and cost savings. These benefits will be determined using quantitative and qualitative evaluation methods.

Several snowbelt states are interested in deploying IVI technologies to enhance snow clearing efforts. However, only four other states are currently involved in operational test projects showcasing IVI technologies on snowplows: Arizona, California, Iowa, and Michigan. The tests being conducted in these states involve driver-assist IVI technologies and IVI technologies aimed at more efficient deployment of chemicals. Preliminary indications from the different IVI operational tests suggest that improvements in snow removal can be made through the application of IVI technologies to winter maintenance activities, such as plowing and sand/salt dispersion. However, further refinement and testing are necessary to determine the optimal combination of technologies for any state's operating conditions.
INTRODUCTION

Project Overview/Purpose

Mn/DOT began the demonstration phase of its IVI program through the initiation of the IVI Snowplow Demonstration Project during the 1998-99 winter. In an effort to address the many challenges and difficulties associated with plowing snow in adverse weather conditions, the SDP showcases two technologies to aid the operator: one to guide the snowplow and another to warn the snowplow operator of possible collisions.

Trunk Highway 19 between Winthrop and Fairfax in Sibley and Renville counties was chosen as the rural demonstration site. Plowing snow in rural areas is complicated by the combination of snow, blowing snow, fog, darkness, and lack of visual cues to locate the roadway. These less-than-favorable conditions create near zero visibility for the driver and produce a “snowcloud” around the snowplow, in effect hiding it from vehicles approaching from either direction.

The snowplow operator is typically under tremendous stress and faces a heavy workload. In a basic snowplow, the operator must control a large truck with plow blades extending into adjacent lanes while traveling on compacted snow, soft snow, or ice and often in poor visibility. The operator is also responsible for the dispersion of sand and de-icing chemicals.

The aim of the SDP during the 1998-99 winter was to test the lateral guidance and collision warning systems during regular operations. However, due to continual
equipment calibration and an unusually low snowfall in Minnesota, only limited testing could take place.

**Phase I and Phase II Focus**

Phase I of the IVI Snowplow demonstration was focused on forming the project team, assembling the technology on the snowplow, training the snowplow operators, and testing the technology on limited snowplow runs. Phase II will cover winter 1999-2000 and will be geared toward a full-scale testing of the technology during plowing operations on TH 19, and snowplow operators' acceptance of the technology. Additionally, a Digital Global Positioning Systems (DGPS) and a Heads Up Display (HUD) will be tested on TH 101 between Rogers (I-94) and Elk River (US 10), a four-lane, divided highway running north-south, with some curvature. The potential benefit areas include:

- Operational efficiency with regard to shorter snowplow cycle times and therefore better clearance of roadways
- Reduction in the frequency of road closures, which will result in costs savings to commercial vehicle operators (CVOs) and the general public
- Increased Traveler Mobility through more effective plowing of roadways, which may result in fewer snow-related accidents and higher average travel speeds for other vehicles

Phase II will also explore the possibility of applying IVI technology to other platforms such as commercial, emergency, and State Patrol vehicles.

**Evaluation Overview/Purpose/Methodology**

To ensure a thorough assessment of the SDP application, Mn/DOT solicited the services of Booz-Allen & Hamilton as project evaluator. The evaluator's primary
objective is to design an independent evaluation process to assess (1) the performance of the different technologies being tested to guide snowplows during snowstorms and (2) the user acceptance of the technology. To accomplish this, the evaluator developed four evaluation goals from which a data management plan was created. The plan integrated the respective objectives, measures, and data required for each goal (see appendix A). The data management plan also included associated questions that were later used in the interview guide.

Personal interviews and focus groups with snowplow operators were conducted in a data gathering effort. A Mn/DOT maintenance supervisor and the system designers were interviewed separately. The interview and focus group were conducted in August 1998, five months after the test runs with the IVI technology. These discussions were very interactive and involved a lively dialogue between the snowplow operators and the evaluator. The objective of these discussions was to assess the snowplow operators’ perceived benefits of the system and to determine their level of comfort with the training provided and with operating the system.

Also included in the evaluation is a market survey of selected snowbelt states to benchmark the status of IVI research and testing for snowplows and to determine the issues surrounding snowplow IVI projects. The states included in this survey are Arizona, California, Colorado, Illinois, Iowa, Maine, Michigan, Minnesota, Montana, Nebraska, New York, North Dakota, South Dakota, Utah, Vermont, Washington, and Wisconsin. The report also examines other projects currently testing IVI technologies on snowplows.
NATIONAL INTELLIGENT VEHICLE INITIATIVE PROGRAM

Definition and Purpose of IVI

Motor vehicle crashes exact high penalties in terms of fatalities and injuries, as well as the economic costs resulting from emergency care, health care, property damage, and highway congestion. The National Highway Traffic Safety Administration (NHTSA) estimates that the financial burden of these crashes exceeds $150 billion per year. If highway safety is to be improved significantly, the number of highway crashes must be reduced.

The National IVI Program is a cooperative program of government agencies working with partners from the motor vehicle industry to develop advanced systems, integrate them into vehicles and appropriate infrastructure, and evaluate performance in real-world conditions. The IVI program also develops and validates performance specifications and design guidelines for systems that can improve significantly the safety of motor vehicle operations.

The intent of the IVI program is to improve significantly the safety and efficiency of motor vehicle operations by reducing the number of motor vehicle crashes. To accomplish this, the IVI program will accelerate the development, availability, and use of driver assistance and control intervention systems to reduce deaths, injuries, property damage, and the societal costs that result from motor vehicle crashes. These systems would help drivers process information, make decisions, and operate vehicles more effectively by providing:
• Warnings to drivers
• Recommended control actions
• Intervention with driver control
• Introduction of temporary or partial automated control of the vehicle in hazardous situations.

The IVI systems are also intended to improve mobility and highway efficiency through the application of selected motorist information services (navigation, adverse weather information, and traveler assistance features). It is planned that sensing, processing, and communications technologies will be installed in passenger vehicles, trucks, and buses, and may be complemented by highway infrastructure technology. These integrated technologies would be linked to automated actuators and controls as well as in-vehicle driver interfaces.

**Goals and Objectives of the IVI Program**

The primary goal of the IVI Program is to accelerate the development, introduction, and commercialization of driver assistance systems and services to reduce motor vehicle crashes and resulting injuries and fatalities (safety). The secondary goals are to improve public access to activities, goods, and services (mobility); improve the utilization of the existing roadway system and reduce travel time (efficiency); improve the economic efficiency of the nation’s roadway transportation system, and reduce operating costs (productivity); and reduce motor vehicle fuel consumption and emissions (environmental quality).
Program "Platforms"

IVI activity has been subdivided to represent four primary vehicle categories: light vehicles, commercial vehicles, transit vehicles, and specialty vehicles.

Table 1: IVI Platforms

<table>
<thead>
<tr>
<th>Platform</th>
<th>Description</th>
<th>Lead Federal Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light vehicles</td>
<td>- passenger cars, light duty trucks, vans, sport utility vehicles&lt;br&gt;- generally owned and operated by the motoring public&lt;br&gt;- significant fleets of light vehicles also operated by private firms and public sector agencies</td>
<td>National Highway Traffic Safety Administration</td>
</tr>
<tr>
<td>Commercial vehicles</td>
<td>- carry freight, locally or interstate&lt;br&gt;- includes inter-city buses</td>
<td>Office of Motor Carriers within the Federal Highway Administration's Operations Core Business Unit</td>
</tr>
<tr>
<td>Public transit vehicles</td>
<td>- small, light duty buses&lt;br&gt;- school buses&lt;br&gt;- full-size public transit buses</td>
<td>Federal Transit Administration</td>
</tr>
<tr>
<td>Specialty vehicles</td>
<td>- variety of special-purpose vehicles&lt;br&gt;- typically owned &amp; operated by public agencies, including DOTs</td>
<td>Turner-Fairbank Highway Research Center within the Federal Highway Administration</td>
</tr>
</tbody>
</table>

The primary subcategories of specialty vehicles are:

- Highway maintenance and construction vehicles, including snowplows, front end loaders, graders, and dumpers
- Law enforcement vehicle, such as the ALERT vehicle, which increases the safety and efficiency of first responders through improved data gathering
and communication between law enforcement and the entire first response community

- Emergency medical response vehicles, including ambulances, emergency medical, and rescue vehicles

- Emergency fire response vehicles, including pumpers, tankers, ladder trucks, and other fire fighting equipment

The Mn/DOT Snowplow Demonstration Project falls within the specialty vehicle platform.

**Core IVI Guidance Documents**

In order to define and set a direction for the IVI program, USDOT developed a pair of guidance documents. The first, an IVI Program Plan, describes the program and sets out a series of steps that it will follow. The second, an IVI Business Plan, attempts to illustrate the broad IVI program elements and the sequence in which these program elements would be accomplished. The USDOT gathered input from many stakeholders as part of the development process for the Business Plan. With these documents in place to provide overall programmatic guidance and direction, USDOT has shifted its focus to carrying out a broad IVI field testing program, demonstrating the technologies which are rapidly approaching commercialization.

**IVI Field Testing**

A significant portion of the early efforts in the IVI program consists of testing emerging technologies to determine their utility in vehicle operation. USDOT-funded Generation 0 IVI Field Tests, which have already begun, will:
1. Evaluate the performance of proposed advanced safety systems and provide a means of informing transportation decision-makers and the general public of potential opportunities for improved safety;

2. Accelerate deployment of advanced technologies which enhance safety;

3. Help forge additional strategic partnerships with transportation stakeholders.

4. Apply and assess the benefits for advanced, vehicle-integrated crash avoidance systems using state-of-the-art analysis.

The Generation 0 Field Tests were solicited by USDOT, to be accompanied by both cooperative research agreements, and formal evaluation. Results of the field test selection had not yet been announced as of mid-year 1999.

**IVI Program Funding**

The USDOT IVI Program is estimated at a budget of $6 million per year for fiscal years 1999, 2000, and 2001, for a total of $18 million. A major portion of this funding is focused on conducting and administering the Generation 0 Field Test program and its evaluation. Each federal Generation 0 Field Test grant requires significant matching funding from project participants. Additionally, IVI sponsoring agencies within USDOT have been conducting IVI-related research funded by other budgetary sources, and are expected to continue to do so.

Federal funding represents only a small portion of the total IVI funding. Much IVI investment is expected to be borne by the private sector. This investment will be made primarily by the automobile manufacturers and their suppliers, as part of their new product development efforts. This investment will be both domestic and international, due to the global nature of today's automotive industry. This effort will
also benefit from early deployments within markets which are less regulated than the U.S. marketplace. Private sector investment will be market-driven, rather than necessarily following the USDOT Program Plan. It is expected that the total private sector IVI investment will be many times larger than the Federal investment.

An additional source of non-federal funding will come from the vehicle user communities. Transit and maintenance fleet owners are contributing to jointly-funded tests and demonstrations, in order to assess the practicality and benefits of IVI elements addressing their specific needs. Examples include projects funded through the National Cooperative Highway Research Program (NCHRP) Ideas Deserving Exploratory Analysis (IDEA) Program and through the regional pool fund, a collaborative effort between state departments of transportation and private industry.
Overview of Year One Test and Site Conditions

The extreme winter conditions in Minnesota present sizable challenges to Mn/DOT’s snow clearance operations. Air temperatures are consistently below 20 degrees Fahrenheit and often below 0. Fifty to 60 inches of snow fall in the state each year, and Minnesota has one of the highest freeze-thaw ratios in the country. Consequently, Minnesota roadways are very heavily stressed by severe weather. Mn/DOT is responsible for keeping approximately 29,000 lane miles of roads in drivable condition. Approximately one-third of these lane miles are in the urban Metro Division while two-thirds are in rural areas. To help accomplish this task, Mn/DOT operates over 830 snowplows. Mn/DOT procures 50 snowplows for its own needs and approximately 100 snowplows for local cities and counties each year. Approximately $6.2 million (53%) of Minnesota’s yearly $11.7 million roadway equipment budget is spent procuring these snowplows (Parsons Brinckerhoff Quade & Douglas, Inc., p. 5). In addition, an average of $30,000 is spent on annual maintenance per snowplow.

The Mn/DOT IVI Snowplow Demonstration Team comprises representatives from Mn/DOT-Office of Advanced Transportation Systems (OATS), Mn/DOT-District 7 (D7), 3M Corporation’s ITS Project Office (3M), and Altra Technologies, Incorporated (ATI).

The team considered combinations of infrastructure and onboard technologies that would assist snowplow operators by providing information about lane edges and obstacles. The system had to perform without interfering with the operator’s existing
functional responsibilities while plowing in adverse weather conditions. During the conceptual design phase, the team determined that two basic concepts would be demonstrated on the snowplow: lateral guidance and collision warning. ATI’s system was selected for collision warning and 3M’s magnetic tape was selected for lateral guidance. Additionally, the system should calculate the distance the snowplow is from the object and the relative speed at which it is approaching the object. The primary elements of the IVI Snowplow Demonstration conceptual system are:

- **Collision Warning Sensors**—designed by ATI to detect obstacles in the path of the snowplow, i.e. approaching vehicles, guardrails, light poles, and snowdrifts
- **Control Module**—houses the microprocessor, memory, circuitry, and firmware to control all system functions and to communicate with the driver
- **Operator Interface**—provides information to the driver in a manner by which the driver can quickly determine action needed to adjust lane position
- **Vehicle Position Sensors**—embedded magnetic tape strips in the roadway of the test site—primary component of the lateral guidance system
- **Magnetometer**—installed on the snowplow, reads the snowplow’s distance from the magnetic tape
Figure 1: IVI Snowplow Demonstration

Figure 2: Radar Sensors
Figure 3: Rear Collision Warning System

Figure 4: Side Collision Warning System
Figure 5: TH 19 Test Site

Trunk Highway 19 is a two land primary arterial serving agriculture, commuting, and commercial transportation needs. During the winter months it experiences frequent snow and blowing snow conditions which make plowing extremely difficult and stressful. Road closures during winter snow storms are frequent. The test is relatively straight with enough horizontal curvature to test the capabilities of the proposed technologies.

Goals and Objectives/Plans

The TH 19 winter 1998-99 IVI snowplow demonstration was the first of a two-phase demonstration of the IVI technologies applied to snowplows. The primary objective of phase I testing was to introduce and train the selected snowplow operators on each of the technologies being applied to the snowplow during a series of snowplow runs. To accomplish this, both the collision warning and the lateral guidance systems were installed on a Mn/DOT snowplow located at the Mn/DOT Gaylord Truck Station.
near TH 19 in Gaylord, Minnesota. The snowplow is a tandem axle dump truck, with a 12' front plow, 9' right handling plow, and 12' underbody plow. It contains a sand spreader that typically holds 60% salt and 40% sand. Average traveling speeds are 30-35 mph in good visibility and 10-15 mph in low visibility. The plow, which costs $125,000 new, has estimated yearly maintenance costs of $30,000 and a life span of 12-15 years.

Collision Warning

The installation of ATI’s Collision Warning System (CWS) on the Mn/DOT snowplow started in November 1998 and was completed by mid-February 1999. Following installation, two snowplow operators were trained and authorized to begin use of the system on TH19 at any speed during good visibility conditions and at low speed during low visibility conditions. High speed driving during low visibility conditions is expected to be authorized after further experience and test evaluation. CWS testing on the Mn/DOT snowplow was limited to one run because ATI delayed training of the operators until performance of the system met ATI’s quality standards and because of limited snowfall in Minnesota after early January 1999. The one application was during a snow storm on March 8-9, 1999. The system performed acceptably under medium to heavy snowfall conditions but not under heavy, wet snow conditions, when it gave off excessive false alarms.

Due to the limited system application, ATI and a subcontractor conducted separate testing on the CWS attached to ATI’s conversion van for over six months. The
CWS testing was under light-to-medium rain and snow conditions with favorable results.

The snowplow operators were very active participants in the calibration of the technologies and improvements to the overall system. Feedback was received from the operators via their daily log report forms (see appendix B). This interactive process between ATI and the operators led to several useful observations and suggestions:

- A display with brightness control would allow snowplow operators to adjust to the different lighting conditions, which can range from bright sun to near total darkness.

- The visual display in the snowplow cab must be able to withstand the high vibrations encountered during snow clearance operations. The large graphic images used on ATI’s CWS are readable to the operator, even during heavy vibrations.

- The CWS is effective in most light to heavy snow conditions. However, heavy, wet snow conditions often lead to false alarms.

- The radar frequencies used by the ATI CWS do not penetrate compacted snow or ice. As such, the radar will see large snowdrifts and/or snowbanks as hazards without being able to detect objects completely buried in the snow.

- Since plastic and fiberglass are somewhat transparent to radar, objects such as fiberglass signs or plastic mailboxes will not be detected by the CWS.

- The rear-looking CWS can detect vehicles approaching at a speed greater than 10mph. Upon detection, the CWS turns on a high intensity flasher to alert the driver of the approaching vehicle. The CWS automatically turns off the high intensity flasher approximately 30 seconds after that vehicle slows down. Additional testing on the visibility of the rear flasher under a variety of lighting and snow conditions is needed. (Altra Technologies, Inc., 1999, 8-9)
As a result of the testing and operator feedback, adjustments were made in the detection thresholds to improve overall performance. The primary mode, which looks at the lanes ahead and behind, was found to be fully operational. The secondary mode, which looks at the shoulder to the right of the snowplow, was not enabled. Although the secondary mode is operational, ATI chose to delay its implementation to give the snowplow operators additional training in the use of the forward-looking primary mode radar. Upgrades to the CWS since its initial installation include:

- Operator Interface display—the brightness of the display was improved and a brightness control was added to allow the drivers to adjust the brightness to meet their needs in a variety of lighting conditions.

- An On/Off switch was added to allow the snowplow drivers to turn the speaker (which provides the beep warning) off if conditions suggested they should.

- The forward-looking radar antenna beam was narrowed to provide improved performance.

- The detection criterion for the forward-looking radar was changed to improve performance in heavy, wet snow.

- The software was upgraded to improve the operation of the rear-facing collision warning system.

- Tests were run on both the forward-looking radar and rear-looking radar to fine-tune the detection thresholds.

The effectiveness of these upgrades will be discussed with operators during Phase II.

**Lateral Guidance**

Approximately 17 linear miles of 3M Magnetic Lateral Warning and Guidance Tape was installed on TH 19. The magnetic tape was installed along the skip line as...
selected and stipulated by Mn/DOT. The installation was completed in September 1998.

Preliminary reports indicate that the tape was installed properly and that the magnetic data taken at intervals along the tape can be used to verify the magnetic tape field performance. Data on actual field performance were not made available at the time of this report.

User Acceptance

The general sense of the snowplow operators regarding the winter 1998-99 IVI Snowplow Demonstration was one of acceptance and promise. The four test drivers' snowplow driving experience ranged from 15 to 20 years. The drivers indicated they were eager to fully test the technologies under winter storm conditions. They thought the training was thorough and relevant to what they needed to know to effectively perform their jobs. The operators commented that the testing that did take place was under direct supervision of the designers and in favorable weather conditions.

The snowplow operators also confirmed that the difficulties typically associated with plowing snow in rural areas applied to the TH 19 test site. Large, open farmland contributed to blowing snow, which oftentimes results in large snowdrifts. Additionally, narrow, poorly lit roads add to the difficulty of plowing during a snowstorm. The operators commented that their intimate familiarity with the roads they plow is a tremendous aid in being able to “feel” their way through routes when visibility is near zero. Most of the operators felt comfortable about the additional
functions they had to observe as a result of the test. However, some of them were uncomfortable about being observed on camera while plowing their route.

All of the operators looked forward to a full-scale testing of the technologies during the 1999-2000 winter. They commented that the IVI technology applied to the snowplow could possibly assist them in plowing more steadily during snow storms. They felt very strongly, however, that there was an upward limit to the driving speed that could be achieved as a result of the IVI technology. Snowdrifts form very quickly. If the snowplow is travelling at speeds above 20mph, operator would not have enough time to react and properly adjust for a newly formed snowdrift. (Driving speeds under low visibility conditions are 10-15 mph).

The snowplow operations maintenance supervisor was interviewed separately from the snowplow operators. He indicated that he solicited support of the Gaylord Station snowplow operators for the TH 19 test. He observed that the operators and the technology designers worked well together and saw the various system adjustments as evidence of that. He commented that he would gladly manage the operators through the Phase II testing during the 1999-2000 winter. He viewed the efforts of the IVI Snowplow Demonstration as a positive step in improving snowplowing safety, efficiency, and effectiveness.
MARKET RESEARCH

The Economic Impact of Road Closure

Road closures exact a significant cost on a state’s economy as estimated by a recent Standard and Poor’s Data Resource Incorporated study commissioned by the Salt Institute. This study covered the states of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, New Jersey, New York, Ohio, Pennsylvania, Virginia, and Wisconsin. The study calculated that $526.4 million a day in federal, state and local tax revenues would be lost if roads were rendered completely impassable in these states. This exceeds the $518.7 million spent by the twelve states for the entire winter season on snow and ice control to keep the roadways open and safe. This figure was provided by state public works officials. Besides lost taxes, a crippling snowstorm would cost $1.4 billion per day in unearned wages and $600 million per day in lost retail sales (“Billion$ at Risk…”). The study assumed complete closure of the states’ road network for the purpose of calculating the economic impacts. While complete road networks closure is an unrealistic scenario, the following data nevertheless offer a picture of the economic value of a state's road network.
Table 2: The Economic Costs of Disruption from a Widespread Snowstorm in Selected Snowbelt States. (All figures are in millions of dollars.)

<table>
<thead>
<tr>
<th>State</th>
<th>Wages and Salaries</th>
<th>State and Local Taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct</td>
<td>Derived</td>
</tr>
<tr>
<td>Illinois</td>
<td>72.99</td>
<td>97.81</td>
</tr>
<tr>
<td>Indiana</td>
<td>31.01</td>
<td>41.56</td>
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<td>Iowa</td>
<td>13.78</td>
<td>18.46</td>
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<td>Michigan</td>
<td>58.45</td>
<td>78.33</td>
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<td>Minnesota</td>
<td>28.28</td>
<td>37.9</td>
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<td>Missouri</td>
<td>29.05</td>
<td>38.93</td>
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<td>New York</td>
<td>121.58</td>
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<td>Ohio</td>
<td>62.62</td>
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<td>Virginia</td>
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</tr>
<tr>
<td>Wisconsin</td>
<td>27.83</td>
<td>37.29</td>
</tr>
</tbody>
</table>

Source: The Salt Institute

In an attempt to obtain a more realistic picture of the economic impact of road closures due to snow, 13 state departments of transportation were contacted for road closure statistics: Arizona, California, Colorado, Illinois, Maine, Montana, Nebraska, New York, North Dakota, South Dakota, Utah, Washington, Wisconsin. In addition, the Bureau of Transportation Statistics and the National Highway Traffic Safety Administration were consulted. Road closure statistics were available only for Interstate 80 in California and for the interstates and main US highways in Montana and North Dakota. In the case of Interstate 80, road closures from the last four winters ranged in number from 30 to 79 per year, with total hours of closure from 96 to 232 for the season (Caltrans, District 3 data). In the case of North Dakota, statistics from the winters 1995-96, 1996-97 and 1997-98 indicate that the state's interstate highways may be subject to road closures totaling three weeks over the course of the heaviest winters. Statistics from Montana for the 1998-99 winter indicate that sections of US highways...
and interstates may be subject to snow-related road closures for as long as thirteen hours. Such statistics indicate that traditional snow removal operations are unable to keep even the most important arteries open at all times.

Minnesota is studying the impact of delays due to road closure on the state’s economy through the Logistics 2020 program, but complete quantitative data are not yet available. The Logistics 2020 program has determined that the number and duration of highway closures is of high concern to commercial trucking. Approximately 8 to 14 snow events occur each year that result in delays to commercial trucking ranging from a few hours to days.

As part of the Snowplow Demonstration evaluation, the Office of Freight and Transportation Planning at Mn/DOT, the Minnesota Trucking Association, the California Trucking Association, and the American Trucking Association were contacted regarding economic loss to CVOs due to snow-induced road closures, but none of these had gathered such statistics. In a limited survey of commercial vehicle operators in Minnesota, it was found that those queried also had not estimated the economic impact to their operations of road closures due to snow.

A number of items should be considered when trying to understand the impact of road closures due to snow events:

- Road closure statistics often are gathered only at the region or district level and are not necessarily compiled on a statewide basis.
- There is not a standardized definition for road closures; some states may differentiate between a legal closure and a physical closure of a road.
• A state may be forced to close a road because of conditions in a neighboring state, even if the maintenance crews are able to clear the first state’s roads sufficiently. Road closure statistics that merely provide the duration for a closure on a particular road without stating that conditions in another state precipitated the closure, would give an inaccurate picture of the ability of the DOT in the first state to maintain its roads.

• A road may be closed only to certain types of vehicles such as CVOs but not to passenger vehicles out of concern for the impact of accidents involving jackknifed tractor trailers. Such accidents block an entire road, while a car that spins out may block just one lane and be more easily removed. [On the other hand, sometimes the decision is made to allow commercial truckers through but to forbid passage of passenger cars because commercial truck drivers are considered better trained and experienced in adverse driving conditions.

• Road conditions may not warrant closing the road but will result in truckers having to travel in convoys (of limited number) behind snowplows, apply chains, use alternate routes or be subject to metered entry to control the mix of commercial vehicle and other vehicles.

These last two factors could result in measurable economic loss for CVOs which could not be extrapolated from simple road closure statistics.

Adverse weather, visibility and road pavement conditions contribute to a high number of snowplow-related accidents. Most snowplow accidents fall into the categories of rear-end collisions from other vehicle, side swipes, collisions with fixed objects, and sliding off the road. The technologies applied in the Minnesota snowplows may help avoid the majority of accidents involving such collisions with snowplows.
Figure 6: Minnesota Snowplow Accidents Summary

Figure 7: Montana Snowplow Accident Summary
Figure 8: North Dakota Snowplow Accidents Summary

Figure 9: South Dakota Snowplow Accident Summary
Figure 10: Washington Snowplow Accident Summary

Figure 11: Wisconsin Snowplow Accident Summary
Market Perception/Acceptance of IVI Technology

A poll of 17 snowbelt states revealed varying degrees of interest in IVI technology for snowplows among state DOT management and maintenance staff. Factors determining the extent of interest include:

- Geographical and climatic conditions (the extent of snow/ice storms, as well as the terrain). Mountain states have different needs than prairie states. Some mountain states, concerned about avalanche threats, are interested in automated snowplow technology in addition to driver-assist technology. Other states might have a problem with snow and ice in particular regions but not statewide. Deployment of driver-assist IVI-technology typically receives lower priority than an initiative affecting maintenance operations in every region of the state.

- Extent of whiteout conditions. Some states do not experience significant whiteout conditions, or report that stakes placed by the side of the road are sufficiently visible to the snowplow operator, even in extremely low visibility conditions.

- Federal funding context. There is the perception in some state DOT's that federal funding for IVI will favor those technologies applicable to passenger vehicles.

- Presence or absence of an ITS champion. Such an individual would track IVI tests in other states with the view to adopt those technologies considered most useful.

- The demonstrated cost/benefit ratio. Some states are following the tests being conducted in Minnesota and California. Cost/benefit estimates from those tests will factor into the decision process in other states.
Table 3: Snowplow IVI Status in Selected Snowbelt States

<table>
<thead>
<tr>
<th>State</th>
<th>Interested, but no commitment to deploy</th>
<th>Conducting research</th>
<th>Conducting operational tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>California</td>
<td>✔</td>
<td></td>
<td>✔</td>
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<tr>
<td>Colorado</td>
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<tr>
<td>Illinois</td>
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<tr>
<td>Iowa</td>
<td>✔</td>
<td></td>
<td></td>
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<tr>
<td>Maine</td>
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<tr>
<td>Michigan</td>
<td>✔</td>
<td></td>
<td></td>
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<tr>
<td>Minnesota</td>
<td>✔</td>
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</tr>
<tr>
<td>Montana</td>
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<tr>
<td>Nebraska</td>
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<tr>
<td>New York</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>North Dakota</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Dakota</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utah</td>
<td>✔</td>
<td></td>
<td></td>
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<tr>
<td>Vermont</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin</td>
<td>✔</td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

*Tests of a concept vehicle will commence winter 99-00
NB: This table refers to all IVI technologies, not just driver-assist.

Snowplow IVI Applications

Currently, there are several snowplow IVI initiatives in the United States:

- Minnesota's IVI Snowplow Demonstration Project;
- Caltrans' Advanced Snowplow Project (ASP);
- The Concept Highway Maintenance Vehicle designed and developed by the consortium of Iowa, Michigan, and Minnesota DOTs and the Center for Transportation Research and Education at Iowa State University;
- Concept vehicle being developed by Wisconsin DOT.
Caltrans' Advanced Snowplow Program

Project Overview

In addition to Minnesota, the only other state currently testing driver-assist IVI technologies for snowplows is California. Caltrans' Advanced Snowplow Project consists of both a magnetic lateral guidance system and a radar collision warning system. Phase 1 of the Advanced Snowplow Project, April 1998 to June 1999, involved five technical steps:

- Establishing a platform for field testing and evaluation;
- Implementing Advanced Vehicle Control and Safety Systems (AVCSS) technologies;
- Developing a Human-Machine Interface (HMI);
- Performing a field evaluation;
- Developing methods for mitigating icepack hazards.

Partners

The magnetic marker lateral guidance system, which supplies information about lane edges and lateral position, was developed by the Partners for Advanced Transit and Highways (PATH). PATH is a collaboration among the California Department of Transportation, the University of California, other public and private academic institutions, and private industry. Technical development for the ASP comes from a partnership between PATH and the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California - Davis. PATH was responsible for software integration, while PATH and AHMCT jointly developed
the Human-Machine Interface. The radar collision warning system, developed by AHMCT, is capable of tracking three objects at a time. The Western Transportation Institute at Montana State University was contracted to evaluate performance improvements. Infrastructure development and field testing are performed by Caltrans and the Arizona Department of Transportation (ADOT).

The aim of the project is to increase both safety for the snowplow drivers and efficiency through increased speed. According to Mike Jenkinson, project manager for Caltrans’ New Technology and Research Program, the goal is to increase the plowing speed two- to fourfold in whiteout conditions (Stone, 1998).

System Description

The snowplow is a conventional snowplow (International Paystar 5000) with front blade and wingplow. Added to it were a data gathering and processing computer, sensors to measure steering angle and vehicle movement, sensors to measure the magnetic markers installed in the road, radar sensors for the collision warning system, and a Human-Machine Interface. The snowplow contains two arrays of seven magnetometers.

The magnetic markers are installed in the center of the lane, approximately 1.2 meters apart. The magnetic guidance system provides information on the snowplow’s lateral position relative to the center of the lane, as well as information on its longitudinal position relative to mileposts. Using binary coding, the magnetic markers can be used to provide advanced information about roadway characteristics, such as curves, speed limits, and the presence of on/off ramps. The PATH system also
estimates the vehicle’s yaw angle (angle of deviation from the direct course). In contrast, the 3M system being tested in Minnesota provides information only on the plow’s lateral position relative to the magnetic tape. PATH’s technology had been tested and evaluated over the course of the last decade, including the Automated Highway System at Demo ’97 on Interstate 15 near San Diego.

Using the readings from the magnetometer, a computer on board calculates the snowplow’s lateral position and trajectory, and conveys this visually to the driver through a liquid crystal display (LCD) in the cab of the snowplow. The ASP explored but rejected two Heads-Up Displays (HUD) as the Human-Machine Interface: special goggles, as well as an off-head HUD. The former was rejected due to past experience with such equipment in Caltrans. The latter was ruled out due to size and locational constraints in the cab. Auditory warnings were rejected due to the noise level in the snowplow cab (Steinfeld and Tan, 1999: 2, 12).

Testing

One test site is a four-mile section of Interstate 80 at the Donner Pass in California, the main artery from the east into mid-California. The test strip is a divided, restricted access highway with three lanes and wide shoulders. This area experiences some of the heaviest snowfall in the continental United States, reaching more than 50 feet total snowfall some seasons, with roadside snow accumulations up to 20 feet high. Plowing operations on the Donner Pass are often performed in fleet formation. One aim of the lateral guidance system is to enable plow operators to maintain the most efficient position in reference to the lead plow. The second test site, also four miles
long, is on U.S. 180 north of Flagstaff, Arizona, near the state's highest mountains. As this is not an interstate, the grades are steeper and the curves tighter than on I-80 in California. Part of this test site is an open valley, subject to high winds and whiteout conditions.

**Results**

The operational specifications on PATH's magnetic markers are as follows:

- Lateral position accuracy of 5 mm (root mean square)
- Longitudinal position accuracy of 5 cm (root mean square)
- Installation costs of $10,000 per lane mile (based on Demo '97); automated installation is expected to reduce these costs significantly
- Not affected by accumulation of snow or rain
- Usable life exceeds that of the pavement (Zhang, et al, 1998)

The Advanced Snowplow was first deployed, to a limited extent, in winter 1998-99. The short duration of the ASP demonstration meant that evaluators could not collect sufficient data to determine changes in operational efficiency and traveler mobility as a result of the technology. At the California test site, the Advanced Snowplow spent very little time in the lane with magnets because it was involved primarily in formation plowing. (The mounting of the wingplow on the right side determined its position within the fleet, and hence its lane position). At the Arizona test site, only one test run was conducted in the snow; all others were in dry conditions (Cuelho, 15). The primary system performance problem was water and salt infiltration of the magnetometers, requiring 156 hours of maintenance (Cuelho, 17).
PATH surveys of the operators involved in the first year of testing revealed that there was more confidence in the lateral guidance system than in the collision warning system. This probably resulted from a lack of trust of the CWS detection, since it exhibited false positives, misses, and collision warnings that did not readily disappear (Steinfeld and Tan, 1999: 14). The learning curve was judged to be relatively short by the drivers, who generally felt that they would achieve comfort levels within one month (Steinfeld and Tan, 1999: 15).

Preliminary results demonstrate that the magnetic guidance system provides useful information regarding position within the lane and also upcoming road conditions. In order to better help the plow operator, though, improvements in the HMI are necessary. The HMI used in the first year of testing did not go to true black at night, causing strain to operators’ eyes. Currently PATH is working to overcome this problem. It also will be important to resolve the problems with the collision warning system in order to increase operators’ confidence in the system.

Future work on the ASP includes improvements in the HMI, both in terms of better visibility and more conducive location, and programming the magnetic markers to identify permanent objects for collision warning. Caltrans also plans to put the technology on rotary plows operating on the Donner Pass in the 1999-2000 winter season.

More testing of the Advanced Snowplow will be necessary in order to compare before and after data to determine any increases in operational efficiency and safety.
resulting from the technology, and whether these benefits are justified by the expense of the technology.

**Concept Highway Maintenance Vehicle**

Another operational test of snowplow IVI technology (though not driver-assist) is the Concept Highway Maintenance Vehicle, which focuses on more effective and efficient application of sand and de-icing materials. The specific aims of this project include improved data collection, cost savings, and improved communications.

**Partners**

The Concept Highway Maintenance Vehicle was developed by a consortium consisting of the Iowa, Michigan, and Minnesota Departments of Transportation, supported by the Center for Transportation Research and Education at Iowa State University and the Federal Highway Administration. The consortium also included several private partners: vehicle manufacturers, vehicle component manufacturers, on-board vehicle tracking and communications manufacturers, and technology manufacturers and integrators.

**System Description**

Three different prototypes of the Concept Highway Maintenance Vehicle were developed to test different configurations of equipment. The electronic components in the three prototypes were the same. The primary difference was in the material application system in each vehicle. The technologies applied in developing the Concept Highway Maintenance Vehicle are:
Global Positioning (GPS) Receiver—Rockwell International’s receiver is mounted above the cab. The receiver records the vehicle’s location every five seconds and stores it on the PlowMaster.

PlowMaster—Rockwell International’s PlowMaster, located in the cab, stores data collected by the vehicles. Data is stored on a standard data card (a PCMCIA card), which can be removed from the PlowMaster for transfer of data to a personal computer. The PlowMaster also conveys data on temperature, friction, and spreader activity to the driver on a Mobile Data Terminal.

Friction Meter—Norsemeter Friction Meter is an additional single tire which measures the friction of the road surface and records that information on the PlowMaster.

Pavement/Air Temperature Sensor—Sprague’s RoadWatch warning system monitors the static air temperature and the surface pavement temperature. The infrared sensors mount on the driver’s side-view mirror and a two-inch digital gauge mounts in the cab. Pavement and air temperature readings are recorded by the PlowMaster.

Reverse Sensor—Global Sensor Systems Inc.’s Search-Eye Sensor system detects the presence of objects behind the vehicle, when it is in reverse, and automatically applies brakes. The system consists of three sensors mounted on the rear of the vehicle, which are wired into the braking system.

Fiber Optic Warning Light System—Federal Signal’s fiber optic warning light system uses a single light motor mounted in the cab to originate four solid or flashing warning lights which supplement the existing strobes and revolving beacon.

The GPS receiver in the Concept Highway Maintenance Vehicle constantly monitors the truck’s location. The performance of the chemicals applied in providing the required friction is determined by the truck location information combined with the friction and temperature sensor information. After having applied chemicals, when the snowplow returns and passes the same point on the road (as determined by the GPS system), the friction meter reading informs the operator about the effectiveness of the
previous chemical application. The operator then observes the temperature reading and determines the amount and mix of chemicals needed for application to the road such that adequate friction is available. This is intended to lead to cost savings through optimum use of chemicals. Safety is enhanced as minimum safe friction is achieved with a higher level of certainty.

Testing

The concept vehicles were assigned to specific maintenance routes for winter 1997-98. The test route in Iowa was on an interstate highway, while routes in Minnesota and Michigan were US highways. In Iowa and Minnesota, the routes were just beyond metropolitan areas, while in Michigan the route was in a less congested area.

Results

Initial reports from the Concept Highway Maintenance Vehicle project suggest that the technologies and the project concept have been successful, and testing of these vehicles is still on-going. The installation of add-on technologies was not without problems, though. Due to the size and clearance requirement of the friction meter, it could not be installed on the Michigan vehicle. It interfered with the operations of the underbody plow of the Iowa vehicle, and was vulnerable to salt and sand damage, as well as excessive movement on the Minnesota vehicle (Smith, et al, 1998, 29). The consortium has worked with the manufacturer to redesign the meter for optimal use. The redesigned friction meter will be tested in Phase 3, as will an enhanced materials application software. The next generation of these vehicles will have a salt-brine
concentration meter which will further help optimize the use of chemicals. The study team is also working on using cellular data links to convey information from the PlowMaster to the DOT in real time.

The problems encountered with the friction meter illustrate that limitations often exist on the ability to add additional technologies onto a standard vehicle without hampering standard vehicle operations or requiring modifications to the technology. This could increase deployment costs and slow down the deployment schedule when redesign becomes necessary, and result in suboptimal use of conventional and/or high-tech systems.

Other Snowplow IVI Technology Projects

Wisconsin has also been applying IVI technologies to snowplow operations. Wisconsin has been using pavement temperature sensors for the past 3 years, which allow operators to better determine which type of salt to spread. A plow operator can spread dry salt, pre-wetted salt, or liquid salt depending on temperature. Wisconsin has now developed a concept vehicle, based partly on the Concept Highway Maintenance Vehicle. The plan is to have three concept vehicles on the road during the 1999-2000 winter and an additional five in the 2000-2001 winter. Each concept vehicle will include GPS/AVL technology, which will be integrated with the chemical deployment system. The integrated system will allow DOT offices to monitor the deployment of salt in real time, as well as to collect data which could be used for a post-storm analysis.
Wisconsin is examining possibilities of joining the consortium testing the Concept Highway Maintenance Vehicle. One impetus for getting involved in the consortium is the possibility of using a friction meter to help detect icing conditions on the road.

The Center for Transportation Research at Virginia Tech is conducting research into options to integrate GPS/AVL technology with a chemical utilization management system. The Virginia Department of Transportation (VDOT) subcontracts a significant portion of its snow clearing operations to private plow operators. Such an integrated system would not only help VDOT verify chemical deployment, but would also facilitate billing to VDOT by the private contractors since all the chemical utilization data could be captured in real time, and in a more accurate manner than the plow operator calculating chemical use by estimating how much salt is left in the bin after snow clearing operations.
CONCLUSION

There is strong interest within the maintenance community to improve the safety and efficiency of snowplowing operations. Many state DOTs are following the testing of Minnesota's driver-assist snowplow, as well as the Advanced Snowplow in California and the Concept Vehicle in Iowa, Michigan, and Minnesota. In addition to an analysis of operational improvements and human factors, states are interested in robust cost-benefit calculations for the various IVI technologies being tested.

Initial testing results from the major IVI snowplow projects in the US indicate that high-tech solutions to increase operational efficiency and safety are available and are at least reasonably reliable. Further refinement and testing are necessary to improve their performance and reliability. After the results of the field tests are available, state DOTs will have to determine the optimal combination of add-on technologies to meet their operating conditions.

Additional training for snowplow operators and refinements in the human factors areas will be necessary to improve the operators' ability to fully utilize the technologies. The most significant gap in the research and evaluation at this point is the issue of cost-benefit analysis. Without accurate assessment of the cost for full deployment and the benefits to be realized by the technologies (alone or in combination), state DOT maintenance officials will be hindered in their procurement decision-making.

Minnesota snowplow operators perform their duties in some of the most extreme winter conditions in the country. Winter road maintenance in Minnesota is a collection
of formidable tasks that involves spreading sand and salt on the roadways before, during, and after a snow storm and plowing snow. The more effectively snowplow operators are able to plow roadways, the safer Minnesota roadways will be.

The first phase of Mn/DOT’s IVI Snowplow Demonstration Project illustrated how two different technologies in the field of IVI can be applied to snowplows: a lateral guidance system and a collision warning system. Although only one test run was made during the first winter, several objectives were achieved:

- Mn/DOT successfully lead an IVI Snowplow Demonstration Team that included both public and private parties.
- Snowplow operators were trained on the function and operation of the lateral guidance and collision warning systems.
- Both the lateral guidance system and the collision warning system were successfully installed and calibrated.
- Improvements were made to the collision warning system based on feedback from the snowplow operators to the system designers.
### APPENDIX A: DATA MANAGEMENT PLAN

#### Evaluate Driver Performance and Reaction To Plowing With And Without Assisted Technology

<table>
<thead>
<tr>
<th>OBJECTIVE</th>
<th>MEASURE</th>
<th>DATA REQUIRED</th>
<th>DATA SOURCE</th>
<th>RESP</th>
<th>METHOD</th>
<th>LEVEL</th>
<th>QUESTIONS</th>
</tr>
</thead>
</table>
| 1. Determine major concerns of operators with respect to traditional driving of snow plows -- w/out technology | • Operator perception of system, enthusiasm with the systems, level of interaction with IV tech | • Operator feedback | • Surveys results from operators and supervisors | BA&H | Surveys, Personal interviews | Operator | • What are your concerns/frustrations with the traditional non tech snow plow?  
• Why?  
• How would you modify snow plows to address your concerns/frustrations? |
| 2. Determine major concerns of operators with respect to driving snow plows --w/ technology | • Operator perception of system, enthusiasm with the systems, level of interaction with IV tech | • Operator feedback | • Surveys results from operators and supervisors | BA&H | Surveys, Personal interviews | Operator | • What was your overall perception of the IV driver assisted tech?  
• How was the idea of a IV driver assisted tech presented to you--optional vs. mandatory  
• What are your major concerns with IV driver assisted tech? |
| 3. Determine correlation between major concerns of operators and solutions provided by IV driver assisted technology | • Operator opinion of system, enthusiasm with the systems, level of interaction with IV tech  
• Performance of tech | • Operator feedback  
• Specs  
• Tech ability to perform specific operations relative to specifications | • Focus groups  
• Spec manual  
• Tech Performance log  
• Supervisor opinion  
• Safety logs | BA&H | Surveys, Personal interviews | Operator | • Have your major concerns w.r.t. snow plow operations been addressed through the application of the IV driver assisted tech?  
• How? |
<table>
<thead>
<tr>
<th>OBJECTIVE</th>
<th>MEASURE</th>
<th>DATA REQUIRED</th>
<th>DATA SOURCE</th>
<th>RESP</th>
<th>METHOD</th>
<th>LEVEL</th>
<th>QUESTIONS</th>
</tr>
</thead>
</table>
| 4. Determine operator performance | • Study system usability by the driver  
• Research driver adaptability to IVI in terms of behavioral compensation and changes in driver vigilance  
• Feedback on owner willingness to pay and perceived quality, value, and product maturity of system | • Longitudinal headway or gap between test and lead vehicles  
• Relative speed between the test and lead vehicles  
• Lateral gap between the test vehicle and vehicles in adjacent lanes  
• Test vehicle speed  
• Break pedal activation  
• Lateral and longitudinal accelerations  
• Steering wheel angular displacements  
• Lateral position of test vehicle within travel lane, and driver eye glance | • Operator performance log  
• Vehicle performance log  
• Vendor log  
• Supervisor survey  
• Manager survey | BA&H | • Surveys  
• Personal interviews  
• Vendor log | Operator  
Supervisor  
Manager | • Research  
• How has your driving been effected by the HUD?  
• Has your driving vigilance changed? i.e. the way you approach curves and hills |
## Evaluate The Performance Of Selected IV Technology

<table>
<thead>
<tr>
<th>OBJECTIVE</th>
<th>MEASURE</th>
<th>DATA REQUIRED</th>
<th>DATA SOURCE</th>
<th>RESPONSIBLE</th>
<th>METHOD</th>
<th>LEVEL</th>
<th>QUESTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Provide operator additional warning during low visibility about road boundaries.</td>
<td>The ability of IV technology to warn operator of surrounding boundaries and vehicles in sufficient enough time to effect change in operator decision</td>
<td>Operator perception—of the effectiveness of IV warnings</td>
<td>Operator surveys</td>
<td>BA&amp;H</td>
<td>Surveys</td>
<td>Operator</td>
<td>How well did the IV technology provide information about road boundaries?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IV tech performance</td>
<td>IV tech performance log</td>
<td></td>
<td>Personal interviews</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Information from vendor instrumentation</td>
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<td>Focus groups</td>
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<td></td>
<td>Vendor log</td>
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<td></td>
<td></td>
<td>BA&amp;H</td>
<td></td>
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</tr>
<tr>
<td>2. Determine effectiveness of applied IV technology that is intended to allow the operators to plow snow at speeds of at least 20 mph</td>
<td>Indications of faster snow plowing</td>
<td>The number of times the operator increases speed as a result of information provided by IV technology</td>
<td>Operator log</td>
<td>BA&amp;H</td>
<td>Research</td>
<td>Research</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Snow plow speed</td>
<td>Snow plow speed log</td>
<td>Vendor log</td>
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<td>Surveys</td>
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<td></td>
<td></td>
<td>Operator</td>
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<td>Management</td>
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<td></td>
<td></td>
<td></td>
<td>BA&amp;H</td>
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<tr>
<td>3. Determine performance of Magnetic Road Boundary System with respect to the performance of the snow plow vehicle in various weather conditions, specific geographic areas, and various topography</td>
<td>Ability of the magnetic tape to forward programmed digit codes to the magnetometer to inform the processor about the location of the snow plow vehicle on the roadway and about the location of curves</td>
<td>Function of the Magnetic Road Boundary System with respect to the performance of the snow plow vehicle in various weather conditions, specific geographic areas, and various topography</td>
<td>Magnetic tape performance log</td>
<td>BA&amp;H</td>
<td>Research</td>
<td>Research</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Magnetometer programming log</td>
<td>Research —log data review</td>
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<td></td>
<td></td>
<td></td>
<td>Processor receiving log</td>
<td></td>
<td>Supervisor</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Manager</td>
<td></td>
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</tr>
</tbody>
</table>

Booz Allen & Hamilton

October 27, 1999
APPENDIX B: COLLISION WARNING SYSTEM (RADAR) DAILY LOG

Collision Warning System (Radar) Daily Log
(Please fill out this form in ink)

Snowplow Operator's Name: ___________________________    _____________________    Signature

Time of Operation: from _____________ to _____________    Date: ___________

Please describe the snowplowing conditions during the time of operation (i.e. outside temperature, weather conditions, visibility, amount of snow, icy roads, light fluffy snow, heavy wet snow, etc.) Please be specific.

Please describe the nature of any snow banks on the sides of the road (e.g. Were there any snow banks? If yes, roughly how high were they? Were the snow banks compact, icy or freshly plowed snow?) Please be specific.

Please describe examples of false alarm conditions that you experienced:

<table>
<thead>
<tr>
<th>Conditions Present</th>
<th>Situation #1</th>
<th>Situation #2</th>
<th>Situation #3</th>
<th>Situation #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>How fast were you travelling?</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Were there vehicles approaching you in the adjacent lane?</td>
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</tr>
<tr>
<td>Were there objects ahead on the shoulder of the road?</td>
<td></td>
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<tr>
<td>Were you approaching vehicles in the same lane ahead of you?</td>
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<tr>
<td>Were you approaching a curve?</td>
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<tr>
<td>Were icy snow banks on the road ahead?</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Were you approaching an intersection?</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Were there overhead signs?</td>
<td></td>
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Other comments

Please describe your overall assessment of the system (i.e. did it alarm when hazardous conditions were present; what did you like; what did you not like; what would you like to see changed?)
APPENDIX C: IVI SNOWPLOW-RELATED WEBSITES

Additional information about the Concept Highway Maintenance Vehicle project can be found at http://www.ctre.iastate.edu/projects/convehcl/

Additional information about the Advanced Snowplow Program in California can be found at

http://path.berkeley.edu/~astein/HFhome.html

and

http://www.ahmct.ucdavis.edu/AHMCT_projects/snowplow.html


"IVI Specialty Vehicles Program Work Plan,"  


"Economic Costs of Snow Disasters," Salt Institute,  


United States Department of Transportation (1997) "Intelligent Vehicle Initiative Request for Information: 4910-22-P," issued jointly by FHWA, FTA, and NHTSA.