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**Exploratory Analysis Programs**

***Intelligence Transportation Systems 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

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***October 2001***

TRANSPORTATION RESEARCH BOARD • NATIONAL RESEARCH COUNCIL

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# EXECUTIVE SUMMARY

The intent of this Phase II Report of the Advanced Snowplow Demonstration Project (ASDP) in the Minnesota Department of Transportation's (Mn/DOT) Intelligent Vehicles Initiative (IVI) is to summarize general progress, identify potential benefits, and to clarify project status including "next steps."

The major activities of Phase I -the development and calibration of the on-board components of 3M's Lateral Guidance System (LGS) and Altra Technologies, Inc.'s Collision Warning System (CWS), as well as the installation of 3M's "smart" magnetic tape along the center line of 16.5 miles of Trunk Highway 19- were the foundation for Phase II's "live" testing of these components installed on a new, standard Mn/DOT snowplow. Winter 1999-2000, roughly the duration of Phase II, proved to be exceptionally mild and, as a result, significant amounts of road test data is yet to be collected. Sections in the body of this Report explore potential safety and operational enhancements of the ASDP's technology solely with the aid of historical Mn/DOT highway traffic data and national highway traffic data sources.

This Phase II Report concludes that the limited testing *did* demonstrate the technological feasibility and the general user acceptance of the LGS and CWS technologies, though further enhancements in the systems are necessary and additional operational experience is needed to better document their benefits and costs. The included discussion of 3M's Installation Report on its Magnetic Warning and Guidance Tape (November 1999), the University of Iowa's Draft Report on Operator Interface Design Rational for the 3M Lane Awareness System for Snow Removal Operations (July 2000), and Altra Technologies, Inc.'s Final Report (June 2000), describes the testing methodologies used in Phase II and further confirms that more road testing including technical data collection and user feedback are necessary. These contractor reports also point to the potential need in the future for testing in a controlled environment (including plans for testing during a mild winter). Cost-benefit analyses and further public-private design collaboration are also needed for the wide-scale deployment of the associated IVI technologies.

# INTRODUCTION

The Minnesota Department of Transportation (Mn/DOT) initiated its Intelligent Vehicle Initiative (IVI) program with Phase I of the Advanced Snowplow Demonstration Project (ASDP) during Winter 1998-99, on State Trunk Highway 19 (TH19) between Winthrop and Fairfax in Sibley and Renville counties. Phase I consisted primarily of installing and calibrating a collision warning system (CWS) supplied by Altra Technologies, Inc. (ATI) and a lateral guidance system (LGS) supplied by 3M on a single snowplow, training the snowplow operators, and testing the technology on limited snowplow runs. An evaluation report for Phase I was completed in late 1999.

Phase II of the ASDP spanned Winter 1999-2000, and saw the full-scale testing of Phase I technology on TH19 plowing operations, as well as system improvements by the technology providers. This Phase was to theoretically coincide with the first full season of the ASDP's data collection efforts. Minnesota experienced a relatively mild winter in 1999-2000, with only eight snow events occurring from mid-December through March. The IVI technology aims to allow the plow operators to "see" during poor visibility conditions, including “whiteouts.” There was just one brief whiteout (approximately ¼ of a mile) during winter 1999-2000 (and none the previous winter), thus the full capability of the system could not be observed. Not all components of the systems were operational during the entire period. Prior to the start of year two, several changes were made to the ATI collision warning system based on the results of year one testing. There were insufficient opportunities for the operators, technology providers, and evaluators to fully use/observe the systems as they were designed. However, some limited operator response to the systems was obtained.

The on-board LGS and CWS components were installed on a new (model year 1998) International, tandem axle, standard transmission plow truck. A forward plow, wing plow, and an underbelly plow were mounted on the truck. A seat vibrator and peripheral vision lighting were added to the LGS, increasing the number of operator interfaces to three (including the visual display). Audio feedback was not included as an operator interface of this system because earlier studies of snow clearing operations indicated that an audible warning system was not desirable due to the already high noise level in the cab.

ATI's collision warning system consists of four major components. ATI's forward collision warning system consists of a primary mode, focused on the lane ahead of the vehicle, and a secondary mode focused on mail boxes, guard rails, signs, and stalled vehicles that may be off to the side of the road but are likely to be in the path of a deployed wing plow. The system also includes a rear collision warning system to alert drivers of vehicles approaching the rear of the snowplow. A fourth component was added prior to the start of the second year to evaluate the benefits of side object detection (for lane changes) on a snowplow. The side object detection system consisted of two radar sensors on each side of the plow (one on each front fender, and one in each rear corner) facing perpendicular to the side. The side CWS provides an audible warning to the driver only when the directional signal is turned on and if an obstacle is within ten feet of the side of the truck. There is an audible tone and visual display for the side object detection system and both primary and secondary modes of the forward collision warning system.. The rear CWS does not warn the driver; it simply flashes an external strobe light when it detects a car approaching too quickly and too closely from behind.

The potential benefit areas for these IVI technologies include:

- *Increased operational efficiency* with regard to shorter snowplow cycle times and therefore better clearance of roadways.

- *Reduced operational costs* with regard to the reduction in infrastructure collisions will result in lower vehicle and infrastructure repair and maintenance costs. Keeping snow plows on the road will impact both operational costs (snow plow recovery and repair) and efficiency (plows in operation).

- *Reduced frequency of road closures* will result in cost savings to commercial vehicle operators (CVOs) and the general public.

- *Increased safety for snowplow operators.*

- *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.

Overall the ASDP in Phase II experienced significant technical improvements for user enhancements without the benefit of having the opportunity to measure the functional performance of these technologies. The LGS and CWS appear to be functional, but their effects on highway driver safety and snowplow-related incidents in various winter conditions is still unclear.

## APPLICABILITY OF IVI TECHNOLOGY TO FULL FLEETS

### User Acceptance

The Mn/DOT ASDP included a systematic human factors evaluation of the LGS driver interface. The evaluation focused on user acceptance and comfort with the system. It should be noted, though, that only two operators used the test vehicle. Decisions about wider scale deployment should take into consideration the needs and opinions of a broader selection of users experienced with the system. The upcoming field operational test on TH 7 will offer the opportunity for more operators to use and assess this and other driver-assist systems.

Improvements and/or fine tuning would need to be made to the systems before considering their applicability to full fleets. The fact that the technologies are mounted on standard vehicles presents potential design constraints. The operators mentioned that the current locations of the visual displays are somewhat problematic and that it would be preferable to mount them in front of the driver. This is also complicated by the addition of two displays, one for the front-mounted CWS and one for the LGS. Dash mounting in front of the driver is not possible on all existing vehicles, given some of the commercially available cab configurations. A wide-scale deployment of the technologies would warrant discussion with vehicle manufacturers considering integration of the display into one unit or into two new electronic displays. 3M is currently addressing the display mounting issue on existing fleet vehicles by providing alternative mounting systems. For example, the display for the LGS can potentially be floor-mounted to the right side of the driver, mounted on the windshield, or mounted on the dash to provide optimum performance and safety. All other electronic components of this system are outside the cab. Thus, the LGS human interfaces would not pose a potential safety hazard to the driver.

Operators were unable to say if they would be comfortable relying on the system in whiteout conditions. The operator reported that it was helpful during the whiteout but that he would need more time to get used to it. Our discussions with operators indicated that they required very little time to get accustomed to the system. They also indicated that the system was helpful even in non-whiteout conditions.

The LGS was reported by the operators to have worked well. The signal was always picked up and the information provided to the driver was accurate. One operator expressed a preference for the seat vibrator as the user interface because it did not require him to monitor anything and it allowed him to immediately realize which way to go. The other operator expressed a preference for the visual display, noting, however, that the seat vibrator was not in working order for a couple of weeks, so he did not have as much time to assess its usefulness. The drivers reported that the visual display, being where it was, required only a quick glance. This statement confirmed that the drivers were using the instrument how it was designed to be used. It is intended that the driver can use the feedback given by the flashing light and/or the seat vibrator and will consult the visual display only when needed to maintain proper lane position. There was concern about the peripheral vision lighting prior to deployment but, according to the operators, this wasn't really an issue. They became used to its presence rather quickly. Operators currently have override capabilities for the lighting and tactile feedback.

The most significant piece of documentation regarding operator behavior and user acceptance is the University of Iowa's Draft Report on Operator Interface Design Rational for the 3M Lane Awareness System for Snow Removal Operations (July 2000). This report is based on ride-along observations and driver survey responses. Its design recommendations reveal specific driver and snowplow issues that are relevant to this Phase II Report, such as the variability of equipment and conventional driver methods used to maintain lane position. One of the most important conclusions from the University of Iowa's studies is that certain display design enhancements are still necessary for universal driver acceptance, and that the overall IVI technologies and related equipment need to be standardized for effective and safe wide-scale implementation.

Two of the University of Iowa Report's most important design recommendations for the LGS display are based on its findings of the two most common conventional lane awareness techniques (looking ahead to evaluate distance from the shoulder line and evaluating distance from the center line):

- The operator interface of the 3M Lane Awareness System (LGS) should be a driver "aid" that augments the driver's visual references in the environment, providing an additional, constant reference point that complements the driver's habitual cues. The display should allow for easy switching between conventional lane awareness techniques and the LGS.
- The operator would be able to switch between either the center line or the shoulder line as a reference point in the display. The ability to do this implies that tape would be installed on both the center and shoulder line.

These design recommendations indicate that more investment is needed for optimum cab configurations and user-friendly displays that would lead to universal driver acceptance of the "smart" plows. The information in the 3M Report suggests that the cost-effectiveness issues of installing reference tapes on both the center line and the shoulder line may be significant.

When the vehicle senses the magnetic tape, it ignores any background magnetic noise. If the vehicle is driven in areas away from magnetic tape installation, there may be occasional instances when it picks up a magnetic signal that is interpreted as tape. In those instances, the seat may vibrate. 3M’s recommendation is to either turn the seat off or power the system down when the vehicle is being driven away from the tape installation.

The 3M Report concerning the installation and durability of its Magnetic Warning and Guidance Tape placed along 16.5 miles of TH 19 between Winthrop and Fairfax, Minnesota in September of 1998, is relevant to the testing user acceptance of the LGS technology. Performance factors were identified and analyzed, yet the 3M Report also reveals that more testing is required to adequately determine all the issues associated with the wide-scale deployment of this aspect of the ASDP's technology.

The three important magnetic tape performance factors as key elements for the success of the project identified by the 3M Installation Report are the ability of the tape to adhere to the road surface, the ability of the tape to withstand vehicle traffic and road maintenance procedures with minimum wear, and the ability of the tape to retain it s magnetic field strength.

The magnetic testing of the tape was done by measuring its magnetism at the same 18 identified test points, corresponding to the relevant mile markers on TH19, on seven different occasions. The Report says the original tape's magnetism did not change statistically over the initial 11 months.

According to the 3M Report, the initial testing of adhesion and durability involved attempting to pull up edges of the tape, after some setup time, to verify a good bond. Then, after several days of use, the entire length of the test strip was surveyed from a vehicle. Problem areas such as missing tape, bubbling, and/or wear patterns were identified. A detailed inspection of a specific area was conducted if a problem area was found. The 3M Report concluded that adhesion and durability problem areas of the tape occurred in intersections where heavy trucks were turning on the tape. Skid-resistant surfaces were being eroded by spring of 1999, and the tape was loosening in the summer months. A significant portion in one intersection was ripped up by July or early August. Although the 3M Report states that the tape was not specifically designed for intersections, 3M understood that it could be an issue, thusinstallation through a number of intersections helped 3M define these "shearing" issues which are now being addressed for upcoming tests. 3M is addressing the mounting issue on existing fleet vehicles by providing alternative display mounting systems. As for these components of the system, the University of Iowa Draft Report on Operator Interface Design Rational gives some indication of the display's design progress.

The four major components of the collision warning system were met with mixed results, some of which need to be corrected before wide scale deployment. At this point, the drivers are not fully comfortable with the system. The results of the primary mode of the forward collision warning system were positive with very low false alarm rates and acceptable performance from a driver’s perspective. During most of the testing, the secondary mode of the forward collision warning system was inactive while the primary mode was being tested. Due to the lack of snowfall, testing of this secondary mode which detects guard rails, mail boxes, stalled vehicles, and signs in the path of the wingplow was not conducted. Additional testing of this major component is needed. Based on the results of the tests, Altra Technologies has determined that further refinements are needed in the rear collision warning system to improve detection performance of vehicles approaching from the rear including reduction of false alarms. The forward-looking radar primary mode CWS offers three settings: clear, foggy, and snow to enable the snowplow to optimize the system performance for different visibility conditions. According to interviews with the operators, the CWS is less sensitive in the clear mode. This should not pose a significant hazard, since the operator would be able to rely on visual sightings of hazards.

The system provides longer range detection and earlier warning for the snowplow operator in low visibility conditions. Although the secondary mode forward collision warning system is of great interest to the drivers due to its intended purpose of assisting with wingplowing operations, it was not evaluated during this winter season due to the lack of snowfall. The side object detection system is currently designed only as an aid with lane changing and provides a warning if there is another vehicle in the blind spot to either side (it is activated only when the directional signal is turned on). The absence of severe winter weather conditions over the last two winters meant that the operators really did not have sufficient opportunities to evaluate the systems. The information provided here is based on limited snowplow runs, and not under the conditions for which they were designed.

ATI's Final Report (June 30, 2000) documenting the results of the two-year effort on TH19 also gives valuable information about the design and execution of the CWS testing, e.g. training snowplow operators. ATI developed a software program that simulated the audible and visual feedback that drivers would experience under various hazardous conditions. The second part of the training took place when ATI staff would ride along with the two assigned prototype drivers for Phase II. The testing process also led ATI to the conclusion that both training methods were valuable and should be conducted in the future.

In its Final Report, ATI also concludes that testing of the CWSs on snowplows is difficult during actual snow plowing operations because, among other reasons, snow events happen at a time of day when it may be impossible to get to the "smart" snowplow in time for a ride-along data collection effort. As a result, one must rely on driver feedback and/or on-board data collection systems. (The in-placeon-board data collection system for the project produced significant raw data that would require further analysis).

One of the questions surrounding the technology is whether younger plow operators, having grown up in the information age, would be more inclined to rely on the technology than would older drivers or, in the extreme, become overly dependent on it. This determination cannot be made without systematically studying user acceptance between two groups, one consisting of younger, technology-proficient operators and the other consisting of older operators inexperienced with information technology.

One of the operators interviewed indicated that for the older drivers, the new technology might give them a better sense of security but that they would still have to rely on their basic plowing instincts. The systems were purposely designed to insure that the operators continue to use their "plowing instincts" by supplementingtheir knowledge and instincts. The operators and supervisor all said that the new technology would not add to the workload of the operators. The lateral guidance and CWSs are two more tools in the snowfighting arsenal, whose true benefits can only be assessed with additional operational experience, including whiteout conditions. The human factors are not seen to be a major stumbling block. Assimilation of the tested technologies for older operators progressed quite well. Rather, the decision whether or not to deploy will come down to a cost-benefit analysis, but the full benefits cannot be determined until testing is performed under appropriate weather conditions.

## Other Vehicle Platforms

IVI technology for use during adverse winter weather would be of potential use to other types of specialty vehicles. Poor visibility conditions pose a problem for the state patrol, local law enforcement agencies, and emergency medical services. The state patrol only responds to emergency calls in whiteout conditions; they do not perform routine patrols during such conditions. If the LGS and CWS were deployed on patrol cars, a different type of interface such as the "Heads-Up" display being tested on TH 7 may be needed due to the presence of other technology and equipment in the cockpit and due to the dual airbags typically found in patrol cars. There is simply not much room to mount an additional visual display.

At the time the ATI Final Report was written, ATI was currently working with several commercial trucking firms in the alpha testing of its CWS, planning for a 76 GHz radar-based system that promises significant accuracy improvements particularly with forward looking primary mode and secondary mode radar features and rear collision warning. This testing was occurring on two commercial combination tractor-trailer rigs in order to get "real world" feedback from the customer. For example, it reports that the "backup assist" function on the rear CWS has proven to work very well for the tractor-trailers. In one driver-report, the system provided the warning that enabled the driver to avoid a fatality while backing to a loading dock.

These alpha tests have been completed since the writing of the ATI Final Report. One of the companies has verbally committed to ordering additional systems from ATI for wide-scale testing. ATI seeks to broaden its testing into Beta Testing on a considerably larger number of vehicles from a larger number of commercial fleet operators.

Results from the deployment of other CWS indicate a high success rate in accident rate reductions for trucking fleets according to the CWS manufacturers. In eight case studies of CWS-equipped trucking fleets, the CWS supplier reports the total reduction rate of accidents per million vehicle miles traveled was 73%, with some fleets experiencing 100% reductions in preventable accidents per million vehicle miles traveled. These studies also report measurable reductions in the incidence of hard braking and distance traveled with the brakes applied.

## Impact On Road Closures And Delays

Severe winter weather conditions on TH 19 do on occasion necessitate closing the road for extended periods of time. In the past decade, road closures lasting between 6 and 18 hours occurred as follows:

Halloween 1991
Thanksgiving 1991
January 1995
December 1995
December 1996, 2 times
January 1997, 6 times

With the exception of winter 1996-97, road closures have not been a common occurrence in the last decade. Gaylord averaged 42.5 inches of snow from winter 1969-70 to winter 1998-99 (excluding the winters 1993-94, 1994-95 and 1995-96, for which no data were available).

IVI technologies that could increase the speed of snow clearing operations (reducing cycle times) could potentially reduce the duration and incidence of road closures. Cycle time for clearing the test run varies considerably, but averages three hours. Even had precise baseline data existed on the length of time it takes to clear the test route, since the rate for snow removal operations is highly dependent on variations in temperature, wind, and type of precipitation, significant comparisons against baseline data are not possible without consideration of those factors.

## Efficiency Of Snow Clearance Operations

Noticeable increases in operational efficiencies during the two test winters could not be scientifically documented, due to lack of snow conditions and issues with the technology. From an operational standpoint, it is not known at this point whether this particular configuration of IVI technology will have a sufficient, positive impact on clearance times (and consequently on occurrence and duration of road closures), under the most common snow conditions.

If the new technology were to enable a snowplow operator to drive at a higher speed, there remains a maximum safe operational speed (which varies considerably according to the comfort level of the driver and the road surface condition). Exceeding the maximum safe speed puts the operators at risk for hitting snow drifts, which could knock a plow off the road. Tandem trucks can safely operate at a slightly higher speed.

## Cost Criteria

The ASDP has shown the basic technological feasibility of the LGS and the CWS, though improvements to the both (the CWS especially) are needed before it can be fully deployed. Therefore, the deployment decision depends upon further cost-benefit analysis.

The 3M Report's discussion of the required road preparation work, re-striping, and road maintenance coordination in the magnetic tape's trial suggests some cost- factors associated with the potential wide-scale deployment of the ASDP's technology. For example, a five-inch wide and 0.1-inch deep groove must be cut in the road for the tape to ensure the proper bonding of the tape to the road, and also so that the tape's flushness with the road reduces the plow's scraping of the tape. Although the report does not offer the costs associated with this exercise, various resources are necessary including the installation crew and necessary cutting equipment, as well as traffic control and inspection personnel. These installation costs, which are on a per mile basis, need to be included in the cost-effectiveness equation. These installation costs would be offset when compared to the accumulated costs (over the warranty period of the magnetic tape) associated with the remarking of lane miles to achieve comparable lane visibility performance. There are, in fact, some states that have justified the grooving in of pavement marking tapes to achieve better life cycle costs.

# SAFETY AND ECONOMIC IMPACT OF FULL-SCALE DEPLOYMENT

## Snowplow-Related Accidents

Data on snowplow accidents for the states of Minnesota, Montana, North Dakota, South Dakota, Washington, and Wisconsin were presented in the Phase I report. The Th 19 technologies have the potential for reducing snowplow accidents including run-off-the-road and collisions with moving vehicles and fixed objects.

## Motor Vehicle Crashes

Improvement in the efficiency of snow clearance operations can reduce the incidence and severity of winter-weather related crashes. Lives could be saved, and cost savings realized through reductions in insurance payments, medical bills, the deployment of emergency services, and lost wages. Nineteen percent of Minnesota crashes are related to snowy or icy road conditions, according to Mn/DOT (1998). Figures taken from the Minnesota Department of Public Safety's annual Motor Vehicle Crash Facts reports present the following picture of winter-weather related crashes.

**Table 1: All Fatalities by Winter Weather Condition—Minnesota**

| **Weather Condition** | **Killed** |
|---|---|
| **1996** | |
| Snow | 28 |
| Sleet/Hail<br>/Freezing rain | 7 |
| **1997** | |
| Snow | 27 |
| Sleet/Hail<br>/Freezing rain | 11 |
| **1998** | |
| Snow | 27 |
| Sleet/Hail<br>/Freezing rain | 12 |

Using the National Safety Council's economic cost figures (based on 1997 data), the economic costs of deaths due to winter weather (snow + sleet/hail/freezing rain) is summarized in Table 2.

**Table 2: Economic Cost Of Deaths Due To Winter Weather—Minnesota**

| Year | Economic Cost of Fatalities |
|---|---|
| 1996 | $34,300,000 |
| 1997 | $37,240,000 |
| 1998 | $38,220,000 |

**Table 3: Fatalities by Winter Road Surface Condition—Minnesota**

| Road Surface Condition | Killed |
|---|---|
| **1996** | |
| Snow/<br>Slush | 15 |
| Ice or Packed Snow | 69 |
| **1997** | |
| Snow/<br>Slush | 25 |
| Ice or Packed Snow | 63 |
| **1998** | |
| Snow/<br>Slush | 25 |
| Ice or Packed Snow | 32 |

Using the same fatality cost multiplier (1 death=approx $980,000) derived from the cost figures in Table 2 and the total annual fatalities in Table 1, the total annual economic costs of deaths in Table 3 (snow/slush combined + ice or packed snow) is summarized in Table 4.

**Table 4: Total Annual Economic Cost of Deaths by Winter Road Surface Conditions - Minnesota**

| Year | Economic Cost of Fatalities |
|---|---|
| 1996 | $82,320,000 |
| 1997 | $86,240,000 |
| 1998 | $55,860,000 |

These figures highlight the significant economic impact of fatalities in Minnesota caused by winter weather events and/or winter weather road surface conditions over the last three years.

### Reduction In Specific Crash Categories

The National Highway Safety Administration estimates that CWSs could reduce rear-end crashes by 49% annually (Advanced Vehicle Collision Safety Systems," Appendix A). In 1992, Greyhound Bus Company equipped its entire 2,400 bus fleet with a Vorad CWS. The accident rate dropped by 21% in 1993, but all systems were removed in 1995 because Greyhound claimed they were too expensive to maintain ("Advanced Vehicle Control and Safety Systems"). Recent improvements in the technology and cost reductions in the products indicate these problems may have been resolved.

## OPERATIONAL LIMITATIONS AND DELAY DURATIONS

The IVI technology currently in use focuses on automatic vehicle location (AVL) for transit, maintenance vehicles, and trucking fleets; CWSs, and in-vehicle navigation (Cadillac's OnStar), and in-vehicle navigation in some rental car fleets. There has been no wide-scale testing of IVI technology for vehicle lane guidance in adverse conditions. Therefore, there is no comparison data for LGS comparison and delay durations with other fleets.

Few calculations of the cost of delays due to snow events have been conducted. The Salt Institute commissioned Standard and Poor's Data Resource Incorporated to estimate the economic cost of a major snowstorm in twelve snowbelt states. Results of this study were presented in the Phase I project report. The study estimated lost wages and salaries, state and local taxes, and retail sales. The study assumed complete closure of the states' road network and was, therefore, not an accurate picture of the costs of snow-relate road delays. Neither the American Trucking Association Foundation nor the Minnesota Trucking Association has conducted studies on the operational limitations or delay durations and costs.

Mn/DOT District 7 estimates that a delay of three hours on I-90 results in economic costs to passenger vehicles and heavy trucks ranging from $36,385 (in low volume) to $77,911 (in high volume). These figures were calculated using Average Annual Daily Traffic (AADT) recorded in District 7 and cost estimates using a model developed by the Texas Transportation Institute (BRW, 1999).

Mn/DOT's Office of Research Services surveyed commercial vehicle operators in 1998 to attempt to determine the value of real-time congestion information for CVOs. The CVOs surveyed were asked to assign from one to ten points those factors which would have the greatest impact on their ability to provide high levels of customer service. As the following table indicates, snow/ice/water on the road tied with road and bridge construction as the factor having the second most significant impact on their ability to provide high level customer service. The report concluded, however, that CVOs are not able to accurately estimate the extent of congestion costs, either due to inadequate costing systems or the lack of technology to capture costs at the vehicle level. The same problem arises with attempts to capture the costs of snow-induced delays.

**Table 5: Importance of Highway Conditions Impacting On Carrier Service**

| **Factor** | **Average Index** (10 = very important) | **Standard Deviation** |
|---|---|---|
| Rush hour congestion | 9.28 | 1.55 |
| Snow/ice/water on the road | 7.92 | 2.11 |
| Road and bridges construction | 7.92 | 2.03 |
| Accidents and incidents | 6.57 | 2.63 |
| Bridge/road restrictions | 6.19 | 3.04 |
| Public event congestion | 4.20 | 2.77 |

Source: Mn/DOT (1999), p. 31

## BENEFITS OF IVI TECHNOLOGIES FOR BROAD FLEET APPLICATIONS AND EXTENSIVE ROAD COVERAGE

Additional testing will be required to assess more fully the benefits of lateral guidance and collision warning IVI technology both for snowplow fleets and for the traveling public. The Trunk Highway 7 field operational test funded by the Federal Highway Administration, which will be conducted in Minnesota during the winter 2001-02 (with perhaps some limited testing in 2000-01) will provide additional opportunities to assess the performance of the technology, its user acceptance, and its potential to increase operational efficiency and safety. Additionally, a number of issues were raised during this demonstration project, which should be considered as part of the deployment decision process.

Integration of current Mn/DOT systems with these new IVI technologies will only enhance the benefits of the LGS and the CWS upon their wide-scale deployment. A Mn/DOT maintenance supervisor indicated that it would be helpful to be able to access real time information from the Road Weather Information System (RWIS) stations, rather than having to radio in to receive the information. It would be useful to access information both for the plow route and the region upwind. Accessing the RWIS data would allow the operators to determine for themselves what needs to be done, whereas having the information reported by an intermediary risks distortion of the details. A snowplow operator indicated that direct communication with his counterparts to the west would also be helpful. Direct communication between districts is currently lacking.

The application of IVI technology to entire fleets could also result in savings on fleet insurance premiums. Such initiatives are underway in Europe. For example, in June 2000, the firm Global Telematics announced a Complete Fleet Management Partnership with Allianz

Cornhill, a large British insurance company, and Knighthood Corporate Assurance Services' Motor Fleet Risk Management service. The partnership will offer to fleet owners employing IVI technologies contracts with the prospect of long term premium stability. Following a thorough evaluation of operational and management risks, risk management controls will be recommended. If successfully implemented, these controls can result in significant savings on fleet insurance. However, insurance providers will likely want to see solid evidence that a system improves safety before lowering premiums. Thus, more rigid testing and evaluation will be required.

Interest was expressed by operators and technology providers as to whether any type of CWS could detect ice dams (when a plow is lifted, a line of snow remains that then can freeze), raised manhole covers, and other small obstacles in the road that can damage the plow. Altra Technologies has indicated that its forward looking radar can detect large ice dams, however, an assessment needs to be made on the size of ice dams in relation to the amount of damage that they cause. This may need to be explored.

The LGS and CWS were designed as stand-alone, independent systems. Thus, there is no interaction between the CWS and the LGS. They function independently and can be shut-off independently. However, Mn/DOT'S vision is that these types of technologies can be applied singly or together in its fleets or public fleets, assuming benefits are proven and exceed costs. It would also seek to encourage their use by private sector fleets, and eventually they will be found in light passenger vehicles. If the systems require infrastructure within highway right-of-way (such as magnetic tape), then the public sector would need to install it or establish partnerships with the private sector to do so (like the Minnesota statewide fiber optic project). With the LGS, Mn/DOT could place tape on its high priority corridors (which have been recently identified in the Interregional Corridor Plan) and instrument its own fleets; other public and private fleets could also instrument their vehicles to utilize this infrastructure. Both 3M and ATI are now offering commercial products that may or may not involve public or public-private partnerships.

## CONCLUSION

The technologies tested on TH 19 have the potential to increase the safety of snow clearance operations in low visibility conditions. During this limited study, it was not possible to determine the impact of the technologies on operating efficiencies and costs. Such operational improvements (reduced clearance times, fewer disruptions due to snowplow accidents, etc.) can produce improvements in road conditions that reduce the incidence and severity of winter road accidents for all vehicles. This translates into fewer deaths, injuries, property damage claims, and emergency calls with resulting cost savings for public safety and maintenance operations.

Part of the decision to deploy these systems will be based upon costs; the price for these systems may fall with increased market acceptance. For example, the costs of magnetic tape is expected to become roughly equivalent to other pavement tape markings. A DGPS LGS will be tested fully during the winter 2000-01 on TH 101 and later as part of the field operational test on TH 7. Results of that system testing should be compared with that of the magnetic LGS.

The performance of ATI's forward-looking CWS was reliable enough to give operators confidence in that portion of the system. Further refinements will be necessary in the rear collision warning system, and the results of those refinements demonstrated before deployment can be considered. The technology must be further observed especially in heavy snow conditions. Side detection results were inconclusive.

Mn/DOT will need to determine whether the addition of CWSs and magnetic LGSs to the arsenal of snowfighting resources would result in significant improvements in personal and public safety and in operational improvements at lower cost. It is worth exploring the integration of these technologies with, or a cost-benefit comparison to, the IVI technologies on the Concept Highway Maintenance Vehicle being tested out of the Jordan maintenance shop. More efficient salting operations have a measurable economic and safety impact. Research by David Kuemmel, Director of the Center for Highway and Traffic Engineering at Marquette University, has documented that:

1. 88.3% of all injury accidents during winter storms can be avoided simply by deicing roadways.
2. Deicing pays for itself within the first 25 minutes
3. During the first four hours after the hour of application of salt, the direct road user benefits were $6.50 for every $1.00 spent on direct maintenance costs for the operation (Briscoe, p. 5).

The test on TH 19 demonstrated the technological feasibility and user acceptance of magnetic lateral guidance and collision warning technologies, though further improvements in the existing systems and the future standardization of the IVI snowplow technology and its related equipment will be necessary, a point made especially clear by the University of Iowa's study on operator interfaces.

The positive LGS and the CWS effects on highway driver safety and reduced snowplow-related incidents in various winter conditions are still unproven. Further technological enhancements should be designed based on driver feedback, functional performance data analysis, and other end-user concerns. Simulation of different plowing conditions (e.g. whiteouts and night driving) to test displays and other equipment can be achieved in controlled environments, as well as during real plowing operations (further testing of the 3M system is planned for the MnRoad test facility in Fall, 2000 during nightime in order to simulate low visibility cinditions). Additional operational experience, such as that planned on TH 101 and TH 7 will allow the better documentation of the benefits and costs of these systems.

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Advanced Snowplow With First Generation Magneatometer

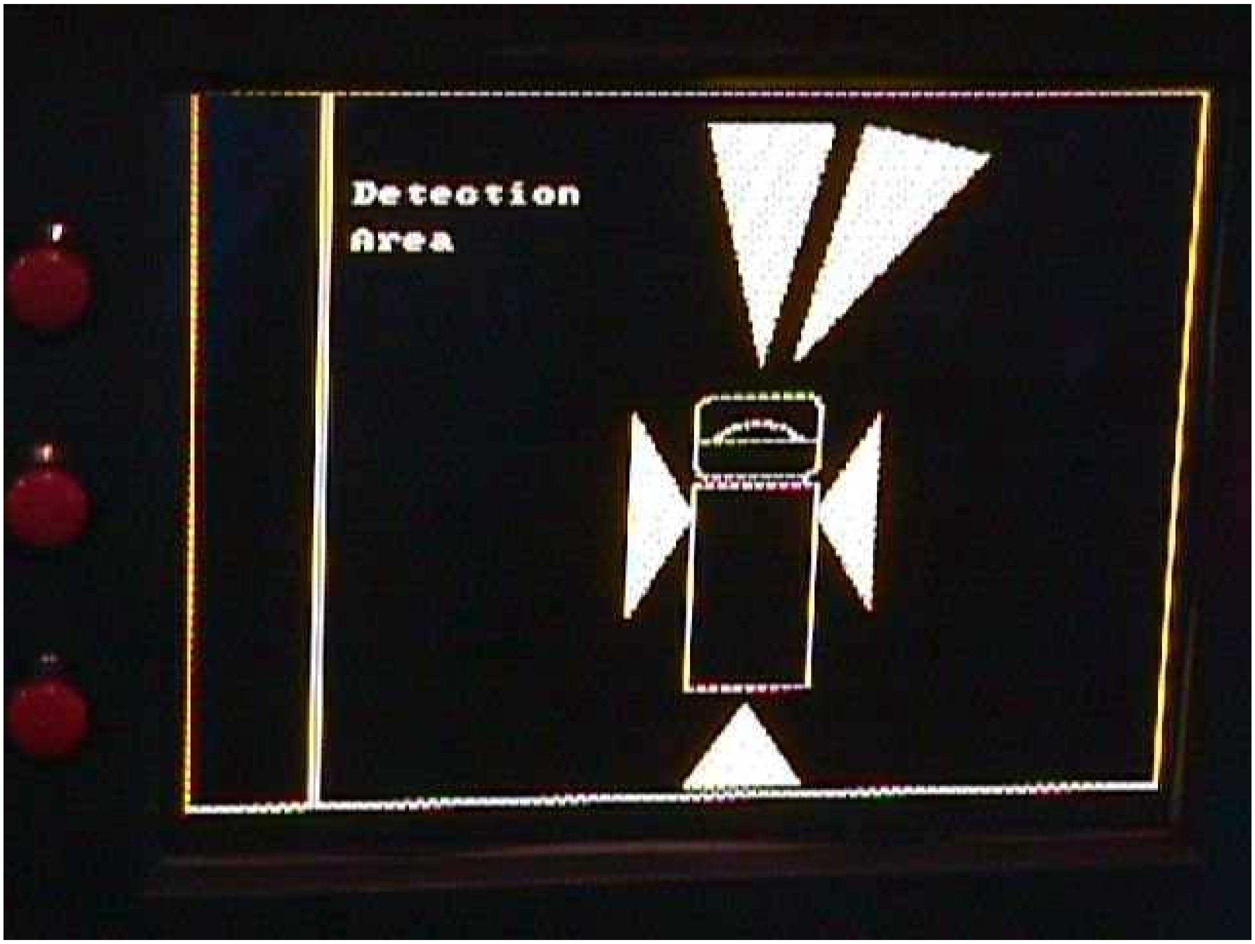
Advanced Snowplow on Trunk Highway 19 with magnetic tape centerline and current generation on-board magnetometer

Current generation magnetometer

Rear radar/strobe collision warning system

Dash-mounted collision avoidance display (with red buttons)

Dash-mounted collision warning display screen


Detection
Area

Side collision warning radar sensor (on mirror mount)

Front collision avoidance radar sensors (on grill and roof-mounted)