Advanced Vehicle Control Systems (AVCS) for Maintenance Vehicle Applications

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Table of Contents

1.0 Abstract ____ 3
2.0 Introduction ____ 3
3.0 Relevant AVCS Work in Highway Maintenance ____ 5
    3.1 Shadow Vehicle Programs ____ 5
    3.2 Snow Removal Programs ____ 7
4.0 Attitudes of Highway Maintenance Departments ____ 8
5.0 Enabling Technologies for Maintenance Vehicle Applications ____ 8
    5.1 Autonomous Shadow Vehicle ____ 9
    5.2 Guided Snow Plow ____ 10
6.0 Airport Ground Vehicle Applications ____ 10
7.0 Recommendations for Future Work ____ 12
8.0 Conclusion ____ 12
Appendix 1: Highway Maintenance Department Survey ____ 14

Feasibility of Advanced Vehicle Control Systems (AVCS) for Maintenance Vehicle Operations

1.0 Abstract

It is widely believed that barriers to an automated highway system (AHS) deployment are due more to institutional, economic, and legal issues than technology limitations. In order to sustain and accelerate the AHS deployment process, it is desirable to demonstrate the benefits of advanced vehicle control systems (AVCS) as soon as possible. An ideal candidate application for early deployment should include the following features: a controlled/structured vehicle operating environment, a user group willing to experiment with developmental systems, and substantial user benefits from automation. Several particularly suitable application areas which meet some or all of those criteria involve the operations of on and off-highway maintenance vehicles. The high cost of maintenance operations, as reflected in labor costs, incident-related injury and damage, and negative traffic impacts could be significantly mitigated through the use of vehicle control systems. This need for improvement, coupled with the willingness of many highway departments to test prototype hardware, provides an excellent opportunity for field testing AVCS. In terms of off-highway applications, an area of opportunity also exists for applying AVCS to airport ground vehicle operations.

Within the context of highway maintenance operations, this study explores opportunities for AVCS-based snow removal and work zone following vehicles. A description of these operations, and their particular suitability for the application of AVCS is presented. For airport operations, the feasibility of AVCS-assisted snow removal and baggage movement is considered. Previous and on-going work related to vehicle automation for these operations is introduced, along with recommendations for the future, based on an assessment of technical feasibility of AVCS and the attitudes of the highway and airport maintenance communities towards this technology.

2.0 Introduction

As microprocessors and sensors continue to shrink in size and cost, the deployment of vehicle control systems has become technically and economically feasible. Vehicle automation programs around the world have demonstrated remarkable capabilities, such as cars that drive themselves along highways, based on such inputs as video images from on-board cameras and satellite-based positioning data. Despite these advances, however, the leap from conventional to automated highways will require years of refinement, not to mention public acceptance. Rather than wait for widespread acceptance of AVCS and the resolution of all automated highway system issues, it is proposed here that existing AVCS technology be leveraged for niche applications that will demonstrate near-term benefits and encourage acceptance of vehicle automation.

In selecting an ideal application domain for field testing AVCS, two requirements must be met: the candidate operation must be appropriate for automation, and the user group associated with that operation must be an interested participant. One particularly suitable user group is the typical state highway maintenance department. Highway maintenance departments operate a variety of vehicles for a wide range of tasks, and are often willing to test prototype equipment that may reduce workload or increase worker safety. Furthermore, as the division most likely to install and maintain an automated highway system infrastructure in the future, early exposure of highway department personnel to AVCS could ease the AHS deployment process. Among those operations performed by a maintenance department, perhaps the most suitable for the application of AVCS are snow removal and work zone following by a shadow vehicle.

While snow plowing is necessary to keep roads passable in the winter, there are associated accidents, injuries, and property damage as well as inconvenience and delay for following vehicles. To guide their plows through deep snow, drivers must often guess at the location of the roadway edge. This is a particularly dangerous practice in the vicinity of curbs, roadside hardware, and bridge abutments. An AVCS providing some means of lateral assistance could safely allow higher plow speeds, yielding less roadside damage and improved operational efficiency and safety. Several initiatives have approached the problem of snow plow guidance, from fully automatic steering control, to edge-of-road warning systems.

Shadow vehicles are used to follow a short distance behind a leading maintenance vehicle or work crew in roadway work zones. They provide a mobile buffer zone against encroachment by approaching traffic. A typical application utilizes a large dump truck equipped with a rear-mounted flashing arrow board to guide passing traffic around lane striping, street sweeping, pothole/crack filling, and other maintenance operations (see Figure 1). This simple but hazardous driving task is a natural candidate for the application of AVCS. Two vehicle control approaches have been prototyped for this task: fully automated control and tele-operated control (remote control) by an operator within the work zone.

Figure 1. Shadow Vehicle

Like highways, airports require a dedicated army of vehicles and drivers to maintain and service runways and aircraft on a regular basis. Two ground vehicle operations in particular have been identified which could benefit from the application of vehicle control: lane keeping for runway snow removal, and baggage movement between aircraft and baggage claim areas in terminals. These areas were explored with experts in the airport maintenance industry, but as described in Section 6.0, show little promise for near-term deployment.

3.0 Relevant AVCS Work in Highway Maintenance

During the last decade there have been several significant AVCS efforts undertaken to improve snow removal and shadow vehicle operations. Within the US, Caltrans (California DOT) and Mn/DOT (Minnesota DOT) have demonstrated a particularly high level of participation in these programs. Outside the US there has been some related work performed in Japan and France.

3.1 Shadow Vehicle Programs

Since 1990 Mn/DOT has participated in the development of an unmanned tele-operated shadow vehicle, the Remote Driven Vehicle (RDV), and is planning to deploy several production systems when they become available. The Mn/DOT maintenance department is extremely pleased with the performance of the initial system and has demonstrated it to other state DOT's around the country to favorable reviews. The RDV program was sponsored by the Strategic Highway Research Program (SHRP) as part of an on-going effort to improve work zone safety. Minnesota became interested in methods for removing the worker from the shadow vehicle following a severe work zone accident in which the driver of the shadow vehicle was paralyzed. Informal interviews with other state maintenance departments confirmed that this accident, while particularly severe, was not very unusual; a handful of major work zone accidents involving the shadow vehicle occur each year in most states.

For the RDV, a maintenance truck was equipped with throttle, brake, steering, and transmission control actuators to allow the truck to be driven via wireless remote control from a distance of several hundred feet. In addition to the safety improvement provided by the RDV, the automation of the driving task now made the former driver available for work on other tasks. Following the successful demonstration of the prototype, Mn/DOT is working with private industry to deploy a RDV kit which can be purchased and retrofitted to existing vehicles.

While the RDV project demonstrates the advantages of driverless shadow vehicles, the RDV still requires a "driver" to operate the remote control handset. As with any tele-operated vehicle, precise control of the vehicle is subject to many factors, including operator skill, vehicle speed, clear view of vehicle from the operator's position, etc. Consequently, to ensure safety, the RDV shall be operated only at relatively low speed, with the operator close to the vehicle. These operational limitations make the RDV less effective than a fully automated shadow vehicle for tasks that require a higher speed and greater following distance. For example, operations such as lane striping which require continuous movement of the shadow vehicle at speeds up to 30 mph would be better suited to an autonomously guided vehicle than a tele-operated vehicle. Conversely, low speed stop-and-go operations like pothole patching would be appropriate for an RDV, as a worker in the work zone would periodically pick up the control unit and move the vehicle closer to the crew when necessary.

Fully autonomous vehicles are significantly more complex and expensive than tele-operated vehicles, but are ultimately more flexible as well as they may perform both low and high speed following operations. In addition to actuators for vehicle control, autonomous vehicles incorporate on-board navigation/guidance systems that calculate and execute necessary vehicle movements. Prototypes of automated shadow vehicles have been developed, but not placed in service. In 1993, MacLeod Technologies, Inc. (MTI) demonstrated an automated shadow vehicle developed under SHRP funding. MTI adapted a laser-based system for accurately locating the position of the shadow vehicle with respect to the back of a lead vehicle. The positional data from this laser beacon system was used to control the steering wheel, throttle and brakes on the shadow vehicle. The system was successfully demonstrated on a test track to maintain a fixed (slow) speed, offset angle, and spacing between the two vehicles. No further development of this system has taken place since its demonstration.

More recently, Sacramento State University researchers, through the Advanced Highway Maintenance and Construction Technology center (AHMCT) at UC Davis developed a prototype autonomous shadow vehicle. The AHMCT is a joint venture between Caltrans and the University of California which explores opportunities for robotics and automation technology in highway maintenance and construction applications. The shadow vehicle utilized multiple sensor systems for guidance, including machine vision and a radio frequency direction-finding antenna array system as the primary sensors. Differential GPS (DGPS) was installed for redundancy. This system was demonstrated on a test track in July 1996 to prove the ability of the shadow vehicle to follow a lead vehicle over hills and around curves. Currently the shadow vehicle operates strictly in a line-of-sight mode; it follows directly behind the lead vehicle, thus limiting operation from a distance in curves. As a consequence the designed following distance is relatively short (approximately 40 ft). A future design will incorporate a system which allows for greater following distances by recording the exact path of the lead vehicle and having the automated vehicle follow that path.

A proposal for the development of a production version of the existing prototype is currently under review by Caltrans. Discussions are underway between Caltrans and Mn/DOT to apply the autonomous guidance system developed by Sacramento State University to the Mn/DOT-developed RDV, for a complete system that can be driven in any of three modes: manual, autonomous, and tele-operated.

There has also been some work performed abroad in this area. Most notably, a two year feasibility study was performed in France by the Laboratoire Central des Ponts and Chaussees (LCPC), under sponsorship of the French Ministry of Transport. A technical development team was assembled to build a machine vision-guided prototype in 1994, but the French government canceled the project due to economic and political concerns. The program leader from the LCPC indicated that the program may be reestablished in the future.

3.2 Snow Removal Programs

There has been less development of AVCS for snow removal vehicles. A real value of AVCS for snow removal operations would be to ensure that the vehicle stays on the road. In the US most snow removal is by means of snow plow. When plowing deep snow, or driving in windy or snowy conditions, it is not unusual for the driver to be temporarily blinded or unaware of covered objects. As a consequence, plows occasionally run off the road and hit curbs or guardrails, causing damage to the infrastructure, the vehicle, and possibly injury to the driver. Several proposals have been made to provide the snow plow driver with steering assistance, or at least lane departure warnings. While such a system might be less useful in urban areas where the driver must constantly provide steering input, it might be very useful on freeways or rural roadways where the plow is trying to maintain its lane at all times. One program through the Japanese Ministry of Transport developed a laterally guided snow removal vehicle in 1992. This system incorporated a magnetic sensor on the vehicle and a magnetic stripe on the road to provide automatic steering control. The prototype system was demonstrated on a test track in a modified truck. In addition to the lane keeping function, the vehicle was equipped with a robotic snow chute that would vary the direction and throwing distance of the snow based on the position of the truck on the road and the roadside topography. The project did not continue beyond the prototype stage.

3M is attempting to demonstrate the feasibility of using a magnetic road tape for snow plow guidance, as well. As with the Japanese project above, a magnetometer on the vehicle is adapted to detect vehicle lateral position with respect to the tape. Efforts in the 3M program have been oriented towards driver warnings rather than steering control. Magnetic tape has been tested on a test track in the snow, however road operations will not take place until Winter '96/'97. Currently a variety of systems based on audible and visible warnings are being reviewed. A major challenge for this program is to provide useful warning information to the driver who is distracted by plow noise, radio transmissions, vehicle traffic, snow, hand controls, etc. Such concepts as electronic rumble strips, which provide an audible rumbling noise through in-vehicle speakers, and lane departure warning LED's placed in the driver's field of view are under consideration. Another challenge is to ensure long term durability of the tape under sustained scraping and pounding by snow plow blades. One proposed solution would place the tape in a shallow pavement groove, just below the road surface.

The University of Minnesota is currently exploring a heads-up display (HUD) driver assistance system which would use DGPS with a digitized map database to locate the plow with respect to the roadway edge. The HUD will project the image of lane boundaries onto the windshield, corresponding to the lateral position of the vehicle on the road. This system may reach a field test stage during Winter '97/'98. In parallel with this development effort, another program is examining the use of forward-looking radar for collision avoidance. Such a system would be particularly valuable for warning a plow driver of a buried car in the road ahead.

4.0 Attitudes of Highway Maintenance Departments

An important element of this project is to understand the attitudes of state highway departments toward AVCS. A telephone survey of US state DOT's (see Appendix 1), has revealed a generally higher level of interest in autonomous shadow vehicles than guided snow plows, primarily due to the fact that all states use shadow vehicles, but only some states have significant plowing operations. The fraction of all states interested in autonomous shadow vehicles was comparable to the fraction of snow states interested in guided snow plows. A few maintenance engineers were very excited about AVCS in general, and already had suggestions for new concepts, like the Wisconsin official who recommended developing drowsy driver warnings for tired plow operators and range-finding systems for locating buried cars in the plow's path. Most respondents were moderately interested in AVCS, but were not already familiar with it. A handful of respondents did not feel that there was a need for applying such a high technology approach to tasks that could be done well enough without automation.

As mentioned previously, worker safety and shrinking maintenance budgets are two critical issues for highway departments, and autonomous shadow vehicles promise to have a positive impact on both. Many expressed concerns about capital costs and maintenance for new systems. It was generally felt that a proper cost-benefit analysis be performed to roughly establish the value of vehicle control systems in terms of reduced labor cost and lower costs associated with worker injury. As an example, some who had seen the Mn/DOT RDV demonstrated guessed that they would purchase several RDV kits if the price were in the $20,000 range.

A number of those interviewed had witnessed an RDV demonstration, but thought that a fully autonomous shadow vehicle would be of greater value, including a Mn/DOT supervisor from the RDV program. They indicated a strong interest in using automated shadow vehicles to protect moving work zones, particularly paint striping operations. A maintenance official from Washington DOT thought that such a vehicle would be "so fantastic". Another official from New Jersey DOT proposed the use of an automated shadow vehicle to protect crews that lay and remove cones for work zones. Others suggested applications for protecting roadside lawnmower crews. In general, if maintenance staff perceived that worker safety or productivity gains could be derived from a new system, they were willing to test it. This finding is perhaps the single most significant result of the study, as it suggests that highway maintenance departments will be valuable partners in the near-term deployment of AVCS.

5.0 Enabling Technologies for Maintenance Vehicle Applications

With so many navigation systems commercially available today and guidance technologies advancing so quickly, determining which system to use for a given application is challenging. The guidance requirements for the two maintenance vehicle operations described in this study are quite different. The autonomous shadow vehicle is designed to maintain a fixed headway and lateral offset with respect to a lead vehicle, without driver input. As a result, the primary guidance task is to determine the shadow vehicle's position, speed, and direction with respect to the vehicle ahead and control the throttle, steering, and brakes accordingly. The required sensor system should therefore accurately reference the relative movement between the two vehicles. Unlike the shadow vehicle, the guided plow must sense where it is with respect to the roadway edge and inform or assist the plow driver accordingly. The following sections describe appropriate guidance systems for these two driving operations.

5.1 Autonomous Shadow Vehicle

While several navigation methods are technically feasible, as illustrated by MTI's laser beacon system, and Sacramento State's radio frequency direction-finding system, DGPS and machine vision currently appear to be the strongest candidate systems for shadow vehicle guidance. Over the last decade a handful of AVCS developers have applied machine vision systems for similar vehicle control applications that involve automatic vehicle following for on and off-road convoying applications. More recently, the positional accuracy of DGPS has become so good, and its cost so low that satellite-based guidance presents a viable alternative to machine vision approaches; one AVCS developer indicated the availability of sub-inch accuracy DGPS for less than $30,000 (including a base station and in-vehicle receiver). For a shadow vehicle application, the lead vehicle would periodically communicate its coordinates to the shadow vehicle. The shadow vehicle would compare that data to its own positional data to derive relative speed and distance (lateral and longitudinal) between the vehicles. It would also be necessary to equip lead and shadow vehicles with inertial navigation systems to provide a temporary guidance signal in the event of a lost GPS signal during operation.

For production systems it would be desirable to include multiple redundant guidance systems (for example, DGPS, inertial, and machine vision) to ensure fail-safe operation in the case of a malfunction in one or more of the sensors. This appears to be the approach selected by Sacramento State researchers in their autonomous shadow vehicle program. In addition, the implementation of a forward-looking collision avoidance system would be advised to bring the shadow vehicle to a stop in the case of obstacles in its path. Likely candidate systems for this application would be ranging sensors, such as radar, ladar, or possibly sonar. Due to its robust operation in all weather conditions and its insensitivity to dirt and other contaminants, radar would likely be the appropriate choice for this sensor.

5.2 Guided Snow Plow

As described above, the guidance task for a guided snow plow is to recognize vehicle position with respect to the roadway edge. Since the envisioned vehicle control system would be either a steering assistance system (the driver still has his hands on the wheel and can overcome the steering controller at any time) or a lane departure warning system, the guidance system operation will be less complex than that of the autonomous shadow vehicle. Because snow removal operations generally take place in a low visibility environment, any optical system utilizing lasers or cameras to derive vehicle position from road markers or other features would be of no value. More promising guidance systems might use a magnetic guidepath in the road. Buried magnetic markers or a continuous magnetic road tape, as described above, would provide this path along the road. A magnetometer on-board the vehicle could be used to recognize lateral displacement of the vehicle from the magnetic path, and thus determine a road departure condition. Such a design would require the installation and maintenance of the magnetic path on all roads of interest. A DGPS system supplemented by inertial guidance sensors could also provide the necessary lateral position data and would work in all weather. This design approach would require very accurate digital maps to be generated for all roads of interest. The map database, or some fraction of it, would be stored on each guided snow plow, and would require periodic updating following modifications to the road network. A more detailed study of the costs of deployment and maintenance for these alternative guidance systems would be valuable in determining the superior approach. As with the automated shadow vehicle, perhaps the best guidance system design would employ both DGPS and magnetic positioning systems for redundancy.

6.0 Airport Ground Vehicle Applications

An entirely different application environment for AVCS was explored for this study, investigating opportunities for unmanned or AVCS-assisted vehicles in airports. Baggage handling operations and snow removal operations were selected for analysis.

It was initially assumed that there would be a strong economic incentive for airport operators to deploy AVCS-based ground vehicles. Furthermore, from a technical standpoint, the highly structured airport environment was expected to provide an ideal testing ground for vehicle control systems. For example, runway snow removal by conventional removal methods can be time consuming and damaging to hardware along the runway (see Figure 2). This operation is typically performed with the runway closed and without interference from other ground traffic in the area, providing a highly predictable vehicle operating environment. Maintenance supervisors interviewed indicated that runway lights are occasionally damaged by errant snow plows and that these lights are expensive and generally require rapid replacement in the case of damage. A guided snow plow, much like that described for highway operations, would allow for rapid removal with a very low risk of damage.

Figure 2. Airport Snow Removal Operation

Similarly, it appeared that the movement of baggage between terminals and aircraft could be automated through the use of automated guided vehicles (AGV's). AGV's have been successfully deployed in both indoor and outdoor environments to move commodities through warehouses, factories, and even shipping ports. One operational scenario would deploy human baggage handlers to arriving or departing aircraft to load/unload baggage trailers. Unmanned AGV's would then shuttle the baggage trailers between the aircraft and baggage claim areas, under direction of a central command-control facility, for substantial labor savings. Similar AGV operations have been demonstrated in service within Rotterdam's Delta Terminal port where shipping containers are autonomously moved between loading and unloading areas.

Unfortunately, due to concerns regarding operational safety, there was little interest expressed by airport executives to deploy either of these systems. In the case of automated baggage handling, there is substantially more intelligence involved in safely moving service vehicles through an airport than might be expected due to the complex and unpredictable traffic patterns in the terminal areas. Drivers must be aware of other service vehicles and moving aircraft at all times. Accidents are likely to be catastrophic so there is no tolerance for failure of a vehicle control system. While it is conceivable that the necessary intelligence required for airport operations could be incorporated into an AGV guidance system, it would require a substantial technical undertaking, and would prove difficult to test in an operating airport. Furthermore, there exist concerns regarding the displacement of workers by automated vehicles that would need to be addressed prior to any deployment.

In the case of AVCS-assisted snow plow operations, there was some interest expressed by interviewed airport managers, but concerns about deploying test equipment and modifying infrastructure (in the case of magnetic tape or markers) made deployment opportunities appear unlikely. In particular, the Federal Aviation Administration has strict regulations regarding the placement of unapproved hardware or materials on runways. In summary, our findings indicate that experimental vehicle systems are unlikely to be approved for testing and development within airports. The best opportunity would exist for a guided snow plow, but the level of effort required to deploy such a system would almost certainly exceed the effort to deploy the same system on a segment of public highway

7.0 Recommendations for Future Work

Highway maintenance vehicle operations offer excellent opportunities for the early deployment of vehicle control systems. The next phase of this study should explore deployment options for guided snow plows and automated shadow vehicles in greater detail. Our survey of state DOT's indicates substantial interest in both vehicle concepts, however the issue of capital cost and cost effectiveness for these vehicles is a constant theme in the responses.

Given the level of technical development already achieved in the shadow vehicle area, the focus for our continued work here should be in assessing the cost effectiveness of autonomous shadow vehicles for specific highway maintenance operations. This task would entail a detailed study of candidate operations, such as lane striping, road sweeping, and crack filling, across several state DOT's. Vehicle and driver movements would be recorded. Depending on the specific maintenance operation, there may be substantial logistical challenges associated with delivering, retrieving, or operating the autonomous vehicle during the course of a work day. There may also be technical challenges associated with some operations, such as lane changing, crossing signalized intersections, and following at large distances, in an automated driving mode. By modeling each operation as it would occur with an autonomous shadow vehicle and comparing that against the conventional (non-automated) operation, a projected net cost or benefit could be associated with the automation.

Unlike the shadow vehicle, little work has been done towards system deployment of a guided plow. As a result, it is proposed that future work focus on the specifics of a deployment for snow plow guidance. This task will require the definition of a detailed concept, test plan, and team of potential participants. The guidance technology (DGPS, magnetic road tape, etc.) and type of control used (steering assistance, warning, etc.) will be selected, and the roles of each participant established along with an estimated cost for a future deployment phase.

8.0 Conclusion

Very few outside of the AVCS field believe that automatic driving operations are technically or economically feasible in the near future. While the issue of cost effectiveness remains open to debate, there is no question that fully automatic driving is technically feasible today, as has been demonstrated by numerous research groups over the last five years. Although technical issues remain, the more immediate challenge for AVCS developers, particularly AHS supporters, is to find a suitable arena for the demonstration of vehicle control systems, both to encourage public acceptance and to refine designs in a real-world environment. For the AVCS community, maintenance operations provide an opportunity to demonstrate the technical feasibility of new systems without the legal and institutional complexities that would plague deployments in conventional vehicles used by the driving public. In particular, maintenance vehicle deployments would allow positive exposure to an important future AVCS user group. For highway maintenance departments, any tool which makes their work safer, easier, or more productive is generally worth evaluating. With control over large fleets of vehicles and the responsibility for maintaining public roads, these departments are well positioned to test prototype systems. As discussed, work zone-following and snow removal are two of the most promising operations suitable for AVCS. Given the positive response by maintenance staff, AVCS developers should aggressively pursue these opportunities.

Appendix 1: Highway Maintenance Department Survey

State	Maintenance Representative	Comments	Shadow	Snowplow
AK	Matt Reckard	-Interested in autonomous shadow vehicle, especially for Anchorage or for Falling Weight Deflectometer operations -Interested in snowplow; they plan to map all roads with GPS in the future. Magnetic tape wouldn't work because pavement markings only last one year there. -Concerned about cost	yes	yes
AL	Mr. Stevens	-Autonomous shadow vehicle with truck-mounted attenuator sounds good if it works well	yes	n/a
AR	Lynn Austin	-Familiar with Mn/DOT's RDV -Liked autonomous shadow vehicle concept -Thought $20K retrofit cost to existing truck would be acceptable, but thought $75K retrofit would be too expensive	yes	n/a
AZ	Larry Scofield	-Interested in both concepts; will present to Research Council for more opinions	yes	yes
CA	Tom West Monika Kress	-R&D program underway developing both autonomous shadow vehicles and guided snow plows (AHMCT Center)	yes	yes
CO	Al Klein	-Interested in autonomous shadow vehicle if the distance between shadow vehicle and other vehicles can be minimized to prevent cars from cutting in between -Snowplow would be helpful in rural or mountainous areas, but probably not in Denver because of traffic	yes	yes

CT	Jim Lewis	-Interested in autonomous shadow vehicle, depending on cost (MN RDV too expensive) -Interested in guided snowplow -Something to control plow speed in snow (when blade down) would be beneficial, because drivers plow too fast now	yes	yes
DE	Bill Thatcher	-Very interested in shadow vehicle concept -Concern with guided snowplow is that many of their plowing is done in high volume traffic and warnings may be distracting. -Cost may be prohibitive on both concepts	yes	no
FL	Bill Arball	-Cautiously interested in shadow vehicle; would require questions answered about its capabilities and operations	yes	n/a
GA	Wayne Sedrick	-Interested in shadow vehicle; would have to see it operational	yes	n/a
HI	Sterling Morikawa	-Not interested in shadow vehicles	no	n/a
IA	Leland Smithson	-Iowa is very interested in both guided plows and autonomous shadow vehicles as well as the RDV concept	yes	yes
ID	Brian Green	-Definitely interested in the guided snow plow concept, if the cost isn't too high -Both auditory warning or steering control are of interest--whichever is better -Preferred the autonomous shadow vehicle concept to the RDV concept	yes	yes
IL	Ken Wood Rich Hunter	-Interested in shadow vehicle, after extensive testing to prove that it operates properly -Technology for both concepts is good, but the bottom line is: What is the cost and benefit to the public? -More interested in DGPS than magnetic tape for snowplow -Advantage of autonomous shadow vehicle over RDV is that a person is not required for operation of it.	yes	yes

IN	Chris McFall	-Not interested in shadow vehicle--they don't have drivers killed, so not worth spending money -Very interested in guided snow plow, particularly if it would warn driver of vehicles in front of the plow	no	yes
KS	Dean Testa	-Shadow vehicle may be possible in metro areas -What is cost? What are benefits and savings? Fail-safe method? -More beneficial for snowplows to detect other vehicles in blind spots and warn driver or use automatic braking; limited interest in run-off-road warning	yes	yes
KY	Janet Coffey	-Not very interested in either concept due to cost and lack of flexibility	no	no
LA	Bill Temple	-Shadow vehicles sound interesting. Sent more information for their review.	yes	n/a
MA	John Glendle	-Interested in autonomous shadow vehicles for moving operations -Interested in guided snowplows, especially to avoid bridge joints and curbs	yes	yes
MD	Charlie Bull	-Interested in both concepts -MD would likely be willing to participate in a pilot test	yes	yes
ME	Warren Spalding	-Interested in both shadow vehicle and snow plow -Depends on cost	yes	yes
MI	Steve Dembecki	-Familiar with the Mn/DOT RDV -Could be interest in autonomous shadow vehicle for moving operations -Not familiar with guided plow concept, but could be interested if the cost is sufficiently low	yes	yes
MN	Paul Keranen	-Minnesota is actively participating in the development of these types of concept vehicles	yes	yes
MO	Jim Jackson	-Limited interest in shadow vehicle for moving operations in cities, but not for entire state -Cost concerns -More interested in guided snowplow, particularly if it could warn of low profile medians or skewed bridge joints	no	yes

MS	Reed McAtee	-Not interested in shadow vehicles because cost prohibitive	no	n/a
MT	George Swartz	-Familiar with the Mn/DOT RDV, but not very excited about it -More interest in autonomous shadow vehicle for following paint striping operations and mowing -Snow poles are usually sufficient to prevent plows from running off the road, but he is willing to test guided plows	yes	no
NC	Pat Strong	-Interested in autonomous shadow vehicle and would support a test deployment	yes	n/a
ND	Jerry Horner	-Interested in autonomous shadow vehicle at low speeds -Moderately interested in guided plow, but doubts cost effectiveness	yes	no
NE	Dallas Ronnau	-Autonomous shadow vehicle could be possibility for highway, but would have to give more thought to deployment--may not be cost effective. Interested in guided snowplow, particularly avoiding obstacles	no	yes
NH	Ed Kyle	-No interest in shadow vehicle concepts because of cost -May have interest in guided plow	no	yes
NJ	Chester Lyszczek	-Interested in autonomous shadow vehicle for paint striping, cone and barrel laying/picking -Less interest in Mn/DOT's RDV concept -Guided plows would be of limited use	yes	no
NM	Fred Cooney	-No interest in the RDV concept -Interested in autonomous shadow vehicle for road striping and sweeping -Would be interested in testing prototypes	yes	n/a
NV	Rick Nelson	-Lukewarm interest in shadow vehicle due to cost -Interested in guided snowplows and obstacle avoidance -Would like system that combines road weather information so plow automatically disperses chemicals	no	yes

NY	Mike Doherty Bob Valenti Terry Venard	-Interested in guided snow plows, and collision avoidance for plows -Not interested in RDV (too expensive), but moderately interested in autonomous shadow vehicle concept -Very limited budget for new equipment and R&D	yes	yes
OH	Did not respond.			
OK	Did not respond.			
OR	Dick Burgie	-Autonomous vehicle possible for sweeping operations, especially on interstates without shoulders -Not interested in RDV because of operator requirements -Guided snowplow of real use to operator -Interested in testing if someone else pays for it	yes	yes
PA	Ray Rugh	-Willing to test snowplow, but doesn't want to spend his own money -Has tested several SHRP products without much success—skeptical of performance of AVCS concepts	no	yes
RI	Mark Felag	-Is unsure how well shadow vehicle would work with their operations -Need cheaper way to perform shadow operations -Snowplow guidance unnecessary--no problems	no	no
SC	G. Ron Wertz	-Shadow sounds interesting--would like to see demo -Not sure that it would be applicable in SC because they may not do enough work to warrant the expense.	yes	n/a
SD	Norm Humpherey	-Does not believe an autonomous shadow vehicle would be cost effective -Very interested in guided plow concept: interstates are closed during bad storms due to poor visibility, not snow depth -System cost and reliability would be major considerations for plow	no	yes

TN	Mr. Baird	-Very interested in shadow vehicle, especially in urban areas -Would like to be involved in tests, but any test should minimize impact on worker and not make their job more difficult. -Lawyers "may get nervous" with autonomous shadow vehicle	yes	n/a
TX	Thomas Bohuslav	-Very interested in shadow vehicle -Would be willing to pay $20,000; MN RDV was too expensive	yes	n/a
UT	Gordon Peterson	-Likes all concepts -Would be willing to test shadow vehicle -Concerned about cost of systems	yes	yes
VA	Andy Bailey	-Familiar with RDV and other automation techniques being prototyped -Interested in autonomous shadow vehicle concept, following testing -Concerns about vehicle after accident -Interested in guided plow concept, but was more interested in a collision avoidance system	yes	yes
VT	Milan Lawson	-Shadow vehicle concept interesting -Concerned with shadow vehicle control and speed, cost -Snowplow would not be useful, very few white-out conditions -Automated mowers for steep grades	yes	no
WA	Dale Keep	-Very enthusiastic about an autonomous shadow vehicle for lane striping operations -Would like to test a prototype -Liked guided snow plow concept (warning-based only), but was strongly against developing steering control system; keep control in driver's hands	yes	yes
WI	Bob Fasick	-Interested in autonomous shadow vehicle -Less interested in RDV concept -Interested in guided plow concept -Other ideas: drowsy driver warning and collision avoidance warning for plow operators	yes	yes

WV	Julian Ware	-Did not believe that either concept could be affordable for all operations -No serious interest	no	no
WY	Ken Shultz	-Interested in autonomous shadow vehicle for testing or deployment -Not as interested in RDV because still need operator; reducing the size of the work crew would be of value -Guided snowplow would be of use -Biggest problem is plows being rear-ended on interstate; benefit if could warn plow driver he may be rear-ended so he can move onto the shoulder or other lane	yes	yes