Arizona Intelligent Vehicle Research Program - Phase Two: 2000 - 2001

Final Report 473(2)

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16. Abstract –

This report documents Phase Two, the third full year of a continuing research program by the Arizona Department of Transportation (ADOT) to study vehicle and infrastructure-based Intelligent Transportation Systems technologies. Phase Two of Arizona's Intelligent Vehicle Research Program focused on the critical 2000-2001 winter season.

Phase One of the research project was basically a partnership with California to test the Caltrans-PATH advanced snowplow in Arizona. One defining element of Phase Two was the search for a satisfactory new system that could be acquired by ADOT and installed on one of the State's snowplows for long-term testing. The final result of the search, in early 2001, was that the Arizona Transportation Research Center (ATRC) and the Flagstaff District concluded an agreement to purchase one of the 3M Company's Lane Awareness Systems, as well as five miles of 3M tape to guide the vehicle.

The second major new factor in Phase Two of this research was the need for formal, unbiased reporting and analysis of the training and evaluation results for the 3M and Caltrans driver-assistance concepts. The ATRC therefore contracted with Northern Arizona University in Flagstaff to monitor the training and testing, to survey stakeholders, to provide evaluation results, and to make recommendations for the future. The ADOT research also was independently supported by the 3M Company, through their own evaluation program contract with the University of Iowa. Despite their prior lack of mountain road snowplow expertise, U-Iowa's driver surveys were of great benefit to ADOT, the ATRC and the NAU evaluation effort.

This project faced a number of unexpected setbacks in the Phase Two winter of 2000-2001. Nevertheless, tests and training proceeded at Flagstaff with both systems. The project team developed creative solutions to many obstacles, and pushed ahead. As a result, a great deal was learned from Phase Two, as Arizona developed the first test program in the West with dedicated real-world high-altitude test sites for both the Caltrans and the 3M systems, only 30 miles apart.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	Inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	Feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	Yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	Miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	Square inches	645.2	square millimeters	mm^2	mm^2	Square millimeters	0.0016	square inches	in^2
ft^2	Square feet	0.093	square meters	m^2	m^2	Square meters	10.764	square feet	ft^2
yd^2	Square yards	0.836	square meters	m^2	m^2	Square meters	1.195	square yards	yd^2
ac	Acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	Square miles	2.59	square kilometers	km^2	km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	Gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	Cubic feet	0.028	cubic meters	m^3	m^3	Cubic meters	35.315	cubic feet	ft^3
yd^3	Cubic yards	0.765	cubic meters	m^3	m^3	Cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	Ounces	28.35	Grams	g	g	grams	0.035	ounces	oz
lb	Pounds	0.454	Kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	Megagrams (or "metric ton")	mg (or "t")	Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot candles	10.76	Lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	Poundforce	4.45	Newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in^2	Poundforce per Square inch	6.89	Kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

EXECUTIVE SUMMARY

Note – a list of the acronyms and abbreviations used in this report appears with the Introduction.

This report documents Phase Two, the third full year of a continuing research program by the Arizona Department of Transportation to study vehicle and infrastructure-based Intelligent Transportation Systems technologies. Phase Two of ADOT's Intelligent Vehicle Research Program began in the spring of 2000. This report focuses on the 2000-2001 winter season, ending in the late spring of 2001.

ADOT's earlier Phase One research (from 1997 to 2000) explored numerous AHS and IV concepts as potential solutions for urban and rural highway congestion problems. ADOT leaders ultimately decided that the best near-term potential use of these technologies was to improve the safety and efficiency of winter maintenance. This initial wide-ranging research program was reported in the ATRC Final Report No. 473(1), *Arizona Intelligent Vehicle Program – Phase One: 1997-2000*.

In Phase One, Arizona developed a winter maintenance research partnership with Caltrans, the California Department of Transportation. Their prototype snowplow guidance system, installed on a Caltrans 10-wheel, 10-yard plow truck, was tested in Arizona during the winters of 1998–99 and 1999-2000. For the ADOT project team, a clear need was soon recognized to obtain driver-assistance systems for full-winter and longer-term testing on an Arizona snowplow.

One defining element of this new Phase Two research was the search for a new advanced snowplow system that ADOT could acquire for long-term testing. The final result in early 2001 was that ATRC and the Flagstaff District reached an agreement with 3M Corporation to purchase their Lane Awareness System package, with five miles of 3M tape to guide the vehicle.

A second new factor in the Phase Two research was the need for formal, unbiased analysis of the Arizona training and evaluation results for both the 3M and Caltrans driver-assistance concepts. The ATRC invited Flagstaff's Northern Arizona University to monitor the training and testing, to provide evaluation results, and to make recommendations for the future. The ADOT effort was also supported by 3M Corporation, through their own evaluation program contracts with the University of Iowa. The Iowa driver survey results were of great interest to both ADOT and the ATRC, and were of value in giving perspective to the NAU evaluation activity.

This project's Phase Two faced a number of unexpected setbacks in the winter of 2000-2001, from both manmade situations and natural events. Nevertheless, the project team developed creative solutions to many obstacles, and pushed ahead. Equipment tests and training proceeded at Flagstaff with both systems. The two Advanced Snowplows were deployed in plowing operations at one or the other test site for nearly the entire winter. As a result, Phase Two was very productive, as Arizona developed the first test program in the West with dedicated real-world high-altitude test sites for both the Caltrans and the 3M systems, just 30 miles apart.

The ATRC is especially grateful to all of those listed below, who played key roles in ADOT's Winter 2000-2001 testing, training and evaluation program for Advanced Snowplow systems in Arizona.

ADOT's I-40 Corridor District Engineers, Maintenance Engineers & Superintendents:
- Flagstaff – Don Dorman, John Harper, Kent Link, Danny Russell
- Holbrook – Jeff Swan, Robert Wilbanks
- Kingman – Debra Brisk, Bill Wang, Larry Thomas

ADOT-3M Team Leaders:
- Robin Nelson, John Robbins, Tyrone Begishie (Gray Mountain)
- Lee Lund, Darwin Brewer (Flagstaff)

ADOT-Caltrans Team Leaders:
- Joseph Chavez, Manuel Santana, Tom Durnez (Flagstaff)

3M Advanced Snowplow Project Development:
- Heinrich Bantli, Gary Nourse, Chin-Yee Ng

Caltrans Advanced Snowplow Project Development:
- Greg Larson, Mike Jenkinson, Kirk Hemstalk of Caltrans
- Dr Ty A. Lasky and the AHMCT project team from UC-Davis
- Dr. Wei-Bin Zhang, Dan Empey and the California PATH / UC Berkeley project team

Project 473 Technical Advisory Committee:
The project stakeholders bear much of the responsibility to enable a successful research project, by providing clear direction for the work, and with both physical and leadership support as well. The Intelligent Vehicle Technical Advisory Committee, by their participation and positive attitude, have been vital to the development of the unique Arizona test sites, and to the ATRC's ability to capture valid and relevant results from the ongoing field activities.

During Phase Two (2000-2001) the TAC included the following ADOT sections and partner agencies:
- ADOT's I-40 Corridor Districts – Flagstaff, Holbrook, Kingman
- Arizona Department of Public Safety – Flagstaff District
- ADOT Transportation Technology Group (TTG)
- ADOT Equipment Services
- NOAA / National Weather Service – Flagstaff -Bellemont
- Federal Highway Administration

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PROJECT ACRONYMS AND ABBREVIATIONS

ACRONYM	DEFINITION
3M	The 3M Company (Minnesota)
ADOT	Arizona Department of Transportation
AHMCT	Advanced Highway Maintenance & Construction Technology (Research Center at UC Davis – Prime Contractor for ASP)
AHS	Automated Highway Systems
ASP-I	Advanced Snowplow, Phase I (Caltrans)
ASP-II	Advanced Snowplow, Phase II (Caltrans - RoadView)
ATRC	Arizona Transportation Research Center (at Phoenix)
AVCSS	Advanced Vehicle Control and Safety Systems
AVL	Automatic Vehicle Location
Caltrans	California State Department of Transportation
CWS	Collision Warning System
DGPS	Differential Global Positioning System
District	ADOT Maintenance / Construction Districts
DOT	Department of Transportation
DPS	Department of Public Safety (Arizona State Police)
GPS	Global Positioning System
HMI	Human-Machine Interface
HUD	Head-Up Display
I-40	Interstate 40 (in Northern Arizona)
I-80	Interstate 80 (in Northern California)
ITS	Intelligent Transportation Systems
IV	Intelligent Vehicle
IVI	Intelligent Vehicle Initiative
LAS	Lane Awareness System (3M)
LCD	Liquid Crystal Display
MP	Milepost
NAHSC	National Automated Highway Systems Consortium
NAU	Northern Arizona University (at Flagstaff)
Org	ADOT Sub-District Level Maintenance Camp / Yard / Organization
PATH	Partners for Advanced Transit and Highways (at UC – Berkeley)
RF	Radio Frequency
UCB	University of California at Berkeley
UCD	University of California at Davis
UofI	University of Iowa (at Iowa City)
US 89	US Highway 89 (NE of Flagstaff AZ)
US 180	US Highway 180 (NW of Flagstaff AZ)
WTI	Western Transportation Institute (at Montana State University)

I. INTRODUCTION

This research report documents Phase Two, the third full year of an ongoing research project by the Arizona Department of Transportation (ADOT). The project, conducted by the staff of the Arizona Transportation Research Center (ATRC), studies the possible practical applications of vehicle and infrastructure-based new Intelligent Transportation Systems technologies.

This long-term research effort is the Arizona Intelligent Vehicle (IV) Project, and this report covers Phase Two of the IV research, which began in the spring of 2000. It focuses on northern Arizona's 2000-2001 winter season, and it carries through to the late spring of 2001.

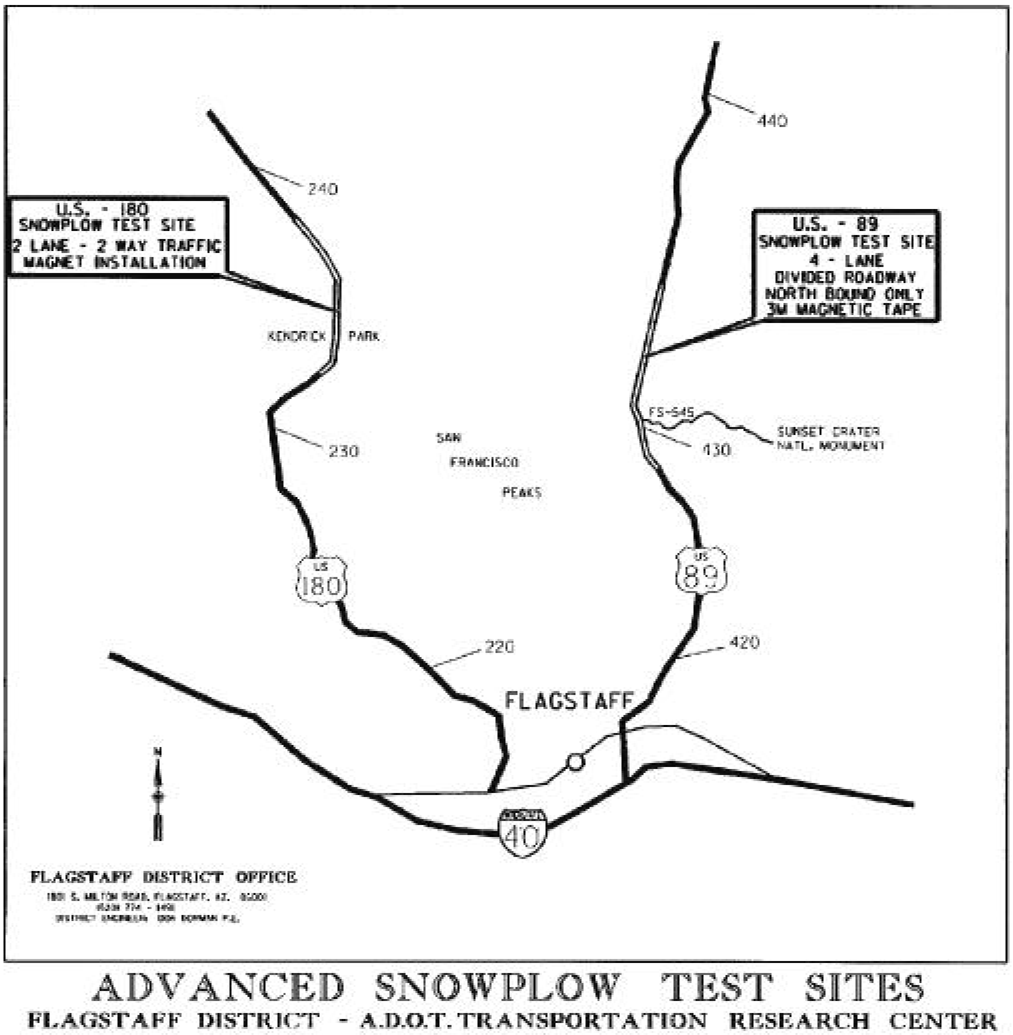


Figure 1: ADOT Snowplow Test Sites – Flagstaff District

The Phase One research, from 1997 to early in 2000, explored numerous IV and AHS (Automated Highway System) technologies and concepts as potential solutions to be applied in Arizona's urban and rural highway congestion problem areas. As this work progressed, ADOT managers came to realize that the best near-term potential of these technologies was in improving the safety and efficiency of winter maintenance. This initial wide-ranging research program was reported in the ATRC Final Report No. 473(1), *Arizona Intelligent Vehicle Program – Phase One: 1997-2000.*

In Phase One of this project, ADOT developed a research partnership with the California Department of Transportation (Caltrans). The Caltrans-ADOT vehicle guidance system, installed on a Caltrans 10-wheel 10-yard snowplow, was tested in Arizona during two winters, in 1998–99 and 1999-2000. The ADOT team members gradually developed a strong desire to obtain a suite of driver-assistance systems for full-winter testing on an Arizona snowplow.

The defining element of Phase Two of this research project has been the search for a satisfactory system that could be acquired by ADOT for long-term testing. The ultimate result, as described in the following sections of this report, was that the ATRC and the Flagstaff District worked out an agreement with the 3M Corporation in the summer of 2000 to purchase a 3M Lane Awareness System, with five miles of 3M's magnetic tape to guide the snowplow.

Report Outline

This report is organized into three distinct areas of research activity, following a brief introduction to Phase One of the project. Section One reviews the efforts to secure an Arizona snowplow IV system, and the development of the 3M Corporation partnership. It also describes the site infrastructure planning, research efforts and the first-year results with this new lane guidance concept.

Section Two describes the third winter of the ongoing RoadView snowplow evaluation partnership between ADOT and Caltrans. It details the 2000-2001 snowplow testing and evaluation program, and the project's Phase Two results.

Section Three reports on the third-party evaluation of this ADOT research project by Northern Arizona University. With two competing vehicle guidance concepts installed for testing on Arizona highways, a neutral third-party project consultant was needed to support future ADOT decisions. A contract was established for an evaluation program, and NAU's efforts and results are detailed in this third section of the report. A second formal evaluation program was sponsored by the 3M Company, with the University of Iowa under contract, which provided further insights into the new magnetic tape system. Caltrans also performed limited analysis of post-season surveys for the third winter of the Advanced Snow Plow (ASP) program in Arizona.

The final section of this report reviews the challenges of the Phase Two research program, of the 2000-2001 winter in Arizona, and the project's results, conclusions, and recommendations for future snowplow research.

II. ADVANCED SNOWPLOW RESEARCH IN ARIZONA

The Arizona Transportation Research Center is performing this project as an in-house research effort. During Phase One of the project, from 1997 to early 2000, ADOT and the ATRC reviewed, tested, evaluated and demonstrated a variety of Automated Highway System (AHS) and Intelligent Vehicle (IV) concepts. These new resources were evaluated with regard to their potential to improve the safety and efficiency of Arizona's highway system. Key project goals were to improve safety for both travelers and ADOT personnel, to defer more highway lane construction, and to improve regional air quality in Arizona.

The initial phase of this wide-ranging IV research program was reported in detail in ADOT-ATRC's Final Research Report 473(1), *Arizona Intelligent Vehicle Program – Phase One: 1997-2000.*

Evolution of ADOT's Snowplow – IV Research Program

After extensive review and analysis of varied concepts, ADOT's senior management found that the greatest near-term potential benefit from these advanced vehicle technologies for Arizona would be the enhancement of safety and efficiency in winter maintenance operations. The focus therefore quickly evolved toward new ITS concepts for snowplow operator guidance assistance, and to other vehicle-related operational resources.

Figure 2: I-40 in Winter – Flagstaff, Arizona

The winter maintenance program on the state highways and Interstate routes of northern Arizona is critical both to the safety of the public and to the economics of commercial traffic. As noted in the Phase One project report, ADOT maintains a fleet of more than 240 snowplow vehicles that are assigned in nearly every section of the state. The major plowing resources are assigned to the northern and eastern districts that include the Colorado Plateau region, traversed by both I-40 and I-17. These two Interstate highways meet at Flagstaff, the focal point of Arizona's snowplow research program.

Arizona winters are quite variable, but weather records since 1898 show that 1991-1992 and 1992-1993 were two of the seven heaviest winters on record for Flagstaff, at 40 percent above average. ADOT's mission is to keep the highways open and safe each winter with a fleet of current equipment, with trained and experienced operators, and with sufficient stockpiled materials to do the job.

The ADOT Traffic Records Section crash statistics for calendar year 2000 show that 58 percent of the fatal crashes in Arizona were on rural highways. The estimated loss to the state's economy from the more than 131,000 reported crashes was nearly 2.8 billion dollars. Across Arizona in 2000, snowy or icy road surface conditions were cited in 1,292 crashes that took 14 lives and caused 567 injuries. Of those crashes, 1,018 were in the northern third of Arizona, and 786 of those were in Coconino County, of which Flagstaff is the county seat.

ADOT's snowplow fleet is subject to serious attrition during major storms, when all available trucks and manpower are deployed on the state's highways. During the winter of 2000-2001, the subject of this Phase Two report, nineteen snowplow damage incidents were entered in the internal repair cost tracking system. These incidents posted a total repair cost of $67,000, a figure that does not include property damage such as guardrail, signs or third party damages. It also does not include various internal costs for repair work, nor repairs charged as ordinary snowplow wear and tear.

In the 2000-2001 winter, fifteen of the above damage reports were during on-the-road snowplowing activity, as opposed to loading de-icing materials or rigging plow equipment. Nine of the incidents involved being struck by other vehicles, and six involved striking fixed objects. In all cases, visibility would logically be a factor to some extent, although not captured in these records.

1997 – 2000: The Phase One Snowplow Research Program

The key accomplishment of this project in Phase One was to develop a working partnership between ADOT and the California Department of Transportation, whose Advanced Snowplow partnership offered significant research benefits for both states. The prototype Caltrans-ADOT RoadView advanced snowplow features lane position indication and lane departure warning, as well as a forward collision warning system. A continuous line of discrete magnetic markers embedded in the roadway provides encoded guidance information to the snowplow.

This RoadView Advanced Snowplow (ASP) guidance system, installed on a Caltrans 10-wheel snowplow truck, has been tested through two winters, in 1998–99 and 1999-2000. Training and evaluation activities have been conducted both at the primary California research project testbed on Interstate 80 near Donner Summit, and at the Arizona dedicated test site on US Highway 180 at Kendrick Park near Flagstaff.

Phase One – ADOT's US 180 Magnet Test Site

The Kendrick Park test site, from Mileposts 235 to 238 on US 180 about 20 miles northwest of Flagstaff, was selected because it is the opposite in most respects to California's Interstate-80 test area at Donner Summit. The Arizona test site's narrow, winding and steep roadway is constructed of asphalt, not concrete. It has a limited average traffic count of less than 3000 cars per day, but as the shortest route between Flagstaff and the Grand Canyon, it is a vital link in the state highway system and for the regional economy.

This section of US 180 is a severe winter maintenance challenge for ADOT. The central section of the test lane, across Kendrick Park, is subject to whiteouts and drifting snow in heavy winter storms. This site is at 8000 feet elevation, and receives on average more than 100 inches of snow each winter.

Because of the severe drifting, as much as 15 feet deep, this is one of the few ADOT highways where a rotary snowblower must sometimes be used to keep the road open.

Winter maintenance research clearly offers significant potential benefits to ADOT and to its partner transportation agencies. With an extensive rural highway network and only limited resources to keep the roads open in the worst weather conditions, Arizona faces major operational challenges each winter. Snow removal and emergency response operations are among the most critical and hazardous duties for highway maintenance personnel. Practical safety and efficiency improvements are greatly needed in the winter maintenance field, and the goal of this research project is to identify real gains that may be achieved with ITS and IV concepts.

The Phase One project report describes in detail how support was developed from ADOT's Research Council, and how this research was championed by the Department's three northern maintenance districts at Flagstaff, Holbrook and Kingman. It also tells how the US 180 test site was designed and constructed in cooperation with Caltrans and their vehicle research partnership.

Phase One – The California ASP Magnets Concept

The Advanced Snowplow system is based on communicative infrastructure concepts developed by the Caltrans/AHMCT/PATH consortium, with the lateral guidance concept derived from technology originally developed by PATH for vehicle control and Automated Highway Systems. The Caltrans snowplow research evolved by 1999 into the RoadView program, which has deployed additional fully-operational ASP vehicles in several maintenance districts in northern California.

The ASP system tracks, with suspended sensor arrays, a continuous line of embedded magnets in the roadway. The magnets are installed in sets of four, in holes drilled into the pavement at 3.94 foot intervals (1.20 meters). To provide a constant signal strength, the magnets must be consistently placed on the lane centerline of the roadway with very demanding tolerances. Accurate surveying support was very important to the project.

The magnets are installed with a polarity coding for each section of the test lane. This identifies each roadway segment and allows the on-board system to know its location along the highway, and what curves and grades are ahead. The Caltrans ASP system offers a predictive display of the roadway on the in-cab screen, to allow the snowplow operator to keep moving despite nearly zero visibility.

In September 1998, to establish the test site for the first winter of joint activity with Caltrans, ADOT maintenance forces put in four miles of magnets as described above. Before the second winter began, two more miles of magnets were set, to complete a two-way test lane across Kendrick Park. The total length was three miles in each direction. The test lane includes some winding and very steep roadway (eight percent grade), a level forested section, and one key mile across the open, windswept Kendrick Park, the worst area of US 180 for drifting and for zero visibility plowing conditions.

2000 – 2001: The Phase Two Research Initiative

In the Spring of 2000, ADOT completed its second season of Arizona winter tests with the ASP, in partnership with Caltrans, and ATRC committed to continue that program for the next winter. At the same time, the TAC realized that the traditional four-week time window for training and operational evaluation was clearly too short to develop sufficient data to support valid decision-making by ADOT in the future. Caltrans, however, was not able to withdraw the ASP from their own District's critical Donner Summit plowing operations on I-80 for any period longer than one month.

At the request of the research project's Technical Advisory Committee, including the three northern District Engineers, efforts began to improve on this situation. ATRC would explore both the Caltrans IV hardware and any other options to permanently install an Arizona system on an Arizona snowplow, and thus to determine the benefits of this technology on ADOT's high-altitude rural highways.

Since ADOT had made a quite significant commitment of research funds, district manpower and other resources to the Caltrans magnet infrastructure, it was logical to purchase an array of the California ASP equipment. A Caltrans system identical to the one being jointly tested in Arizona was requested, and ATRC began negotiations with the ASP / RoadView designers at the AHMCT Research Center of the University of California at Davis.

Unfortunately, the AHMCT and Caltrans could not reach an agreement with Arizona. At this stage of pre-commercial development, as a research-oriented team, the Caltrans consortium could only offer a complete system at a cost that was several times more than their projected mass-market commercial deployment pricing goal of $15,000 to $20,000. Arizona's ASP system purchase budget would have to include not only the pre-commercial, semi-prototype equipment system, but also significant new part-time funding and travel for a support technician or engineer, based on the record of earlier seasons of testing in Arizona.

While disappointing to ADOT, it was clear that the Caltrans system was not really ready to be offered to third-party partners or other customers in mid-2000. The ASP program was still in an aggressive research and development phase, and was not yet considered robust enough for AHMCT to release it with a commitment of full technical support for the customer. At this time, AHMCT continues to pursue third-party commercialization of the RoadView system, so the potential still exists in future.

Phase Two Research Realities

Faced with developmental "R&D" pricing far in excess of the anticipated future market cost of the ASP system, ADOT had to look elsewhere due to the realities of the research budget. Clearly ATRC did not have the funding, the facilities or the technical staff to develop an IV system independently. The only other viable guidance technology, already fully commercialized and marketed at this time, was the 3M company's Lane Awareness System. This concept was based on a magnetized roadway striping tape infrastructure, rather than discrete embedded magnets.

The possibility of a research program with 3M Corporation offered ADOT two valuable benefits, should the program move ahead as planned. First, it would give ATRC a valid research baseline of a commercial product to fully evaluate the Caltrans system's potential. Second, if successful, Arizona would then be the only state in the west to have constructed closely-linked test sites for the only two viable infrastructure-based snowplow guidance systems currently in or near deployment.

The ADOT contacts, meetings and negotiations with 3M's ITS Group, and the near-term and later developments that resulted, are described in the following section of this report.

PART ONE:

THE ARIZONA – 3M CORPORATION PARTNERSHIP

III. PROGRAM EXPANSION – AN ARIZONA VEHICLE SYSTEM

ADOT already had significant prior experience with the 3M Company's marketing efforts, both nationally and locally. From the mid-1990's onward, 3M's Intelligent Transportation Systems Group was heavily involved in testing of their tape-based system with several agency customers in the north-central United States, most notably with the Minnesota Department of Transportation.

Field tests and operational deployments were already in progress since 1996 at several sites, developing research results for this and related vehicle technologies. However, 3M had little market penetration outside of the upper Midwestern region, and no deployment of their infrastructure and vehicle system package in the western United States.

Just as with the Caltrans program, Arizona provided a good opportunity for 3M to diversify the application of their product into a region with unique climatic conditions and highway design parameters. Arizona's regions of mountains and canyons would be an excellent new locale to validate the wider marketing of this fully-commercial product.

Figure 3: The 3M Lane Awareness System Display

The Lane Awareness System was designed around a magnetized form of 3M's durable striping tape. This tape has a molded skid-resistant surface with magnetic material embedded in it, and may be applied to the road surface, grooved below grade, or fully embedded in the roadway paving operation. While the surface mounting of this tape, if colored, would provide lane delineation and allow striping cost savings for the Department, the tape is also more exposed to damage during plowing.

The 3M magnetic guidance tape is manufactured in 60-meter rolls, and is 100 mm (4 inches) wide and 2.3 mm (about 1/8 inch) thick. The magnetic field reverses at one-meter intervals, and it provides a positive-negative sine wave that the truck's magnetometers can sense to determine lateral position over the installed tape.

The 3M sensor bars are 24 inches long and are normally mounted below the front bumper or the plow frame of the snowplow vehicle. The optimal mounting height is 12 inches above the tape. The bars sense the magnetic field and provide a position indication within the lane to the operator. Lane departure warnings include a vibro-tactile seat, peripheral vision lights, and directional arrows on a control display unit.

Both the sensors and the display units came to Arizona with a significant history of development and refinement. One advantage for ADOT was this field-deployment history in other locations of the fully commercialized and operationally tested product. The 3M system provided ADOT with a robust, more advanced and less complex baseline for evaluation of all aspects of the Caltrans ASP prototype system. 3M offered a valid, market-developed, more practical option that could be deployed in the present time if it was proven to be suitable for regional needs and conditions.

ADOT's Early Experience With 3M Magnetic Tape

The Arizona Transportation Research Center had early contacts with the 3M Lane Awareness program at various conferences and demonstrations, as early as the national-scale IVI Demo '97 in San Diego, California. When ADOT initiated plans with Caltrans to partner on snowplow testing in northern Arizona, 3M continued to pursue the possibility of an alternative testing plan, to better demonstrate the capabilities and advantages of their tape-based system.

The 3M staff traveled to make formal presentations to both ADOT's Transportation Technology Group and the Flagstaff District in mid-1999. They provided in-depth information to ADOT on the advantages of the system, and made extensive efforts to investigate, analyze and better respond to the unique aspects of the winter maintenance conditions in northern Arizona.

Figure 4: Underlay Installation of 3M Tape

At that time, ADOT managers and field personnel were very interested but not optimistic, due to the cost of the 3M tape itself, in the range of $4 to $5.50 per lineal foot. It was also noted that while one key benefit under Arizona conditions was in the area of traveler safety, by keeping the roadways open and passable, the savings for the State in this area are very difficult to identify.

At the national Rural ITS Conference in Flagstaff, in August 1999, 3M also participated by bringing rolls of tape and laying out a demo route for visitors. Since the Caltrans ASP-ADOT snowplow was on display also, this put Arizona's winter operations and research in the spotlight.

The Arizona State Capitol Demonstration

3M's marketing program reached a new level of visibility for Arizona state officials in mid-2000. This activity was described in this project's Phase One report, but it is significant to note again that 3M made a very significant effort to raise the visibility of their Lane Awareness products when ADOT contacted them about a June, 2000 demonstration at the State Capitol in Phoenix.

This Demo took place as one element of a New Technology Open House for the Governor's Vision 21 Task Force, a high-level commission tasked to explore long-term solutions to Arizona's growing congestion and air-quality problems. By focusing on the economic and traveler safety issues of storm-closed highways and chain-reaction pileups, the benefits of the 3M system to transportation efficiency in Arizona were clearly illustrated.

The 3M team laid out 200 meters of their magnetic striping tape in front of the Capitol building, and a sensor-equipped Ford Expedition was used to give rides to key members of the Vision 21 task force, to members of the legislature, and to the press. Reactions and media attention were very positive, although no promise of specific action resulted directly from this event.

Budget Constraints

While viewed very favorably by ADOT maintenance supervisors and managers, the basic cost of the commercialized tape product was always the critical factor that prevented ADOT from going ahead with an analysis of the 3M system during Phase One of this research program.

As proposed to ADOT in Flagstaff in mid-1999, a small quantity of tape could cost up to $5.50 per foot, or $29,000 per lane-mile, depending on the mode of placement. This figure could double or quadruple for any given roadway because the tape was intended to be placed in the center of each travel lane. On that basis, a single center-sensor system was needed for each deployed test vehicle, costing about $9,500. Despite their ongoing marketing campaign in Arizona, the 3M ITS Group did not have the ability to cut their prices significantly for a small-scale test program by ADOT.

In meetings in April and May, 2000, the research project TAC strongly recommended that an ADOT snowplow be equipped with guidance and related ITS safety systems, and directed the ATRC to negotiate on firm figures from both the Caltrans project team and the 3M Company.

The prototype California ASP guidance system was explored by ATRC initially, as the TAC had requested, since the roadway infrastructure was already in place at Kendrick Park. However, as described at the end of the previous section, it was not considered ready to be released outside of California by its developers. Since there was no success after negotiating with Caltrans, 3M thus remained the obvious, and only, other possibility.

Since even the Vision 21 Demo at the State Capitol aroused high-level interest, but did not produce any new funds, ADOT's research program had no resources available to enter into a new meaningful evaluation effort with 3M. The limited research budget was fully committed to the Caltrans long-term partnership.

At this point, in addition to the pending 3M Company presence at the Vision 21 Demo in June 2000, two new factors developed that would change the prospects for a successful negotiation with 3M.

The ADOT Flagstaff District clearly was and is the key supporter of this IV research program. There were no research funds available for ATRC to meet the cost of the 3M vehicle equipment and the tape, nor could research monies be used to purchase a commercially marketed, production-status product. However, the District had the ability to assign construction contingency funds for such new products or systems as would specifically enhance the safety of a roadway. In order to advance the research and to enable a valid assessment of the potential of the 3M technology, ADOT's Flagstaff District made a commitment to select a current roadway construction project for which the needed costs could be assigned from the contingency budget.

At the same time that this new and viable source of funding was offered by the District, the 3M Company also decided that they could compromise further with ADOT on the program budget, in order to see their product employed in a new region of the country. There had been very little new application of the 3M system nationally in the past year, and the necessity for flexibility was clear, with ADOT finally being in a position to put some tape on the roadway. 3M proposed some new ideas regarding sharing of costs that ultimately would enable the research to move ahead.

The 3M Tape Compromise

Because of the high cost of the tape, ADOT intended to install only a short segment of three or four miles. The 3M group emphasized that continuous time in motion over the tape was the key to an effective evaluation, and that much longer continuous sections were needed to prove the value of their system. A practical minimum installation in 3M's view was ten miles of roadway. As negotiations proceeded, they further offered to donate for evaluation about one-fourth of the total tape quantity, as well as the truck's on-board systems. This still appeared to be too expensive for ADOT, but then a new proposal from 3M was received in February 2000 offering sufficient tape for a five-mile test installation. With the installation of two sensor-bar systems, one on each side of the snowplow, ADOT could then plow ten lane-miles using one five-mile tape line between the two travel lanes.

Ultimately, a compromise was reached on this basis, and ADOT agreed to purchase and install five miles of 3M tape. This installation was planned for a section of highway that was being upgraded from basic two-way geometry to a four-lane, divided design. The 3M tape would be placed under the dashed white skip line between the new northbound lanes of US 89 near Sunset Crater (the test site review and the selection decision are described later in this report). ADOT also agreed to consider placing more tape in the southbound lanes as well, during the next construction season.

IV. US 89 SITE SELECTION – SUNSET CRATER

As the plan began to crystallize for installing 3M magnetic tape in northern Arizona, the question of site selection had to be resolved. There were a number of clear and less clear factors to be considered. First of all, the construction contingency funding approach meant that an active project in the right time window had to be identified, and in the high elevations of northern Arizona, that time window frequently was closed by October as winter conditions developed.

Technically, the project obviously had to be in asphalt paving, not concrete, so that the tape could be surveyed and placed accurately between the layers of pavement. Also, the roadway geometry and terrain needed to relate to the basic nature and operational challenges of the Caltrans ASP test site on US 180, in the Kendrick Park location. Ideally there would be a variety of grades and curves, as well as similar open park-like terrain where drifting and whiteout conditions were known to be existing problems for ADOT snowplow operators.

Significant logistical issues that needed to be considered included the location relative to the Flagstaff maintenance yard and Equipment Services shops, and other support resources. Travel distance and time to the new site needed to be roughly the same as Kendrick Park. Viable access from the new site to the Caltrans site on 180, and the total distance between the two were factors, especially for research project staff and evaluation personnel.

Figure 5: US 89 Reconstruction - Northbound Grade at MP 428

There were basic research-related concerns too, in order to limit the variables and establish a consistent basis for future evaluations. A site was needed that would meet the basic research goals, and the methods of the testing and training program. The 3M test site should be closely comparable to the Caltrans-180 site, so that training and operating comparisons could be made. The new site needed to be similar in such data categories as traffic volumes, crash records, and winter weather conditions and long-term records.

The site that was finally recommended by the project TAC as most suitable and practical is located on US 89 within about 15 miles of Flagstaff, between Mileposts 428 and 433. It has generally become known as the Sunset Crater Test Site. The northbound side of this segment of roadway from Lenox Park to Deadman Flat was currently being redesigned and reconstructed as a divided highway, and the northbound lanes were to be completed shortly, in the late summer of 2000. On that basis, the TAC proposed a single five mile 3M tape installation, rather than two parallel sections of half that length.

This five-mile segment of US 89 lies at the foot of the San Francisco Peaks on the east side of the mountains. It starts in an open semi-rural park area, fringed by timber, and it climbs quickly onto a high forested ridge that gives access into the Sunset Crater National Monument area. US 89 crosses a divide at 7232 foot elevation, and then drops down a long grade northward to the open valley of the Little Colorado River. This highway leads to the Navajo Nation communities of Gray Mountain and Cameron, and eventually to Lake Powell and the Four Corners region.

This test corridor has numerous parallels with the Kendrick Park test site for the Caltrans plow on US 180. It has a section in forest and two wide open areas at either end. It climbs to run for about a mile at 7300 feet, still less than Kendrick Park's 8000 foot elevation. It is directly across the mountain from Kendrick Park, and it is expected to see similar weather conditions in major storms, although average snowfall is about 10 percent less.

On the other hand, US 89 has about twice the average traffic volume as US 180, and it was being rebuilt as a divided highway. It definitely has a higher volume of commercial vehicles. There are several weather monitoring points in the vicinity, providing a more reliable set of winter storm records than for the US 180 site.

The Sunset Crater test site is somewhat closer to Flagstaff than is the US 180 Caltrans site (Figure 1), and the total road distance between the two is about 30 miles, or a 45 minute drive through Flagstaff. This proximity would enable demonstrations, training, and the comparative evaluation program to proceed more effectively, ideally with personnel being trained at both sites in one day .

V. US 89 TEST LANE – 3M TAPE INSTALLATION

Although the 3M magnetic tape was designed so that it could be laid on surface, grooved below grade, or embedded between pavement layers during construction, only the third option was acceptable to the Flagstaff District. The basic uncertainty of placing tape in the pavement, between layers of asphalt, had already raised durability and bonding concerns. The concept of cutting a groove into the new pavement for the tape was a greater issue, for the tape's exposure to physical damage, as well as for the effect on the permanent roadway surface. And, as for laying the tape directly on the final roadway surface, it was understood that snowplows would quickly destroy the tape unless it was safely buried in the paving process.

The high visibility and traffic volumes of the US 89 project corridor meant that for ADOT, those options that exposed the tape to possible future damage would not be acceptable. The more complex embedment approach certainly added to the challenges of coordination among the tape installers, the paving crews and the ADOT inspectors. However, it minimized the damage issues and enhanced the long-term durability of the installation.

Pre-Installation Planning

As a matter of fact, the history of prior schedule delays and other problems with this roadway paving project soon created so much concern about placing the tape between pavement layers, that a further challenge arose.

Figure 6: Test Installation of 3M Tape at Black Mesa

The ADOT construction forces requested a test of the installation methods, in advance of the critical path activity on US 89. This test would ensure that the asphalt delivery trucks and the pickup / spreader system of the contractor's paving train would not rip the tape from the lower paving course and ball it up on the spreader bars. This was a legitimate concern based on the tight clearances involved, and on the need for precision and care in the paving operation.

Unfortunately, the only viable test site in the region for this effort was on another paving contract, the Red Hill project, located about 100 miles northeast of the research site. This project was located at Black Mesa on US 160 in the ADOT Holbrook District. The Flagstaff and Holbrook construction offices worked together to enable this important test to occur without overly hampering the paving work on US 160. The 3M materials and installation subcontractor personnel were assembled and coordinated, and the tape was laid down on July 18th, and quickly paved over.

As hoped, there was no sign of stray 3M tape in the finished roadway surface. This whole test effort was filmed by ATRC for discussion of the methods with the Flagstaff Construction staff, and from that point, the plan to place five miles of tape on US 89 near Flagstaff moved ahead. The day after the field test, July 19th, 3M shipped 135 rolls of magnetic tape to Flagstaff.

Tape Installation – US 89 Construction Project

As noted above, coordination for the tape installation was critical and depended entirely on the District's Huntington Construction Office in Flagstaff. The Construction team made an excellent effort to coordinate the construction project prime contractors, and ADOT's field inspectors and surveyors, with the research project's new and unexpected group of third parties including 3M, the tape install subcontractor, and the ADOT Research Center. As the enabling construction supplemental agreement was developed, the tape vendors were actually working under contract to the prime contractor for the entire roadway reconstruction and repaving job.

Figure 7: Tape Layout and Adhesive Placement - US 89

The project went fairly smoothly considering that this work was during the rainy season along the Mogollon Rim of Arizona. Also, this paving project was being conducted mainly at night, for several reasons - to reduce impacts to (and from) traffic, to avoid the afternoon thunderstorms, and to pave more effectively in Arizona's summer temperatures. This situation helped the 3M tape installers, the ATRC, and the District surveyors, because their layout and installation work, and the project documentation, could be done in daylight.

The tape installation was done by an Arizona-based striping contractor with 3M staff oversight. The work was done in two phases, based on the needs and limitations of the paving work. The constraints were to install the tape the day before the paving was done, but not to install it too soon so it was exposed to damage by vehicles or other elements if the paving had to be delayed.

The installation of the first 2.2 mile 3M tape segment began on July 25th at Milepost 428.0. The tape was placed up the long grade from Lenox Park, and the day's effort ended at the Sunset Crater turnoff. After the paving of this section was done on July 28th, and after some weather delays, the second phase of 2.8 miles was completed out to MP 433.0, near the foot of the long downhill run into the open plain. The tape was in place by August 6th, and was completely paved over within a few days after that.

Practical Concerns for the Snowplow Research on US 89

A short time after the last of the 3M tape was installed, the northbound lanes of US 89 in the test area were "completed," that is to say, the temporary striping was applied and the construction detour plan shifted all traffic onto the new northbound roadway on August 18th. This freed up the southbound side of the project for full-scale construction from that point on. However, due to many weather delays over the course of the summer, the goal of completing the second half of the new roadway was not possible before winter. Also, because of these various delays, the proposed final ½-inch friction course of asphalt could not be applied.

One result of this program delay was that the temporary striping would now have to serve as the "permanent" lane alignment over the coming winter season, and so this temporary striping that was hurriedly laid down had to be incorporated into the commissioning phase of the ADOT-3M snowplow effort. The impact of this delay was significant on the activities and results of this phase of the research.

The temporary striping in the test area was not at all like the final design for the roadway striping. The northbound roadway of US 89 at this time would carry two-way traffic, and because of the long steep grades at either side of the divide, it also was striped for climbing lanes. Further, a striped divider island and a center turn lane were required at the Sunset Crater turnout. With two-way traffic on this road, the highway shoulders were symmetric, and all this temporary striping was centered in the 38-foot width of the asphalt pavement that overlaid the 3M tape.

Figure 8: Installation of 3M Tape on US 89

The result of the delay was simple, but the significance of these conditions was great. Since the tape had been laid in the final position of the center skip line of the northbound traffic lanes, it ran straight and true, while the striping wandered, by its temporary design, three to four feet away from the tape.

At best, the use of the 3M guidance system in this situation could only be advisory during this initial winter. It would have to be used primarily for orientation and training, rather than in whiteout storms.

Naturally ATRC worked closely with the District and 3M to develop practical plans to employ the system in this constrained circumstance. The measurements taken by ATRC before the road was opened to traffic showed that some segments would be usable in one or the other direction.

From the surveys, offsets were developed for the plow operators to show that the tape could provide dependable position guidance for about one mile northbound and 3.5 miles southbound, as follows:

- **Northbound, Upgrade - MP 428.0 to 429.0 -**
  Tape is in the Passing Lane, 36 inches inside of the Yellow Center Stripe
  (Use Left Sensor)

- **Southbound, Upgrade - MP 433.0 to 431.5 –**
  Tape is in the Passing Lane, 36 inches Left of the Skip Line Stripe
  (Use Right Sensor)

- **Southbound, Level in Forest - MP 431.0 to 429.5 –**
  Tape is in the SB Two-Lane, 48 inches inside of the Yellow Center Stripe
  (Use Left Sensor)

While this was clearly an insufficient basis for a formal evaluation of the system, it was the outcome of weather delays and other circumstances beyond the control of the research program. With special efforts by the primary operators, or Team Leaders, it was feasible to carry out limited orientations and initial training for ADOT volunteer student operators from around the region. The Flagstaff maintenance crews set out snow stakes along the roadway as visual cues for the training phase, to indicate where in the lanes the tape could still be monitored reliably, and where it made the referenced shift as the striping pattern changed over.

During the winter, the Team Leader operators were able to use the system fairly effectively in plowing the roadway, because of the extent of training they had given to others along this route. This topic will be discussed further in a later section of the report.

As a matter of record, the project's final striping on the northbound roadway was not finished until June, 2001, when the other side of the highway was opened to mid-summer southbound traffic. At that time, the measurements with 3M's handheld sensors showed the tape to be an average of one inch or less from the center of the final paint stripe, with a maximum deviation of three inches. Under the circumstances, this was an excellent result that reflects highly on the Flagstaff District survey and construction staff.

VI. CREATING THE ADOT-3M ADVANCED SNOWPLOW

One of the key aspects of developing an ADOT snowplow with advanced driver assistance systems was to conduct a fair and equitable comparison with the prototype Caltrans snowplow system and its suite of driver services. Not all of these components related to the magnet-based lanekeeping driver-assistance functions, nor were all of the Caltrans secondary subsystems as expensive as the primary California guidance technologies. The Caltrans concept integrated the lanekeeping and predictive roadway display with its independent collision warning radar, and it also carried an AVL system for snowplow fleet management.

ADOT's research project TAC was very enthused about all aspects of the Caltrans ASP concept, but they also recognized that the potential for deployment of Automatic Vehicle Location (AVL) or Collision Warning Systems (CWS) in Arizona was just as beneficial, and economically much more feasible. Additionally, the two competing guidance concepts – 3M and Caltrans - needed to be rated on an equal footing overall, to ensure that one did not outscore the other in the operator evaluations due to the merits of the secondary Intelligent Vehicle system features.

ATRC therefore not only involved the ADOT districts successfully with the 3M product team, but they also worked with the vendors of these other technologies to enable the most balanced and fair comparison possible with Caltrans. As a result, those related concepts were also installed on ADOT's own winter maintenance research snowplow, and were evaluated in parallel.

3M Vehicle System Assignment to US 89

When the Sunset Crater test site was selected by the research project TAC, the decision was made to involve another of the District's Maintenance field offices in addition to the Flagstaff Yard, with their extensive Caltrans experience. This approach was meant to take advantage of the level of interest in the program at other regional sites, and to involve more ADOT field personnel in learning the details of the guidance systems and the functional procedures involved.

The Flagstaff District's decision was to assign this new 3M Lane Awareness System to the ADOT Gray Mountain Maintenance facility, which shares the snowplowing duties with the Flagstaff crew for the Sunset Crater segment of US 89. Typically the plowing coverage overlaps slightly between maintenance teams, so that plowing at the limit of a route can be assisted by a second plow if conditions should require it.

Gray Mountain Maintenance Camp is located on US 89 about 20 miles north of the Sunset Crater test area. Eight miles further north, State Route 64 cuts off and climbs westward to the East Rim entrance of Grand Canyon National Park. The Gray Mountain crews plow this roadway, but their main emphasis is on US 89 from the Flagstaff area to the Tuba City junction with US 160. Gray Mountain has equipment barns for the snowplows, but no mechanics are assigned there. All mechanical work on the vehicles is normally done at the District Equipment Shop in Flagstaff.

The vehicle that was selected to be ADOT's winter maintenance research snowplow was Truck Number F342, a 400 horsepower 1999 Mack tandem axle, Model RD688S. This was one of the District's newest and most powerful plow trucks, representing a commitment to upgrade the fleet of older International, White, and Autocar plows. The ADOT Mack vehicles are equipped with Monroe 11- foot nose plows and wing plows, and sanders.

Gray Mountain crews had been involved in the Phase One magnet installation work at Kendrick Park over the past two seasons, and had trained with the Caltrans systems. Therefore, the local operators were knowledgeable and enthusiastic when challenged to take on the role of snowplow trainer-operators, or Team Leaders, for the ADOT – 3M advanced snowplow at the Sunset Crater project evaluation site.

3M Vehicle System Installation – US 89 Test Program

The ATRC received complete support from the 3M product engineering team with the vehicle installation activities. The 3M engineers made a preliminary visit to Gray Mountain and to Flagstaff on August 2nd to meet key operations and equipment services staff, to inspect the snowplow first-hand, and to discuss how ADOT normally operated these plow trucks.

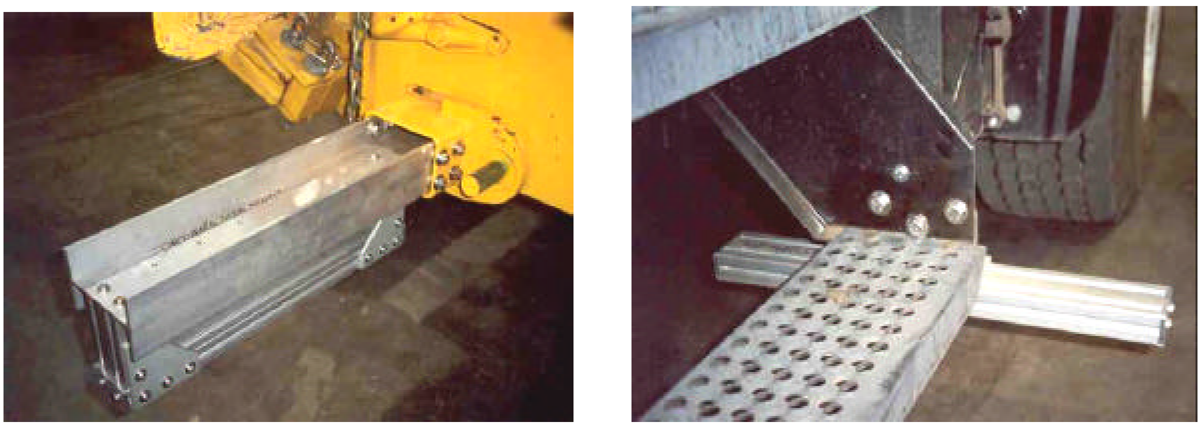


Figure 9: Left Side and Right Side 3M Sensor Bar Mounts

Agreements were quickly reached on how the 3M sensor units would be mounted on the truck's undercarriage, and how the cabling and interior components would be installed. As a result of this visit, the 3M research team was able to design and fabricate permanent mounting hardware and semi-custom adapters so that the system would not interfere with, or be imperiled by, the normal operation of F342 – in winter or summer. To do so, the sensor bars would be mounted asymmetrically, on the left front bumper and the right side cab step, at 11.5 inches clear height. These units, as well as the several warning systems and new driver's seat, were shipped to Flagstaff in advance so that the hardware installation could begin.

The actual installation and commissioning of the 3M Lane Awareness System on F342 was a very successful activity. The 3M engineers came to Flagstaff on September 26-27, and carried out the installation and calibration with the help of ADOT's Flagstaff Equipment Services Shop.

The initial test runs were done with rolls of temporary tape laid on the edge line and center line of the concrete pavement of old US 66, which still runs directly south of ADOT's Flagstaff Yard. After the initial tests, the snowplow was taken out to US 89 and it was run on the Sunset Crater test segment until the calibrations, checks and operator orientations were completed. At this time, the Team Leader operators received their first training sessions on use of the 3M equipment, and on proper interpretation of the display information.

The system was installed with several different operator warning interfaces. In addition to simple and clear graphics on the operator's display screen, the system provided visual or vibratory warning options. The drivers could switch their secondary warning between small peripheral vision lights and directional seat vibrators. Either warning would activate whenever the truck drifted off of its proper alignment over the 3M tape line. Reactions to these warnings were basically intuitive, both to steer away from the stimulus and to quickly scan the display screen for specific guidance.

The 3M display screen was mounted on the dashboard, with the radio and spreader controls. This put the unit just below the driver's line of sight to the right side mirror, as requested by the Gray Mountain plow operators. The two peripheral warning lights also were mounted below eye level, about 4 inches above the dash. The systems control junction box was installed behind the driver's seat.

Figure 10: Temporary 3M Tape on Old Route 66 for Commissioning System

For all practical purposes, the 3M truck system installation was complete as of September 27th. The Team Leaders were given sufficient training time out on the test lane, as well as calibration and trouble-shooting guidelines, to initiate field use of the system at any time.

Further 3M Marketing Participation in Arizona

While the installations were completed in late September, there was no likely necessity to plow the highway before late October or even mid-November. ADOT conducted limited internal training with the Team Leaders for Flagstaff and Gray Mountain but for the most part had other uses and activities for the F342 snowplow during this time.

One significant exception was an invitation in early November, 2000, to participate in a winter maintenance conference organized by ADOT's LTAP, the Local Technology Assistance Program. This annual conference in Pinetop, Arizona, was an opportunity for ATRC and ADOT, as well as 3M, to communicate with the local and regional entities supported by the LTAP program with regard to the state's efforts to be more innovative and effective in the winter maintenance arena.

The Flagstaff District released the F342 snowplow and its primary Team Leader operator for the trip to eastern Arizona, and both the ATRC and the ITS Group from 3M were on the conference agenda. As had been done earlier at the State Capitol, the 3M team provided extra magnetic tape so that ADOT could give brief demonstrations to the local agency operators in the parking lot of the convention center in Pinetop. This program was a success, with about 40 visitors inspecting the snowplow and with numerous test rides taken.

From this point forward, the ADOT-3M snowplow was considered operational. As early winter storms occurred in late November, the Team Leader operators became familiar with the system and were able to develop a level of confidence in its performance. Although the striping was not in the desired location, the 3M system was giving consistent and effective position signals to the operators in the segments of the test lane where the buried tape was laterally within range of one of the two sensor bars. The first plowing with the 3M equipment in the Sunset Crater test area took place during storms on the nights of both November 10th and 11th .

Figure 11: 3M Operator Display Screen in ADOT Plow F342

The ATRC-3M partnership, and ADOT's trial field deployment, suffered a major unexpected setback on December 21, 2000. On that date, 3M announced that they would discontinue the development and commercialization of the Lane Awareness System. Nationally, only a few customers had made the commitment to the magnetic tape concept, and in some cases, with only a single testing or research site. While unable to develop the market for this IV product to the point of viability, 3M did firmly commit to provide its customers such as Arizona, Michigan, and Minnesota with full technical support and product services, including the warranties on all system elements.

It should be noted that since that milestone date, there has been consistent, valuable ongoing support from 3M on request by ADOT, including components, repairs, technical advice and new products. Also, 3M did commit to completing its evaluation contracts with the University of Iowa, which included significant work with surveys of ADOT snowplow operators.

In early 2001, the research project's TAC agreed to buy four rolls (800 feet) of tape for future IVI demonstration opportunities with the Gray Mountain snowplow, F342. However, the hope of completing US 89 on the southbound side near Sunset Crater fell by the wayside. It was clearly desirable to develop both sides of the roadway with 3M tape, but the ongoing construction project suffered further setbacks in early 2001. The District thus lost the flexibility to apply any further contingency funds to applications of the Lane Awareness system, and so was unable to do any more.

Regardless of these setbacks to the program, ADOT nonetheless had achieved its snowplow research goal, with the creation of a second test lane in Arizona, for a commercially-developed system that in many ways had both inspired and competed directly with the Caltrans concept. Although taken off the market, the 3M technology was fully functional, and state-of-the-art, and it provided an invaluable baseline for ADOT to further evaluate the evolving California system and to support future decisions. Northern Arizona at this time was the only fully operational test area in the country with both major infrastructure systems installed in practical quantities, and in regular use for winter storm operations and research.

Eaton VORAD Vehicle System Installation – US 89 Test Corridor

Arizona's fleet of some 240 snowplows represents a major cost obligation for a state that is more than half desert in terrain and climate, and with nearly 90 percent of its population in desert areas. Therefore, ADOT has practical and perceptual limits on spending to augment the capabilities of its specialized winter maintenance equipment. The point of balance between cost, and improved safety and efficiency, is never completely clear. However, ADOT clearly has a strong incentive to consider ITS components for its fleet that would need no permanent infrastructure and may add only a few percent to the vehicle's total cost.

As noted before, the goal of the ADOT Advanced Snowplow effort was to develop a snowplow on the eastern (3M) side of the San Francisco Peaks that would be directly comparable to the Caltrans equipment on US 180 to the west. This meant, for example, that a collision warning radar system (CWS) was needed for F342. It should be noted that this component was generally of more interest, and perceived value, to the various ADOT plow operators for heavy storm activity than even the California advanced predictive guidance system.

After some exploratory contacts and consultations, the ATRC negotiated to procure an Eaton VORAD EVT-300 radar system for F342. The EVT-300 was also a component of the system on the Caltrans ASP vehicles, and was integrated into that display. While ADOT did not intended it to be integrated with the 3M system, this stand-alone commercial radar technology would provide a robust, reliable and proven warning system. ADOT could evaluate it not only in the worst winter storms, but in its normal highway operations year-round.

This collision warning system could apply not only to snowplows, if successful, but also to all other heavy trucks in the ADOT fleet. On this basis, the ATRC negotiated for not only the forward-looking EVT-300 system and blind-side radar, but also an adaptive cruise control , the SmartCruise System.

Because of its commercialized status, the Eaton VORAD system was a relatively simple procurement. It was readily justified since it was also a Caltrans component, based on the need for ADOT-ATRC to evaluate matching advanced snowplow systems. Overall, the radar componentry for plow F342 was priced at less than $4,000, and this evaluation offered a great deal of safety potential to ADOT.

This installation was a parallel effort with the 3M guidance system, and Eaton VORAD was able to deliver the radar system and support the installation on November 8th. The radar processor components were installed inside the truck cab, and the antenna locations were adapted to the snowplow design. The side blind-spot radar antenna had to be adjusted to clear the wing plow, while the main radar antenna was installed on a warning-light bar nine feet high on the truck roof. The SmartCruise feature, however, had to be mounted at bumper height. This component was therefore deferred until after the winter, when the plow blade would be removed.

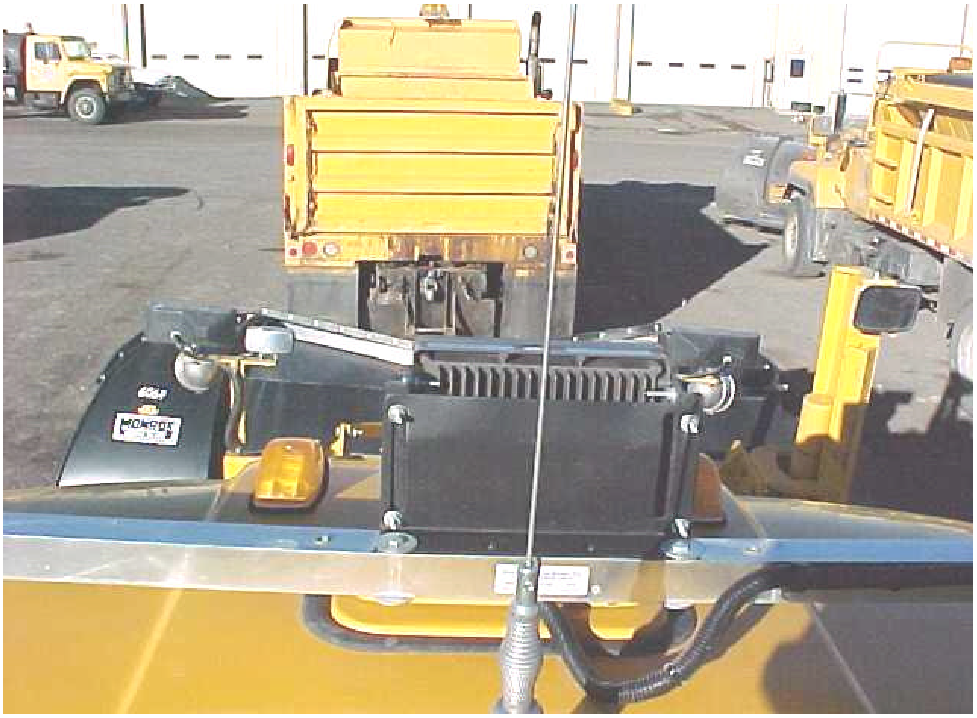


Figure 12: Rear View of EVT-300 Installed On Rooftop Mounting Bar

The EVT-300 warning radar antenna was designed for bumper mounting, but in a variety of snowplow examples it had to be mounted higher, for example on the plow headframe or the radiator grille. The ADOT trucks use a large snowplow blade that rises 5'-8" above the roadway when not plowing. That blade limits visibility in front of the truck, so the shop crew and Eaton VORAD personnel set up F342 with the roof mount. The measurements for this mounting showed that the main antenna was able to "see" the roadway about 28 feet ahead of the blade, while the antenna's effective range is about 350 feet. Afterwards, the system was electronically calibrated and road tested, and the Eaton factory technician turned it back to ADOT, with all systems described as functioning very well.

Eaton VORAD Complications

The installation of the EVT-300 system went smoothly, and the results were satisfactory to those involved. However, two related and unexpected issues soon arose. As noted earlier, ADOT's F342 snowplow was driven to the LTAP winter maintenance conference in Pinetop on November 8th, for the presentation and demonstration to the local stakeholders from around Arizona. The radar functioned as expected on the trip but on the morning of the demonstration, it failed to self-test on startup. On the same day, Eaton VORAD asked that ADOT accept a waiver of liability for their collision warning radar system.

These two new developments were inextricably linked, in that the vendor would not repair the failed unit without the waiver of liability. This new requirement resulted from discussions of the roof mounting by the Eaton installer and system engineers. The unit was basically designed to interpret horizontal radar echoes at bumper level and to give the appropriate warnings. The rooftop mount was beyond the antenna's proven design window for response, and this caused concerns about signal quality, computations and reliable system performance.

The situation for ADOT was also complex, as the State is self-insured and is legally barred from any such "hold harmless" agreements. A series of meetings and internal consultations did little to solve the problem, although options discussed included various compromise language efforts, specific testing condition limits, modification of the plow blade, or the use of an evaluation loan agreement instead of the original system purchase. ADOT submitted a specific compromise plan in December, but in late February it was finally agreed by both parties to step away from the agreement. ADOT agreed to support the removal of the equipment by the vendor.

The ATRC pursued other possible collision warning systems but with little success at that time. In early 2001, there did not seem to be a great deal of other vendor interest in Arizona's potential market for such systems, and many of those were still in the research and development phase. By the time that this issue had played out, the winter was nearing its end. The ADOT training and testing program with snowplow F342 continued with the radar system inoperable.

GreyLink Vehicle System Installation – US 89 Test Corridor

As with any transportation agency, improved efficiency and operator safety are ADOT's primary goals for adding the expense of new ITS systems. An Automatic Vehicle Location (AVL) system was the other key technology that was needed to enable direct comparisons by ADOT with the Caltrans RoadView snowplow program.

Here again, the precedent set by California with their prototype snowplows gave ATRC the logical direction for a test system procurement. In prior winters, Caltrans had equipped its research snowplow, and other fleet units, with the GreyLink 1000 AVL system developed by Greystone Consultants, and provided regionally by Logistixx Fleet Sales. The GreyLink system had shown excellent results for Caltrans, in tracking their ASP vehicle both on its travels to Arizona and during the testing on US 180. ADOT had been loaned demo software and already had been tracking the California plow in the previous winter, using the Caltrans cell phone link.

GreyLink was therefore the obvious choice for training the ADOT Snow Desk staff in Flagstaff, and to maintain compatibility with Caltrans during ongoing and future plow tests in Arizona. It was important for ADOT's research program to proceed in this direction for several reasons:

- A local cell phone number would limit the download call costs to a practical level.
- Analog cellular provided better backup communication than digital in the Flagstaff area.
- A cell phone link was needed for safety to back up ADOT radios in known "dead spots."
- This system was one of the less costly systems per vehicle and per workstation.

For ADOT management at the District level, AVL systems were of great interest. These systems offer managers the ability to identify, track, and contact their local or regional fleet of snowplows in real time, and to dispatch the plows to where they are most needed. AVL offers major safety benefits to the operators and to the traveling public as well. It can flag vehicles that are not moving, and query the status of the driver on the route. Additionally, some AVL systems can monitor key operating factors including engine performance, materials usage, blade position and other performance indicators. This ability to track one or all of the plows through a major storm, and to recreate and learn from that storm event, is very attractive to local and regional managers.

AVL systems, based on GPS satellite location technology, differ in complexity and in effectiveness of communications. A variety of analog and digital methods including satellite phone, pager, cellular, and radio are available. As noted above, the GreyLink system employs analog communication, which was a good match for ADOT to carry out its initial evaluation of the larger AVL concept both for operator safety and for fleet management purposes.

The AVL approach requested by ADOT was to test two mobile units, with a workstation at the Flagstaff District Snow Desk. The project would equip Gray Mountain's F342 with a basic hard-wired installation, and purchase a second portable unit to be moved between other vehicles for evaluation purposes throughout the year. The portable AVL could also be placed in the Caltrans snowplow to avoid the cost of frequent dial-up queries to the California phone number.

AVL System Acquisition

As with the other key ITS components of the ADOT Advanced Snowplow, the AVL system was negotiated into procurement in the Fall of 2000. With the base station software priced at $1,995, and each mobile unit costing $995, the GreyLink system was an attractive package for a first-time evaluation by ADOT district forces and ATRC. The total cost to the project for two units was about $7,000 for the first winter including installation, extra components, software maintenance and two local analog cell phones. The systems were purchased and installed in early November.

In this first winter, the AVL system was reasonably successful. GreyLink/Logistixx has always been prompt and supportive with their training, troubleshooting and software upgrades, and with modification support to deal with communication problems. However, the snowplow application was a relatively new market for GreyLink, and to learn about and effectively train and support ADOT's real winter maintenance needs took some time and mutual effort. The basic training materials, in that regard, were not completely sufficient.

The GreyLink system in general was hampered in its first ADOT season by some minor problems which limited its reporting consistency. To successfully evaluate the AVL system, much of the responsibility lay with ADOT to provide the proper technical conditions, and to follow through on efforts begun. The AVL system preferred a dedicated computer workstation and it demanded dedicated phone lines. These parameters had a significant effect in the first winter, as ADOT could not maintain those conditions. Combined with spotty cellular service and very heavy caller traffic, especially during storms, it became more difficult for the Flagstaff Snow Desk personnel to get peak system performance. Additionally, very limited ADOT staff resources meant that plow tracking record requests and followup on problems was not always consistent during storm events when the data was needed.

Nonetheless, the GreyLink AVL system in its first year of evaluation was a functional ITS tool that did provide ADOT with the information that was requested, although hampered by cellular service, phone hardware problems and other issues. GreyLink/Logistixx provided responsive support and upgrades through the winter, and committed to further training late in the season. As described earlier, AVL was the third critical ITS component in the ADOT advanced snowplow research program.

VII. US 89 - 3M SYSTEM TRAINING AND OPERATIONS

The ADOT–3M Advanced Snowplow research program offered key new opportunities as planned for the initial winter of 2000-2001, and, it also faced some major challenges. Arizona was successful with its ambitious goal of creating a second independent test lane, and equipping an ADOT snowplow with a full set of IV technologies. This achievement would enable direct comparisons with, and more critical evaluations of, the prototype Caltrans system as well as the individual ITS components. Just as importantly, the advanced snowplow systems on F342 would be fully operational in all storms on US 89 for the entire winter of 2000-2001.

However, there were major shortcomings in the system that could not be rectified during this third winter of the research project. As described above, the collision warning radar system had failed and no repairs could be done because of the issue of the evaluation agreement language. Even more significant was the delay in construction that had left the northbound lanes of US 89 with temporary striping and two-way traffic for the entire winter. Under these constraints, however, ADOT efforts still went ahead to make the most of the first year's operations, training and evaluation program.

Operational Evaluations

The two goals of the ADOT-3M evaluation program were to conduct a full winter of normal snowplowing operations using the IV systems, and at the same time to support the training and evaluation efforts of the research project. The overall time window for this program was from November 2000 through March 2001.

The system installation and initial training by 3M were completed in September and October. The other IV components were also in place by early November, and the US 89 site construction program had been shut down for the winter in mid-November as early storms began to cycle through the area. In December, Flagstaff Maintenance installed snow stakes along the test lane to identify the site limits, and the crossover points where the striping and the buried tape would change orientation.

The Team Leader operators from Gray Mountain continued with self-training and familiarization, in an effort to gain complete confidence in the performance and behavior of each new ITS system in poor visibility. This early-winter phase was intended to establish a baseline by initially using the systems in an advisory manner, before any training of other plow operators might take place. As occasional storms occurred, the Team Leaders plowed the Sunset Crater route normally with F342, while observing the performance of the systems in various weather and traffic conditions.

To document the conditions and the performance of the various advanced snowplow systems, there were a variety of ADOT report forms that the plow operators maintain to record usage of each vehicle. Basically, the operator for each plow maintains a running vehicle mileage record, as well as a daily equipment inspection and safety condition logbook. However, this was very basic and often cryptic information. The ATRC also developed Team Leader activity reports for both project test sites.

These activity reports were designed to collect as much information as possible on conditions and activities during those times that the ASP systems were in use. The key activities, of course, were plowing and training. Onerous paperwork requirements already faced the ADOT plow operators at the end of their 12-hour storm shifts. A heavy burden was placed on the ATRC to capture all of the critical research information without driver protests or refusals. The activity report form was set up to allow most of the responses to be either circled or checked off, and only in cases of equipment problems would more detailed descriptive feedback be requested. Overall, this effort was successful, and the combined ADOT and ATRC report forms produced a good history of the times that the research snowplows were deployed for significant plowing or training activities.

Stand-alone ITS Systems

The initial year of evaluation for the ADOT-3M Advanced Snowplow was subject to many setbacks. Among these, clearly, the inability to repair the Eaton-VORAD collision warning system for effective use during plowing was a significant problem. This failure also impacted the project's plan to test the Eaton SmartCruise feature later, since it could not be installed as long as the plow blade was mounted on the truck. Despite the issues, ADOT kept this key ITS system in place, in hope of a future solution.

The GreyLink AVL system was also being tested by the Flagstaff Snow Desk, although there were concerns about the limited supporting materials for training and reference. The goals of ADOT's snowplow operations were to locate the snowplow at any time, to contact it for location records and for voice communication, and to retrieve the vehicle's movements on the plow route during storms. The stated emphasis was on improving operator safety, and on enhanced plow fleet management.

A variety of problems affected the success of the GreyLink AVL evaluation, as noted in the previous section. The issues were compounded because the responsibility lay with several different parties, and no single factor blocked the system from functioning as intended. From ADOT's perspective, the use of a dedicated computer, phone line and modem were recommended but were not established due to budgetary and space issues. Further ADOT problems included adequate staffing and focused training for this operational role, and coordination with internal technical support. GreyLink made numerous contacts and support efforts to improve performance, but communications were not always clear.

The largest uncertainty, however, was with the analog cellular service network. There were no viable alternatives to cellular for Flagstaff, where even ADOT's radios often encounter terrain dead zones around the mountain peaks.

The two snowplow test sites, and the entire area, had very spotty cellular signal coverage. The ATRC used vehicles with cellular phones from two different local service providers to measure signal strength along the two snowplow routes. Both carriers were found to have different blind spots at critical locations, and in some spots like Sunset Crater, neither system could get a signal. Also, the sheer volume of cellular call traffic in Flagstaff at peak hours was found to defeat the automatic dial-up settings for the AVL software.

As time passed, GreyLink / Logistixx consistently worked to improve the training and to refine the AVL software. ADOT's efforts could not totally overcome some of the staffing problems and equipment concerns, nor could the cellular service problems be fixed except by avoiding the peak periods with the calls for system records.

During this first winter, the Flagstaff District Snow Desk staff were basically able to run the AVL system, locate the research plows, and recover route maps and records. However, they were not able to build a consistent database over time that would support District management's goal of recreating the history of maintenance activity during a major winter storm.

ADOT-3M Snowplow Results – US 89 - The First Winter

ADOT-3M research snowplow F342 was used operationally on US 89 in the Sunset Crater area for the entire 2000-2001 winter. This snowplow logged over 7,000 miles over the winter, and more than 1000 miles of plowing on the 22 mile Sunset Crater route between Flagstaff and Antelope Hills.

During this period, significant snow events in the Flagstaff District between October 28 and April 11 resulted in driver callouts and snowplow deployments on at least thirteen days when four inches or more of snow fell – with a high mark of 16 inches on Valentine's Day, 2001.

Of the storm activity reports received for plowing and sanding shifts on US 89, the ADOT-3M plow was used roughly 25 percent of the time on night shift (all storm plowing shifts are 12 hours long). Conditions on the higher elevations of this route varied from slush to snowpack, and generally with strong winds reported.

Figure 13: ADOT Advanced Snowplow F342 On US 89 Northbound

On the average, F342 ran 333 miles during each callout shift on US 89, with mileage logs ranging from 261 to 404 miles per shift. It should be noted that due to the construction project, the traffic was still two-way on the critical Sunset Crater section of this plow route, and the striping did not correctly match with the embedded 3M tape. Nevertheless, using the roadside reference markers and the 3M system as an advisory tool, the plow operators reported that the system was effective in low visibility and blowing snow. They also noted that the vibrating seat was effective and did not require them to frequently look away from the road at the display screen.

The only drawback identified for the 3M system, from the operators' perspective, was that it shows the plow's lane position but it is not predictive of the road ahead. Some ADOT drivers had prior experience with the Caltrans predictive system, and references to that more powerful and costly second-generation concept were to be expected. Similarly, several ADOT operators suggested that Caltrans really should install one of the 3M system's vibrating seats.

3M Winter Training Program – US 89 – Sunset Crater

The 2000-2001 research plan developed by the TAC and ATRC for the 3M plow systems called for both an early and a late phase of training. As described above, the Team Leader operators received 3M staff training in September, and they then transitioned to familiarization and self-training in the early part of the season.

The next phase on US 89, in December and January, was organized so that drivers from maintenance teams all across northern Arizona could come to Flagstaff for an introduction to the ADOT-3M advanced snowplow. Because of the system limitations in this season, it was not practical to try to coordinate 3M training with the Caltrans phase of the project in February. Having two separate time windows for the training at the two sites allowed more flexibility for the participating maintenance sections, and it allowed the research effort to be concentrated fully on each ASP system in turn. This allowed the trainees to concentrate their focus on each system individually, but on the other hand, it also meant that there was less consistency for their comparisons of the two systems.

Figure 14: The ADOT-3M Advanced Snowplow F342

This training approach had been the basis of the research program since its first winter with Caltrans. It allowed the three northern Arizona districts that made up the core of the research TAC group to send two or three operators from each of several sub-district yards for orientation and training on the various new ITS systems. These drivers, both experienced and novice, made up an excellent cross-section for the evaluation based on the diversity of their experience, age, training, equipment, local terrain and conditions, and also their receptiveness to new technology.

As detailed in previous project reports, the operator trainees from the outlying Districts and Orgs were scheduled in by twos and threes, to meet one of the Team Leader operators at the test site. While weather, shift work, staffing levels, communications, and operational issues made it difficult to schedule the training effectively, this effort was a success overall. For the 3M plow training on US 89, the holiday season and storm events led to sporadic training sessions that continued for a month after the planned time window. This did produce a larger database of information, but it was less consistent as a result of subtle changes in training over time.

The operator trainees from the three Districts were asked to fill out a simple survey at the end of their orientation and training sessions. The survey asked about each driver's experience level, and it asked for a satisfaction rating, on a 10-to-1 scale, with various elements of each IV system on the research snowplow. The research program started winter training on the 3M plow systems in November. The ATRC had to develop a standard survey for both the 3M and Caltrans systems, so that the trainee responses would be relatively consistent for future evaluation.

This ATRC survey was based on the format used by Caltrans from earlier years, with added sections for the new types of equipment installed on F342.   While it was relevant to the Caltrans ASP, it still created confusion with some of the student operators because of the "missing" elements between the two snowplows.   However, neither 3M nor Caltrans had developed specific day-of-training operator questionnaires, and so the ATRC surveys were used for the 2000-2001evaluations.

Training Records – The ADOT-3M Advanced Snowplow

The surveys developed by ATRC were reviewed and summarized by this project's evaluation team from Northern Arizona University (see Appendix C). Meanwhile, the 3M evaluation program involved a research team from the University of Iowa, who delivered and then analyzed the post-season surveys that were sent out to all of the ADOT trainees on F342.

As noted previously, some of the Team Leaders on ADOT plow F342 initially received their first-level training directly from the 3M technical staff in September 2000. From that point on, the records show that they carried out internal self-training among their own group in December and January. The regional operator pool training took place primarily in late January, involving students from Holbrook, Winslow, Flagstaff, Kingman and Seligman as well as one operator-in-training from Yuma.

There were a total of 11 ADOT student operators who drove F342 on four dates, and who filled out the day-of-training surveys. All of them received their orientation and training from just two of the Team Leaders, who were the two operators from Gray Mountain who normally plowed the Sunset Crater route on US 89. None of these trainees drove the research plow at a time when snow was on the roadway.

The most noteworthy results of Arizona's first-year plow operator training on the 3M system are summarized in the next section of this report. The complete report by Northern Arizona University is included for reference as Appendix C.

VIII. ADOT - 3M PROGRAM RESULTS – WINTER 2000-2001

In general, the results of the first season of snowplow tests with the ADOT-3M system are not a valid basis for agency decision making, and yet, a great deal was learned about both the system's potential, and its merits relative to the Caltrans system.

Analytical Research Efforts

There were actually three distinct programs to glean information from the 3M-based snowplow training and operational use during winter storms in 2000-2001. Each of these efforts was contracted with neutral third parties in order to develop the most consistent and unbiased results possible from the information collected over the winter. Each of the three evaluation activities was guided by the system owners, ADOT and 3M, but was performed by universities.

Before the Lane Awareness System was taken off the market 3M had contracted with the University of Iowa to track the usability of their system at the three test sites in Minnesota, Michigan, and Arizona. With regard to the Arizona program, 3M's intent was that U-Iowa would develop the surveys to be distributed by the ATRC, and U-Iowa would ultimately analyze and interpret the responses. This analysis would provide results based on the Arizona deployment that would be valid for comparison with other applications of the 3M Lane Awareness system.

The University provided two separate detailed surveys for ADOT snowplow operators. The first was a detailed baseline questionnaire on the state's winter maintenance practices including training, equipment, operations, and weather factors. This survey was generic to most state DOTs, but U-Iowa also developed a special new supplement to this survey that focused on plowing in mountainous conditions. As noted before, the 3M effort did not include day-of-training evaluations, but a second, detailed post-season survey was provided for ADOT in support of this research. Both the pre-season and post-season survey efforts by Iowa were funded by 3M as part of their program to better interpret the potential market for these ITS systems.

As noted previously, ATRC also developed one standard ADOT operator survey for both the 3M and Caltrans advanced snowplow systems, to capture the driver reactions, comments and suggestions and to gauge satisfaction with each component. The completed day-of-training surveys were provided by ATRC to ADOT's evaluation contractor, Northern Arizona University, and they were also given to the U-Iowa team for reference.

One other key project survey was conducted by Northern Arizona University for ATRC, which explored attitudes and knowledge about both Advanced Snowplow concepts among maintenance supervisors and managers from the rural districts up to the highest departmental levels of ADOT.

All of the university-based evaluation results provided to ADOT are discussed in Part Three of this volume, and the Northern Arizona University report on the evaluations is included as Appendix C.

Operational Results With The 3M System

As stated earlier, ADOT achieved its basic goal of deploying an advanced vehicle guidance system for long-term evaluation in Arizona in 2000-2001. The project overcame many obstacles to install ten lane-miles of 3M's state-of-the-art magnetic tape on a heavily traveled highway with severe winter weather conditions. ADOT also installed the 3M vehicle lane-awareness system equipment on a new Mack snowplow assigned to that critical section of US 89. The plow operators received all needed training, and their truck was also equipped with commercial radar and vehicle tracking systems.

Even the weather cooperated, bringing a series of frequent storms to the Flagstaff area that resulted in a total snowfall that was significantly above the long-term average.

The operational results can be interpreted in different ways, but snowplow F342 was certainly both operational and effective on US 89 through this winter. There were no major difficulties or failures with the 3M lane awareness system. The radar was never operational, and many factors constrained the full function of the AVL system. The failures that impacted the program in its initial year were related to insufficient resources and uncompleted tasks, in many cases those of ADOT. The failures to complete the US 89 reconstruction, or to reach a legal compromise on liabilities, or to dedicate more resources to the tracking system, all reveal limits to ADOT's abilities or control in these areas.

More specifically, the operational assessment of the ADOT-3M program in this first winter of the expanded research program has to come from the stakeholders, including the District partners, the Technical Advisory Committee, and the Team Leader operators. In TAC meeting discussions and in the storm activity reports, the comments were frequently positive and even enthusiastic.

Although the disappointment over this system's removal from the market was very obvious, the ability of 3M to honor warranties and the commitment to provide technical support in the future made a strong positive impression. ADOT's impression of the system overall, and its potential to improve performance and enhance safety, is best expressed by Flagstaff District correspondence with ATRC and 3M from early 2001. At that time, as the reconstruction of southbound US 89 was resumed after the winter shutdown, the District made inquiries about the cost and viability of purchasing five more miles of 3M magnetic tape.

The ATRC pursued various pricing options with 3M, who could produce new tape material for any firm order from an existing client. The costs to ADOT would be approximately the same as the first five miles of tape purchased. A second truck system was also considered. With ATRC support, the District considered a variety of factors including the benefits for this specific Sunset Crater site, the operators' perspectives, and the expected life of the tape, the hardware, and the roadway itself.

This second tape line could have provided full lanekeeping abilities for F342 and perhaps a second ADOT snowplow to operate in both directions over the pass on US 89 at Sunset Crater. Although the discussions with 3M appeared to be quite positive, the ADOT inquiry finally was dropped due mainly to unrelated problems in finishing that US 89 construction project, and to the related lack of remaining contingency funding.

Nonetheless, the TAC and ATRC agreed to operate and test the ADOT-3M plow on US 89 for the foreseeable future, as long as 3M can provide their support commitment to their clients. Also, the TAC directed ATRC to procure 800 feet of 3M magnetic tape to conduct other tests, workshops, or conference demonstrations of this successful technology in the future, as opportunities arise.

PART TWO:

ARIZONA – CALIFORNIA SNOWPLOW RESEARCH

IX. KENDRICK PARK – THE US 180 TEST SITE

Throughout 2000, as the ATRC developed its plans for the newly-expanded winter program of advanced snowplow technology training and evaluation on two highways on opposite sides of the San Francisco Peaks, the early emphasis was primarily on completing the procurement and installation of the 3M magnetic tape-based lane awareness system.

Nonetheless, as the ADOT research project entered its third winter season, there were numerous reminders of the long partnership and shared obligations with Caltrans, the California Department of Transportation, and their extensive research and development team.

The initial sections of this report describe in detail the background of the ADOT research partnership with Caltrans, and the roles of the key agencies and universities on the team. It is only necessary in this section to review the highlights of the system concepts, and pertinent details of the Phase One ADOT effort to create the Kendrick Park test site on US 180 northwest of Flagstaff.

The Caltrans ASP Concept

The Advanced Snowplow system was developed by the Caltrans/AHMCT/PATH consortium, with the lateral guidance concept derived from technology originally developed by PATH for vehicle control and Automated Highway Systems. The Caltrans snowplow research effort evolved by 1999 into the RoadView program, with two additional operational ASP units deployed in northern California.

The ASP system tracks, with suspended sensor arrays, a continuous line of embedded magnets in the roadway. As detailed in the ATRC Phase One report, the magnets themselves are 7/8 inch diameter and one inch in height. They are installed in sets of four, in holes drilled in the pavement at 47-1/4 inch intervals (1.20 meters). To provide a constant signal strength, the magnets must be consistently placed on the lane centerline of the roadway with very demanding transverse (3/8 inch) and vertical (1/4 inch) tolerances. These requirements meant that accurate survey support was very important to this ADOT project.

The magnets are installed with a unique binary polarity coding for each control section of the test lane. Each 204 meter section of 170 magnet points begins with 16 magnets coded in plus-minus orientation, as designed by the California PATH contractor for Caltrans. This coding identifies each roadway segment and allows the on-board snowplow system to know its exact location along the roadway, and what geometrics and references are ahead in the next 204 meters (670 ft). In this way, the Caltrans ASP system offers a predictive display on the in-cab screen, to allow the snowplow operator to keep moving in situations of nearly zero visibility.

Kendrick Park Magnet Infrastructure

In 1998, the ADOT-Caltrans test site was established for the first winter when maintenance crews put in four miles of magnets on US 180. One year later, magnets were installed for two more miles to complete a two-way vehicle research course, three miles long in each direction. This Caltrans test area begins at northbound Milepost 235, in a forested section near Hart Prairie Road, then it crosses for one mile across open windswept Kendrick Park, the worst area for drifting and for zero visibility plowing conditions. Continuing north, the test lane climbs a ridge and then twists down an 8 percent grade to MP 238, where the plow turns around for its southbound run.

Prior to the phased decisions to install the 8000-plus magnets at Kendrick Park on US 180, there were many concerns that the drilling for the magnets would damage the roadway surface or the subgrade.

ADOT initially conducted long-term tests along the I-40 corridor, where 12 to 16 magnets were installed into the lane centerline at six locations from Seligman to Holbrook.

These tests identified the most practical methods, materials and equipment for the larger program of creating a dedicated test lane. The six sites were monitored periodically by ATRC and by the local maintenance crews to observe the performance of the sealants and the magnets, and any effects on the asphalt pavement of this heavily traveled Interstate highway.

Based on the information gained from this initial process evaluation phase, the initial four miles of magnet installation were completed on US 180 at Kendrick Park in late 1998. ADOT's three northern Districts provided volunteer crews to provide survey control, to man the four electric core drills, to set and seal the magnets, and to do traffic control. The project was expanded in the second year (1999) to six miles total, with a similarly complex joint district effort.

It is worth noting that while the US 180 pavement was actually less thick in most areas than the drilled holes are deep, there were very few observed problems with the asphalt material during installation. Some holes as surveyed fell in areas of significant cracking, but the use of rotary core drills reduced stresses and did not create any new cracking or spalling of the holes. Many of the holes went through the pavement into the subgrade, so durability will be a concern over time with this old roadway.

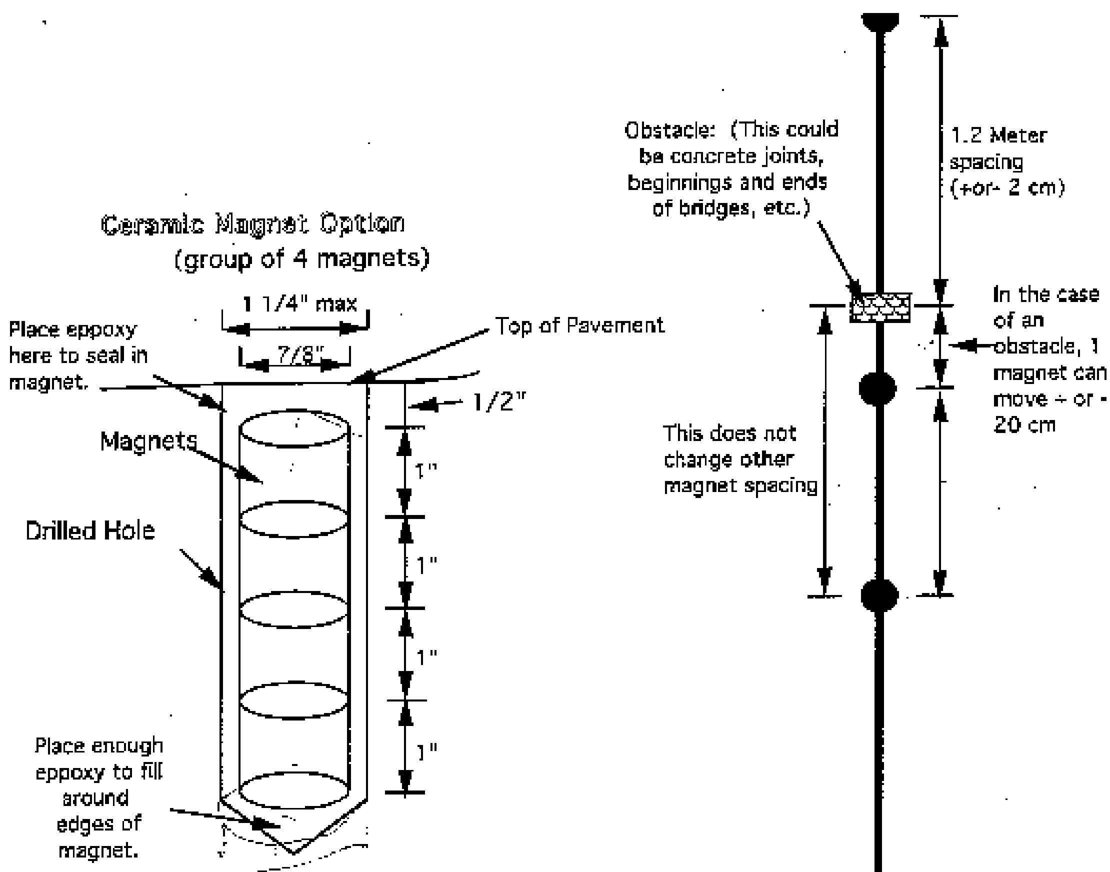


Figure 15: Magnet Installation Requirements [graphic courtesy of Caltrans]

Overall, the project's Caltrans magnets have now proven to be stable and inert in the roadway through three winters. Inspections each Fall have only found between 10 and 20 magnet points that need to be reeset and resealed before the Caltrans RoadView testing cycle can begin. While the sealant caps may sometimes come out, only a few holes have ever lost one or more of their embedded magnets. ADOT maintenance crews continue to inspect the site periodically.

Costs – Caltrans Magnets

The ADOT-Caltrans magnet installation was reported in detail in this project's Phase One report, published by the ATRC in February 2001. The results are discussed briefly here in reference to the new installation of 3M magnetic tape on US 89.

ADOT volunteer crews from as many as ten maintenance Orgs in three Districts cooperated on the two ATRC-led magnet installation projects in 1998 and 1999. Over these two seasons, the two projects installed 8,037 magnets by hand at an overall average rate of 382 per day, in 21 ten-hour work shifts, not including weather delays and start-up problems.

The magnet installation operation ran four electric drills and normally required a 14-man crew. The overall cost to ADOT was roughly $17,500 per lane-mile, with a burdened labor rate of $12.00 per hour. Labor costs were 52 percent of the total budget. The costs of magnet materials and consumable supplies were only about $2,150 per mile, while the drilling cost ran $2,000 per mile.

These are difficult costs to capture, as so many factors were internal or unique to ADOT. Control surveying was very costly and was determined to have been unnecessary, so is not included here. For comparisons with the 3M system's tape installation in this Phase Two of the project, the key factors for the Caltrans magnets are the material cost, the total lane-mile cost, and the number of work shifts. The magnet installation effort averaged about 50 man-shifts, or 3.5 crew-shifts, per completed mile.

Lessons – Caltrans Magnets

One key lesson learned was that precise surveying to the roadway geometric design was not relevant, since the efforts of the roadway stripers did not relate to those lines. Especially where the road went through tight reverse curves down a hillside, it was clear that the magnet lines had to follow the actual roadway striping, which controlled the paths of all vehicles travelling in both directions.

Another key lesson was that work-zone traffic control was critical, and that setting roadway magnets precisely required lane closures and a high degree of protection for the crews. The best solution on this two-way roadway was to use a pilot vehicle to control the speed of workzone traffic, but on a high-volume roadway, physical barriers may be required. Side road traffic was also a continual problem at some points along this roadway, and required constant vigilance.

These lessons from the magnet installation phase are relevant to the 3M magnetic tape option. The 3M tape was installed during construction, and the factors and issues noted above were rigidly controlled and mechanized. On the other hand, the 3M tape placement was all performed by third party forces, and there was no maintenance personnel involvement as was required with the magnets.

One positive aspect of the California concept was that the maintenance crews who put in the magnets, one by one, were also the snowplow operators who would later train with and use the Caltrans system in winter storm operations. This buy-in, for drivers from across the entire region, would be very significant later in terms of enthusiasm, scheduling of training, and commitment.

X. ARIZONA ASP-ROADVIEW ACTIVITY – FEBRUARY 2001

According to the project's master plan for the winter's training and evaluation program, the 3M operational testing would be ongoing from Fall to Spring on US 89. It would begin with Team Leader training, progress to regional operator orientations and test drives, and then phase back to operational plowing by February. That simple plan would switch the major effort west to US 180 at Kendrick Park, when the Caltrans RoadView Advanced Snowplow (ASP) prototype arrived.

As described earlier, there were local scheduling problems that led the 3M training effort to be pushed hard at the end of January. This last effort was successful in getting a reasonable sample of operators from several regions into the cab of F342 for training, and it did finally allow the focus to swing back to the US 180 Caltrans program. It also led to some problems in preparing for the arrival of the ASP from California on February 5, but they were minor issues. Ultimately there were serious delays to the Caltrans training and operational testing, but they involved the RoadView ASP equipment itself.

Caltrans Testing and Evaluation Planning

The Caltrans snowplow training program for 2001 allowed ADOT to operate the ASP for a four-week period. The plow would be on the ground in Flagstaff on Monday, February 5, and after calibration by the Caltrans technical team, it would be at ADOT's disposal for the next four weeks, until March 2. The ATRC plan for this third year of ASP research was to commission the plow and conduct the initial Team Leader refresher training in Week One, and to finish the regional operator training sessions before Week Two was over. That plan would allow training for 15 to 20 student operators, and still allow two full weeks of operational evaluation by the Flagstaff District during storms on US 180.

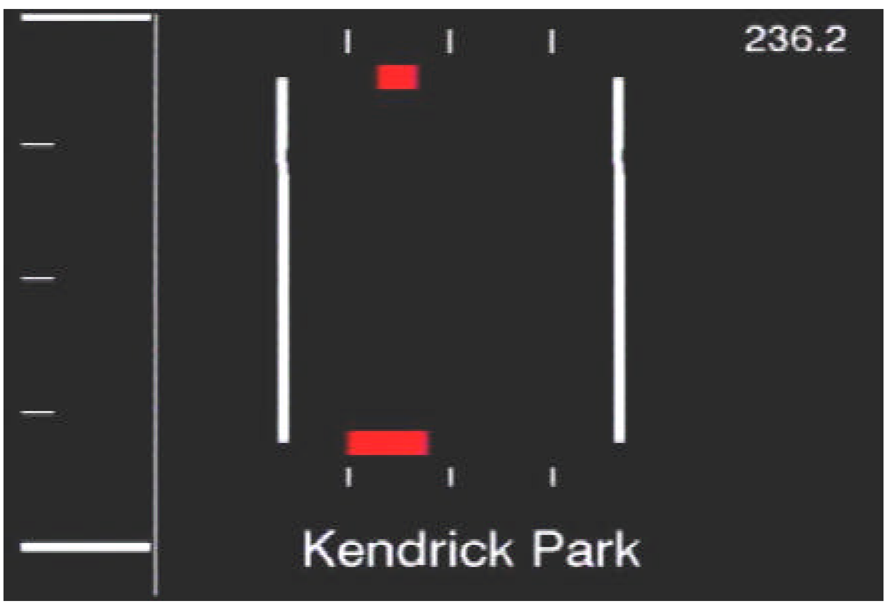


Figure 16: The Caltrans – PATH Operator's Display Screen

Significant ASP system enhancements over the prior year, such as enhanced display information, would provide the Team Leaders with additional efficiencies and safety factors. For example, route segment and milepost information was provided on the display screen, as well as the roadway alignment, radar warnings, and steering cursors. New calibration refinements and more system robustness were among the anticipated improvements. On the other hand, there were still concerns as to the performance of the dual-radar system, which was still calibrated for Interstate highway operations rather than narrow two-way secondary roadways with numerous obstacles on the roadsides.

One key aspect of utilizing the RoadView ASP in Arizona was the critical need for effective radio communications. As noted in the prior phase report for this project, the ASP was not fully utilized in its February 2000 Arizona evaluation period because of safety issues. The snowplow could not be used for storm events at night unless an ADOT plow was close by. This was due to an earlier incident when the operator of the ASP could not call out for help on his hand-held radio or the AVL cell phone because of the location of the accident in a communications "dead zone." For that reason, Flagstaff Maintenance and the DPS radio shop were prepared to install an ADOT radio in the Caltrans plow as soon as it arrived for the 2001 test program. This critical step would enable the rest of the project activities to proceed as planned.

Figure 17: The Caltrans ASP Approaching Kendrick Park on US 180

Unfortunately, the 2000-2001 Arizona ASP program's schedule was soon set aside, as new issues arose with the Caltrans snowplow itself. The truck had a number of problems when it arrived, primarily in the dual-radar system, and although some of these were readily solved, others were not. The technical team from Caltrans partners AHMCT (UC Davis) and PATH (UC-Berkeley) put in some long shifts over more than a week before the snowplow was considered ready for ADOT training and testing to proceed. After eight days of shop and test site servicing and calibrations, the ASP was ready for ADOT to begin the delayed training cycle.

Caltrans ASP Winter Training Program – US 180

Because of the unpredictable nature of the troubleshooting on the Caltrans snowplow systems, the planned ASP training program was not fully initiated until February 15. The effort went ahead smoothly from that point, and despite some storm interruptions, operator training was conducted until the 26th. The operational evaluation of the RoadView plow in snowstorms was ADOT's highest priority during the Caltrans phase, taking precedence over the training activities.

This training effort in February was somewhat more focused than that with the 3M plow, for a variety of weather-related and other scheduling reasons. As noted earlier, the largest winter storm of the season dropped 16 inches of snow on the Flagstaff region on February 14th, while the ASP was still being repaired. It is significant that the Caltrans RoadView snowplow was fully functional on US 180 during its brief training cycle, unlike ADOT's F342 with its ongoing CWS radar problems and the temporary striping restrictions at the Sunset Crater test site.

Training Records – Caltrans RoadView ASP

As noted previously (see 3M discussion), the ATRC developed a standard training-day debriefing survey that was used by operators after their orientation on either of the two research snowplows, since neither 3M nor California provided this for their concepts at this time. Both organizations, however, did provide post-season debriefing surveys for the operator pool to comment on system-specific questions.

The ADOT standard survey was reasonably effective, and provided consistent information to Caltrans that related to the survey materials from prior years. More importantly, it produced a consistent set of responses for both advanced snowplow concepts that could effectively be reviewed and analyzed by ADOT's evaluation team from Northern Arizona University.

The final training phase results for the Caltrans plow were that a total of 18 ADOT operators were trained by the two Flagstaff Team Leaders on the 2001 RoadView ASP systems, over a period of seven training days. These students represented ADOT maintenance camps at Holbrook, Kingman, Seligman, Flagstaff, Winslow, Williams, and Gray Mountain.

Operations – US 180 - Kendrick Park

From the time that the collision warning radar repairs were completed, the RoadView ASP was used by ADOT for plowing in five storm events. District records indicate that the ASP was actually used for plowing on five day shifts and three night shifts. This activity is discussed further in the next section of this report.

XI. ASP-ROADVIEW RESULTS – WINTER 2000-2001

During this Caltrans testing phase of the 2000-2001 research program, the RoadView ASP performed at a high level of efficiency and reliability, although that statement refers basically to the last two weeks of the program. Overall, a great deal was learned both about the system's potential advantages, and its limitations, as compared to the ADOT-3M advanced snowplow.

Analytical Research Efforts

As in prior years, the Caltrans ASP program relied to some extent on its partnership with ADOT to document Arizona training and operational use during winter storms. In the larger perspective, Caltrans had long since proven the need and the benefits of the ASP concept, and the research now was focused more on their specific sites and operators.

The Caltrans evaluation effort was tasked primarily to analyze performance of the RoadView ASP plows in their design environment, especially on I-80 at Donner Summit. The ASPs are equipped to record an extensive range of performance data for use by the research team to further enhance the system's effectiveness, and that of the operators assigned to these critical areas. It should be noted that the Caltrans group did not record any data from Arizona during this year's efforts.

Figure 18: Loading Cinders During Plowing Operations – Kendrick Park

The ADOT winter evaluation program placed a high priority on regional operator demonstrations, orientation, and training, with the intent that positive reactions from the Org and District levels would help to win support from upper management to implement key ITS systems for winter maintenance. The ATRC's research therefore depended heavily on operator surveys. ATRC had developed one standard operator survey for both the 3M and Caltrans advanced snowplow systems. These day-of-training surveys were provided by ATRC to Northern Arizona University, under contract for evaluation of this program, and they were also given to Caltrans for reference.

As described earlier, the ADOT training-day surveys were the primary effort to capture first impressions and commentary on specific positive or negative aspects of the systems. The team from Caltrans did not emphasize this approach, but did provide a post-season survey for ADOT, as had the 3M group.

One other key project survey was conducted by Northern Arizona University for ATRC, which explored attitudes and knowledge about both Advanced Snowplow concepts among maintenance supervisors and managers, from the rural districts up to the highest departmental levels of ADOT.

The third-party evaluation results developed for ADOT will be discussed in Part Three of this volume, and the complete reports on these evaluations are included in the Appendices.

Operational Results with the Caltrans ASP System

The overall results from Arizona's brief and intensive winter test program with Caltrans can be viewed in two ways. Everything on the ASP worked perfectly when it worked, but, it did not always work.

Figure 19: Operational Evaluation on US 180

The key to the extensive system problems on delivery of the plow to Flagstaff was the pressure to meet the partnership's schedule. The ASP was taken off of its assigned route on I-80, and almost immediately loaded for shipment to Arizona. Had the truck been serviced and all systems fully inspected and calibrated before shipment, the commissioning in Arizona might have been simple and straightforward. As it was, nearly two weeks were lost, with impacts to all the project partners.

In the larger perspective, the Caltrans RoadView ASP performed very well in ADOT's hands. Already at a disadvantage because of the time limit for Arizona evaluations, the servicing issues made training and testing even more of a challenge. Nevertheless, during the compressed weeks of activity in late February, special efforts were made by the Team Leaders and the involved Orgs to have the final total of 18 ADOT trainees participate.

The weather also cooperated with the operational evaluation program, as snow fell on five days over two weeks. These storms required the crews to mobilize the ASP for eight shifts of plowing on US

180 and also on I-40. Activity reports for these shifts show that blowing snow, winds of 20 to 40 mph, and visibility from zero to 50 feet were often encountered in the Kendrick Park section of the test site.

The Caltrans ASP was operated in a variety of storm conditions, and late in the test period it was run several times on Interstate 40 near Flagstaff, which had no continuous magnet testing installation in the roadway.   These off-track activities were an ADOT effort to better evaluate the collision warning radar system and display, under the Interstate conditions for which the ASP was basically designed. Likewise, these operations included tests of the AVL system on I-40 and on other corridors around Flagstaff. The onboard ADOT radio allowed more effective coordination with other plows in the area.

RoadView ASP Results - US 180 - Kendrick Park

Overall in this 2000-2001 season, the Caltrans plow completed 1,870 miles of plowing activity, including 469 lane-miles on I-40. Most of the plowing was done on the 35–mile US 180 plow route from Flagstaff, through Kendrick Park, and down the grade out of the forest towards Valle and the Grand Canyon. The average RoadView ASP use by ADOT was about 235 miles per shift. It is worth noting that the Caltrans ASP was actually used mostly – 63 percent of the total mileage – for plowing Arizona snow in storms, rather than for training and system testing.

Since the vehicle's borrowed ADOT radio and the cellular-based AVL system were both functioning, there were no constraints on plowing activities during this winter testing period.

As a result of these factors, excellent evaluation results were recorded for the 2000-2001 winter. Despite the initial delays, the Caltrans systems were fully operational and provided steady, reliable service during the several storms late in the evaluation period. Numerous comments from the Team Leader activity reports show that all systems were consistently working well and providing significant help to the drivers in snow removal, and in safe operation.

PART THREE:

THE IV SYSTEMS EVALUATION PROGRAM

XII. THIRD-PARTY EVALUATION – FIELD ACTIVITY

From the end of the project's Phase One (1997-2000), it was clear to the TAC and to the ATRC that significant research support would be needed in the second phase of the advanced snowplow project. Throughout 2000, as ATRC developed its plans for the newly-expanded winter program with two separate advanced snowplow guidance concepts, a parallel effort was made to bring an independent third-party evaluator into this research project.

Background

This project's evaluation program must deal with two competing lanekeeping systems as well as with a variety of other niche ITS technologies that might or might not be successful as stand-alone resources for ADOT's winter maintenance program. The intent was to bring in a completely neutral third party who would analyze, interpret, and judge the relevance of a variety of raw sources of project information. The basic evaluation program for the coming winter was expected to fairly evaluate the two competing advanced snowplow systems, and also, to seek the perspectives of senior ADOT managers on the project's ITS winter maintenance concepts.

This research effort would involve a thorough analysis of the project's evaluation surveys, activity reports, and stakeholder interviews. It also would require coordination with the system owners to interpret the results in light of ADOT's goals. It would further require an effort to clarify and examine those goals, in particular by performing a separate project survey of, and interviews with, several key levels of ADOT's management and maintenance field supervisors.

Based on the extent of the background research required, the need for an extensive field presence to include callouts, and the uncertainty of the winter storm activity, it became clear that this evaluation project should involve Northern Arizona University (NAU) in Flagstaff. The TAC recommended that NAU be considered for the work. The University's expertise and prior research in ITS-related transportation areas, and their proximity to the two test program sites, justified the selection of NAU for this task.

Negotiations for an intergovernmental agreement were completed with NAU's Dr. Craig Roberts of AZTrans: The Arizona Laboratory for Applied Transportation Research. The third-party evaluation program was formally initiated on December 5, 2000. The ATRC's workscope document defined the project basis for NAU as follows:

"ADOT intends to employ a Consultant for a third-party, neutral evaluation of the two similar but competing vehicle guidance systems. The proposed winter evaluation program will focus on operator reactions to the "driver assistance" guidance systems, and also to a lesser extent on the secondary collision warning and vehicle location systems. Each plow will carry similar secondary systems to reduce the perceived differences between trucks, and so to maintain the operators' focus on use of the lane-keeping guidance technology. "

"The primary goal is to evaluate and compare the two advanced guidance systems, to support deployment recommendations. The secondary goal is to evaluate the stand-alone commercial radar and AVL systems on the snowplows, to support field deployment of one or both systems."

This project workscope developed by the ATRC, defining the NAU evaluation requirements during the 2000-2001 winter, is included in the Appendixes. Throughout this section of the report, the key elements of Northern Arizona University's research narrative will be inserted. The Final Report for the NAU-AZ*Trans* evaluation program has also been included in Appendix C of this document. [3]

12.1 Field Evaluation Activity – Northern Arizona University

Upon completion of the joint project agreement between the ATRC and the University, the NAU research team began preparations for review of existing information, and for contacts with key stakeholders and equipment suppliers. Dr. Craig Roberts, the Principal Investigator for the AZ*Trans* subcontract to ADOT, attended his first Technical Advisory Committee meeting on December 12. The TAC meeting notes from that session defined the plans and the roles for this activity as follows:

- *<u>Schedule, Goals & Methods</u> – Steve introduced Dr. Craig Roberts of NAU, whose team will provide a third-party viewpoint on ADOT's comparison of the two advanced vehicle systems, and on their potential to provide clear benefits. Craig discussed his plans and verified contact info, so that he can observe training and ask questions. The main effort on the evaluation program will commence in January and February, with a report draft due in March. <u>The main first-year goals are to report and to recommend</u>. Craig plans to attend some of the December Team Leader training, to find out more about the systems and the training approach. During this project, on a limited basis, NAU may occasionally ride along to observe training and plowing operations.*

- *<u>Info Needs; Additional Support from TAC</u> - The evaluation program will depend on the TAC to provide current information on costs, traffic, weather, accidents, repairs, etc. ADOT will collect and copy all activity reports and driver surveys for NAU. Craig Roberts noted that the Team Leaders have a vital role in advising NAU's personnel, recording data, reporting on training, and encouraging trainees to provide detailed responses and suggestions on the systems.*

The NAU research team soon became closely involved with the ADOT crews and the supervisors in the field. Numerous visits were made to the field sites, the equipment shops and the maintenance Orgs. At this point, all of the field activity was out on US 89 with the ADOT-3M system, but planning for the Caltrans phase of the research was already in progress.

The NAU team also pursued interviews and briefing sessions at the Flagstaff District offices. At the District, the greatest emphasis was on the Snow Desk and the relationship of the GreyLink AVL system to the other operational functions, and problems, during winter storms. The researchers also sought perspectives from the maintenance superintendents and engineers on the TAC and in ADOT's offices, and NAU participated in all TAC meetings through the winter season.

Later, as the winter research program moved into the training phase for operators from Flagstaff's partner Orgs and other Districts, the orientation phase for NAU evolved into more field site visits for interviews and for ride-alongs. The research team spent time over the winter with vendors and with the Team Leaders, so as to clearly understand the subtleties of the systems being evaluated. NAU had to observe and learn the system functions under varying weather and light conditions in order to effectively relate to the trainees and to analyze their responses to questions and to the surveys. More basically, NAU needed to understand the winter maintenance practices used by ADOT so that the systems, and the stakeholder perspectives, could be evaluated as to their effectiveness and utility.

As the 2000-2001 winter progressed, the NAU team concentrated more on the ATRC's training-day surveys. As described earlier, these debriefing worksheets basically measured operator satisfaction and perceptions about the ITS systems on the two snowplows. The surveys solicited comments, sketches and suggestions on refinements to the two guidance systems, the radar, and the AVL system.

In general, the ATRC's training-day surveys produced high satisfaction ratings and numerous comments on the display and on the controls. NAU made an effort to develop statistical analyses of the responses, but the samples were not large enough to be valid. Because of the time involved, and the various records needed, the NAU efforts to process and summarize the results could not be done until the ASP training season was over. As the data for the project evaluation report developed, the input from both test sites were reviewed both together and separately by the project team.

12.2 Snowplow Training And Evaluation Survey (T&E Survey)

ATRC Note: All the following material in the rest of this chapter is directly excerpted from the NAU evaluation project report, unedited. The entire NAU report is included in this volume as Appendix C.

Target Respondents

The Snowplow Training and Evaluation Survey was targeted at two tiers of snowplow operators:

- The first tier was composed of those snowplow operators who received their training from the system developers. There were only three of these; two of them were Team Leaders and the other was a senior operator who could fulfill the duties of a team leader if need be.
- These first tier snowplow operators then trained the second tier of snowplow operators that included operators from the Northern ADOT Districts, which experience the most wintertime snowplow operations.

The number of first-tier operators was too small to analyze, there being only one on the CALTRANS system and two on the 3M system. The primary focus was on the training of the second-tier snowplow operators. The final sample analyzed contained 31 trainee surveys. A trainee's survey was included in the sample only for his first training session during the 2000-2001 winter season. A few operators had more than one training session, but only their first training session's survey was included for analysis. Some of the trainees on the CALTRANS system had received training on this system in prior years. Since this was the first time the 3M system was involved, all of the trainees on this system had no prior training on this system in prior years. Eleven of the trainees trained on both systems, while nine only trained on one system. There were 18 trainee surveys in the CALTRANS sample and 13 trainee surveys in the 3M sample.

Survey Instrument

A survey format (Appendix C, Attachment A) was developed in prior years for the CALTRANS training program and was used again in the 2000-2001 winter season, with modifications to accommodate the 3M system training that was being tested for the first time. Five topics were explored:

- Overall Satisfaction with Driver-Assistance/Guidance Systems
- Lane Position Indicator Screen
- Lane Departure Warnings: Alarm Lights, Vibrating Seat (only on 3M system), Screen Display
- Collision Warning System (inoperative on the 3M system)
- Displays and Warnings

Analysis of Training and Evaluation Survey

The analysis of the data revealed no statistically significant difference between the two systems ratings, CALTRANS and 3M, on any topic. The rating scale on every question was the same and was described on the survey as "10 as best, 1 as worst."

While the trainees are representative of all ADOT snowplow operators, the sample is small compared to the total number of all ADOT snowplow operators. By "the luck of the draw" one could get a group of trainees that might rate a system higher than if all the snowplow operators were actually trained, or visa versa. The project team simply can't tell from the data. Therefore, we have to report that they are not statistically different, based on the data collected.

None of the topics explored in the Training and Evaluation Survey showed statistical differences between the two systems. Also none of the questions asked had a lower 95% confidence interval less than about 6.6, while most had a lower limit of about 8 or greater.

Trainer Observations During Actual Winter Snow Removal Conditions Using the ASPs

The three key first-tier ADOT snowplow operators, who provided the training to the other ADOT driver trainees, were also the normal operators of the Advanced Snowplows (ASPs) during regular day-to-day operations. For this reason, they had the most experience by far with the ASPs, and essentially had all of the experience during actual snowstorms. Comments of these trainer-operators are listed in Table 1 (NAU-3). In reviewing these comments, recall that the 3M-equipped snowplow had a stand-alone Eaton VORAD EVT-300 Collision Warning System (CWS) which was inoperable, so the 3M-related comments by operators of plow F342 do not include any evaluation of the CWS.

The comments are all favorable. Interviews and discussions with two of these individuals, one each from both systems, confirm this. These interviewees are identified as Trainers CALTRANS-T1 and 3M-T1 in Table 1 (NAU-3). For these two operators, the performance of the ASPs during "*whiteout*" conditions was a particularly significant improvement. Whiteout conditions are when a combination of snow, wind, and/or lighting create a total loss of visual perception of the roadway looking forward. One operator described it as being "like someone wrapped a white sheet over all the windows." It can occur during the day or at night. If a whiteout persists for more than a few seconds, the driver typically experiences disorientation, which often leads to run-off-the road type crashes.

While snow, wind, and natural lighting conditions are uncontrollable, other factors that contribute to whiteout-type conditions have the potential to be controlled. Windshield freezing, poorly functioning wipers, and blowback from the plow contribute significantly to whiteout-type conditions. Whiteouts can occur during the day, but during the night the artificial lighting from the plow headlights and other forward lights can also contribute significantly toward whiteout-type conditions. All four of these potentially controllable factors were the most cited improvements needing attention. The snowplow operators highlighted these factors during interviews and the ADOT supervisory and management personnel cited these on the survey administered to this group as a part of this evaluation, which is discussed later in this report.

During discussions with several snowplow operators, "whiteout" conditions were universally described as being the most dangerous and accident-prone. The two operators with the most experience on the ASPs, discussed having heightened degrees of confidence and increased feelings of safety when using the ASPs. Their experience in the ASPs during whiteout conditions gave them confidence that they could "handle" a whiteout should it occur.

This evaluation considers this increased sense of confidence and safety, coming from the two operators with the most actual snowstorm experience, to be a highly significant piece of qualitative evidence. It supports the effectiveness of both ASP systems to improve operator safety.

Table 1: Comments of ADOT Operator-Trainers In Winter Snow Removal Conditions (NAU-3) [3]

Trainer ID	Date	Wind Speed	SNO= Snowing SUN= Sunny CLD= Cloudy	Time	Visibility Feet	SPK= Snowpack ICE= Ice SLU= Slush DRY=Dry	Plow &/or Sand	Vehicle Status	System Status	Comments
CALTRANS Advanced Snowplow System										
CAL TRANS T1	14-Feb-01		SNO	DAY	ZERO, 50	SPK,ICE	P	Is good, no problems. The computer H.M.I. Is working well.	OK	The H.M.I. Helped me with snow removal, and helped me stay on the road through the test areas.
CAL TRANS T1	23-Feb-01	20-40	SNO	DAY	ZERO, 50, 100	SPK,ICE	P	The truck is working with no problems at all.	The H.M.I. System helped me in snow removal, in white-out conditions.	Also it was a long day. The H.M.I. Helped me all the way around.
CAL TRANS T1	26-Feb-01	20-30	SNO	DAY	ZERO, 50, 100, >500	SPK,ICE	P	OK	OK	OK
3M Advanced Snowplow System										
3M-T1	10-Nov-00		SNO	NIGHT	ZERO	SPK	P & S	Good	Good	White-out conditions used to find road and stay out of oncoming traffic.
3M-T1	25-Dec-00		SNO, CLD	DAY	>500	SPK	P & S			
3M-T2	17-Jan-01		CLD	DAY	>500	SPK, ICE, SLU	P	In good condition.	Great!	
3M-T1	27-Jan-01		SNO. SUN, CLD	DAY	>500	SPK, SLU	P & S	N/A	N/A	Good

Summary of ASP Trainee Comments and Recommendations

The Training and Evaluation Survey included three questions that asked for "Comments and Recommendations." The detailed responses to this question are listed in Appendix C, Attachment C, and the reader is encouraged to review them. The responses are summarized here. [3]

1. *Were there any system problems when you were operating the vehicle? (describe)*
2. *Did the system ever lead you to make a wrong maneuver or error in judgment?*
3. *What suggestions would you make to improve any feature's usefulness to you?*

The only system problem reported on the CALTRANS snowplow was the collision warning system (CWS). The comments of one trainee described the warning given as being "very quick" that led the operator to believe he "would not be able to avoid a collision." During this evaluation, it was observed that an approaching vehicle did close the distance "very quick" - the rate of closure was the sum of the speeds of both vehicles. No observation was made regarding a parked vehicle, which would be more representative of a stalled vehicle during a snowstorm. It was noted that the CWS would sometimes give "false" readings on signs and other roadside objects. The Eaton VORAD CWS installed on the ADOT-3M snowplow was inoperative, therefore no observations were made during this investigation or by the trainees or trainers.

There was universal agreement on both systems that they did not ever prompt the operator to make a wrong move or error in judgment, with one exception. One trainee commented, "Sometimes, because need to know more about the operation of the truck." This was an experienced snowplow operator (ten years), but it wasn't determined if this comment referred to the truck or the system being unfamiliar.

Suggestions were made on possible improvements to the CALTRANS systems as follows:

- Add vibrator seat option (like the 3M System used)
- The mile marker and location name options on the monitor are a definite plus
- Maybe improve radar system somewhat [CWS]
- Training needs to be done during actual snowstorm conditions
- Good improvement from previous years to make screen smaller and position nearer normal field of view (FOV) of the operator. It was suggested to move it even farther to the left so that it would be even more in the operator's FOV. However, it was also observed that the screen needed to be moved “farther away from the sun.”
- Put marker flags on plow

Comments regarding the ADOT-3M snowplow are as follows (the Eaton VORAD CWS was inoperative the entire test period):

- Need something to indicate on-coming traffic, i.e., a CWS
- System needs to be improved when there is a turn or an increase/decrease in grade
- Screen still a little cluttered, but a distinct improvement over screen in CALTRANS snowplow
- Make the display a heads-up, reflected off the windshield
- Training needs to be done during actual snowstorm conditions

Recommendations Regarding Comments of Trainers and Trainees

Based on discussions with the plow operators, both trainers and trainees, and the survey comments, a few useful conclusions can be drawn. First is that the "3M vibrating seat" as a primary feedback mechanism is a superior interface. Only the 3M snowplow has the vibrating seat feature, but the CALTRANS system would benefit by adding it.

It is recommended that this system be added to the CALTRANS system for next year's research.

From discussions with several snowplow operators, the concept of a collision warning system (CWS) is considered a crucial system by the operators. Observations and operator comments regarding the integrated CWS on the CALTRANS system were favorable in concept. However, testing under actual or simulated snowstorm conditions was limited. One concern is if the snowplow operator would have enough time to react safely to avoid a collision. This evaluation's impression is that the lack of an operative system on the 3M snowplow was considered a significant handicap by those operators that had training in both systems.

It is recommended that the collision warning system be a primary focus of investigation in next year's research program.

Training during actual snowstorm conditions is deemed difficult by ADOT because (a) the logistics of moving an operator from his home organization to the training site "just before" a snowstorm and (b) the lack of a sufficient number of trained snowplow operators at a trainee's home organization to back up his snow removal route during a snowstorm, while he is away at the test site. Acknowledging this, there is still no substitute for a trainee experiencing the system during actual winter snowstorm conditions.

It is recommended that at least a few trainees be given the opportunity to work the ASPs during actual winter snowstorm conditions in next year's research program.

XIII. THIRD-PARTY EVALUATION – MANAGEMENT SURVEY

As discussed earlier in this ATRC report, the research TAC felt the need to determine more accurately what were the potential benefits of wider deployment of Advanced Snowplow systems in Arizona.

Background

Because of the high infrastructure cost required to develop the two field sites for the Caltrans magnets and the 3M magnetic tape, this project needed to make a realistic estimate of the potential extent of deployment sites for these systems on a statewide basis.
It was equally important for the project TAC to assess the opinions and perspectives of ADOT's managers and supervisors towards the candidate winter maintenance systems being tested, to better determine what level of current knowledge and future support might exist outside of the three northern ADOT Districts. While the project was in an expanded third year of field research activities, there had not been any extensive campaign to inform managers and to win support on a statewide basis.

As a significant part of NAU's project evaluation workscope, the management survey now offered an opportunity to answer several key questions about perceptions and priorities within ADOT.

ATRC Note: All the following material in the rest of this chapter is directly excerpted from the NAU evaluation project report, unedited. The entire NAU report is included in this volume as Appendix C.

Target Respondents

The Management Survey was targeted at both District and Statewide ADOT supervisory and management personnel. At the district level four positions were targeted:

- Maintenance Supervisor (MSV),
- Maintenance Superintendent (MST),
- District Maintenance Engineer (DME), and
- District Engineer (DE).

Two positions were targeted at the statewide level:

- Equipment Services (ES) and
- Senior Management (SM).

Eighty-five surveys were mailed and seventy-two responses were received, an initial response rate of 85 percent. The respondents identified themselves in the survey, which allowed two follow-up contacts to the recipients who had not responded. Three respondents did not fill out the survey for stated reasons. These were removed from the sample. Three anonymous surveys were received. Two of these were not included in the sample because the handwritings were matched with surveys that were received after the follow-up contacts were made. The handwriting of the third anonymous survey could not be matched with any other survey and was included in the sample. The final sample contained 69 respondents, a final response rate of 81 percent.

Survey Instrument

A survey instrument was developed, pre-tested, and refined in collaboration with the TAC. The complete survey form is shown in Appendix C, Attachment B. Five topics were explored:

- Ability to Improve Safety and Efficiency Using an ASP System
- Extent of Deployment Needed and Reasonable Cost of an ASP System
- Usefulness of Employing ASP System Components Individually
- Questions To Be Answered During the Next Year's Research Activities
- Other Useful Winter Maintenance Operations Research Topics

The results of each topic are reported individually in the following sections. The more detailed statistical results and discussions thereof are found in the complete NAU report in Appendix C.

13.1 Conclusions – The Ability To Improve Safety And Efficiency Using An ASP System

The target ADOT Management personnel firmly "Agree" that the ASP systems will (1) significantly improve the snowplow operator's safety and that (2) they can be used effectively in all Districts having snowplow operations. They also "Agree", with only slight reservations, that the ASP systems will (3) noticeably improve the traveling public's safety and improve operations by enabling (4) operators to safely plow their routes faster and (5) Districts to keep their roads open much better during winter conditions.

The responses were subdivided by District and Job Title and examined. However, no significant differences were observed. Because the "spread" or variance of the response distributions before subdivision is fairly small, the 95% confidence intervals shown in Figure 3 are "narrow." This uniformity in responses means that when subdivided, each subdivision is not statistically different that all the other subdivisions. The responses were also subdivided so that "snow" Districts could be examined independently. Likewise all District Maintenance Supervisors and Superintendents were grouped and examined as a separate subdivision. Again, in both of these cases, no statistically significant differences were observed.

13.2 Conclusions – Extent Of Deployment Needed And Reasonable Cost Of An ASP System

A crude estimate was developed of the range of lane miles of roadway needing magnetic material embedded in it. The estimate is crude because only 23 respondents estimated the mileage for their district, giving very small sample sizes. Also, the distinction between estimating for especially troublesome lane miles versus a more extensive program was completely disregarded. It would appear that the minimum lane miles would be approximately 1000, but that in all the respondents believed that 2000 to 3000 lane miles would need magnetic material embedded in it.

The mean highest cost that would be reasonable for ADOT to pay is approximately in the range of $5,000 to $11,000 per lane mile. If the crude estimate total lane miles is combined with this estimate of highest mean cost, a very crude estimate of total "desirable" funding can be made. In this case "desirable" means applying the highest reasonable cost per lane mile estimated by the ADOT supervisory and management personnel to the crude estimates of total lane miles needed to deploy the ASP system. This yields a "minimum" system wide "desirable" estimate of $9 million ($8,400 per lane mile times 1000 lane miles) and a more likely estimate of between $17 to $25 million ($8,400 per lane mile times 2000 to 3000 lane miles). These estimates are not related in any way to the current cost of installing an ASP system nor to a defensible estimate of the actual lane miles needing an ASP system. Again, they are only crude estimates without any basis for estimating the uncertainty involved with the estimates.

13.3 Conclusions – The Usefulness Of Employing ASP System Components Individually

The target ADOT Management personnel firmly “Agree” that the lane-keeping guidance system component by itself will (1) significantly improve the snowplow operator’s safety. They also “Agree”, with only slight reservations, that (2) the collision warning system component by itself will significantly improve the snowplow operator’s safety and (3) the vehicle tracking system component by itself will significantly improve the District’s ability to monitor and allocate its materials and equipment. They are “Undecided” about (4) the ability of the vehicle tracking system component by itself to significantly improve the snowplow operator’s safety.

The responses were subdivided by District and Job Title and examined. The responses were also subdivided so that “snow” Districts could be examined independently. Likewise all the District Maintenance Supervisors and Superintendents were grouped and examined as a separate subdivision. Due to the uniformity of the data, no statistically significant differences were observed in any of these subdivision cases.

The lane-keeping guidance system component was clearly regarded as a useful component when coupled with either the vehicle tracking or collision avoidance components.

13.4 Suggested Questions To Be Answered During the Next Year’s Project Activities

The ideas, while somewhat unique to each respondent, can be grouped into common topics. Common topics raised by the respondents regarding next year’s advanced snowplow research program are:

- Cost effectiveness regarding actual deployment (12 respondents)
- Effectiveness of Collision Warning System (CWS) (7 respondents)
- Quantify changes in safety of driver and motorists (5 respondents)
- Design the operation and arrange the location of instrumentation in the cab to optimize driver ergonomics and comfort (5 respondents)
- Investigate alternate lane-keeping guidance technologies, e.g., GPS/GIS (4 respondents)
- Evaluate the productivity/efficiency of the systems (3 respondents)
- Evaluate effectiveness of the ASP system in difficult conditions (sharp curves, narrow roads, heavy snow) (2 respondents)
- Evaluate deployment realities of high versus low volume roads (interstates versus rural) (2 respondents)
- Does the limited number of districts and orgs conducting the trials create a slanted viewpoint (2 respondents)
- Evaluate maintenance and failure of equipment (1 respondent)
- How deep can the magnetic material be buried and still be effective (1 respondent)

<u>Conclusions</u> On Questions To Be Answered During The Next Year’s Research Project Activities:

The detailed responses to this question are listed in Appendix C, Attachment E. As previously discussed, two constraints limit the questions that can be pursed in next year’s program: (1) can research actually address the question, e.g., it isn’t an administrative type decision and (2) can the question be addressed within the available resources.

After weighing these constraints, it is recommended that four topics be pursued. The first three questions listed can be addressed through a detailed evaluation survey administered to the snowplow operators and their direct supervisors. The last question can be addressed by inviting additional districts and orgs to sponsor some of their snowplow operators as participants in the training.

1. Effectiveness of Collision Warning System (CWS)
2. Design the operation and arrange the location of instrumentation in the cab to optimize driver ergonomics and comfort
3. Evaluate the productivity/efficiency of the systems
4. Does the limited number of districts and orgs conducting the trials create a slanted viewpoint?

13.5 Suggested Questions On Other Useful Winter Maintenance Operations Research Topics

This topic was explored in Question 6 of the Management Survey, which had 2 parts.

Q6a. *What else <u>about vehicles</u> could ADOT be researching that might improve <u>snowplow operations</u>?*
Q6b. *What other <u>equipment, methods, materials, or personnel procedures</u> could ADOT be researching that might improve <u>winter maintenance operations</u>?*

The detailed responses to this question are listed in Appendix C, Attachment E and the reader is encouraged to review them. Over three-fourths of the respondents answered one or both of these questions, i.e., 54 out of 69. Each of these 54 respondents described research topics that he believed would be useful to improve snowplow and other winter maintenance operations.

13.5.1 Suggestions On Other <u>Vehicle Research</u> Topics For Winter Operations

Each idea is unique and was often identified by a single respondent. Each of these is an important topic that bears serious consideration. Several topics, however, were identified by multiple respondents and these are placed first in the listing below.

- Investigate how to improve headlights to eliminate blinding during storm activity (18 respondents)
- Investigate how to improve windshield wipers, windshield freezing, and blow back on windshield (14 respondents)
- Investigate how to improve rear warning lights, which freeze over with ice, and curb lights (ref: Minnesota DOT Whelan Warning Lighting Systems) (6 respondents)
- Investigate how to best determine road surface conditions and application residue (8 respondents)
- Establish an additional snowplow driver certification; establish post-training testing and annual refresher training and testing; more training needed on chemical usage and effects (8 respondents)
- Investigate new developments in plow and spreader products, e.g., improved sander/deicer equipment, snow blowers, use of brooms for high speed snow removal, lower blade snowplow trucks; chemical friendly equipment (7 respondents)
- Devise a better/simpler method to record material usage by route and milepost; be able to reconstruct storm and plowing activities, perhaps via GPS or similar (5 respondents)
- Investigate changing motorist behavior about winter operations, i.e., by warning the public of the dangers of rear-ending snowplows using public service announcements and ads (radio and T.V.) and/or displaying advisory speeds of snowplow. Need “real” information, e.g., “if it snows, you will face bad conditions and ADOT cannot perform miracles.” (4 respondents)
- Investigate use of an infrared-type vision capability and/or a heads-up display (3 respondents)

- Are there times when snowplow operations should not be done, e.g., nighttime, whiteouts (2 respondents)
- Investigate use of sensors located in pavements and bridges to identify and report worst areas in a timely manner (2 respondents)
- Investigate using a simulated snowplow for research testing and actual training (like an airplane simulator) (2 respondents)
- Investigate use of snowplow shock absorbers to prevent chatter (1 respondent)
- Investigate use of automatic transmissions instead of manual thereby increasing concentration on the road (1 respondent)
- Investigate use of a uniform setup for all snowplows to promote operator efficiency/safety (1 respondent)
- Devise a safer plow mounting and/or method of mounting the plow on the truck (1 respondent)
- Investigate use of radio headsets with voice activated microphones (1 respondent)
- Add capability for interagency communications, e.g., law enforcement personnel (1 respondent)
- Collect and analyze snowplow maintenance by brands (1 respondent)
- Get an update on Iowa prototype vehicle (1 respondent)

<u>Conclusions</u> On Other Vehicle Research Topics for Winter Operations:

As discussed before, when reviewing these research topics keep in mind that a "good" research question could be raised by a single respondent. Identification of the same potential research topic by several respondents does not make it "better" than others.

It is beyond the scope of this investigation to recommend new research topics beyond those directly involved with the ASP program. However, the following two topics have substantial support and in interviews are identified as long-time and well-known snowplow problems. Therefore, it is recommended these two topics be given high priority as future research topics.

- *Investigate how to improve headlights to eliminate blinding during storm activity (18 respondents)*
- *Investigate how to improve windshield wipers, windshield freezing, and blow back on windshield (14 respondents)*

Several of the other topics that were identified might actually be best investigated by simply having a district/org try a solution on a prototype basis. The evidence from this single prototype could be shared and a decision made: (a) the evidence was great enough by itself to warrant adopting it or rejecting it or the evidence was sufficient to warrant (b) further investigation by additional districts/orgs and/or (c) a formal research project should be initiated.

13.5.2 Suggestions On Other <u>Non-Vehicle Research</u> Questions For Winter Operations

The ideas below are more diverse due to a broader topic area, i.e., what other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter operations.

- Investigate what materials/chemicals are available and their respective best application conditions/methods; find better de-icing chemicals; find chemicals that don't require special equipment for application (11 respondents)
- Develop ADOT policy for a stronger chemicals for de-icing program (6 respondents)

- Need more resources implement the technologies we now understand, i.e., need proper amounts of manpower, equipment, and materials; need to find ways to convince legislators of our needs (5 respondents)
- Investigate Road Weather Information System (RWIS) usage versus no usage and/or integrating RWIS with onboard devices for proper chemical usage (2 respondents)
- Maintenance orgs need a better understanding of the calibration of snow plow spreader system, rather than just the mechanics (1 respondent)
- Develop a procedure to stockpile winter chemicals in bulk quantities to lower cost (1 respondent)
- Define how much equipment it takes to keep a lane-mile plowed to a reasonable service level and consistently apply this standard around the state (1 respondent)
- ACFC; when new pavement, snow covers faster than older pavement (1 respondent)
- Develop EPA approved mixing and storage for road salt and wash bay for after storm cleaning of equipment (1 respondent)
- Investigate using automatic ramp gates, remotely operated, in conjunction with variable message signs as conditions deteriorate (1 respondent)
- Perform lab tests on winter chemicals to see if they meet specifications (1 respondent)
- Achieve more enforcement on chain regulations for trucks and cars (1 respondent)
- Improve computers for spreaders, which break down a lot (1 respondent)
- Investigate use of operations center(s) for snowplow support, e.g., using ADOT TOC versus District support (1 respondent)
- Highway 260, MP 377.5 to 383 is at 9100 feet elevation, has high wind and constant whiteouts; it is ideal for an ASP system (1 respondent)

Conclusions On Other Non-Vehicle Research Topics for Winter Operations:

Again, numerous valid and significant suggestions were offered.

Unfortunately it is beyond the scope of this investigation to recommend research topics outside the Advanced Snowplow Program scope.

13.6 Task Conclusions - Value Of Other Research Topics To ADOT Managers

The topics listed in this section are a valuable resource to ADOT managers. The people surveyed include almost all of the supervisory and management level people involved in winter operations throughout the entire ADOT organization. These people are the ones closest to the problems and the potential solutions. They typically have many years of experience with ADOT in these winter operations. These people know ADOT. Their ideas are typically practical, always sincere, and hold the promise of significant improvement to ADOT's operations.

ADOT managers at all levels are encouraged to take ownership of as many of these ideas as they can and try to implement them. Many can be implemented unilaterally at the org or district level. Others take statewide action. Most of these ideas are not fancy or, in some cases, even new. Many don't require a research program or a consultant; they only require a manager who can see their value and find a way to implement them.

XIV. OTHER THIRD-PARTY EVALUATION SUPPORT

The primary purpose of the NAU evaluation program, as described before, was to develop a valid, neutral third-party analysis of the ADOT ASP research effort. This program was focused specifically on ADOT needs for deployment decision information. Part of that effort was to accurately collect and interpret the reactions and comments of the IV system users and beneficiaries. A second aspect was to both communicate IV concepts to, and solicit perspectives from, both field and upper-level supervisors and managers of ADOT's statewide winter maintenance program.

As detailed in the preceding chapters and the Appendixes, the ATRC and Northern Arizona University developed activity reports and day-of-training surveys for the snowplow operators to record their opinions of the new technologies, and suggestions for refinements. These reports were the primary resource for NAU's Training and Evaluation (T&E) analysis and reporting.

It was also the intent of the Arizona program to provide new testing opportunities and site-specific information to the project's sponsoring partners, Caltrans and 3M. ATRC provided copies of its own day-of-training surveys to both groups for reference. As noted earlier, the Caltrans research team had in the past provided ADOT with training-day and post-season surveys.

The 3M research and marketing group, in this initial year of their partnership, also had a very strong interest in collecting data from ADOT on the performance of their ITS products. This chapter briefly describes the efforts by these third parties, and the results. Where possible, as of this report's date, the more detailed reports of these project partners are identified for reference.

Caltrans Project Team ASP Evaluations – US 180

Appendix B of this report contains the Caltrans Closeout Survey that was developed by project partner California PATH for debriefing of participants in the training program. This new driver survey was virtually unchanged from that of the previous winter, which has also been included as an attachment to Appendix A, the original evaluation project workscope for Northern Arizona University.

The Caltrans closeout questionnaire was updated this season with a reference to the ADOT-3M research snowplow. This note would differentiate the comments of a novice driver from one who might have experience on the fully-commercialized displays and warnings of that competing system. A similar question asked if the driver had been exposed to the Caltrans ASP in the prior winter, in order to flag reactions to new enhancements this season.

Generally the Caltrans surveys focus on ratings, on a "one to five" scale, of the various features and the performance of the Caltrans system design. This type of question reveals a strong emphasis on the human factors side, with regard to driver acceptance and levels of confidence. The survey also asks how long it would take to become comfortable with the system, and it offers the ADOT drivers the opportunity to draw their own concept of an ideal in-cab display.

The California surveys, when completed, were also copied and provided to ADOT's NAU evaluation team. However, the ADOT training-day survey (Attachment A of Appendix C), based largely on earlier Caltrans versions, was the primary resource used by NAU both to analyze the responses and to collect the subjective training and evaluation comments on both the 3M and Caltrans systems.

Finally, it should be noted that the Caltrans project team did not derive nor publish any specific conclusions with regard to this winter's training from the Arizona survey information provided.

U-Iowa-3M: Evaluation Plan For US 89 Testing

While it was still heavily involved in both testing and marketing of the Lane Awareness system, the 3M Company had developed a systems evaluation relationship with the University of Iowa. The Iowa team had designed the warnings and display systems for the 3M operator interface, and the Arizona deployment was an important element of 3M's field evaluation of those systems. U-Iowa provided their surveys and questionnaires for ADOT's snowplow operators, in order to collect as much information as possible for the first winter of use of the 3M technology in Arizona.

Even after the withdrawal of the 3M system from the market, the commitment was maintained to complete the research and to learn as much as possible about the system's potential for the western regions of the United States. The Human Factors and Vehicle Safety Research Program of the University of Iowa's Public Policy Center, at Iowa City, developed several in-depth survey instruments for the 3M program, including one specifically for Arizona's mountainous conditions. It should be noted that all of the Iowa-3M surveys were administered anonymously. The three Iowa-3M surveys were:

- Forward Visibility in Snowplow Operations
- Arizona Mountain Areas Survey
- Arizona Training and Evaluation Survey

Although impractical to include in detail in this ADOT project report, the U-Iowa research approach and the most significant findings will be discussed as relevant to the Arizona program. The University of Iowa's report, *Snowplow Lane Awareness System: Operator Interface Design and Evaluation,* is referenced at the end of this report volume. [2]

Generally the University of Iowa surveys were far more detailed and comprehensive than those in use by Caltrans and the ADOT research group. As the contractor for 3M, the University was obligated to apply significant resources to the development of the surveys and to the interpretation of the results. As noted above, ADOT and the evaluation team from NAU utilized a day-of-training survey in order to capture reactions and comments in regard to both the Caltrans and 3M systems and the other IV technologies on board. These were the primary survey resources discussed in the NAU report. They were also copied for the University of Iowa, in the interests of consistency and the sharing of data.

U-Iowa-3M: Forward Visibility in Snowplow Operations

This questionnaire was a baseline instrument to evaluate the normal winter maintenance operating conditions in Arizona, or in the other states with significant 3M involvement, Michigan and Minnesota. U-Iowa's eight-page anonymous survey contained the following seven sections:

- Some Background Information – Agency and experience.
- Your Snowplow Vehicle(s) – Year, make, model, driveline.
- Your Snow Route(s) – Miles, road types, shift hours, speeds, plow accessory systems.
- Vehicle Alarms and Devices – Visibility aids, glass, displays, alarms – best and worst.
- Low-Visibility Operations – Day vs night, wind, traffic, plow design, lane awareness, whiteouts, halted progress, crashes, incidents, near-misses.
- About You – Background, education, computer skill levels, eyeglasses and sunglasses use.
- Your Comments and Suggestions – Visibility and lane-keeping ideas.

For ADOT's purposes, to demonstrate the need for and potential of driver-assistance IV systems, this Iowa-3M survey will be very valuable in the future. Not only does it capture the experience, skills, and working conditions of ADOT's northern Arizona snowplow operators, it also has been given to more than a thousand operators from Iowa and Minnesota. The detailed information derived from this broad pool of operating experience is likely to be relevant for all states and agencies that maintain snowplow fleets for rural highways.

Since the Iowa surveys are anonymous, the drivers are free to express their opinions and to relate their most difficult and dangerous plowing experiences in the worst storm conditions, without fear of censure from their peers or supervisors. One drawback, however, is that there is no way to follow up for more detailed information on some of the specific conditions that few DOT managers and agency decision-makers can comprehend without experiencing them first-hand. The 28 anonymous responses to these surveys from Arizona do provide some valuable insights about ADOT's plowing conditions.

Some relevant U-Iowa-3M Baseline Survey questions and Arizona responses include the following:

- *How often per season have you unintentionally crossed into the other lane?*
- Responses range from "none," "once" or "a few," to "three," "many," "a lot," or "a bunch."

- *How often / how long have you completely lost sight of the roadway and shoulders?*
- Responses range from "never" up to 50 seconds or more, and nearly half the respondents indicate this happened between four and ten or more times in a season. The responses on "average duration" of a whiteout range from "4 to 9" to "50-plus" seconds.

- *Have you ever hit an object or run off the road due to low visibility?*
- Responses range from "no" to four and even six times. Causes noted include poor lighting, snow blowback, whiteout visibility, other traffic, and slick road surfaces

- *What helps you the most to stay in your lane while plowing in low visibility?*
- Most common answers were delineators, rumble strips, shoulder line, guardrail, work light on plowed lane stripe, other vehicle tracks, and watching striping in mirrors. Several drivers also commented that extra off-road lights installed on their trucks were useful.

One relevant comment from several of the ADOT plow operators was that this survey focused only on their most recent prior winter season, that of 1999-2000. While valid in defining a baseline, it did not really recognize the quite variable nature of winters in the southwestern United States. 1999-2000 was a relatively mild winter in Arizona, so many ADOT drivers did not have what they felt was a "normal" winter season to describe as requested in this survey. In that light, the Iowa-3M team recommended that their results be viewed as conservative.

There were one or two other survey aspects that might have been unclear to some ADOT respondents, and the drawback to anonymity is that no clarification can be made. ATRC had no direct involvement in the development of any of the Iowa-3M surveys, nor in their analysis. This approach preserved the consistency and neutrality of the 3M third party evaluation. However, it meant that ATRC could not help refine the relevance of the questions, nor aid U-Iowa in interpretation or clarification of answers about the somewhat foreign Arizona conditions, language and practices, nor discuss the ADOT training and operational program details.

Despite those concerns, in general, the baseline U-Iowa Forward Visibility survey provides much useful information on the conditions encountered when plowing in Arizona's winter storms. When their report is finally completed and published, it is expected that the University of Iowa will have included more detail about the Arizona responses and conditions, both as averages and as relative extremes. This information with regard to the other states in the baseline study may also be very useful to ADOT managers and supervisors in Arizona's mountain areas.

U-Iowa-3M: Arizona Mountain Areas Survey

3M also requested that the University of Iowa supplement the baseline Visibility Survey with another "mountain conditions" survey developed for the Arizona test program. At this time, there was no mountain experience with the 3M Lane Awareness System outside of the Upper Midwest, and so the Iowa-3M evaluation team had to develop a new set of questions to assess its potential to improve snowplowing performance. This two-page Mountain Survey was also an operating practices baseline survey to be used in the future as further advanced snowplow systems might be deployed.

One aspect of the Mountain Areas Survey was on plowing operations with unique geometric aspects such as tight turns, steep grades, uphill walls or banks, and shoulder drop-offs. It asked about full road closures for plowing and about how much of a plow route had drop-offs or obstacles. A second section of the survey dealt with practices and problems in regard to tandem plowing.

From the Arizona drivers' responses to the Iowa-3M supplementary survey, the following significant conclusions on plowing in mountainous terrain are <u>excerpted</u> from their preliminary report:

- In the survey, drivers evaluated to what extent roadway characteristics contribute to poor forward visibility. It is interesting to note that drivers gave the highest scores to 'roadways with a high downslope or upslope gradient' and to 'tight turns'; narrow shoulders followed closely, and "narrow roadway" seemed to contribute to poor forward visibility the least often. If magnetic tape for the Lane Awareness System could be installed only on certain portions of the roadway, however, it appears that it should be where there is a high downslope or upslope, as well as where the turns are tight and the shoulders narrow.

- Drivers were also asked which lane markings they use as guides during low-visibility conditions. A third answered that they use the centerline as a reference, with another third divided between the left and the right shoulder line. The last third indicated that they use 'other cues', which included delineators and other shoulder fixtures such as guardrails and trees. These findings are interesting in that they suggest that visual cues such as delineators are as important, if not more important, than lane markings.

As to tandem plowing operations, a significant aspect of the ADOT program across the I-40 Corridor:

- Most of the time while plowing in tandem, snowplow drivers indicated that they used 'the feeling of the rumbling strips on the shoulder' to help maintain their lane positions during *poor* forward visibility conditions. The other cues most frequently selected were 'evaluating distance from milepost delineators', and 'feeling the crown of the road.' However, when drivers were asked which of a possible thirteen cues helped them the most in maintaining lane position, they ranked 'evaluating distance from milepost delineators' as being the most important. This finding corroborates the information mentioned previously.

- Finally, when asked about the advantages and disadvantages of tandem plowing compared to single-vehicle operations, most drivers indicated that the main advantage was that it made it possible to get the roadway cleared faster or more effectively (i.e., possible to do more than one lane at once). Other advantages included the fact that the traveling public does not have a chance to pack the snow before it is removed or to throw new snow (slush) into the just-cleared lane, and that two or more plows means there is someone to count on if something were to happen. Amongst the disadvantages, the most prominent was the greater risk of involving two plows in a crash—either by both running off the road, both being hit, or one running into the other. The other disadvantages listed were the fact that traffic tended to back up behind the plows and that the benefits of plowing in tandem were lost if one snowplow vehicle could not keep pace with the other vehicle.

- Although not directly linked to the purpose of this survey, the most frequently cited comments or suggestions dealt with the need for better lighting systems for snowplow vehicles. Here, as in a survey distributed widely through the Iowa and Minnesota DOTs, drivers commented on the need for better defroster/wiper systems, as well as for better side-view mirrors. Finally, some drivers mentioned the need for better road markings such as using more delineators.

Among the comments from the ADOT operators' mountain survey supplement were the following points on tandem plowing:

Iowa-3M Question No. 10: What would you say are the advantages and disadvantages of using tandem plowing rather than single-vehicle plowing during low forward visibility?

Advantages
• Can clear the roadway faster. (7 respondents) • Can clear two or more lanes at once. (6 respondents) • Less chance of throwing snow back onto the driving lanes, or of traffic to pack it down. (2 respondents) • Cover more miles with abrasives and fewer passes. (2 respondents) • Having someone you can count on if something happens. (1 respondent)
Disadvantages
• None. (2 respondents) • If something happens (e.g., tie-up, crash, running off the roadway), there is a risk that the all snowplow vehicles in tandem will be involved, rather than just one vehicle. (2 respondents) • Risk of hitting the other(s) snowplow vehicles. (2 respondents) • Traffic tends to back up behind the snowplow vehicles. (1 respondent) • Having to wait or travel slower to wait for the other snowplow vehicle(s). (1 response)

In their first attempt to develop specific information related to specific conditions and practices in Arizona and other mountain states, the University of Iowa developed a number of sound conclusions, some of which may seem fairly predictable to ADOT personnel. Nevertheless, establishing a baseline for future research was a very important goal of these surveys, and frequently the results when viewed in detail can contain surprises and valuable lessons for any agency involved in these activities.

U-Iowa-3M: Arizona Training and Evaluation Survey

To follow up on the baseline surveys at the end of the 2000-2001 plowing season, the University of Iowa sent a two-page survey to ADOT snowplow operators who had received training on the 3M Lane Awareness System. A total of 16 out of 17 anonymous surveys were completed and returned.

The survey had 32 items organized into five separate sections. The first section was seven questions on the drivers' training with the 3M System and other systems; the second had 13 questions evaluated their actual experience with the 3M System. The third section focused on driver trust and confidence in the system (five questions), and the fourth section asked for suggestions on how to improve the system (four questions). Three last questions asked about the safety benefits of such systems.

In addition to distributing this Iowa-3M survey, ATRC also provided copies of the ADOT Snowplow Training and Evaluation Survey, and Team Leader Activity Reports, to the University of Iowa. Since ADOT operators completed these specifically for the 3M Lane Awareness System, some of those findings are included in the Iowa post-season summary report.

Some of the most relevant findings and conclusions from the Iowa-3M supplementary survey, with additional data from the ADOT project reports, are excerpted below:

- To anchor drivers' opinions about the 3M System, we also asked about their experiences with other lane awareness systems. Almost every one (93%) had used the California Department of Transportation (CALTRANS) system before. While we did not ask drivers how many hours they had spent using the CALTRANS system, we did ask which of the two systems they preferred and why. Drivers liked both systems—43% preferred CALTRANS while 57% favored 3M. The advantages listed for the CALTRANS system included the visual display (ability to see the curves in the road) and the collision warning capabilities. Where the 3M System was preferred, drivers indicated that they liked the seat component and the fact that it relieved them of the need to look at the visual components. Three people simply indicated that the 3M was the 'better, easier, and simpler system.' Overall, drivers found both systems attractive, but indicated a slight preference for the 3M System.

  - When asked "Why did you prefer this system?" the driver comments included:

Caltrans
• When cornering it shows the curve in the highway
• Collision warning, (display) bars
• The visuals were easier to watch
• Better graphics
3M System
• Better visibility and don't have to look at screen
• Better, easier, simpler system (3 respondents)
• Because of the arrow

- Of the three warnings available (i.e., visual scale display, peripheral flashing lights, and seat vibration), the seat vibration was by far the preferred warning. Drivers rated seat vibration 'extremely useful' (average ranking of 6.2 on the University of Iowa survey) and reported that this feature significantly increased their perceived level of safety, as indicated by an average ranking of 9.1 out of 10 on the ADOT survey. Comments in the Team Leader Activity Reports echoed these findings. Drivers indicated that they liked this component because it allowed them to keep looking forward to the road. They also liked being able to adjust the intensity of the vibration (11 out of 16 respondents).

- In general, drivers' experience with the system was positive. Apparently, the 3M System did not prompt any driver to an erroneous action or judgment (14 out of 16 respondents), and most had no difficulties with the system (12 of 16). Drivers indicated that, in general, the 3M LAS made them 'much more' aware of their lane position—they ranked this item highly, with an average ranking of 5.9. In addition, respondents felt that the warnings enabled them, or would enable them, to respond quickly to a lane departure (average ranking of 5.8). The ADOT survey also reflected drivers' general satisfaction with the system. Drivers rated the display and warnings an average of 8.6 (1 to 10 scale) in terms of being clear and easy to understand. They also felt that the lane awareness system provided them with enough information to be useful (average 8.6) and that the system responded quickly enough to be useful (average 8.9).

- Drivers did not seem to think, however, that the 3M System would reduce their workload significantly and thereby help them to allocate more resources to other tasks, such as radio communications (average 4.4 out of 7). They indicated that the system might help them a little (4.8) to spend more time looking for stopped vehicles or objects in the roadway. They also felt that it augmented their traditional outside visual cues (4.9). Overall, drivers felt that the system was useful but would not ultimately impact their workload (average ranking of 4.3).

- In both surveys, drivers were asked about the safety benefits of the 3M System. On the ADOT Snowplow Training and Evaluation Survey, drivers indicated that the system had a very high potential of improving their safety, giving an average ranking of 9.2 on a scale of 1 (not at all) to 10 (completely). They felt similarly about the system's ability to improve motorists' safety (average of 9.1). The University of Iowa survey responses were similar—on a scale of 1 to 7, drivers rated the 3M System's ability to improve their safety an average of 5.8. They also indicated that the system had good potential for improving their efficiency (average 5.7); this item on the ADOT survey received an average ranking of 8.4 out of 10.

Finally, ADOT operators offered the following comments on the 3M Lane Awareness System and its related features, and some suggestions for improving snowplow vehicles or snow removal operations:

- Encountered white-out conditions and we used the system to find the road.
- The screen is still a little busy or cluttered. It needs to be simplified even further. A distinct improvement over screen in CALTRANS truck.
- Would be nice to use during snow conditions to get feel for actual effectiveness.
- Put display on a head-up – reflected on windshield.
- (Show) when there is a turn or an increase or decrease in grade.
- Put the sensors higher on the truck.
- The system needs something to indicate an oncoming traffic.
- The collision warning system needs to be fixed to have all the safety features.
- The VORAD system needs to be repaired for further safety during whiteout conditions.

General comments on winter maintenance from the ADOT operator pool:

- Better lighting on the plows – they need to be mounted differently (i.e., lower) and have a different light color, especially for night operations. One driver suggested to add curb lights aimed at the side of the road, with an ability to turn either the right, left, or both on.
- Better wiper system and defroster for windshield, as well as electric wipers and heated mirrors.
- Better road delineation, such as installing delineators every 500 ft, with yellow over green on median side (e.g., interstate).

- Drivers should slow down and stay alert to traveling public, for slide-offs, etc. They should make sure that their equipment is in good working condition. ADOT should provide more training for new employees in actual plowing situations.

Conclusions – the University of Iowa-3M Evaluation

The 3M-sponsored evaluation by the U-Iowa human factors team was very thorough and detailed. Many of the results from the larger multi-state operator surveys are quite relevant to ADOT's future planning, and certainly the Arizona surveys provide valuable support to the ongoing research program.

It is noteworthy that the University of Iowa, in their report on the operator interface design, made the point that the display was designed as the final reference for the system, not the primary warning or driving guide. The human factors design intent was for the sensory warnings to inform the driver without his having to shift his eyes from the roadway ahead. This principle is clearly the opposite of the Caltrans predictive display design, which combines its several types of key driving information on the driver's screen.

In fact, U-Iowa noted that because the display screen was so prominent in the cab, and because of the emphasis of 3M's training and marketing materials, drivers in the Minnesota field tests felt compelled to depend primarily upon it. The Iowa team noted that drivers in general today may have expectations from other technologies, such as the Caltrans ASP, various head-up displays, or other commercial telematics products, that the primary interface would be visual. This is a significant issue that should be considered in future ADOT training and IV system evaluations.

In general, the Iowa team reported that interaction with and survey feedback from the snowplow operators was the key to any successful system design, stating that "many product designs fail because they do not include input from the ultimate users." They also noted that these interactions gave them a better perspective on state and local funding limits as a critical factor in system design decisions.

The final recommendations from the University of Iowa are very supportive of, and significant to, the Arizona research program. They reflect favorably on ADOT efforts as guided by this project's Technical Advisory Committee. Basically, the key U-Iowa recommendations are for a collision warning system and for a navigational unit to provide information on the roadway being plowed. As noted before, Caltrans has installed both of these systems on its ASP on US 180, and the ADOT-3M snowplow on US 89 has the (currently inoperable) Eaton VORAD radar system.

One other significant recommendation is to develop a truck simulator with a snowplow cab and controls. Because of the vagaries of winter weather, and the difficulty in getting experienced plow operators from other areas to come to the test sites during major storms, this is the logical way to train operators and to evaluate the effects of driver-assistance systems. The topic has been considered by ADOT but currently costs are prohibitive. The project TAC suggests that perhaps other partner states such as Iowa or Minnesota, or a pool of states, can support such research and development in the future.

The full report on this operator interface design and evaluation program by the University of Iowa (McGehee and Raby) will be published in 2002, as indicated in the References section. [2]

CONCLUSION:

RESULTS OF PHASE TWO – WINTER 2000 – 2001

XV. PHASE TWO RESEARCH SUMMARY – THE THIRD YEAR

The Crucial Year: Winter 2000-2001

The Phase Two Advanced Snowplow research program in Arizona, from mid-2000 to early 2001, was the most involved and most rewarding such effort for ADOT since the first Caltrans magnets were installed at six sites along I-40 for materials tests in January 1998.

In this third year of the project, ATRC and the core of sponsoring ADOT Districts committed to procure and install a complete array of Advanced Snowplow equipment on an ADOT plow truck. This initiative would give Arizona its own local testing and training facility for the full extent of the winter, and in years to come as well. It would provide full-winter evaluations in Arizona conditions, and give the plow operators more long-term experience and confidence with each storm that occurred.

ADOT's first goal was to acquire a Caltrans snowplow equipment system, using the ASP magnet-guided concept. This ultimately was not feasible, and the ADOT Advanced Snowplow was equipped with the off-the-shelf commercial 3M Lane Awareness System. Other key ASP components were the Eaton VORAD EVT-300 Collision Warning Radar, as well as the GreyLink 1000 Automatic Vehicle Location system.

Joining with 3M in this venture required ADOT to install 3M's magnetic striping tape in the roadway, creating a continuous low-strength magnetic signal for the snowplow to track while in motion. The test site selected was on US 89, about ten miles northeast of Flagstaff, where five miles of tape were installed in the Sunset Crater area. Placing the tape on the centerline of the two northbound lanes gave ten lane-miles of magnetic-guidance infrastructure at this test site.

The partnership with Caltrans was not affected by the decision to acquire the 3M lanekeeping system, and plans were made for a third season of training and operational plow tests with the Caltrans ASP in February. Arizona at this point had developed two complete infrastructure sites, with the Caltrans magnets and with 3M magnetic tape, for a total of 16 lane-miles. Training would be done on both systems, and the ADOT-3M plow would be used in the field all winter long. During the February '01 tests, ADOT would be able to assign two Advanced Snowplows to training and plowing operations on two mountain roadways just 30 miles apart.

Circumstances and Realities

Looking back at the positive factors from this third year of the project, it was an excellent winter for testing snowplows. The winter of 2000-2001 was about ten percent above average in snowfall for northern Arizona, based on the figures for the Flagstaff region, and 125 inches of snow were recorded. For ADOT's research program, however, a series of major issues arose, most of which could not have been predicted and could not be mitigated. As a result, the project did not develop a full set of data on either snowplow, for the training program or for the operational evaluation.

Briefly reviewing the obstacles that arose, perhaps the greatest single issue was the temporary striping on the new 3M test lane at Sunset Crater. Because the roadway was carrying two-way traffic through the winter, the striping did not at all match up with the alignment of the embedded 3M magnetic tape. Another obvious problem for the US 89 test program with ADOT's new in-house research snowplow was the decision by 3M in December to withdraw from the snowplow guidance market. Despite excellent ongoing technical support, the system could no longer be a viable option for deployment.

Certainly the ADOT research plow carried other IV systems for evaluation. However, the breakdown of the collision warning radar, and unresolved repair issues, meant that the entire winter would pass without the ability to test and evaluate this critical vehicle safety system. It should be noted, however, that the blind-side radar did not fail.

When February arrived, and with it the Caltrans ASP for training and testing, the schedule was set back by eight days of systems troubleshooting, with California's own collision warning radar system as the primary issue. While a great deal was still accomplished at the test site on US 180, the end date of the Caltrans schedule was firmly fixed, and ADOT was able to effectively utilize the snowplow for only two weeks.

Finally, the AVL system was functional in its first year of deployment, however, the major issues of cellular coverage and cell service traffic loads were definite problems. Considering the difficulties in contacting the test vehicles, and the limited time for ADOT's operations staff to become proficient, the AVL system's tracking abilities were proven, but the level of success was quite limited.

Phase Two Results

ADOT achieved some very significant results in Phase Two, in this critical third year of the project. While beset by unexpected problems, the goals of training and operations at two mountain snowplow test sites were achieved.

Approximately 25 snowplow operators from eight maintenance camps in three ADOT Districts were trained on one or both of the advanced snowplows. Seven Team Leaders were involved, to varying degrees, and at least four of these operators were able to use the two Advanced Snowplows during regular plowing operations during significant winter storms over several months in 2000-2001.

Records show that the two snowplows accumulated nearly 3,000 miles of day and night plowing on their assigned routes on US 89 and US 180, in a dozen winter storms and many more call-outs. The ADOT plow was driven nearly 7000 miles over the winter, without damage or new failures of its operating IV systems. As noted earlier, the Caltrans snowplow actually recorded more than 60 percent of its Arizona mileage in plowing operations during its few weeks of activity.

At both sites, the 3M or PATH magnetic infrastructure media was installed at the one most critical segment of each plow route. The Team Leader drivers frequently commented in their activity reports, and in the surveys, that the systems had improved their confidence and helped them stay on track in their lane, during poor visibility and with heavy snow on the roadway.

The determination of the real cost of the systems to ADOT is somewhat complex. While 3M enabled the project to go forward by sharing the cost of the vehicle system and the five miles of tape, the Flagstaff District and the ATRC had other budget concerns with prime and sub-contractor costs.

The 3M Lane Awareness System as installed on US 89 was valued at $14,500 for the truck equipment and $130,000 for five miles of tape. While some costs were shared, other contract costs were added. The value of the 3M tape infrastructure installed on the road centerline position, with two lane-miles covered with each mile of tape, therefore approximated $13,000 per lane mile.

This figure compares to the $17,500 cost of the Caltrans magnets installed by ADOT, as noted in ATRC's Phase One project report. That cost, however, is based on ADOT's low wages and other participation, such as equipment loans and other resources, and without any profit or fee factors.

The key results of this project in the 2000-2001 winter season are twofold. ADOT completed the development of a second independent test site, and also maintained the long-standing successful research partnership with Caltrans. Despite setbacks and constraints, ADOT's Flagstaff District carried out extensive training and plowing operations, keeping key Arizona highways open with advanced snowplow IV technologies. With all systems fully operational, more could have been accomplished.

The results of the ADOT evaluation program were also significant. ATRC brought a neutral third party into the research program, Northern Arizona University, which conducted extensive surveys and interviews with all levels of project stakeholders. The NAU team also collaborated effectively with the evaluation programs of California and Iowa, enabling refinements of the work products for all concerned. With a larger sample size, more consistent training schedules, and all vehicle systems operational, more could have been achieved.

Recommendations

Based on the achievements of this research project in Phase Two, the ATRC strongly supports further research efforts in the coming winter of 2001-2002. It is clear that much more can be gained from this research program in the coming winters, when both the test site and the IV system problems have been resolved, repaired, or replaced. The key recommendations arising out of Phase Two are:

- Calibrate and commission the 3M Lane Awareness system on US 89 as soon as construction ends and the permanent northbound lane striping is in place. Maintain a close working relationship with 3M for future support to the deployment, at ADOT cost.

- Repair the Eaton VORAD EVT-300 collision warning radar or replace it with another suitable system. If possible, evaluate the SmartCruise feature during the summer season.

- Continue the Caltrans partnership on US 180. Request full vehicle systems servicing prior to shipment to Arizona next winter. Request Arizona data collection on-board, as the vehicle is equipped to do. Based on driver comments, suggest Caltrans deploy the 3M vibrating seat.

- Resolve phone line and modem issues with the GreyLink AVL system. Seek additional training materials and classes for ADOT staff. Renew the software maintenance agreement.

- Extend the evaluation agreement with Northern Arizona University. Seek additional funding to enable a higher level of effort for NAU in the field, and in final data analysis and reporting. Refine the key studies, such as deployment estimates by management, from Phase One.

- Upgrade existing equipment and pursue new systems and concepts as the TAC may direct, with available resources. One issue from the stakeholder surveys is improved visibility. ATRC should study night vision systems, other vehicle radars, improved displays and warnings, etc.

- Expand the training and evaluation program at ADOT's two advanced snowplow test sites, to involve more maintenance personnel and other stakeholders from other parts of Arizona.

- Ensure that training is consistent for all generations of operators. The training should emphasize the unique aspects of each system design, and the non-standardized hierarchies of warnings which vary for each proprietary system (lights, chimes, vibrators and/or displays).

ADOT's Advanced Snowplow Program Summary

This advanced snowplow systems research program offers very significant benefits to ADOT and the public, in both safety and efficiency. The one principal goal of this project is to support Arizona's snowplow operators.

Figure 20: Caltrans and ADOT Snowplows "In The Barn" in Flagstaff

By improving the ability of the plow truck to keep moving in poor visibility, and to identify obstacles or hazards in the roadway, the risk of a collision from ahead or being struck from the rear will be lessened. By better monitoring of snowplow locations, materials usage, and plowing progress, supervisors can better manage the regional effort to clear the roadways, and can also respond much more quickly in situations that affect snowplow operator safety.

The Arizona Transportation Research Center has the resources and the funding for future research activity through this Advanced Snowplow project. With continuing stakeholder and vendor support, ATRC expects that a future Phase Three, with all systems fully functional, will resolve the key issues about the potential of these IV technologies for rural states such as Arizona.

APPENDIX A

EVALUATION PROGRAM WORKSCOPE -WINTER 2000-2001

Attachment A - Arizona ASP Test Plan – December 2000 – February 2001

Attachment B - Caltrans ASP Evaluation Questionnaire 1999 / 2000

Attachment C - ADOT-ATRC Test Record / Operator Evaluation 1999 / 2000

APPENDIX A

Arizona Department of Transportation
Advanced Snowplow Project (SPR 473)
Evaluation Program Workscope
Winter 2000 - 2001

A - Background:

The advancing field of intelligent vehicle (IV) technology offers many advantages to both light and heavy highway vehicles. In particular, specialty vehicles that must operate in all types of severe weather conditions are ideal candidates for such systems. These include emergency vehicles such as fire, police, towing, and medical, and key public agency units such as snowplows and school buses. In the worst of conditions, the greatest increases in public safety and highway system efficiency may be realized.

The Arizona Department of Transportation (ADOT) initiated an intelligent vehicle research project in late 1997 to explore the most practical benefits from IV technology for a state DOT's vehicle fleet. Based on severe weather and safety issues, northern Arizona was selected for tests of technology to improve winter maintenance safety and efficiency.

A cooperative research partnership was established in early 1998 with the California Department of Transportation (Caltrans) to jointly test and evaluate their prototype magnet-guided Advanced Snow Plow in Arizona's winter conditions at a test site near Flagstaff.

In the past two years, ADOT has installed six miles of roadway magnets on US 180 for the Caltrans system, and has conducted one month of testing each winter with the shared snowplow unit. This Caltrans truck also features integrated collision warning radar (CWS), and has a GPS-based automatic vehicle location system (AVL) for tracking its progress.

In mid-2000, ADOT significantly expanded this research program. An agreement was reached with 3M Corporation to evaluate their commercial lane-keeping system, using embedded magnetic tape, in the Flagstaff area. ADOT installed 5 miles of 3M magnetic tape in the roadway on US89, and installed 3M's commercial guidance system in a snowplow to monitor its position over the embedded tape. The ADOT vehicle will also have CWS and AVL systems, to be consistent with the Caltrans truck's equipment.

B - ADOT Evaluation Program:

This project's 2000-2001 deployment of a second advanced guidance concept will require an evaluation program to compare reliability and durability of the competing systems in Arizona weather and operational conditions.

ADOT intends to employ a Consultant for a third-party, neutral evaluation of the two similar but competing vehicle guidance systems. The proposed winter evaluation program will focus on operator reactions to the "driver assistance" guidance systems, and also to a lesser extent on the secondary collision warning and vehicle location systems. Each plow will carry similar secondary systems to reduce the perceived differences between trucks, and so to maintain the operators' focus on use of the lane-keeping guidance technology.

C - 2000-2001 Evaluation Program Basis:

The evaluation program goals to be accomplished by the Consultant and ADOT are:

1. The primary goal is to evaluate and compare the two advanced guidance systems, to support deployment recommendations.
2. The secondary goal is to evaluate the stand-alone commercial radar and AVL systems on the snowplows, to support field deployment of one or both systems.

ADOT desires to jointly develop an evaluation program that first, will use any and all of the proprietary survey responses gathered in Arizona by Caltrans and the 3M Corporation. Both system vendors have specific internal goals and have developed evaluation surveys focused on their own unique guidance systems (sample – Attachment B). Approximately twenty of these first-tier, baseline questionnaires will be filled out by all trainees on each of the two snowplow systems, to be provided to the evaluation team for analysis and interpretation.

The Department will develop and conduct a second level of survey for snowplow Team Leader operators. They are responsible each day for logging the training activities, roadway and weather conditions, traffic status, incidents, and other operating constraints during the training and evaluation phases of the program (sample – Attachment C). This Team Leader survey will also assess performance of the secondary radar and tracking systems on the two snowplows.

Finally, the evaluation team and project staff will jointly develop third-level ADOT goals surveys aimed at the local, District, and Departmental-level staffs. This may involve the Team Leaders, technical and operations support personnel, maintenance supervisors, District staff, the State Engineer, and other key stakeholders. These surveys, conducted by the third-party consultant evaluation team, will gather additional information relevant to ADOT's specific goals, operating plans and practices, and other unique requirements.

ADOT's key concerns include the ease of training, ease of use, accuracy, reliability, operator level of confidence, improved safety, improved efficiency, human factors, and, the cost and benefit measurements needed to support any future Arizona deployment decisions.

D - 2000-2001 Evaluation Program Tasks:

During the Winter 2000-2001 testing season, with support from the ATRC and the project TAC, the Consultant will perform at least the project tasks listed below. Attachment A is the current draft of the program schedule. Since the plowing season may finish by mid-March, it is desired that this evaluation study should be completed in April, 2001:

1. Participate in two ADOT planning sessions, two hours in length, to be held in Flagstaff.
2. Attend project Technical Advisory Committee (TAC) meetings, two hours in length, held roughly every six weeks. During testing season, assume four meetings, all in Flagstaff.
3. With TAC guidance, incorporate identified ADOT goals and information needs for this program into a new third-level stakeholder survey worksheet (as described above).
4. Receive first and second-tier evaluations from ADOT for participating plow operators. Review, analyze and summarize this lower-tier evaluation data for the test program including performance and utility of the guidance, radar and tracking systems.
5. Participate in a limited ride-along orientation for each system, either during initial training or during winter storm operations. Assume one half-day orientation for each system.
6. Conduct third-tier surveys and interviews with Team Leader operators, ADOT's project partners, and Departmental support and management personnel. This activity would be limited to one day for each guidance system, plus one day with support staff and stakeholders, and may also involve additional phone interviews and / or mailed surveys.

7. Receive, review and summarize all ADOT-provided testing activity logs, historical records on weather conditions and storm data, traffic data, accident records and other related snowplow operational information.
8. Compile, summarize and interpret all of the collected information.
9. Produce a written Evaluation Task Report, summarizing all of the above activities and relevant information. Report on evaluation goals, activities, conditions, issues, operator inputs, overall results and recommendations for the winter test program. This evaluation report will be included as a chapter in the future ADOT-ATRC research project report describing this year's snowplow guidance program.
10. Make a summary evaluation project presentation to the Technical Advisory Committee.

E - Program Responsibilities

ADOT, the Transportation Research Center and the project TAC will provide all possible support to the Consultant as noted above. The quality or consistency of data, however, may be variable and the evaluation effort should recognize and accommodate any such shortcomings. Conclusions should be based on the extent of valid and comparable data.

The ADOT project team will collect and provide the following information for the evaluation, to the extent that they are available:

- First tier vendor evaluation surveys for 3M and Caltrans systems (~20 each).
- Second tier reports / summaries of training and operational activities, by the Team Leader operators.
- The Department's goals and objectives, to aid the Consultant in developing the third tier stakeholder survey.
- Weather records from regional monitoring sites for training and testing time periods.
- Historical weather data for relevant regional sites.
- Historical traffic ADT data for the two test site areas.
- Accident records for the test site snowplow routes and test areas.
- Accident and related cost information for snowplowing operations on the test routes.
- Contact information for conducting interviews and surveys.
- Descriptive, technical and training information on the primary and secondary systems being evaluated.

F - Evaluation Program Constraints:

ADOT wishes to conduct a limited but fully valid first-year program to evaluate the two competing snowplow systems. Due to ongoing construction at the Sunset Crater site, there are certain <u>temporary</u> constraints this year on US 89 that will prevent direct comparisons in operating efficiency. If this initial evaluation is successful, a more extensive program will be considered for the next winter. However, the two highways are by no means identical and the design and traffic variations will always be a factor in comparing the guidance concepts.

Because the training schedules for the two ASP test programs differ, this evaluation project will primarily focus on the February 2000 testing period. At that time, the Caltrans system training and evaluations will be conducted on US 180, followed by the Team Leader operational evaluation phase. Prior to and concurrent with this activity, the 3M system will be operational on the ADOT snowplow on US 89. Thus the long-term operational evaluation in storm conditions with Team Leader personnel will be done at this time for both systems.

The program's continuity lies in the use of the same operator pool for the initial training on each plow, and the Team Leader core group performing second-phase crossover activities between the two testing sites. By collecting lower-tier evaluation surveys from the trainees and by working with the Team Leaders, the desired continuity can be achieved.

G - Evaluation Program Background:

Attachments B and C are sample worksheets from previous winter training and demonstration cycles with the Caltrans snowplow on US 180 in northern Arizona. The test program for the last two winters (March '99 and February '00) was basically the same. Caltrans staff and contract personnel from their project partner agencies conducted the evaluations. The evaluation forms completed for the past two winters, and the Caltrans annual project reports which detail those efforts, are available for reference.

ADOT participated each winter in a formal program of demonstration rides and hands-on tests of the systems with some 15 to 18 ADOT plow operators, representing the three northern districts of Arizona. Of those, three drivers were initially trained by Caltrans and PATH as Team Leaders / instructors. These three drivers then carried out the rest of the training program.

Each season, ADOT conducted approximately two weeks of training and half-day evaluations, and then operated the Caltrans plow as a normal fleet vehicle for an additional two weeks, mostly on dry roads. Some night-time testing was done during brief storm events, and operators drove the plow over the full assigned route during the significant snowstorms.

ADOT's operators were very enthused about the systems on the snowplow, despite radio problems that reduced effectiveness, and they made numerous comments and suggestions. For the winter of 2000-2001, even more constructive input is expected.

Attachment A - *sample*

Arizona ASP Test Plan
Caltrans Advanced Snowplow *and* ADOT-3M Snowplow
December 2000 - February 2001

1. 3M System Testing & Evaluation Schedule (November 2000 – March 2001)

• 3M Install, Site Test & Commissioning:	*September 26/27 - ***done***
• Core Staff / Team Leader Training by 3M:	*September 27/28 - ***done***
• Planned AVL and Radar Systems Install:	November (dates to be confirmed)
• LTAP Snow Control Conference (Pinetop):	November 8 / 9 – w/ 3M and Logistixx
• **Student Operator Training & Evaluation**:	**Late November and December**
• Long-Term Field Evaluation -	From November onward
• Phases of Evaluation (?) -	Early Winter vs. Late Winter
• Demo Day (?) -	***TBD***

2. 3M System - T&E Workplan – Project Goals and Tasks

- Confirm Snowplow System is Operational – Care & Maintenance Procedures - ***done***
- Confirm Infrastructure Conditions at Test Site / Resolve Striping Issues - ***done***
- Concurrent Evaluation of Peripheral Systems – Radar and AVL
- Training of & Evaluations by Team Leaders - ***training by 3M and TL Self-Training***
- Training of & Evaluations by (20?) Student Operators – 3 Districts – 5-day weeks
- Long-Term District Evaluation – Gray Mountain Maint Yard - Use Plow on US 89
- Test site: Sunset Crater area – US 89 Northbound Lanes MP 428 to 433
- Full Snowplow Route – East Flagstaff to Antelope Hills (US 89 MP's 418 - 440)
- Demo Day – Local Agencies / Community Relations / Media (??-waiver issues)

3. Caltrans Testing & Evaluation Schedule (February 5 / March 2, 2001)

• Initial Site Testing & Commissioning:	February, Week 1 (M – W)
• Initial Training – Core Staff / Team Leaders:	Week 1 (M – W)
• Student Operator Training & Evaluation:	Weeks 1 & 2: **Feb 5 → 16**
• Long-Term Field Evaluation -	Weeks 3 and 4
• Demo Day (?) -	***TBD***

4. Caltrans T&E Workplan – Goals and Tasks

- Accept Snowplow from Caltrans Staff – Confirm Care & Maintenance Procedures
- Installation of Spare ADOT Radio – by DPS Radio Shop – Coordination by District
- Confirm Infrastructure Conditions at Test Site – Field Repairs or Changes
- Training of & Evaluations by Team Leaders
- Training & Evaluations by Stakeholder Operators – 3 Districts – same group as w/ 3M
- Long-Term District Evaluation – Flagstaff Maint Yard - Use Caltrans Plow on US180
- Full Snowplow Route – MP 215 (Flagstaff) to MP 250
- Test Site at Kendrick Park – Both directions, MP 235 to 238
- Demo Day – Local Agencies / Community Relations / Media (??-waiver issues)

5. Snowplow Project Workplan 00-01: Partners Goals and Elements

5a. Caltrans Goals:

- To Test and Document Upgraded Systems & Displays in AZ Conditions - - -
  - With ADOT Winter Maintenance Operating Practices
  - With Independent Pool of Skilled ADOT Operators
  - With Two-Lane Roadway – Oncoming Traffic & Shoulder Obstacles

5b. 3M Corp Goals:

- To Test and Document Commercial Systems & Displays in AZ Conditions - - -
  - With ADOT Winter Maintenance Operating Practices
  - With Independent Pool of Skilled ADOT Operators
  - With Two-Lane Roadway – Oncoming Traffic & Shoulder Obstacles
  - *Marketing / Outreach to Local and Regional Agencies*

5c. ADOT Goals:

- Operator Training – Skills, Acceptance Level, Learning Curve, Perceived Benefit
- Operator Contributions – Comments and Suggestions reflecting ADOT Perspectives
- Impartial third-Party Evaluation – Northern Arizona University or Consultant
- Evaluate Each ASP System - Efficiency & Safety Measurements vs Cost to Deploy
- Evaluate Durability and Reliability of Each Unique Infrastructure
- Evaluate 3rd-Party Commercial GPS Vehicle Tracking System (AVL)
- Evaluate 3rd-Party Commercial Vehicle Radar System (CWS)
- Technology Transfer Within Agency – Other Districts and Divisions
- Advisory and Demonstration to Other Partner Agencies

Attachment B - *sample*

Advanced Snowplow Evaluation Questionnaire
Caltrans ASP - 1999/2000

We would like to ask you some questions regarding your opinion of the driver assist system. We will not be recording your identity and this information will not associated with you or be used as a means of evaluating your performance. We are only interested in evaluating the system. We may share this with Caltrans/Arizona DOT.

Your participation is voluntary. You are free to refuse to take part. You may refuse to answer any question and may stop taking part in the study at any time. Whether or not you participate in this research will have no bearing on your standing in your job.

How long have you been driving snowplows?

How much time have you logged on the Advanced Snowplow?

For the following questions, please circle the number of your choice:

1) How easy is the system to use overall?

   (Not easy at all) 1 2 3 4 5 (Very easy)

2) How much do you like the system overall?

   (Not at all) 1 2 3 4 5 (A lot)

3) If you had more time to practice with the system, would you like it more?

   (No) 1 2 3 4 5 (Yes)

4) Please rate the potential of the system to improve your safety:

   (Not at all) 1 2 3 4 5 (A lot)

5) Please rate the potential of the system to improve your efficiency:

   (Not at all) 1 2 3 4 5 (A lot)

Please answer the questions on the back/next page.

For each component (Collision Warning, Lane Keeping):

Collision Warning
How easy is this component to use?
(Not easy at all) 1 2 3 4 5 (Very easy)

How much do you like this component?
(Not at all) 1 2 3 4 5 (A lot)

Comments:

Lane Keeping
How easy is this component to use?
(Not easy at all) 1 2 3 4 5 (Very easy)

How much do you like this component?
(Not at all) 1 2 3 4 5 (A lot)

Comments:

How long do you think you would need to become comfortable with this system?

Please draw or describe what you feel would be an ideal display:

Attachment C - sample

ADOT–ATRC / US 180 SNOWPLOW TEST RECORD / OPERATOR EVALUATION

Site: US 180 – MP 235.0 -→ 238.0 (Kendrick Park Test Lane) – 1999-2000

Date: _______________ **Time Start:**_____________ **Time End:**________________

Name: _______________ Org No:________________ Org Name:_______________

** * SITE CONDITIONS DURING TESTING * **

	235.0 – 235.5 NB	235.5 – 237.0 NB	237.0 – 238.0 NB	238.0 – 237.0 SB – Return
CONDITIONS (check all that apply)	*Hart Prairie*	Kendrick Park	Steep Downgrade	Steep Upgrade
Wind (Speeds?)				
Snow Falling				
Sunny				
Cloudy				
Dark				
VISIBILITY				
Zero				
50 feet				
100				
200				
300				
Over 300 feet				
ROAD COVER				
Snowpack / Ice				
Slush				
Clear				
ACTIVITY				
Plowing				
Sanding				
Dry Test Run				

Operator's Background: Years of Snowplow Experience: _____ Hours on the Test Plow: _____

Satisfaction with Caltrans Driver-Assistance Systems (10 – best, 1- worst):

1 to 10 Scale - Ease of Use of Automated Systems: ___________________

1 to 10 Scale - Potential to Improve YOUR Safety: ___________________

1 to 10 Scale - Potential to Improve Your Efficiency: ___________________

Lane Position Indicator:

Did this feature Increase your level of safety ?? ___________________

How often did you look at the display screen? ___________________

Lane Departure Warning:

Did this feature Increase your level of safety ?? ___________________

Collision Warning System:

Did this feature Increase your level of safety ?? ___________________

Displays / Warnings:

Were these features clear and easy to understand? ___________________

Did the system provide enough information to be useful?___________________

Was the system response fast enough to be useful? ___________________

Comments and Recommendations (please use back of page):

1. Were there any system problems when you were operating the vehicle? (Describe):
2. Did the system ever lead you to make a wrong maneuver or error in judgment?
3. What suggestions would you make to improve any feature's usefulness to you?

APPENDIX B –

Caltrans ASP Evaluation Questionnaire - RoadView 2000 / 2001

APPENDIX B

Caltrans Advanced Snowplow Evaluation Questionnaire
RoadView 2000/2001

California Advanced Snowplow Partners would like to ask you some questions regarding your opinion of the driver assist system. We will not be recording your identity and the information will not associated with you or be used as a means of evaluating your performance. We are only interested in evaluating the system. We may share this with Caltrans / Arizona DOT.

Your participation is voluntary. You are free to refuse to take part. You may refuse to answer any question and may stop taking part in the study at any time. Whether or not you participate in this research will have no bearing on your standing in your job.

How long have you been driving snowplows? ____________________

How much time have you logged on the CA Advanced Snowplow? ____________________

Did you experience this system last winter? Yes No (If "No" skip to Question 2)

For the following questions, please circle the number of your choice:

1) Is the system better than last year?
   (Not at all) 1 2 3 4 5 (A lot)

2) How easy is the system to use overall?
   (Not easy at all) 1 2 3 4 5 (Very easy)

3) How much do you like the system overall?
   (Not at all) 1 2 3 4 5 (A lot)

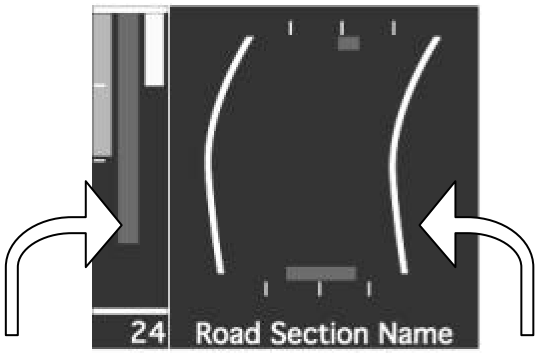
4) If you had more time to practice with the system, would you like it more?
   (No) 1 2 3 4 5 (Yes)

5) Please rate the potential of the system to improve your safety:
   (Not at all) 1 2 3 4 5 (A lot)

6) Please rate the potential of the system to improve your efficiency:
   (Not at all) 1 2 3 4 5 (A lot)

Please answer the questions on the next page also.

For each *component* (Collision Warning, Lane Keeping):



Collision Warning

How easy is this component to use?

(Not easy at all) 1 2 3 4 5 (Very easy)

How much do you like this component?

(Not at all) 1 2 3 4 5 (A lot)

Comments:

Lane Keeping

How easy is this component to use?

(Not easy at all) 1 2 3 4 5 (Very easy)

How much do you like this component?

(Not at all) 1 2 3 4 5 (A lot)

Comments:

How long do you think you would need to become comfortable with this system?

Please draw or describe what you feel would be an ideal display:

Are you a trainer / team leader for a magnetic snowplow? (circle one):

Caltrans-ASP

ADOT-3M

APPENDIX C

ADVANCED SNOWPLOW EVALUATION PROGRAM
WINTER 2000-2001 - FINAL REPORT
Prepared by
AZ*Trans*: The Arizona Laboratory for Applied Transportation Research
Northern Arizona University

Attachment A - ADOT Snowplow Training & Evaluation Survey 00-01

Attachment B - ASP Research – ADOT Management Survey 00-01

Attachment C - ASP Training & Evaluation Survey Responses 00-01

Attachment D - ASP Management Snowplow Research Survey Responses

Attachment E - ASP Management "Other Winter Research" Responses

Arizona Advanced Snowplow Research Program
ADOT ECS File: JPA 00-193
Project: SPR-473 / R0473 08P
NAU: EGR373R

Advanced Snowplow Evaluation Program - Winter 2000 - 2001

Final Report

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15 December 2001

Prepared for:
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Arizona Transportation Research Center
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Advanced Snowplow Research Project
Evaluation Program
Winter 2000 - 2001
Final Report

PURPOSE OF REPORT

This is a final report to the Arizona Transportation Research Center of the Arizona Department of Transportation on the Evaluation Program for the Advanced Snowplow (ASP) Research Program conducted by AZ*Trans:* The Arizona Laboratory for Applied Transportation Research of Northern Arizona University. The Principal Investigator was Craig A. Roberts, Ph.D., P.E. with the assistance of Rachel LaMesa, Research Assistant.

EVALUATION PROGRAM GOALS

The goals of the Evaluation Program are to provide an independent evaluation of two major items: (1) the ASP operator training program and (2) the attitudes of the ADOT management personnel regarding the ASP research program. These evaluations rely on the interpretation of the judgments, opinions, and attitudes of involved ADOT personnel, and not on direct observations of the Principal Investigator. In other words, this is an evaluation of the perceptions of others, not a technical evaluation of the efficacy of the systems themselves. Direct observations of the snowplow systems were made during familiarization rides by the Principal Investigator (PI), but these were designed to acquaint the PI with the snowplow operator's general environment, work tasks, and the basics of the two advanced snowplow systems.

Two ASP guidance systems were evaluated, one developed by the California Department of Transportation (CALTRANS), and the other developed by the 3M Corporation (3M). One Collision Warning System (CWS) developed by Eaton VORAD was evaluated. One Automatic Vehicle Location system (AVL) developed by GreyLink was evaluated.

SURVEY INSTRUMENTS

In addition to participating in limited ride-along orientations for each of the two systems, two survey instruments were administered by ADOT and NAU:

1. *Snowplow Training and Evaluation Survey*—Administered to Trainers / Team Leaders (first tier) and Operators (second tier).
2. *Advanced SnowPlow Research Survey*—Administered to ADOT Supervisory and Management Personnel (third tier).

This final report presents the findings of these survey instruments supplemented by discussions and interviews conducted during this evaluation.

SUMMARY OF REPORT CONCLUSIONS AND RECOMMENDATIONS

The detailed data and analysis of this investigation are presented in the sections following this one. This section of the report presents an overall summary of all the conclusions and recommendations drawn from those data and analysis. This section is designed to be brief and the reader is referred to the later sections in this report for more detailed explanations of the conclusions and recommendations presented here.

Snowplow Operator and Motorist Safety

It is beyond the scope of this investigation to evaluate quantitative changes in safety to the snowplow operators and/or the motorist. The ASP systems would have to be deployed on a significantly more extensive basis than is available under this research program in order to gather meaningful "after" safety data. Besides needing more miles of test roadways, safety data typically requires approximately three years of "before" and three years of "after" data to be regarded as statistically valid.

When quantitative safety data cannot be developed, qualitative data can be gathered and evaluated. This was done. During discussions with several snowplow operators, "whiteout" conditions were universally described as being the most dangerous and accident-prone. Discussions were held with the two operators with the most experience on the ASPs during actual winter conditions. These are the Team Leaders who have the test routes as a part of the normal snowplow route; one had the CALTRANS test route and the other had the 3M test route. The conclusion was drawn that both of these operators experienced heightened degrees of confidence and increased feelings of safety when using the ASPs. Their experience in the ASPs during whiteout conditions gave them confidence that they could "handle" a whiteout should it occur.

This evaluation considers this increased sense of confidence and safety, coming from the two operators with the most actual snowstorm experience using the ASPs, to be a highly significant piece of qualitative evidence. It supports the effectiveness of both ASP systems to improve operator safety. No conclusion was drawn concerning changes in motorists' safety.

Comparison Between the CALTRANS and the 3M ASP Systems

A "Snowplow Training and Evaluation Survey" was administered to the ADOT ASP trainers and trainees. On this survey, the trainees ranked various attributes of a system on a scale of 1 to 10 and gave their comments and recommendations.

A direct comparison between the CALTRANS and the 3M systems yielded no statistically significant differences between the two systems' ratings by the trainees. Therefore, it cannot be concluded that one ASP system was superior to the other.

An evaluation of the comments and recommendations of the trainers and trainees did yield some differences between the two systems that are useful. The first is that the "3M vibrating seat" mechanism is a superior feedback mechanism. When the snowplow strays from its lane, this mechanism vibrates the same side of the driver's seat as the direction the plow is straying from the lane. The vibrating seat, of course, complements the screen's feedback capabilities. Only the 3M snowplow has the vibrating seat feature, but the CALTRANS system would benefit by adding it.

It is recommended that the "3M vibrating seat" feedback mechanism be added to the CALTRANS system for next year's research program.

The concept of a Collision Warning System (CWS) is considered a crucial system by the snowplow operators for safety. Observations and operator comments regarding the integrated CWS on the CALTRANS system were favorable in concept. The CWS on the 3M snowplow was inoperative during all the testing. This evaluation's impression is that the lack of an operative system on the 3M snowplow was considered a significant handicap by those operators that had training in both systems.

It is recommended that the Collision Warning System be a primary focus of investigation in next year's research program.

Training during actual snowstorm conditions is deemed difficult by ADOT because (a) the logistics of moving an operator from his home organization to the training site "just before" a snowstorm and (b) the lack of a sufficient number of trained snowplow operators at a trainee's home organization to backup his snow removal route during a snowstorm, while he is away at the test site. Acknowledging this, there is still no substitute for an evaluation by a trainee experiencing the system during actual winter snowstorm conditions.

It is recommended that at least a few trainees be given the opportunity to work the ASPs during actual winter snowstorm conditions in next year's research program.

Attitudes and Opinions of ADOT Supervisory and Management Personnel
A "Management Survey" was administered to supervisory and management personnel throughout ADOT. These included the District Engineer, Maintenance Engineer, Maintenance Superintendent, and Maintenance Supervisor of each ADOT District as well as appropriate people in Equipment Services and Senior Management. There was an 81% response rate. Several statistically significant conclusions could be drawn from this survey regarding the attitudes and opinions of this target group.

It is concluded that the target ADOT Management personnel firmly “Agree” that the ASP systems will (1) significantly improve the snowplow operator’s safety and that (2) they can be used effectively in all Districts having snowplow operations. They also “Agree”, with only slight reservations, that the ASP systems will (3) noticeably improve the traveling public’s safety and improve operations by enabling (4) operators to safely plow their routes faster and (5) Districts to keep their roads open much better during winter conditions.

An almost universal comment from all involved in the ASP project is the need to determine the costs and benefits. Toward this end, a crude estimate was made of the number of lane miles requiring embedded magnetic material in order to deploy an ASP system throughout the state. It is emphasized that this estimate was only inferred from the opinions of the target group. It is not a useful engineering estimate. Its only value is to give a very broad <u>magnitude</u> as to the possible extent of deployment needed statewide.

It is concluded that a very rough estimate of the magnitude of lane miles requiring embedded magnetic material to deploy an ASP system statewide is from 2,000 to 3,000 miles. A minimum value aimed at especially troublesome miles could be in the range of 1,000 lane miles.

While this evaluation is hesitant to provide even these rough estimates of the magnitude of a fully deployed ASP system in the state, the need to do so is compelling. Such estimates are needed for any type of cost benefit analysis, even one based largely on qualitative benefits. However, using these rough estimates will most probably lead to wrong conclusions because there is no basis whatsoever for estimating the uncertainty involved with these lane mile estimates.

It is recommended that each district be asked to prepare more accurate estimates of the lane miles requiring embedded magnetic material for a fully deployed ASP system in next year's research program. This will allow an estimate of potential costs to be made that has significantly more reliability.

The target group of supervisory and management personnel were asked about "reasonable" costs for an ASP system.

It is concluded that this target group believes the mean highest cost that would be reasonable for ADOT to pay is in the approximate range of $5,000 to $11,000 per lane mile, with a sample mean of $8,400 per lane mile. This assumes that the ASP systems are proven to substantially improve snowplow operator safety and efficiency.

If the crude estimate total lane miles is combined with this estimate of highest mean cost, a very crude estimate of total "desirable" funding can be made. In this case "desirable" means applying the highest reasonable cost per lane mile estimated by the ADOT supervisory and management personnel to the crude estimates of total lane miles needed to deploy the ASP system. This yields a "minimum" system wide "desirable" estimate of $9 million ($8,400 per lane mile times 1000 lane miles) and a more likely estimate of between $17 to $25 million ($8,400 per lane mile times 2000 to 3000 lane miles). These estimates are not related in any way to the current cost of installing an ASP system nor to a defensible estimate of the actual lane miles needing an ASP system. Again, they are only crude estimates without any basis for estimating the uncertainty involved with the estimates.

The wide range in these estimates reinforces the earlier recommendation that a more accurate estimate of lane miles requiring embedded material be sought in next years program.

The ASP system has three components that work together, but can be used individually or in pairs. The perceived usefulness of deploying these components alone or in various combinations was explored. The three components are the lane-keeping guidance system, the collision warning system, and the vehicle tracking system.

It is concluded that the target ADOT Management personnel firmly "Agree" that the lane-keeping guidance system component by itself will (1) significantly improve the snowplow operator's safety. They also "Agree", with only slight reservations, that (2) the collision warning system component by itself will significantly improve the snowplow operator's safety and (3) the vehicle tracking system component by itself will significantly improve the District's ability to monitor and allocate its materials and equipment. They are "Undecided" about (4) the ability of the vehicle tracking system component by itself to significantly improve the snowplow operator's safety.

Vehicle Tracking System

The vehicle tracking system was never fully implemented during the testing and its usefulness could not be evaluated. The vehicle tracking system holds great promise in two arenas: (a) increased operator safety, primarily during emergencies, and (b) improved ability for a District to monitor and allocate its materials and equipment.

It is recommended that the vehicle tracking system be a primary focus of next year's research program.

Additional Research Questions to Pursue in Next Year's Research Program
In addition to the ratings, the target group of ADOT supervisors and managers were asked what research questions should be pursued in next year's ASP research program. Many topics were raised. An evaluation of these was made using two constraints: (1) can research actually address the question, e.g., it isn't an administrative type decision and (2) can the question be addressed within the available resources.

After weighing these constraints, it is recommended that four topics be pursued. The first three questions listed can be addressed through a detailed evaluation survey administered to the snowplow operators and their direct supervisors. The last question can be addressed by inviting additional districts and orgs to sponsor some of their snowplow operators as participants in the training.

1. *Effectiveness of Collision Warning System (CWS)*
2. *Design the operation and arrange the location of instrumentation in the cab to optimize driver ergonomics and comfort*
3. *Evaluate the productivity/efficiency of the systems*
4. *Does the limited number of districts and orgs conducting the trials create a slanted viewpoint?*

It is noted that exploring the CWS was also a recommendation made based on an evaluation of the trainer and trainee surveys and interviews.

Future Research Questions to Pursue Outside of the ASP Program
Many good research topics were raised by the target ADOT supervisor and management group.

It is beyond the scope of this investigation to recommend new research topics beyond those directly involved with the ASP program. However, the following two topics have substantial support and in interviews are identified as long-time and well-known snowplow problems. Therefore, it is recommended these two topics be given high priority as future research topics.

- *Investigate how to improve headlights to eliminate blinding during storm activity*
- *Investigate how to improve windshield wipers, windshield freezing, and blow back on windshield*

The other winter operations research topics listed later in this report are a valuable resource to ADOT managers. The people surveyed include almost all of the supervisory and management level people involved in winter operations throughout the entire ADOT organization. These people are the ones closest to the problems and the potential solutions. They typically have many years of experience with ADOT in these winter operations. These people know ADOT. Their ideas are typically practical, always sincere, and hold the promise of significant improvement to ADOT's operations.

ADOT managers at all levels are encouraged to take ownership of as many of the winter operations ideas as they can and try to implement them. Many can be implemented unilaterally at the org or district level. Others take statewide action. Most of these ideas are not fancy or, in some cases, even new. Many don't require a research program or a consultant; they only require a manager who can see their value and find a way to implement them.

SNOWPLOW TRAINING AND EVALUATION SURVEY (T&E SURVEY)

Target Respondents

The *Snowplow Training and Evaluation Survey* was targeted at two tiers of snowplow operator personnel.

- The first tier was composed of those snowplow operators who received their training from the system developers. There were only three of these; two of them were Team Leaders and the other was a senior operator who could fulfill the duties of a team leader if need be.
- These first tier snowplow operators then trained the second tier of snowplow operators that included operators from the Northern ADOT Districts, which experience the most wintertime snowplow operations.

The number of first-tier operators was too small to analyze, there being only one on the CALTRANS system and two on the 3M system. The primary focus was on the training of the second-tier snowplow operators. The final sample analyzed contained 31 trainee surveys. A trainee's survey was included in the sample only for his first training session during the 2000-2001 winter season. A few operators had more than one training session, but only their first training session's survey was included for analysis. Some of the trainees on the CALTRANS system had received training on this system in prior years. Since this was the first time the 3M system was involved, all of the trainees on this system had no prior training on this system in prior years. Eleven of the trainees trained on both systems, while nine only trained on one system. The characteristics of the 31 trainees are listed in Table 1. There were 18 trainee surveys in the CALTRANS sample and 13 trainee surveys in the 3M sample.

Table 1: Characteristics of Second-Tier Trainee Survey Sample

```
 Includes both US180 (CALTRANS System) and US89 (3M System)

     trainer       site    wind (mph)   conditions      TOD
 Begishie: 8   US180:18   10 to 20: 9    CLOUDY: 3    DAY:29
   Chavez:18    US89:13   10 to 30: 4   SNOWING: 7  NIGHT: 2
   Nelson: 5              20 to 30: 5     SUNNY:21
                              NA's:13

     visibility (ft)   activity   road.cover  1st.train.00-01
               V0: 2   train:31       dry:24          yes:31
            V500+:24             snowpack: 2

VO.V50.V100.V500+: 5       snowpack & ice: 5

          plow.exp  hrs.test             trainee orgs
      Min:  1.000     0.500          8751:8  8253:1
     Mean:  7.419     2.397          8750:6  8550:5
      Max: 32.000    10.000                  8551:2
  Total N: 31.000    31.000                  8552:3
    NA's :  0.000     2.000                  8650:2
 Std Dev.:  5.638     2.366                  8651:4
```

Survey Instrument

A survey instrument was developed in prior years for the previous CALTRANS training program and was used again in the 2000-2001 winter season program, with slight modifications to accommodate the 3M system training that was being tested for the first time. A complete survey form is shown in Appendix A. Five topics were explored:

- Overall Satisfaction with Driver-Assistance/Guidance Systems
- Lane Position Indicator Screen
- Lane Departure Warning – Alarm Lights, Vibrating Seat (only on the 3M system), and Screen Display
- Collision Warning System (was inoperative on the 3M system)
- Displays and Warnings

Analysis of Training and Evaluation Survey

The results of all topics are reported together. The analysis of the data revealed no statistically significant difference between the two systems ratings, CALTRANS and 3M, on any topic. As an example, Figure 1 graphically illustrates the overlapping 95% confidence intervals between the two systems on the critical question, [does the system have the] *"Potential to improve YOUR Safety."* The rating scale on every question was the same and was described on the survey as "10 as best, 1- worst." The reason that a confidence interval is used, rather than the mean itself, is to account for sampling error.

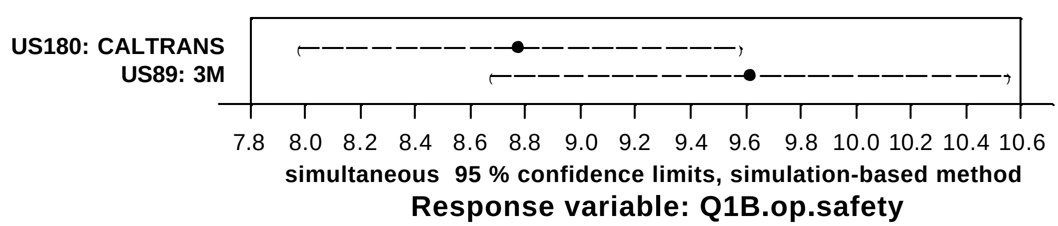

Figure 1: Means and 95% Confidence Intervals of Responses to Training and Evaluation Survey Question 1B

In other words, while the trainees are representative of all ADOT snowplow operators, the sample is small compared to the total number of all ADOT snowplow operators. By "the luck of the draw" one could get a group of trainees that might rate a system higher than if all the snowplow operators were actually trained, or visa versa. So we have to include a margin for error, which is the range of the confidence interval. So we interpret the US180: CALTRANS data this way: we are 95% confident that the true mean of all the ADOT snowplow operators on this question would lie between about 8.0 to 9.6. Likewise, we interpret the US89: 3M data as: we are 95% confident that its true mean lies between about 8.7 and 10 (the 10.6 shown is allowable in "theory" but, of course, not in practice since 10 is the highest rating available). Since these intervals overlap, it is quite possible that the true means of both are, say, 9.2. Or CALTRANS could be 8.0 while 3M is 9.9. We simply can't tell from the data. Therefore, we have to report that they are not statistically different, based on the data collected.

None of the topics explored in the Training and Evaluation Survey showed statistical differences between the two systems. Also none of the questions asked had a lower 95% confidence interval less than about 6.6, while most had a lower limit of about 8 or greater. The results are shown in Table 2.

Table 2: Means and 95% Confidence Intervals of Responses to Training and Evaluation Survey of Second-Tier Trainees

Topic	CALTRANS (US180) Lower Bound (2.5%)	CALTRANS (US180) Mean	CALTRANS (US180) Upper Bound (97.5%)	3M (US89) Lower Bound (2.5%)	3M (US89) Mean	3M (US89) Upper Bound (97.5%)
Overall Satisfaction with Driver-Assistance/Guidance System						
Ease of Use of Automatic Systems	7.9	**8.7**	9.3	8.1	**9.0**	9.5
Potential to Improve YOUR Safety	7.8	**8.8**	9.4	8.5	**9.6**	9.9
Potential to Improve Motorists' Safety	8.0	**8.9**	9.4	8.3	**9.5**	9.9
Potential to Improve Your Efficiency	8.0	**8.7**	9.2	6.7	**8.5**	9.3
Lane Position Indicator Screen						
Did this feature increase your level of safety??	7.7	**8.4**	9.1	8.1	**9.1**	9.5
How often did you look at the display screen?	6.6	**7.6**	8.3	7.2	**8.2**	8.8
Lane Departure Warning						
Alarm Lights: Did this feature increase your level of safety?	8.0	**9.0**	9.5	6.6	**8.7**	9.6
Vibrating Seat: Did this feature increase your level of safety?	NA	**NA**	NA	8.9	**9.5**	9.8
Screen Display: Did this feature increase your level of safety?	7.6	**8.5**	9.1	7.4	**8.7**	9.5
Collision Warning System: Did this feature increase your level of safety?	7.3	**8.4**	9.2	NA	**NA**	NA
Displays and Warnings						
Were these features clear and easy to understand?	8.1	**8.9**	9.4	8.5	**9.2**	9.6
Did the system provide enough information to be useful?	8.3	**9.0**	9.4	8.3	**9.1**	9.5
Was the system response fast enough to be useful?	8.1	**9.0**	9.4	8.4	**9.2**	9.6

Summary of Trainer Observations During Actual Winter Snow Removal Conditions Using the ASPs

The three first tier ADOT snowplow operators, who provided the training to the other ADOT operators, were also the normal operators of the Advanced SnowPlows (ASPs) during regular day-to-day operations. For this reason, they had the most experience by far in the ASPs and essentially had all of the experience during actual snowstorms. The comments of these trainer-operators are listed in Table 3. When reviewing these comments, recall that the 3M equipped snowplow did not have a functioning Collision Warning System (CWS) so the comments by the 3M operators do not include the CWS.

The comments are all favorable. Interviews and discussions with two of these individuals, one each from both systems, confirm this. These interviewees are identified as Trainers CALTRANS-T1 and 3M-T1 in Table 3. For these two operators, the performance of the ASPs during "*whiteout*" conditions was a particularly significant improvement. Whiteout conditions are when a combination of snow, wind, and/or lighting create a total loss of visual perception of the roadway looking forward. One operator described it as being "like someone wrapped a white sheet over all the windows." It can occur during the day or at night. If a whiteout persists for more than a few seconds, the driver typically experiences disorientation, which often leads to run-off-the road type crashes.

While snow, wind, and natural lighting conditions are uncontrollable, other factors contribute to whiteout-type conditions that have the potential to be controlled. Windshield freezing, poorly functioning window wipers, and blow back from the plow contribute significantly to whiteout-type conditions. Whiteouts can occur during the day, but during the night the artificial lighting from the plow headlights and other forward lights can also contribute significantly toward whiteout-type conditions. All four of these potentially controllable factors were the most cited improvements needing attention. The snowplow operators highlighted these factors during interviews and the ADOT supervisory and management personnel cited these on the survey administered to this group as a part of this evaluation, which is discussed later in this report.

During discussions with several snowplow operators, "whiteout" conditions were universally described as being the most dangerous and accident-prone. The two operators with the most experience on the ASPs, discussed having heightened degrees of confidence and increased feelings of safety when using the ASPs. Their experience in the ASPs during whiteout conditions gave them confidence that they could "handle" a whiteout should it occur.

This evaluation considers this increased sense of confidence and safety, coming from the two operators with the most actual snowstorm experience, to be a highly significant piece of qualitative evidence. It supports the effectiveness of both ASP systems to improve operator safety.

Table 3: Comments of ADOT Operator-Trainers During Actual Winter Snow Removal Conditions

Trainer ID	Date	Wind Speed	SNO= Snowing SUN= Sunny CLD= Cloudy	Time	Visibility - Feet	SPK= Snowpack ICE= Ice SLU= Slush DRY=Dry	Plow &/or Sand	Vehicle Status	System Status	Comments
CALTRANS Advanced Snowplow System										
CAL TRANS T1	14-Feb-01		SNO	DAY	ZERO, 50	SPK,ICE	P	Is good, no problems. The computer H.M.I. Is working well.	OK	The H.M.I. Helped me with snow removal, and helped me stay on the road through the test areas.
CAL TRANS T1	23-Feb-01	20-40	SNO	DAY	ZERO, 50, 100	SPK,ICE	P	The truck is working with no problems at all.	The H.M.I. System helped me in snow removal, in white-out conditions.	Also it was a long day. The H.M.I. Helped me all the way around.
CAL TRANS T1	26-Feb-01	20-30	SNO	DAY	ZERO, 50, 100, >500	SPK,ICE	P	OK	OK	OK
3M Advanced Snowplow System										
3M-T1	10-Nov-00		SNO	NIGHT	ZERO	SPK	P & S	Good	Good	White-out conditions used to find road and stay out of oncoming traffic.
3M-T1	25-Dec-00		SNO, CLD	DAY	>500	SPK	P & S			
3M-T2	17-Jan-01		CLD	DAY	>500	SPK, ICE, SLU	P	In good condition.	Great!	
3M-T1	27-Jan-01		SNO. SUN, CLD	DAY	>500	SPK, SLU	P & S	N/A	N/A	Good

Summary of ASP Trainee Comments and Recommendations

The Training and Evaluation Survey form included three questions at the end of the ratings section that asked for the respondent's "Comments and Recommendations."

1. *Were there any system problems when you were operating the vehicle? (Describe):*
2. *Did the system ever lead you to make a wrong maneuver or error in judgment?*
3. *What suggestions would you make to improve any feature's usefulness to you?*

The detailed responses to this question are listed in Appendix C and the reader is encouraged to review them. The responses are summarized here.

The only system problem reported on the CALTRANS snowplow was the collision warning system (CWS). The comments of one trainee described the warning given as being "very quick" that led the operator to believe he "would not be able to avoid a collision." During the course of this evaluation, it was observed that an approaching vehicle did close the distance "very quick." Of course, the rate of closure was the sum of the speeds of both vehicles. No observation was made during this evaluation regarding a parked vehicle, which would be more representative of a stalled vehicle during a snowstorm. It was observed that the CWS would sometimes give "false" readings on signs and other roadside objects. The CWS on the 3M system was inoperative, therefore no observations were made during this investigation or by the trainees or trainers.

There was universal agreement on both systems that they did not every prompt the operator to make a wrong move or error in judgment, with one exception. One trainee commented, "Sometimes, because need to know more about the operation of the truck." Although this was an experienced snowplow operator (10 years), it wasn't determined if this comment referred to the truck being unfamiliar or the system being unfamiliar.

A few suggestions were made on possible improvements to the systems. A summary of the comments regarding the CALTRANS snowplow is:

- Add vibrator seat option (like the 3M System used)
- The mile marker and location name options on the monitor are a definite plus
- Maybe improve radar system somewhat [CWS]
- Training needs to be done during actual snowstorm conditions
- Good improvement from previous years to make screen smaller and position nearer normal field of view (FOV) of the operator. It was suggested to move it even farther to the left so that it would be even more in the operator's FOV. However, it was also observed that the screen needed to be moved "farther away from the sun."
- Put marker flags on plow

The comments regarding the 3M snowplow are as follows. Recall that the CWS was inoperative on the 3M system during the entire test period.

- Need something to indicate on-coming traffic, i.e., a CWS
- System needs to be improved when there is a turn or an increase/decrease in grade
- Screen still a little cluttered, but a distinct improvement over screen in CALTRANS snowplow
- Make the display a heads-up, reflected off the windshield
- Training needs to be done during actual snowstorm conditions

Recommendations Regarding Comments of Trainers and Trainees

Based on discussions with the snowplow operators, both trainers and trainees, and their training survey comments, a few useful conclusions can be drawn. First is that the "3M vibrating seat" feedback mechanism is a superior feedback mechanism. It, of course, complements the screen's feedback capabilities. Only the 3M snowplow has the vibrating seat feature, but the CALTRANS system would benefit by adding it.

It is recommended that this system be added to the CALTRANS system for next year's research program.

From discussions with several snowplow operators, the concept of a collision warning system (CWS) is considered a crucial system by the operators. Observations and operator comments regarding the integrated CWS on the CALTRANS system were favorable in concept. However, testing under actual or simulated snowstorm conditions was limited. One concern is if the snowplow operator would have enough time to react safely to avoid a collision. This evaluation's impression is that the lack of an operative system on the 3M snowplow was considered a significant handicap by those operators that had training in both systems.

It is recommended that the collision warning system be a primary focus of investigation in next year's research program.

Training during actual snowstorm conditions is deemed difficult by ADOT because (a) the logistics of moving an operator from his home organization to the training site "just before" a snowstorm and (b) the lack of a sufficient number of trained snowplow operators at a trainee's home organization to backup his snow removal route during a snowstorm, while he is away at the test site. Acknowledging this, there is still no substitute for a trainee experiencing the system during actual winter snowstorm conditions.

It is recommended that at least a few trainees be given the opportunity to work the ASPs during actual winter snowstorm conditions in next year's research program.

ADVANCED SNOWPLOW RESEARCH SURVEY (MANAGEMENT SURVEY)

Target Respondents

The Management Survey was targeted at both District and Statewide ADOT supervisory and management personnel. At the district level four positions were targeted:

- Maintenance Supervisor (MSV),
- Maintenance Superintendent (MST),
- District Maintenance Engineer (DME), and
- District Engineer (DE).

Two positions were targeted at the statewide level:

- Equipment Services (ES) and
- Senior Management (SM).

Table 4: Characteristics of Management Survey Sample

sample	title	district
size: 69	Anonymous: 1	anonymous: 1
	DE: 8	equip: 4
	DME: 8	flagstaff:10
	ES: 5	globe: 9
	MST: 7	holbrook: 9
	MSV:35	kingman: 6
	SM: 5	mgmt: 5
		phoenix: 3
		prescott: 7
		safford: 7
		tucson: 5
		yuma: 3

org number

7001:1	8350:1	8550:1	8752:1
7045:1	8352:1	8551:1	8753:1
7200:1	8354:2	8552:1	8754:1
7300:1	8355:1	8553:1	8755:1
7340:1	8356:1	8554:1	8769:1
7800:2	8357:1	8555:1	8800:2
7873:1	8369:1	8569:1	8850:1
8100:1	8400:1	8600:2	8851:1
8150:1	8450:1	8650:1	8852:1
8152:1	8451:1	8651:1	8853:1
8154:1	8452:1	8652:1	8869:1
8169:1	8453:1	8669:1	9000:2
8200:2	8454:1	8700:2	9060:1
8252:1	8469:1	8750:1	9800:2
8300:1	8500:2	8751:1	NA's:1

Eighty-five surveys were mailed and seventy-two responses were received, an initial response rate of 85 percent. The respondents identified themselves in the survey, which allowed two follow-up contacts to the recipients who had not responded. Three respondents did not fill out the survey for stated reasons. These were removed from the sample. Three anonymous surveys were received. Two of these were not included in the sample because the handwritings were matched with surveys that were received after the follow-up contacts were made. The handwriting of the third anonymous survey could not be matched with any other survey and was included in the sample. The final sample contained 69 respondents, a final response rate of 81 percent. The characteristics of the 69 respondents are listed in Table 4.

Survey Instrument

A survey instrument was developed, pre-tested, and refined in collaboration with the TAC. The complete survey form is shown in Appendix B. Five topics were explored:

a. Ability to Improve Safety and Efficiency Using an ASP System
b. Extent of Deployment Needed and Reasonable Cost of an ASP System
c. Usefulness of Employing ASP System Components Individually
d. Questions To Be Answered During the Next Year's Research Activities
e. Other Useful Winter Maintenance Operations Research Topics

The results of each topic are reported individually in the following sections.

Ability to Improve Safety and Efficiency Using an ASP System

This topic was explored in Question 1 of the survey, which had 5 parts.

Q1a. *The ASP systems will significantly improve the snowplow operator's safety.*
Q1b. *The ASP systems will enable the snowplow operator to safely plow his route faster during poor visibility.*
Q1c. *The ASP systems will enable a District to keep their roads open much better during winter conditions.*
Q1d. *The ASP systems will noticeably improve the traveling public's safety during winter operations.*
Q1e. *The ASP systems could be used effectively in all Districts that have snowplow operations.*

The rating system used the following scale:

Strongly Agree (1)	Agree (2)	Undecided (3)	Disagree (4)	Strongly Disagree (5)

Rather than rating the statements, the respondent could choose a "Don't Know" response. The results of the survey are shown in Figure 2 using a set of histograms, one for each of the five parts of Question 1: Q1a through Q1e. For example, in the lower left-hand corner of Figure 2 is the histogram for part e of question 1 labeled "Q1.part: Q1a." Approximately 40 respondents rated this part with an "Agree", which has a value of 2. A little less than half this number rated this part with a "Strongly Agree", which has a value of 1. Still fewer respondents rated this part with an "Undecided", which has a value of 3 and an even lesser number rated it with a "Disagree" having a value of 4. Collectively these form a statistical distribution of responses, which the histogram represents pictorially.

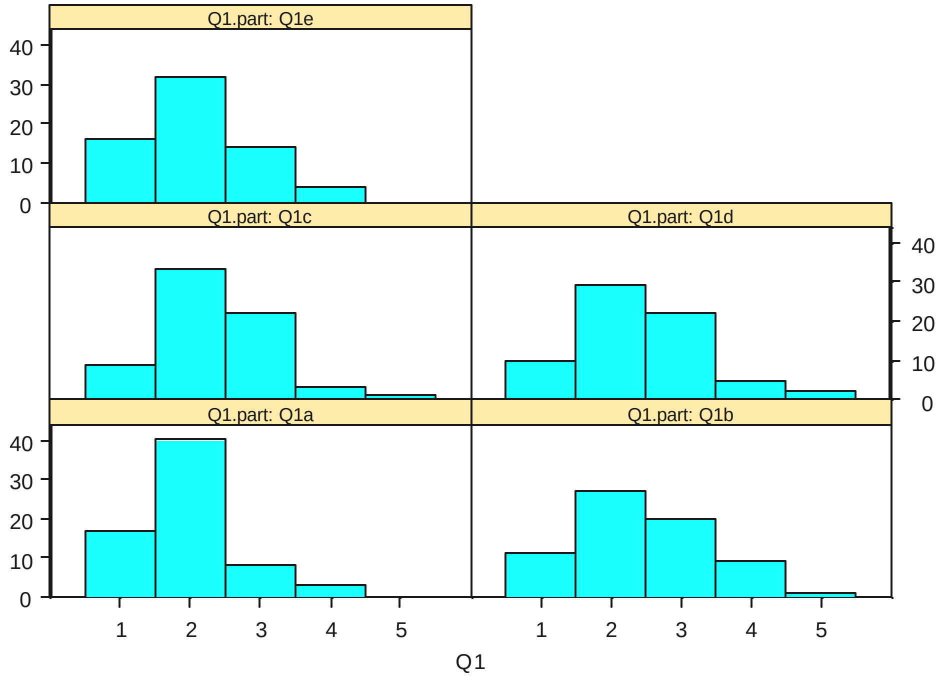

Figure 2: Distributions of Responses to Management Survey Question 1

When drawing conclusions from a distribution of data it is useful to use its mean. The mean of distributions typically is located near its "high" point on the histogram. However, the mean only represents the average response and doesn't tell us anything about how spread out the data is, which is measured by the variance of data making up the distribution. The variance can be used to construct boundaries around the mean that tells us how confident we are in its value. Table 5 lists the means for Question 1 as well as the lower and upper bounds of a 95% confidence interval constructed on the mean.

Table 5: Means and 95% Confidence Intervals of Responses to Management Survey Question 1

Question	Lower Bound (2.5%)	Estimate (mean)	Upper Bound (97.5%)
Q1a: Improves Operator Safety	1.69	**1.96**	2.22
Q1b: Operator Can Plow Faster	2.17	**2.44**	2.71
Q1c: District Keep Roads Open Better	2.06	**2.32**	2.59
Q1d: Improves Public's Safety	2.14	**2.41**	2.68
Q1e: Effective In All Snow Districts	1.82	**2.09**	2.36

A confidence interval helps us evaluate the data. For example, Question 1a has a mean of 1.96 <u>for the sample data evaluated</u>. Only about 80% of the target management personnel responded to the survey. If say 90% had responded, the mean of the surveys would be slightly different. But if 100% had responded, then the mean would be of all the possible surveys and would have been the "true" mean. Since only about 80% responded, our "sample" mean is only an <u>estimate</u> of this "true" mean. We use the confidence interval to evaluate our faith in our estimate given by our "sample" mean. The 95% confidence interval for the 1.96 sample mean is 1.69 to 2.22. What this says is that if we were to repeatedly do this survey and get the same number of responses each time (but each time from a different group of 69 people within the target group of 85 people), 95 out of 100 times the confidence interval we calculate would contain the "true" mean value. So practically speaking, we conclude that our sample had a mean of about 2.0 but the true mean could be any number between about 1.7 to 2.2. From this we can conclude that the targeted ADOT management people as a whole "Agree" that *"The ASP systems will significantly improve the snowplow operator's safety*."

The data in Table 5 is graphically represented in Figure 3. The dot represents the mean value and the dashed line represents the "width" of the 95% confidence interval.

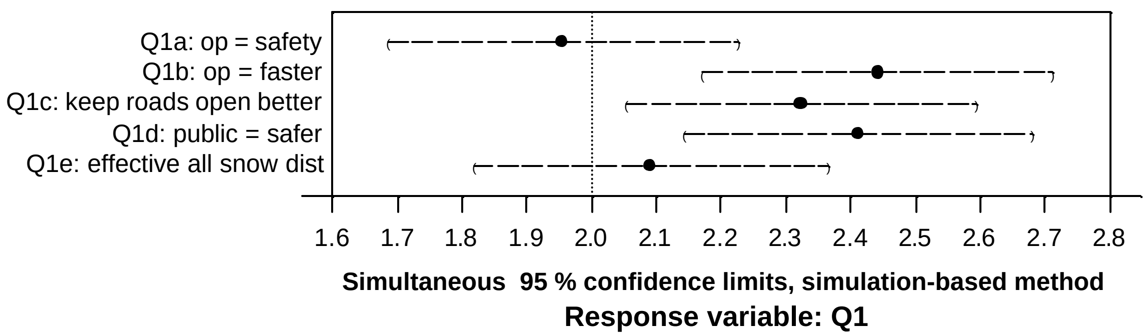

Figure 3: Means and 95% Confidence Intervals of Responses to Management Survey Question 1

Conclusions Regarding The Ability to Improve Safety and Efficiency Using an ASP System
The target ADOT Management personnel firmly "Agree" that the ASP systems will (1) significantly improve the snowplow operator's safety and that (2) they can be used effectively in all Districts having snowplow operations. They also "Agree", with only slight reservations, that the ASP systems will (3) noticeably improve the traveling public's safety and improve operations by enabling (4) operators to safely plow their routes faster and (5) Districts to keep their roads open much better during winter conditions.

The responses were subdivided by District and Job Title and examined. However, no significant differences were observed. Because the "spread" or variance of the response distributions before subdivision is fairly small, the 95% confidence intervals shown in Figure 3 are "narrow." This uniformity in responses means that when subdivided, each subdivision is not statistically different that all the other subdivisions. The responses were also subdivided so that "snow" Districts could be examined independently. Likewise all District Maintenance Supervisors and Superintendents were grouped and examined as a separate subdivision. Again, in both of these cases, no statistically significant differences were observed.

Extent of Deployment Needed and Reasonable Cost of an ASP System

The extent of the deployment needed was explored in Question 2 of the survey, which had 3 parts.

Q2a. *If the ASP systems were installed in your District or Org., estimate how many lane miles of roadway would need magnetic material imbedded in it.*

- ☐ 0 to 24 lane miles in your entire District/Org.
- ☐ 25 to 49 lane miles in your entire District/Org.
- ☐ 50 to 74 lane miles in your entire District/Org.
- ☐ 75 to 124 lane miles in your entire District/Org.
- ☐ 125 to 200 lane miles in your entire District/Org.
- ☐ More than 200 lane miles in your entire District/Org. (fill in your estimate: ________ lane miles)
- ☐ Don't know (skip questions 2b and 2c ➔ go to question 3).
- ☐ Not applicable because my duties cover more than one District (➔ go to question 3).

Q2b. *In the previous question 2a, what management unit were you using for your estimate?*

- ☐ Org.
- ☐ District

Q2c. *In the previous question 2a, what approach did you use for estimating lane miles?*

- ☐ Estimated the especially troublesome lane miles.
- ☐ Estimated a more extensive program based on ____________________________.

The results of Question 2 was fragmented because the estimates were either for a district or an org and further fragmented because the estimate was either for especially troublesome lane miles or for a more extensive program. A crude inference was drawn from this data by first ignoring the troublesome/extensive question entirely and then removing the estimates that were done for an org versus a district. This left only district-level estimates of the lane miles of roadway that would need magnetic material embedded in it. The results of are shown in Table 6.

Table 6: Crude Estimates of Lane Miles Needing Magnetic Material Embedded In It As Inferred from Management Survey Question 2

District	Number Respondents	Minimum	Median	Mean	Maximum
Flagstaff	3	300	900	900	1500
Globe	3	163	275	646	1500
Holbrook	3	37	100	512	1400
Kingman	4	100	250	450	1200
Phoenix	2	12	25	25	37
Prescott	3	163	270	644	1500
Tucson	2	37	50	50	62
Yuma	2	12	12	12	12
Safford	1	100	100	100	100
Statewide Totals	*23*	*924*	*1982*	*3339*	*7311*

The reasonable cost for ADOT to pay per lane mile for an ASP system was explored in Question 3 of the survey.

Q3. *ASP systems provide benefits but cost money. Assuming the ASP systems are proven to substantially improve snowplow operator safety and efficiency, what would be the highest cost you believe would be reasonable for ADOT to pay?*

- ☐ **More than $30,000 per lane mile**
- ☐ **$25,000 to $30,000 per lane mile**
- ☐ **$20,000 to $24,000 per lane mile**
- ☐ **$15,000 to $19,000 per lane mile**
- ☐ **$10,000 to $14,000 per lane mile**
- ☐ **$5,000 to $9,000 per lane mile**
- ☐ **Less than $5,000 per lane mile (fill in your reasonable value: $________ per lane mile)**
- ☐ **Don’t know**

The results of Question 3 are plotted in a distribution showing the mean and a 95% confidence interval on the mean in Figure 4.

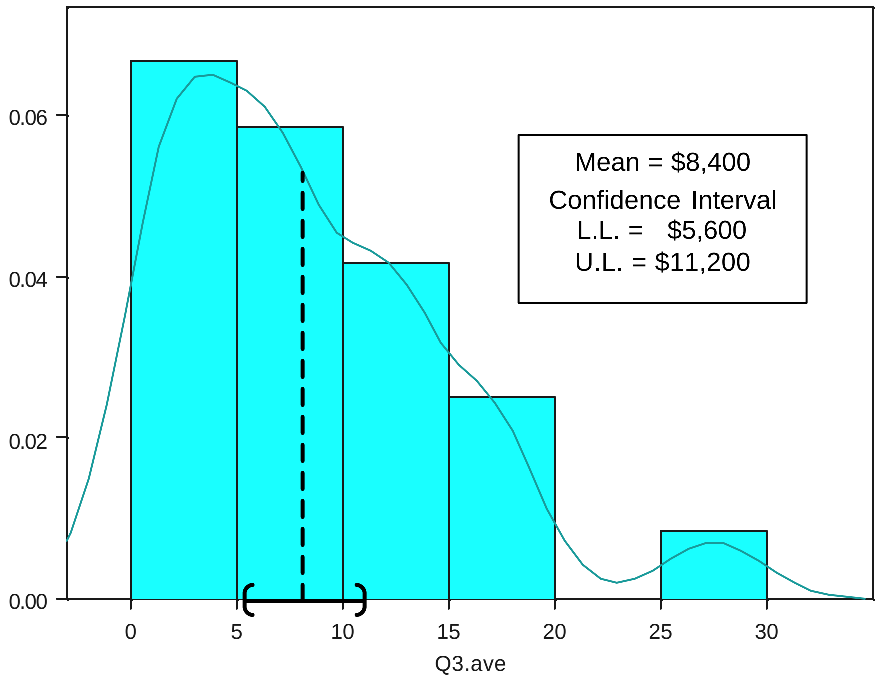

Figure 4: Estimates of Reasonable Cost Per Lane Mile in Management Survey Question 2

Conclusions Regarding Extent of Deployment Needed and Reasonable Cost of an ASP System

A crude estimate of the range of lane miles of roadway needing magnetic material embedded in it can be drawn from Table 6. The estimate is crude because only 23 respondents estimated the mileage for their district, giving very small sample sizes. Also, the distinction between estimating for especially troublesome lane miles versus a more extensive program was completely disregarded in Table 6. It would appear that the minimum lane miles would be approximately 1000, but that in all the respondents believed that 2000 to 3000 lane miles would need magnetic material embedded in it.

The mean highest cost that would be reasonable for ADOT to pay is approximately in the range of $5,000 to $11,000 per lane mile. If the crude estimate total lane miles is combined with this estimate of highest mean cost, a very crude estimate of total "desirable" funding can be made. In this case "desirable" means applying the highest reasonable cost per lane mile estimated by the ADOT supervisory and management personnel to the crude estimates of total lane miles needed to deploy the ASP system. This yields a "minimum" system wide "desirable" estimate of $9 million ($8,400 per lane mile times 1000 lane miles) and a more likely estimate of between $17 to $25 million ($8,400 per lane mile times 2000 to 3000 lane miles). These estimates are not related in any way to the current cost of installing an ASP system nor to a defensible estimate of the actual lane miles needing an ASP system. Again, they are only crude estimates without any basis for estimating the uncertainty involved with the estimates.

Usefulness of Employing ASP System Components Individually

This topic was explored in Question 4a of the survey, which had 2 parts, and Question 4b.

Q4a.A. *The lane-guidance system, by itself, will significantly improve the snowplow operator's safety.*
Q4a.B. *The collision warning system, by itself, will significantly improve the snowplow operator's safety.*
Q4a.C. *The vehicle tracking system, by itself, will significantly improve the snowplow operator's safety.*
Q4a.D. *The vehicle tracking system, by itself, will significantly improve the District's ability to monitor and allocate its materials and equipment.*

The rating system for Question 4a used the following scale:

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
(1)	(2)	(3)	(4)	(5)

Rather than rating the statements, the respondent could choose a "Don't Know" response. The results of the survey are shown in Figure 5 using a set of histograms, one for each data distribution of the four parts of Question 4a: Q4a.A through Q4a.D. The means and 95% confidence intervals are listed in Table 7 and graphically depicted in Figure 6.

Table 7: Means and 95% Confidence Intervals of Responses to Management Survey Question 4a

Question	Lower Bound (2.5%)	Estimate (mean)	Upper Bound (97.5%)
Q4a.A: Lane-guidance Improves Operator Safety By Itself	1.78	**2.06**	2.33
Q4a.B: Collision Warning System Improves Operator Safety By Itself	2.01	**2.28**	2.56
Q4a.C: Vehicle Tracking System Improves Operator Safety By Itself	2.52	**2.79**	3.07
Q4a.D: Vehicle Tracking System Improves District Monitor/Tracking of Materials	2.15	**2.42**	2.70

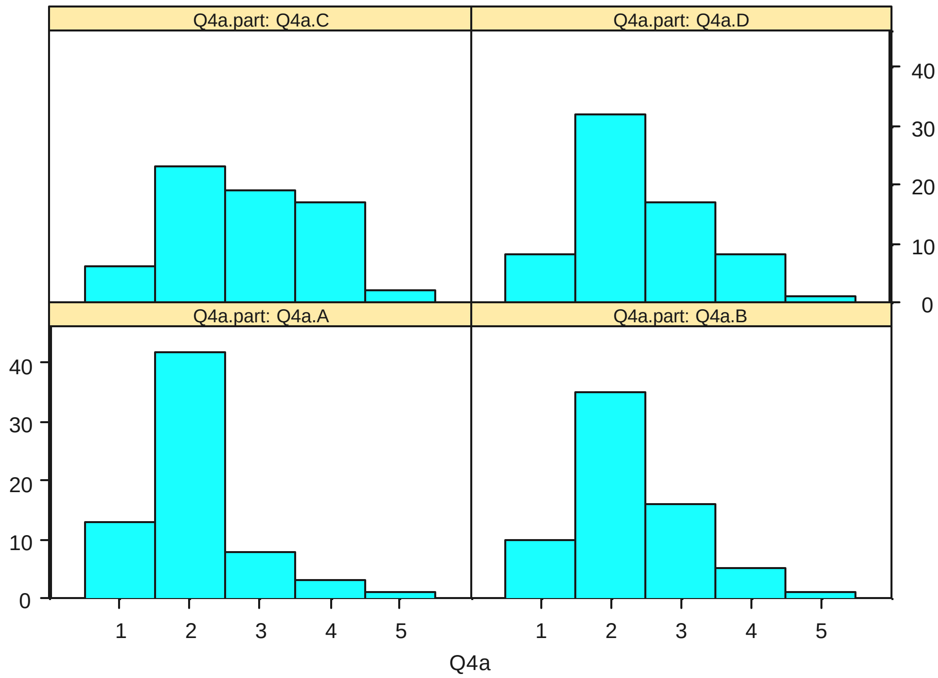

Figure 5: Distributions of Responses to Management Survey Question 4a

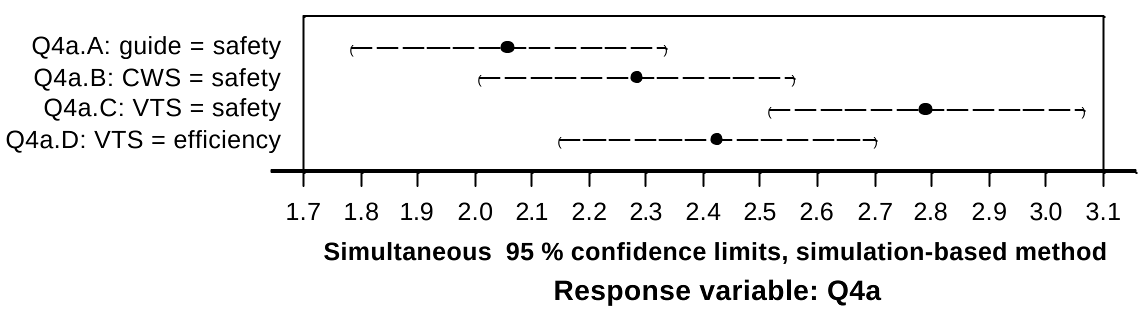

Figure 6: Means and 95% Confidence Intervals of Responses to Management Survey Question 4a

This topic was further explored in Question 4b, which looked at combinations of the three components that comprise the ASP system.

Q4b. *Is there some combination(s) of two of the individual systems that should be considered? (you may check more than one box)*

The results of this question are listed in Table 8.

Table 8: Responses to Management Survey Question 4b

Component Combinations	Responses
AB: Lane-keeping and Collision Avoidance	41
AC: Lane-keeping and Vehicle Tracking	14
BC: Collision Avoidance and Vehicle Tracking	7
No Opinion	13
Blank	1

Conclusions Regarding The Usefulness of Employing ASP System Components Individually
The target ADOT Management personnel firmly "Agree" that the lane-keeping guidance system component by itself will (1) significantly improve the snowplow operator's safety. They also "Agree", with only slight reservations, that (2) the collision warning system component by itself will significantly improve the snowplow operator's safety and (3) the vehicle tracking system component by itself will significantly improve the District's ability to monitor and allocate its materials and equipment. They are "Undecided" about (4) the ability of the vehicle tracking system component by itself to significantly improve the snowplow operator's safety.

The responses were subdivided by District and Job Title and examined. The responses were also subdivided so that "snow" Districts could be examined independently. Likewise all the District Maintenance Supervisors and Superintendents were grouped and examined as a separate subdivision. Due to the uniformity of the data, no statistically significant differences were observed in any of these subdivision cases.

The lane-keeping guidance system component was clearly regarded as a useful component when coupled with either the vehicle tracking or collision avoidance components as can be inferred from Question 4b results as tabulated in Table 8.

QUESTIONS TO BE ANSWERED DURING THE NEXT YEAR'S RESEARCH ACTIVITIES

Summary of Responses About Next Year's ASP Research Activities

This topic was explored in Question 5 of the Management Survey.

> Q5. *What questions should next year's research be sure to answer about the Advanced Snowplow system?*

The detailed responses to this question are listed in Appendix D and the reader is encouraged to review them. Only 37 of the 69 survey respondents answered this question. Each of these 37 respondents described research questions that he or she believed would be useful to have answered next year by the ASP research program. A respondent could list as many questions as he wanted: 32 respondents raised no questions, 30 raised one question, 6 raised two questions, and one respondent raised three questions.

Their ideas, while somewhat unique to each respondent, can be grouped into common topics. The common topics raised by the respondents regarding next year's advanced snowplow research program are:

- Cost effectiveness regarding actual deployment (12 respondents)
- Effectiveness of Collision Warning System (CWS) (7 respondents)
- Quantify changes in safety of driver and motorists (5 respondents)
- Design the operation and arrange the location of instrumentation in the cab to optimize driver ergonomics and comfort (5 respondents)
- Investigate alternate lane-keeping guidance technologies, e.g., GPS/GIS (4 respondents)
- Evaluate the productivity/efficiency of the systems (3 respondents)
- Evaluate effectiveness of the ASP system in difficult conditions (sharp curves, narrow roads, heavy snow) (2 respondents)
- Evaluate deployment realities of high versus low volume roads (interstates versus rural) (2 respondents)
- Does the limited number of districts and orgs conducting the trials create a slanted viewpoint 2 respondent)
- Evaluate maintenance and failure of equipment (1 respondent)
- How deep can the magnetic material be buried and still be effective (1 respondent)

It is important to note that a "good" research question could be raised by only one respondent. In other words, the fact that several respondents raise the same question does not make it a "better" research question than another. But of course, a question that is raised by several respondents will probably continue to be raised in future forums until it can be answered.

It is also important to note that some of the questions raised cannot be answered in the research forum. One example is cost effectiveness. Research can probably identify several costs and benefits. However, benefits are typically "soft" while costs are "hard." What value to place on a benefit (for example, a driver "feels" safer) and what benefit/cost "ratio" will motivate action, require administrative judgment that typically lies outside the research forum. Another layer of complexity, again using the example, is who decides what is sufficient "ratio" that motivates a call to action. Specifically, is this a decentralized decision or a centralized decision within ADOT. Other questions also lie outside the research forum, if not totally, then partially.

A last constraint, of course, is the resources available for next year's research program. Some of the questions raised would require a new line of inquiry or an expansion beyond the resources available. One such example is evaluating the ASP systems under "difficult" conditions (sharp curves, narrow roads, heavy snow). Whereas heavy snow conditions are occasionally captured by the existing experimental design, the test road sections are very costly to expand. So a new test bed with sharper curves and narrower roads than what is already installed is almost certainly beyond the program's ability to investigate.

Recommended ASP Research Questions to Pursue

As previously discussed, two constraints limit the questions that can be pursed in next year's program: (1) can research actually address the question, e.g., it isn't an administrative type decision and (2) can the question be addressed within the available resources.

After weighing these constraints, it is recommended that four topics be pursued. The first three questions listed can be addressed through a detailed evaluation survey administered to the *snowplow operators and their direct supervisors. The last question can be addressed by inviting additional districts and orgs to sponsor some of their snowplow operators as participants in the training.*

5. *Effectiveness of Collision Warning System (CWS)*
6. *Design the operation and arrange the location of instrumentation in the cab to optimize driver ergonomics and comfort*
7. *Evaluate the productivity/efficiency of the systems*
8. *Does the limited number of districts and orgs conducting the trials create a slanted viewpoint?*

OTHER USEFUL WINTER MAINTENANCE OPERATIONS RESEARCH TOPICS

This topic was explored in Question 6 of the Management Survey, which had 2 parts.

Q6a. *What else about vehicles could ADOT be researching that might improve snowplow operations?*

Q6b. *What other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter maintenance operations?*

The detailed responses to this question are listed in Appendix E and the reader is encouraged to review them. Over three-fourths of the respondents answered one or both of these questions, i.e., 54 out of 69. Each of these 54 respondents described research topics that he believed would be useful to improve snowplow and other winter maintenance operations.

Summary of Responses About Other Vehicle Research Topics for Winter Operations

Each idea is unique and was often identified by a single respondent. Each of these is an important topic that bears serious consideration. Several topics, however, were identified by multiple respondents and these are placed first in the listing below.

- Investigate how to improve headlights to eliminate blinding during storm activity (18 respondents)
- Investigate how to improve windshield wipers, windshield freezing, and blow back on windshield (14 respondents)
- Investigate how to improve rear warning lights, which freeze over with ice, and curb lights (ref: Minnesota DOT Whelan Warning Lighting Systems) (6 respondents)
- Investigate how to best determine road surface conditions and application residue (8 respondents)
- Establish an additional snowplow driver certification; establish post-training testing and annual refresher training and testing; more training needed on chemical usage and effects (8 respondent)
- Investigate new developments in plow and spreader products, e.g., improved sander/deicer equipment, snow blowers, use of brooms for high speed snow removal, lower blade snowplow trucks; chemical friendly equipment (7 respondents)
- Devise a better/simpler method to record material usage by route and milepost; be able to reconstruct storm and plowing activities, perhaps via GPS or similar (5 respondents)
- Investigate changing motorist behavior about winter operations, i.e., by warning the public of the dangers of rear-ending snowplows using public service announcements and ads (radio and T.V.) and/or displaying advisory speeds of snowplow. Need "real"

information, e.g., "if it snows, you will face bad conditions and ADOT cannot perform miracles." (4 respondents)

- Investigate use of an infrared-type vision capability and/or a heads-up display (3 respondents)
- Are there times when snowplow operations should not be done, e.g., nighttime, whiteouts) (2 respondents)
- Investigate use of sensors located in pavements and bridges to identify and report worst areas in a timely manner (2 respondents)
- Investigate using a simulated snowplow for research testing and actual training (like an airplane simulator) (2 respondents)
- Investigate use of snowplow shock absorbers to prevent chatter (1 respondent)
- Investigate use of automatic transmissions instead of manual thereby increasing concentration on the road (1 respondent)
- Investigate use of a uniform setup for all snowplows to promote operator efficiency/safety (1 respondent)
- Devise a safer plow mounting and/or method of mounting the plow on the truck (1 respondent)
- Investigate use of radio headsets with voice activated microphones (1 respondent)
- Add capability for interagency communications, e.g., law enforcement personnel (1 respondent)
- Collect and analyze snowplow maintenance by brands (1 respondent)
- Get an update on Iowa prototype vehicle (1 respondent)

Recommended Future Research Questions to Pursue Outside of the ASP Program

As discussed before, when reviewing these research topics keep in mind that a “good” research question could be raised by a single respondent. Identification of the same potential research topic by several respondents does not make it “better” than others.

It is beyond the scope of this investigation to recommend new research topics beyond those directly involved with the ASP program. However, the following two topics have substantial support and in interviews are identified as long-time and well-known snowplow problems. Therefore, it is recommended these two topics be given high priority as future research topics.

- *Investigate how to improve headlights to eliminate blinding during storm activity (18 respondents)*
- *Investigate how to improve windshield wipers, windshield freezing, and blow back on windshield (14 respondents)*

Several of the other topics that were identified might actually be best investigated by simply having a district/org try a solution on a prototype basis. The evidence from this single prototype could be shared and a decision made: (a) the evidence was great enough by itself to warrant adopting it or rejecting it or the evidence was sufficient to warrant (b) further investigation by additional districts/orgs and/or (c) a formal research project should be initiated.

Summary of Responses About Other Ways To Improve Winter Maintenance Operations

The ideas below are more diverse due to a broader topic area, i.e., what other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter operations.

- Investigate what materials/chemicals are available and their respective best application conditions/methods; find better de-icing chemicals; find chemicals that don't require special equipment for application (11 respondents)
- Develop ADOT policy for a stronger chemicals for de-icing program (6 respondents)
- Need more resources implement the technologies we now understand, i.e., need proper amounts of manpower, equipment, and materials; need to find ways to convince legislators of our needs (5 respondents)
- Investigate Road Weather Information System (RWIS) usage versus no usage and/or integrating RWIS with onboard devices for proper chemical usage (2 respondents)
- Maintenance orgs need a better understanding of the calibration of snow plow spreader system, rather than just the mechanics (1 respondent)
- Develop a procedure to stockpile winter chemicals in bulk quantities to lower cost (1 respondent)
- Define how much equipment it takes to keep a lane-mile plowed to a reasonable service level and consistently apply this standard around the state (1 respondent)
- ACFC; when new pavement, snow covers faster than older pavement (1 respondent)
- Develop EPA approved mixing and storage for road salt and wash bay for after storm cleaning of equipment (1 respondent)
- Investigate using automatic ramp gates, remotely operated, in conjunction with variable message signs as conditions deteriorate (1 respondent)
- Perform lab tests on winter chemicals to see if they meet specifications (1 respondent)
- Achieve more enforcement on chain regulations for trucks and cars (1 respondent)
- Improve computers for spreaders, which break down a lot (1 respondent)
- Investigate use of operations center(s) for snowplow support, e.g., using ADOT TOC versus District support (1 respondent)
- Highway 260, MP 377.5 to 383 is at 9100 feet elevation, has high wind and constant whiteouts; it is ideal for an ASP system (1 respondent)

Again, it is beyond the scope of this investigation to recommend research topics outside the ASP program scope.

Value of Other Research Topics to ADOT Managers

The topics listed in this section are a valuable resource to ADOT managers. The people surveyed include almost all of the supervisory and management level people involved in winter operations throughout the entire ADOT organization. These people are the ones closest to the problems and the potential solutions. They typically have many years of experience with ADOT in these winter operations. These people know ADOT. Their ideas are typically practical, always sincere, and hold the promise of significant improvement to ADOT's operations.

ADOT managers at all levels are encouraged to take ownership of as many of these ideas as they can and try to implement them. Many can be implemented unilaterally at the org or district level. Others take statewide action. Most of these ideas are not fancy or, in some cases, even new. Many don't require a research program or a consultant; they only require a manager who can see their value and find a way to implement them.

ATTACHMENT A

ADOT SNOWPLOW TRAINING & EVALUATION SURVEY
ATRC PROJECT 473 - 2000-2001
PLOW SYSTEM TESTING – TRAINING - OPERATOR EVALUATION

Date: _______________ Time Start:______________ Time End:_________________
Trainee Name (Optional): ____
Org No:_________________ Org Name:____
Trainee: Years of Snowplow Experience: _________Hours on the Test Plow: ___________

Overall Satisfaction with Driver-Assistance / Guidance Systems (10 as best, 1- worst):

1 to 10 Scale - Ease of Use of Automated Systems: __________________
1 to 10 Scale - Potential to Improve YOUR Safety: __________________
1 to 10 Scale - Potential to Improve Motorists' Safety: __________________
1 to 10 Scale - Potential to Improve Your Efficiency: __________________

Lane Position Indicator Screen:

1 to 10 - Did this feature increase your level of safety ?? __________________
How often did you look at the display screen? __________________

Lane Departure Warning – Alarm Lights:

1 to 10 - Did this feature increase your level of safety ?? __________________

Lane Departure Warning – Vibrating Seat:

1 to 10 - Did this feature increase your level of safety ?? __________________

Lane Departure Warning – Screen Display:

1 to 10 - Did this feature increase your level of safety ?? __________________

Collision Warning System:

1 to 10 - Did this feature increase your level of safety ?? __________________

Displays / Warnings:

1 to 10 - Were these features clear and easy to understand? ____________
1 to 10 - Did the system provide enough information to be useful? ____________
1 to 10 - Was the system response fast enough to be useful? ____________

Comments and Recommendations

1. Were there any system problems when you were operating the vehicle? (Describe):

2. Did the system ever lead you to make a wrong maneuver or error in judgment?

3. What suggestions would you make to improve any feature's usefulness to you?

ADOT-asp-evalform-2b ***(use back of page if needed)*** Rev: 12-01-00

ATTACHMENT B

Advanced SnowPlow Research – ADOT Management Survey 2000-2001

What is the "ASP" system? ADOT deploys over 200 snowplows in the state and is conducting research to improve safety and productivity. The Advanced SnowPlow (ASP) system typically includes 3 components:

- Lane-keeping guidance system on the snowplow (uses magnetic fields technology)
- Collision warning system on the snowplow (uses radar technology)
- Vehicle tracking system in the District office (uses GPS technology)

The guidance system component uses magnetic materials imbedded in the pavement, which are detected by sensors installed on the snowplow. This enables the operator to accurately steer the snowplow within the proper lane even in "whiteouts" and other types of poor visibility conditions. All of the components act together to form an ASP system.

Why do we need you to fill out this survey? ADOT's Research Center is finishing the third winter of an ongoing research project to evaluate the ASP systems. Refinements are made each year based on previous results. This year--for the first time--ADOT is testing two competing ASP systems at two different sites. Many people in the Flagstaff, Holbrook, and Kingman Districts and the Equipment Services Group, on behalf of all of ADOT, are actively supporting this research with their time and budget dollars.

The research now needs your input to help us evaluate our results to date and to guide next year's program. In order to have an independent evaluation, the Applied Transportation Research Laboratory at Northern Arizona University is conducting this survey and evaluating the results.

1. Based on your experience and judgment, to what extent do you agree or disagree with these statements? Circle one number on each line.

	Strongly Agree (1)	**Agree (2)**	**Undecided (3)**	**Disagree (4)**	**Strongly Disagree (5)**	**Don't Know (6)**
The ASP systems will significantly improve the snowplow operator's safety.	1	2	3	4	5	6
The ASP systems will enable the snowplow operator to safely plow his route faster during poor visibility.	1	2	3	4	5	6
The ASP systems will enable a District to keep their roads open much better during winter conditions.	1	2	3	4	5	6
The ASP systems will noticeably improve the traveling public's safety during winter conditions.	1	2	3	4	5	6
The ASP systems could be used effectively in all Districts that have snowplow operations.	1	2	3	4	5	6

What about costs? The Advanced SnowPlow (ASP) systems have two major cost components:

(1) magnetic material imbedded in the pavement (per mile cost) and
(2) various types of sensing equipment installed in the snowplow (per snowplow cost).

For all practical purposes, these can be reduced to a simple per mile cost. Magnetic material can be imbedded in only a few miles of especially troublesome winter plowing roadway in a District. From there, it can be expanded to more miles of roadway as desired. On the other hand, a more extensive installation program can be implemented from the very beginning.

2a. If the ASP systems were installed in your District or Org., estimate how many lane miles of roadway would need magnetic material imbedded in it.

- ☐ 0 to 24 lane miles in your entire District/Org.
- ☐ 25 to 49 lane miles in your entire District/Org.
- ☐ 50 to 74 lane miles in your entire District/Org.
- ☐ 75 to 124 lane miles in your entire District/Org.
- ☐ 125 to 200 lane miles in your entire District/Org.
- ☐ More than 200 lane miles in your entire District/Org. (fill in your estimate: ________ lane miles)
- ☐ Don't know (skip questions 2b and 2c ➔ go to question 3).
- ☐ Not applicable because my duties cover more than one District (➔ go to question 3).

2b. In the previous question 2a, what management unit were you using for your estimate?

- ☐ Org.
- ☐ District

2c. In the previous question 2a, what approach did you use for estimating lane miles?

- ☐ Estimated the especially troublesome lane miles.
- ☐ Estimated a more extensive program based on ____________________________________

  ____

For this next question, consider the lane miles you estimated in the previous question.

3. ASP systems provide benefits but cost money. Assuming the ASP systems are proven to substantially improve snowplow operator safety and efficiency, what would be the highest cost you believe would be reasonable for ADOT to pay?

- ☐ More than $30,000 per lane mile
- ☐ $25,000 to $30,000 per lane mile
- ☐ $20,000 to $24,000 per lane mile
- ☐ $15,000 to $19,000 per lane mile
- ☐ $10,000 to $14,000 per lane mile
- ☐ $5,000 to $9,000 per lane mile
- ☐ Less than $5,000 per lane mile (fill in your reasonable value: $__________ per lane mile)
- ☐ Don't know

What about only using part of the ASP system?

The ASP system's three components work together, but can be purchased and used individually.

- (A). The lane-keeping guidance system, when used by itself, allows the snowplow operator to accurately guide the snowplow within the proper lane even in "whiteouts" and other types of poor visibility conditions.
- (B). The collision warning system, when used by itself, allows the snowplow operator to be warned if there is an obstruction (slow moving or abandoned car) directly ahead, regardless of visibility conditions. It can also be used on any other type of vehicle that might need it.
- (C). The vehicle tracking system, when used by itself, allows the District office to monitor the snowplow's location, operating status, route segments covered, speed and direction. If the snowplow does not move for a significant time, the District can check on the safety of the operator. It can also be used on any other type of vehicle that might benefit from it.

These next questions explore the possibility of using these three components individually.

4a. Based on your experience and judgment, to what extent do you agree or disagree with these statements? Circle one number on each line.

	Strongly Agree (1)	**Agree (2)**	**Undecided (3)**	**Disagree (4)**	**Strongly Disagree (5)**	**Don't Know (6)**
The lane-guidance system, by itself, will significantly improve the snowplow operator's safety.	1	2	3	4	5	6
The collision warning system, by itself, will significantly improve the snowplow operator's safety.	1	2	3	4	5	6
The vehicle tracking system, by itself, will significantly improve the snowplow operator's safety.	1	2	3	4	5	6
The vehicle tracking system, by itself, will significantly improve the District's ability to monitor and allocate its materials and equipment.	1	2	3	4	5	6

4b. Is there some combination(s) of two of the individual systems that should be considered? (you may check more than one box)

☐ Yes, consider the combination of the (A) Lane-keeping and (B) Collision Avoidance systems.
☐ Yes, consider the combination of the (A) Lane-keeping and (C) Vehicle Tracking systems.
☐ Yes, consider the combination of the (B). Collision Advoidance and (C). Vehicle Tracking systems.
☐ No opinion

What should next year's testing of the ASP system include?

5. What questions should next year's research be sure to answer about the Advanced Snowplow system?

Finally, what else should be researched?

6a. What else about vehicles could ADOT be researching that might improve snowplow operations?

6b. What other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter maintenance operations?

ATTACHMENT C

ASP TRAINING AND EVALUATION SURVEY 2000-2001

Trainee Responses, Comments and Recommendations

Operator ID	Were there any systems problems when you were operating the vehicle?	Did the systems ever prompt you to make a wrong move or error in judgement?	What comments or suggestions would you make to improve any feature's usefulness?
CALTRANS Advanced Snowplow System			
CAL01	NO	NO	Add seat vibrator option It's been two years since I operated this truck and system. In missing the interim improvements, working with this system is like experiencing a new system altogether. The mile marker and location name options on the monitor are a definite plus. I felt slight disorientation as I read the monitor going into a curve. The changing position of the fog lines on the monitor. Slight improvement in monitor position. H.U.D. is ideal. One time an approaching vehicle set off the collision avoidance bar. I took the bottom of the scale to be the position of the truck. As the car approached the bar went down but disappeared before reaching the bottom of the scale. Another car approached and the bar went all the way to the bottom as the car passed the truck. (inconsistent display). Trainer was very knowledgeable. He answered all my questions clearly and patiently. Trainer did good job of explaining systems and prepping me to operate equipment.
CAL02	No, other than the collision is very quick, to make me believe the operator would not be able to avoid a collision.	NO	The vibrating seat that is installed in the 3 com truck is a valuable tool because you do not have to be looking at any instruments to be warned which gives valuable time to correct your movements. Also to properly evaluate these systems I believe training needs to be done during conditions for which they were meant.
CAL03	Collision warning sys. Failed once. Probably drivers fault. Plow to high etc?	NO	The screen is smaller and positioned in front by window. Very good improvement. Instructor very helpful and knowledgeable, good job Jo!
CAL04	N/A	NO	NONE

Operator ID	Were there any systems problems when you were operating the vehicle?	Did the systems ever prompt you to make a wrong move or error in judgement?	What comments or suggestions would you make to improve any feature's usefulness?
CAL06	NO	NO, did not use at night in a snowstorm.	Move screen away from sun, put marker flags on plow.
CAL07	NO	NO	
CAL08	NONE	NO	Maybe improve radar system somewhat.
CAL09	NO	NO	Maybe inform what is coming at the plow on the radar.
CAL10	NO	NO	
CAL11	NONE	No, everything seems to be working in order.	None, it has all.
CAL12	NO	NO	
CAL13			
CAL14	NO	NO	
CAL15	Just need more time in truck to learn the operation of it.	Sometimes, because need to know more about the operation of the truck.	I think it is a very good idea and will not only improve safety for the driver, but the public as well.
CAL16	NO	NO	Move the screen over to the left a little more to see screen and road at same time.
CAL17	NO	No, I like the way the screen shows the curves.	I think a vibrating seat would be good to have.
CAL18	NO	NO	NONE
CAL19	NO	NO	The system will work, if other org. are interested and work with it.
3M Advanced Snowplow System			
3M02	NO	Not to my knowledge.	Need something to indicate on-coming traffic.
3M03	Radar didn't work.	NO	Put sensor higher on truck.
3M08	NO	NO	Bring one to Yuma.
3M09	Car passed on right side - warning didn't work.	NO	
3M10	NO	NO	NONE
3M11	NO	NO	When there is a turn or an increase or decrease in grade (uphill/downhill).

Operator ID	Were there any systems problems when you were operating the vehicle?	Did the systems ever prompt you to make a wrong move or error in judgement?	What comments or suggestions would you make to improve any feature's usefulness?
3M12	NONE	NO	
3M13	NO	NO	NONE
3M14	NO	NO	NONE
3M15	NONE	No, the feature on plow truck helps you from making wrong moves.	NONE
3M16	Collision avoidance inoperative.	NO	For me the screen is still a little busy, or cluttered. Needs to be simplified even further. A distinct improvement over screen in Cal-Trans truck. Thank you for sharing this technology with me.
3M17	Vorad was down?	NO	Put display on a heads op reflected on windshield.
3M18	NO	NO	Would be nice to use during snow conditions to get feel for actual effectiveness.

ATTACHMENT D

ADOT MANAGEMENT SURVEY RESPONSES 2000-2001

Questions To Be Answered During The Next Year's Snowplow Research Activities

Sample No.	Title	5. What questions should next year's research be sure to answer about the Advanced Snowplow system?
1P	Maint. Superintendent	Is it cost effective?
		What are the cost/benefit ratios?
1	Hwy. Maint. Supervisor	
2	Equip. Mgr.	I only attended 1-2 mtgs and one demo while in Flag on other state business. I was very impressed with what I saw. However, not being involved at the District level and more attendance at the mtgs rct. I don't feel I have enough information to answer all the questions in the survey.
3	Engineer	How many accidents have there been due to poor visibility? (between snowplow & private vehicle)
		How many run off the road accidents have there been in regards to snowplows & poor visibility?
		I think it would be very difficult, if not impossible to get the snowplow operators to "fly blind", than rely on the navigation system and not visual.
4	Hwy. Maint. Supervisor	Results, data from research areas.
		Costs of ASP
5	Hwy. Maint. Supervisor	I would not know because, I have no knowledge of how it works, never been around it.
6	Hwy. Maint. Supervisor	Accuracy of Radar System
7	District Maint. Engineer	Cost/Benefit
		Determine what the term "significantly improve safety" really means.
		A Collision Warning System needs to be fully tested.
8	Maintenance Supervisor	If system will be cost effective.
9	Supervisor	How well will it work in remote and mountain regions on narrow roads with sharp curves, with large trees, cloud cover and heavy snow.
10	Maint. Supervisor	Need to improve the distance on the radar to allow more reaction time.
11	Maint. Supervisor	
12	Hwy. Maint. Supervisor	
13	Supervisor	
14	Hwy. Maint. Supervisor	Cost per lane mile.

Sample No.	Title	5. What questions should next year's research be sure to answer about the Advanced Snowplow system?
		Cost to modify current fleet of snowplows.
15	Supervisor	
16	District Maint. Engr.	Work on refining instrumentation in truck as per driver's recommendations to simplify operating requirements for drivers.
17	Maint. Supervisor	Maintenance of equipment and failure
18	Equip. Mgr.	To make a recommendation as to the safety and effectiveness of the ASP System. Yes or No.
19	Maint. Supervisor	
20	Maint. Supervisor	
21	Maint. Superintendent	Does the system save time? (C speed will run while plowing compared to speed without system)
22	Supervisor	
23	Hwy. Maint. Supervisor	How close to stopped vehicles will an alarm sound.
24		
26	Supervisor	
27	Maint. Superintendent	
28	District Engineer	Users viewpoint
		Benefit vs. Cost
31	Engineer	What are expected cost - per vehicle & per mile?
		What are expected benefits?
32	Operations Engineer	Need to identify success of ASP system.
33	Equip. Mgr.	Determination of a Collision Avoidance System that is commercially deliverable and sold for use on snowplow equipment.
34	District Maint. Engineer	
35	District Maint. Superintendent	Cost & where or how will the cost be covered.
		If this is not fundable then cease research for lack of funds to implement.
36	Maint. Engineer	I am concerned if the driver needs to take their eyes off the road. The report was not clear or I missed the part about any of the guidance systems not needing attention by the driver.
37	Hwy. Maint. Supervisor	
38	District Engineer	Comparison of the magnet vs. tape systems, reliability, etc.

Sample No.	Title	5. What questions should next year's research be sure to answer about the Advanced Snowplow system?
		Cab environment needs to be examined more closely.
39	Maint. Engineer	Cost Benefit Analysis
40	Hwy. Maint. Supervisor	
41	Hwy. Maint. Supervisor	
42	Hwy. Maint. Supervisor	
43	Supervisor	
44	Dist. Maint. Engr.	How cost effective is the system in a district which gets periodic snow fall in a season from none to light?
		All above answers were based on the snowplow needs for a district in the desert with very limited snowfall.
45	Maint. Supervisor	Possibly only using a satellite tracking system to monitor truck & lane position.
46	Maint. Superintendent	Costs, ability to do what is claimed in question four on a consistent basis.
47	Hwy. Supervisor	
48	Supervisor	
49	Hwy. Maint. Supervisor	High volume roads vs. low volume
50	Supervisor	Will they put these test section on rural roads also or just on interstates. Like always.
51	District Maint. Superintendent	More accurate way of monitoring what we are applying.
52	Supervisor	We have not worked with this system so we can't make any comment.
		Just judge from what we hear.
53	Supervisor	
54	District Maint. Supervisor	Are magnetic material embedments the only option?
		How deep can we imbed the magnet and is it still effective?
56	Hwy. Maint. Supervisor	Cost Effectiveness!
57	Maint. Supervisor	
58	Maint. Superintendent	Operators and Citizens safety?
59	Maint. Supervisor	
60	Hwy. Maint. Supervisor	Not sure, because it doesn't snow in the Yuma district.
61	Hwy. Maint. Supervisor	Should look at time spent plowing routes without system and with system for quality of plowing, and tracking of time.

Sample No.	Title	5. What questions should next year's research be sure to answer about the Advanced Snowplow system?
62	Hwy. Maint. Supervisor	
63	District Maint. Engineer	
64	District Engineer	Does the collision warning work effectively.
65	District Maint. Engineer	
66	District Engineer	A. A test route
		B. Comprehensive monitoring
		C. Running with equip. on AND with off.
		D. Comparative evaluations
67	Engineer	
68	Equipment Services	
69	District Engineer	Need to provide more accurate condition information on weather and road conditions.
70	District Engineer	How would these systems be expected to operate on Arizona's most challenging geometric roads, specifically SR 366 (Swift Trail) and US 191 (Coronado Trail) in southeastern AZ. No highways in AZ maintained by ADOT are their equal for narrowness, sharp curves, and excessive gradients.
71	District Engineer	Do a trial of all these systems and see how effective each one is, but use multiple orgs & districts to get an overall look rather than a slanted evaluation
73	District Engineer	

ATTACHMENT E

ADOT MANAGEMENT SURVEY RESPONSES 2000-2001

Other Useful Winter Maintenance Operations Research Topics

Sample No.	Title	6a. What else about vehicles could ADOT be researching that might improve snowplow operations?	6b. What other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter maintenance operations?
1P	Maint. Superintendent	Maybe "Simulated" snowplowing to test equipment, rather than actual snowplow in the field.	Better deicing materials, research on; data on those materials.
			Simulator training as used in Airline industry, do supplement field training.
1	Hwy. Maint. Supervisor	Lights to see by.	
		Windshield wipers that have the ability to remove the snow from my windshield.	
2	Equip. Mgr.		
3	Engineer		Chemical devices need to be studied and tested a lot more and they also need to be funded!
4	Hwy. Maint. Supervisor	Windshield Freeze, improved wipers.	Anti-icing materials: both liquid and Granular
		Headlights-Rear warning lights.	Hwy 260 M.P. 377.5 to 383 is 9100 ft elevation. High wind area. Constant white-outs. Ideal area for 1) Lane keeping guidance, 2) Collision Warning
5	Hwy. Maint. Supervisor	A better method or mounting on snowplow, one man operation not two or three, the way it is, it's unsafe.	On equipment: better understanding from maintenance on the snow spreader calibration system, not just the mechanics.
			Road surface material ACFC: when new pavement, snow covers faster than old pavement.
			Liquid de-ice material plus storage for that material.
			E.P.A. approved mixing and storage for road salt, and wash bay after storm cleaning equipment.
6	Hwy. Maint. Supervisor	Better lighting	Something other than the Ravens and Dickey-Johns for keeping track of what materials are being used.
7	District Maint. Engineer	Lighting systems for "seeing" by the operator in snow and fog conditions.	Automatic gates, remotely operated, that can close ramps and maintain routes as conditions deteriorate and in conjunction with variable message boards.
		Friction wheel to determine roadway surface condition.	Need lab testing of our winter chemicals to see if they meet specs.
		A system to "record" material usage by route and milepost by individual plow.	Ability to reconstruct the "storm" and where our plows were and what they did via GPS or similar concept.
8	Maintenance Supervisor	Different types of wiper blades.	Train the traveling public with T.V. ads, about winter driving.
			More enforcement of chain regulations on trucks and cars.
9	Supervisor	Light placement on the snowplow.	A snow blower that will attach equipment that we already have.

Sample No.	Title	6a. What else about vehicles could ADOT be researching that might improve snowplow operations?	6b. What other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter maintenance operations?
			Lower blade snowplow trucks.
10	Maint. Supervisor	Headlights	We need to improve the computers for the spreaders, they seem to break down a lot.
11	Maint. Supervisor	Windshield wipers, lighting	
12	Hwy. Maint. Supervisor	Lower plows to see over, and curb lights on plow trucks.	
13	Supervisor	The better the visibility, the easier it is on snowplow operators. I think that is their biggest complaint.	Ways of keeping snow and ice off windshields.
14	Hwy. Maint. Supervisor	Radio headsets with voice activated microphones.	Lighting for snowplows.
		Inter agency capability of communicating with law enforcement agencies.	Warning light enhancements for plow trucks. (Reference: Minnesota DOT Whelan Warning Lighting Systems.)
		Infrared surface temperature senses for monitoring road surfaces for optimum application of anti-icing or de-icing materials. (Vehicle installed)	
15	Supervisor		How much "De-Icers" is enough.
16	District Maint. Engr.	Lighting - both front and rear.	Reports on Ice-Slicer have been glowing.
			Work out a procedure to buy and stockpile in bulk quantities to lower cost.
17	Maint. Supervisor	Snowplow Headlights and wipers.	Chemical friendly equipment
			Stronger chemical program
			More training on chemical usage and effects.
18	Equip. Mgr.		
19	Maint. Supervisor		
20	Maint. Supervisor	Need better plow lights to improve driving conditions at night.	
		Need better windshield wipers to keep windshield clean. Something to keep ice from forming on wipers.	
		Need something to keep rear lights from freezing over with ice.	
21	Maint. Superintendent		
22	Supervisor		
23	Hwy. Maint. Supervisor		The use of freeze guard at higher elevations.

Sample No.	Title	6a. What else about vehicles could ADOT be researching that might improve snowplow operations?	6b. What other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter maintenance operations?
24			
26	Supervisor		
27	Maint. Superintendent		
28	District Engineer	Equipment cab - feasibility/location; ergonomics in cab.	Chemicals for de-icing and policy from agency as to application. (Benefit vs. Cost)
			RWIS usage vs. no usage
			Global training for snowplow operators
			Operation center for snowplow support; ADOT TOC vs. District support?
31	Engineer		
32	Operations Engineer		Use of chemicals, where & when, to combat ice.
33	Equip. Mgr.	Lighting	
		Windshield wiper operation and windshield defrost operations - trucks are not designed for this vocation due to the fact snowplow vocation is less than 1/2 -1% of total U.S. truck vocational usage.	
34	District Maint. Engineer		
35	District Maint. Superintendent	Is there a time when snow removal should not be done? (Night - White outs -)	I think we are researched out! What we need is the resources to use the technologies!!
36	Maint. Engineer		
37	Hwy. Maint. Supervisor	Public service broadcast that traveling public should back off when sanding/plowing (signs on rear of spreader are worthless) driver can concentrate on driving not worrying about people who drive 65-75 in snow or ice conditions.	
38	District Engineer	Linking to some type of "heads up" display where hard tracking is not required.	How to sell the legislators and public the need for better equipment, materials, and personnel for winter maintenance.
		Continued efforts on collision avoidance hardware.	Integrating RWIS and on board devices to assure proper chemical usage.
39	Maint. Engineer	New developments in plow & Spreader products	
		Update on the prototype vehicle being tested in Iowa	

Sample No.	Title	6a. What else about vehicles could ADOT be researching that might improve snowplow operations?	6b. What other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter maintenance operations?
40	Hwy. Maint. Supervisor	More effective lighting	Real public awareness programs based on reality, not "touchy-feely good news fluff". If it snows, you will face bad conditions and ADOT cannot provide miracles.
		Warning lighting	
		Windshield wipers	
		Operator comfort and anti-fatigue measures	
41	Hwy. Maint. Supervisor	Wipers	
42	Hwy. Maint. Supervisor		
43	Supervisor		Available Personnel & Available funds to cover cost of equipment and materials. That is where the loss effects the maint. Org's.
44	Dist. Maint. Engr.	LIGHTS(type and mounting locations on plow equipment)	
45	Maint. Supervisor		Deicing agents that don't require special equipment for application.
46	Maint. Superintendent	Not sure	How much equipment it takes to keep a lane mile plow to a reasonable level of service. Define that service so we are consistent around the state.
			Use of chemicals - what & how much.
47	Hwy. Supervisor		
48	Supervisor	Improved sand/deicer equipment.	Ice Sensors to a central monitor, especially on bridges.
		I have one Raven and Dicky John; Raven was broken 80% of the time, Dicky John 60%.	
49	Hwy. Maint. Supervisor	Thermometers onboard so operators could tell when to use chemicals & what kind.	Thermometers onboard so operators could tell when to use chemicals & what kind.
50	Supervisor	Get all the Orgs involved in these operations.	Same or treat everybody the same and don't leave others out.
51	District Maint. Superintendent	A way to monitor the application residue that exists on the pavement.	Devices for tracking, monitoring, products that are applied and how they are doing in a more simpler way (know what amount of products are in the pavements at any one time).
52	Supervisor	Infrared vision seems to work for other eastern states maybe ADOT might look into that.	Snow plows that are the Mack trucks seem to block the roads and the headlights.
			The procedures that we have works very well, it's just the materials that we have: salt and cinders to work with, maybe there's other's available that we may get , but we don't have the training on it.
53	Supervisor		
54	District Maint. Supervisor	Advising speed of snowplow truck.	Anti-icing management technique.

Sample No.	Title	6a. What else about vehicles could ADOT be researching that might improve snowplow operations?	6b. What other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter maintenance operations?
		Sensors in pavement to tell where the worst area is located.	Need to evaluate the cost & benefit of the "ASP" system like past accidents &/or increase of productive, like be able to plow more & safer with "ASP" system.
56	Hwy. Maint. Supervisor	More on G.P.S. for navigation!	Have training that makes sure the student learns what he or she has been taught and do refresher training on a yearly basis.
57	Maint. Supervisor		
58	Maint. Superintendent	Change from manual transmissions to automatic so driver can concentrate on road.	Wide spread use and extensive training.
		Better wipers and visibility out of windshield.	
		Plow blow back on windshield	
		Lights to see better at night, night vision.	
59	Maint. Supervisor		Some sort of equipment mounted in the trucks to let us know how much material we used on the roads (salt) or to monitor how much is left on roadway.
60	Hwy. Maint. Supervisor		
61	Hwy. Maint. Supervisor	That all plows would be set up uniformly so there would be no confusion to operators.	Having the three systems in all plows and use this to help establish a budget for winter maintenance operations in areas where there is a substantial amount of snow and ice, thus increasing costs to maintain highways.
62	Hwy. Maint. Supervisor		
63	District Maint. Engineer		GPS Systems for guiding vehicles.
64	District Engineer	Lights & effect on driver's vision & fatigue.	The use & cost of chemicals for anti-icing.
			What is available & how effective is it with significant temp. variation & quantity of snow. Can it be effectively used with existing equipment?
65	District Maint. Engineer	We could take another look at light placement, defrost & wiper functionality to improve operator's vision.	At least one Org does not have enough staff on its personnel compliment to man needed plows for two-12 hour shifts, yet the District was required to give up 2 FTE's a year ago.
			We are looking at using more chemical deicer, but it is costly.
66	District Engineer	PLOW Shock absorbing system to prevent CHATTER.	More extensive chemical research
			More financing for maintenance!!
67	Engineer	How can the headlights be placed on plows - so that the driver is not blinded during storm activity.	We had a great success last winter with snow chemicals in the Flagstaff District. I would like more info about the various types/cost/when to apply etc.
68	Equipment Services	Use of brooms for high-speed snow removal.	Snow removal material lay down - new type of material and optimal lay - down rates.

Sample No.	Title	6a. What else about vehicles could ADOT be researching that might improve snowplow operations?	6b. What other equipment, methods, materials, or personnel procedures could ADOT be researching that might improve winter maintenance operations?
69	District Engineer	Should review out policy regarding snowplow safety, i.e. -Should we plow at night? -How much should we spend? -How should resources be allocated? -Should drivers receive add'l certification. -What chemicals should we use? We should be consistent on a statewide basis.	Should review out policy regarding snowplow safety, i.e. -Should we plow at night? -How much should we spend? -How should resources be allocated? -Should drivers receive add'l certification. -What chemicals should we use? We should be consistent on a statewide basis.
70	District Engineer		Chemical additives or chemical applications that are effective, cost efficient and environmentally acceptable.
71	District Engineer	The windshield wipers are presently very suspect. The operators have a hard time just looking through them.	Eliminate uses of abrasives altogether & ADOT an ice management system through chemical application.
		Maybe a camera on plow equipped w/ several cameras located prior to or in front of the plow could hold or better wiper system.	
73	District Engineer		

REFERENCES

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