Arizona Intelligent Vehicle Research Program - Phase Three: 2002 - 2003

Final Report 473(4)

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16. Abstract –
This report covers Phase Three of a long-term advanced vehicle research program of the Arizona Department of Transportation (ADOT) and its Arizona Transportation Research Center (ATRC). The primary focus of the research has evolved to topics in winter operations. Phase Three, the fifth year of this program, included the 2002-03 winter season.

Phase One of this research (1997-2000) began with intelligent-vehicle concept demonstrations relevant to Arizona’s specific transportation needs. These early efforts led to a joint program with California to field-test the Caltrans advanced snowplow (ASP) in Arizona conditions. In 1999 and 2000, over two winters, ADOT crews evaluated California’s ASP lane-guidance system in four-week test cycles at a three-mile long two-way test loop of embedded roadway magnets near Flagstaff.

In Phase Two (2000-01), the key goal was to acquire and test a driver-assistance system for an ADOT snowplow. The project selected the 3M Lane Awareness System, and installed 5 miles of 3M magnetic striping tape at a second test site. The partnership with Caltrans was continued to compare both guidance concepts in similar operating conditions. However, system problems with both research snowplows reduced the ability of ADOT and its partners to evaluate either concept.

In Phase Two(b), the 2001-02 winter, ADOT’s test and evaluation plans were successful, as the technical issues of the previous winter had been resolved. The key goal of side-by-side plowing operations was hampered by a lack of snowfall during the test period, and the ADOT-3M snowplow’s field tests were limited to only a few storms all winter. Overall, both concepts proved their effectiveness and reliability in 2001-02, but the mild weather did not allow the project to document their performance. At this point it was clear to ADOT that the cost of either system was prohibitive, and the research focus for 2002-03 was shifted from roadway-based guidance concepts to commercial on-board warning systems.

In the current Phase Three (2002-03), ADOT expanded the research activities to the “I-40 Corridor” districts east and west of Flagstaff. The project equipped seven snowplows with either collision warning radar or passive infrared night vision, at a much more practical level of cost. With these new units in service on seven snowplow routes across northern Arizona, the project determined winter performance results for both of the commercial on-board warning systems. Despite a mild winter, results for the warning radar were positive overall, but ice buildup in storms hampered the night vision system. Both of these systems were judged to be effective and operationally successful, with certain limitations. Their field deployment in northern Arizona will be extended with some refinements for the 2003-04 winter season.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE AND PRESSURE OR STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	KPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS		
N	Newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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TERMS, ACRONYMS AND ABBREVIATIONS

TERM	DEFINITION
3M	The 3M Company (originally Minnesota Mining & Manufacturing)
ADOT	Arizona Department of Transportation
AHMCT	Advanced Highway Maintenance & Construction Technology (AHMCT Research Center at UC Davis: Core Contractor for RoadView ASP)
AHS	Automated Highway Systems
ASP	Advanced Snowplow (early Caltrans project term, now evolved to general use)
ASP-I	Advanced Snowplow, Phase I (Caltrans program 1998-1999)
ASP-II	Advanced Snowplow, Phase II (Caltrans program 1999-2000)
ATRC	Arizona Transportation Research Center – ADOT (at Phoenix)
AVL	Automatic Vehicle Location
Caltrans	California Department of Transportation
CPU	Central Processing Unit
CWS	Collision Warning System
DGPS	Differential Global Positioning System
District	ADOT Maintenance & Construction Districts
DOT	Department of Transportation
DPS	Department of Public Safety (Arizona Highway Patrol)
DVI	Driver-Vehicle Interface
GPS	Global Positioning System
HMI	Human-Machine Interface
HUD	Head-Up Display
I-17	Interstate 17 (in north-central Arizona)
I-40	Interstate 40 (in northern Arizona)
I-80	Interstate 80 (in northern California)
IR	Infrared
ITS	Intelligent Transportation Systems
IV / IVI	Intelligent Vehicle / 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)
NWS	National Weather Service (of the National Oceanic & Atmospheric Administration)
Org	ADOT's Local-Level Maintenance Organization (Camp or Yard)
PATH	Partners for Advanced Transit and Highways (Core Contractor for Caltrans RoadView ASP - at UC Berkeley)
RF	Radio Frequency
RoadView™	2000-2002 Evolution of the Caltrans Advanced Snowplow (ASP)
SR 87	Arizona State Route 87 (southwest of Winslow)
UCB	University of California at Berkeley
UCD	University of California at Davis
U of I	University of Iowa (at Iowa City)
US 89	US Highway 89 (northeast of Flagstaff)
US 180	US Highway 180 (northwest of Flagstaff)

I. EXECUTIVE SUMMARY

Figure 1: Winter Storms Close the Interstate 40 Corridor

INTRODUCTION

This report summarizes Phase Three of a long-term Intelligent Transportation Systems (ITS) research program by the Arizona Department of Transportation (ADOT) to study cooperative vehicle and infrastructure-based guidance technologies. ADOT's Arizona Transportation Research Center (ATRC) in Phoenix has conducted this research project as an in-house effort.

Phase Three of Arizona's advanced-vehicle research, the 2002-03 winter season, was Year Five of the program. In four previous years, the project efforts focused on advanced lane positioning and predictive guidance technologies that required a complex roadway infrastructure component. This concluding Phase Three of the project, in contrast, has evaluated two commercial on-board driver-warning systems on seven snowplow routes across northern Arizona.

BACKGROUND TO PHASE THREE

Phase One of the ADOT Intelligent Vehicle Research Program (1997-2000) involved Arizona demonstrations of Intelligent Vehicle (IV) and Automated Highway System (AHS) concepts. The program soon became focused specifically on snowplow research, as a promising near-term application to enhance the safety and efficiency of ADOT winter maintenance operations.

In Phase One, the ATRC partnered with the California Department of Transportation (Caltrans) to field-test their prototype Advanced Snowplow (ASP) in Arizona. The project developed a three-mile test lane on US 180 near Flagstaff in northern Arizona. This site allowed Caltrans to diversify their research experience in different weather and terrain conditions, with a unique pool of Arizona snowplow operators. For two winters in the Phase One program, ADOT maintenance crews trained on and evaluated the Caltrans lane-guidance system in four-week test cycles.

In Phase Two (2000-01), the project sought to equip an ADOT snowplow with a guidance system for long-term testing. Caltrans could only assign their newest RoadView™ ASP to Arizona for four weeks each winter, which did not allow for a thorough evaluation of the Caltrans system and its components. The project's Technical Advisory Committee (TAC) therefore made a decision to procure and commission similar snowplow vehicle guidance technology in Arizona.

At this time, the Caltrans program did not have staff resources to support a second ASP system outside of California. Also, the RoadView ASP was a developmental prototype. Many key components were not packaged systems, but were unique or even hand-built. Therefore, ADOT acquired a 3M Lane Awareness System (LAS) with five miles of 3M's magnetic striping tape. The tape was installed in the roadway at a site near Flagstaff, in a construction project on US 89.

ADOT continued its long-term program with Caltrans in Phase Two, with a new goal to compare both guidance systems operationally in similar weather and road conditions. Phase Two was not a complete success, for reasons that were mostly technical. Both test snowplows had various ASP system issues, and at the 3M site, temporary lane striping did not match the embedded tape.

These problems dictated a fourth testing winter, Phase Two(b) for ADOT, and in 2001-02 the project finally achieved a higher level of success. The Caltrans RoadView ASP and the ADOT-3M plow both were reliable and effective in their respective training, evaluation and operational phases, but the Phase Two(b) winter had less than half of the normal snowfall. Also at this point, ADOT recognized that the current costs of either roadway-infrastructure system would limit their application for Arizona, and the project was steered toward new on-board concepts.

PHASE THREE: NEW RESEARCH DIRECTIONS

This Phase Three research report, on the 2002-03 season, covers the fifth and final project year of the ADOT-ATRC evaluation program for advanced snowplow systems. The research efforts for Year Five were refocused to a thorough and complete evaluation of two promising on-board commercial warning systems. These two systems were the Bendix XVision passive-infrared (IR) night vision system, and the Eaton VORAD EVT-300 collision warning radar system (CWS).

The fundamental problem to be addressed by this research program is poor visibility for plow operators in severe winter storms. The new on-board warning systems do not provide the 3M or Caltrans predictive guidance abilities to keep snowplows moving in very poor visibility, but they do improve operator awareness of conditions, hazards, and potential obstacles in the road ahead.

The project goals were to determine the state of development, effectiveness, flexibility, and reliability of the two on-board driver-warning systems in winter storms, and, to identify the key factors for their successful implementation for snowplowing in rural states such as Arizona.

Winter 2002-03: Phase Three Research Plan

With the project newly focused on tests with off-the-shelf, self-contained, on-board systems, the ATRC's research plan was both simpler and more complex. The project's key mandates were to evaluate practical, affordable warning systems, and, to expand the playing field to involve more winter maintenance stakeholders and decision-makers. The research plan for 2002-03 would therefore expand the number of active project partners across three ADOT maintenance districts, and a total of seven test locations were identified.

The TAC's goal was to place at least one radar and one XVision system in each of ADOT's three northern districts across the Interstate 40 corridor. The project obtained four CWS radar systems and three IR night vision systems. The units were assigned to snowplows on both Interstate and state highway routes, and the plows had the flexibility to work on other routes as needed.

Arizona's evaluation program for Phase Three evolved from the partnership with the Caltrans test program. Over four winters, various report formats had been developed and standardized as much as possible for both ASP concepts. ATRC continued to employ the basic project reporting tools, including shift activity reports and surveys of driver perceptions and preferences.

The two new suppliers had to be considered in the research plan and evaluation approach. Both systems were commercial units designed as driver-support systems for long-haul transport fleets. The CWS radar system was widely marketed, and Eaton was not focused on niche markets such as snowplowing. The Bendix IR night vision was less widely distributed, and their program was still exploring the marketing potential for specialty vehicle applications.

As a result, the ADOT evaluation would seek driver feedback with a Bendix incident report to describe events when the system did or did not give a warning, or, impacted a driver's decisions. While not required by Eaton, the ATRC also used a similar event report for the CWS radar units, providing one more consistent evaluation tool for both on-board systems.

Winter 2002-03: Training & Evaluation Activities

The Year Five evaluation of these two off-the-shelf commercial systems was focused only on the key drivers assigned to each of the project snowplows. The main emphasis was on their level of effectiveness for the ADOT snowplow operators in storms at the widely scattered test sites.

There was a learning curve for the commissioning of the two driver-warning systems. The Eaton VORAD system was fully developed, with extensive installation, training, and trouble-shooting manuals, and an introductory videotape. This level of training support was required for driver acceptance due to the sophistication of the radar concept and its array of warning signals.

Bendix, on the other hand, offered a night vision concept that was clear and intuitive, with only limited training material and operating guidelines. Still, these aids were needed to ensure that every driver understood the abilities and limitations of the thermal imaging equipment.

Overall, the evaluation was ongoing rather than episodic. The ATRC provided basic shift reports for storm events so that driver comments or system issues could be documented without adding too much more paperwork. These reports were augmented with frequent project meetings and by periodic driver surveys on both systems, including a final survey at the end of the season.

Winter 2002-03: Operational Activities

The project's Phase Three, Year Five winter was a meteorological disappointment, but the winter weather was adequate to give the two systems a fair evaluation across the seven test sites. There were 14 storms with an inch or more of snow, compared to only ten in 2001-02. The snowfall at Flagstaff for 2002-03 totaled 55 inches, compared to a 30-year historic average of 107 inches.

The last of the seven project snowplows was fully operational by early February 2003, and all were employed on storm watch, materials application, and plowing activities. Overall, the seven snowplows logged a total of 37,250 miles in these operations, with 140 use-days from October to April, despite having only about 50 percent of the normal regional snowfall.

WINTER 2002-03 PROJECT RESULTS: ON-BOARD SYSTEMS

The Phase Three winter was the first season of testing and storm operations for the six newly-equipped project snowplows, and the Phase Two ADOT-3M snowplow was the seventh. This level of deployment definitely fulfilled the TAC's fundamental mandate for the research project. This relatively mild winter still validated the research plan, and it effectively demonstrated the long-term potential for the selected on-board commercial systems.

There are some issues, however, for wider distribution of units in the field. Driver acceptance is one concern, as the test plows were selected based on their operational route assignments. Some drivers were enthusiastic about the new systems and others were not. There is no clear pattern to the level of acceptance, but many factors may apply. With the wide dispersal of the units and the limited training program, drivers were really on their own. There were also problems with snow and ice buildup on the night vision camera lens that its heating element could not overcome.

Operational results were positive overall, despite the few major storms that occurred. The ADOT operators had no failures or reliability problems with the on-board systems through the winter, except as noted above. For the more committed drivers, their level of confidence was good with both the warning radar and the night vision system. The project concluded this fifth season with TAC recommendations to extend both field evaluations, to work to overcome the snow buildup issue for the XVision system, and to promote these two solutions within ADOT and regionally.

1997–2003 PROGRAM RESULTS: ADVANCED VEHICLE SYSTEMS

The key result of five winters of ADOT's snowplow research program is the confirmation that effective and reliable driver-assistance systems exist that, if deployed, can provide significant benefits to Arizona for winter maintenance operations in extreme storm conditions. The benefits include more efficient plowing operations, which will enhance the safety of ADOT snowplow operators and the traveling public.

This project has validated the potential of roadway-based vehicle guidance concepts developed by 3M and by the Caltrans program, but they are not the best solution for Arizona at their current cost levels. The project has also shown the potential in fleet operations for collision warning radar and night vision systems, although each has basic design limitations for snowplowing. Further field experience is needed to verify full winter storm functionality, but both on-board warning systems are operationally effective, robust and reliable.

The extra cost of equipping a snowplow with either on-board warning system would be minimal, and it is far less than the economic impact of even a single injury accident.

The project recommends further operational use of both systems for a second winter, to confirm that wider implementation of these units in Arizona can meet the local districts' needs.

II. PROJECT BACKGROUND

Travelers crossing Arizona in winter find that their long-held images of the desert's arid terrain, cacti and climate can be quickly shattered, as snowstorms often blanket the high country from early October into April. Commercial transport delivery schedules, regional economies, and personal mobility and safety expectations are all critical factors in the struggle to keep Arizona's highways open through the long winter storm season. As later chapters of this report will show, the cost impacts of winter storm-caused crashes are very high for Arizona.

Figure 2. Arizona's Highway Corridors are Critical to Commerce and Travel

Over the past five years, this ADOT advanced-vehicle research project has demonstrated and tested several sophisticated technologies, as described below, that have significant potential to support the snowplow operators and highway agencies of other rural states such as Arizona.

PROJECT PHASES

Phase One of this research began in 1997 with intelligent-vehicle concept demonstrations and tests focused on Arizona's transportation needs. The early efforts soon led the project to focus on winter maintenance operations. In 1998 and 1999, ADOT crews evaluated California's ASP lane-guidance system over two winters, at a six-mile roadway magnet test site near Flagstaff.

In Phase Two (2000-01), the project evaluated a 3M Lane Awareness System, with five miles of magnetic striping tape installed at a second test site. The joint research program continued with Caltrans with an added goal to compare both vehicle guidance concepts in similar conditions.

In Phase Two(b), during 2001-02, ADOT's goal of same-day operator training on both advanced snowplows was hampered by a lack of snowfall at Flagstaff. Both systems were effective and reliable, but the mild weather did not allow either to excel. It also was clear to ADOT that the cost of either system infrastructure was prohibitive. As a result, the research focus in 2002-03 shifted from roadway-based guidance systems to commercial on-board driver warning systems. In the current Phase Three winter (2002-03), ADOT has expanded the research activity area to the I-40 corridor districts east and west of Flagstaff. Four snowplows have been equipped with collision warning radar, and three more with passive infrared night vision systems. With the new systems in service at seven diverse sites across northern Arizona, the project has documented the driver ratings and performance results in local winter conditions for these two on-board warning concepts.

PROJECT SPONSORSHIP AND FIELD PARTICIPATION

The project stakeholders on the Technical Advisory Committee (TAC) bear the responsibility for a successful research project, by giving clear direction and leadership for the work, and providing generous resource support. The Intelligent Vehicle (IV) project TAC, by their participation and their positive attitude, were vital to the development of the two unique Arizona test sites, and to the ATRC's ability to capture valid and relevant results from the ongoing field activities.

Many individual stakeholders have had key roles in the long-term joint testing, training and evaluation program for advanced snowplow systems in Arizona. Many of the project partners named below have been actively involved in this snowplow research from its beginning in 1997 *(asterisks (*) designate Phase Three TAC membership).*

ADOT's I-40 Corridor District Engineers, Maintenance Engineers, Superintendents (1997-2003):
- Flagstaff District – *John Harper, *Kent Link, *Danny Russell, Don Dorman
- Holbrook District – *Jeff Swan, *Robert Wilbanks, David Sikes
- Kingman District – *Sam Elters, *Mike Kondelis, *Rance Spurlock, Debra Brisk, Bill Wang

ADOT Maintenance Yard or Camp (Org) & Equipment Shop Supervisors (1997-2003):
- *Tim Bighorse (Gray Mountain Maintenance Org)
- *Mike Gutzwiller (Little Antelope)
- *Ernie Sanchez, Jack Gray (East Flagstaff)
- *Bruce Mejia (Seligman)
- *Tom Steinberger (Kingman)
- *Gilbert Nastacio (Chambers)
- *Frances McCauley (Winslow)
- *Carl Eyrich (Flagstaff Equipment Shop)
- *Dave McNally (Kingman Equipment Shop)
- *Jim Finley, Ed Zamora (Holbrook Equipment Shop)

During the entire project, from 1997 to 2003, the project TAC included personnel both from key ADOT sections and from partner agencies. In addition to the ADOT field personnel listed in the preceding section, the other project TAC partners were:

Project 473 Technical Advisory Committee (1997-2003):
- Dennis Halachoff, Larry Presnall, Dean Murgiuc, Mike O'Malley, Mike Signa (ADOT Equipment Services)
- Tim Wolfe, Manny Agah (ADOT Transportation Technology Group (TTG))
- Doug Nintzel, Matt Burdick, Howard Boice (ADOT Community Relations Office)
- Lt. Dan Wells (Arizona Department of Public Safety: Flagstaff Patrol District)
- George Howard, Mike Campbell (NOAA / National Weather Service: Flagstaff –Bellemont)
- Alan Hansen, Jennifer Brown (Federal Highway Administration)

ADOT Project Snowplow Operators (2002-03, Phase Three: On-Board Systems):
- Robin Nelson, Seymour Tso (Gray Mountain)
- Chuck Bement, Robert Lyons, Jeff Saligoe (Little Antelope)
- Darwin Brewer, Harley Cody (Flagstaff)
- Stetson Baker, Lamar James, Bertram Billy, Dick Nez (Chambers)
- Jerry Pfalzgraff, Dave Henderson (Kingman)
- Curtiss West, Danny Solberg (Seligman)
- Ronnie Baca, Rick Sedillo, Steven Sanchez (Winslow)

PROJECT PARTNER & VENDOR SUPPORT: 1997-2003

Eaton VORAD System Technical Support (2002-03):
- Jeff Hall, Tom Mattox

Bendix XVision System Sales and Technical Support (2002-03):
- Craig Stark

Caltrans Advanced Snowplow Project Development (1997-2002):
- Bob Battersby, Kirk Hemstalk, Mike Jenkinson, Greg Larson of Caltrans
- Dr Ty A. Lasky and the AHMCT project team from the University of California at Davis
- Dr. Wei-Bin Zhang, Dr. Han-Shue Tan and the California PATH / UC Berkeley project team

3M Advanced Snowplow Project Development (2000-02):
- Heinrich Bantli, Gary Nourse, Chin-Yee Ng

III. WINTER MAINTENANCE: THE EXTREME CHALLENGE

Winter travel in rural Arizona is a true challenge for a number of key reasons. The terrain in the northern and eastern areas of the state rises from just 500 feet above sea level at the Colorado River, to 7,300 feet on Interstate 40 near Flagstaff. Over 250 miles of I-40 are at elevations above 5,000 feet. Many other route corridors in the northern, eastern and central mountains rise above 8,000 feet and even as high as 9,500 feet above sea level.

Figure 3: Dawn Patrol on Interstate 17 in a Winter Storm

Across the state, the Arizona Department of Transportation maintains a fleet of more than 240 snowplows to patrol and maintain nearly 4,000 miles of designated plow routes in the 6,200 mile state highway system. Of these snowplow routes, ADOT maintenance forces around the state have identified more than 1,300 miles of highway with moderate to severe visibility impairment in winter storm conditions.

Keeping Arizona's highways open and operating smoothly for commercial and tourist traffic in winter is always a tremendous challenge. In the harsh reality of this new millennium, each state, regardless of size and population, must do more with less. For ADOT's highway maintenance crews, new technology offers the ability to cope with winter operational problems that include reduced budgets, high crew turnover, growing truck and passenger car volumes, motorists with varying driving skills, and increasing traffic speeds.

The Arizona Transportation Research Center began this project in 1997 as an in-house research effort for ADOT. The project's mission was to study the possible practical applications in Arizona for vehicle-based and infrastructure-based Intelligent Transportation Systems (ITS) technologies, to enhance both efficiency and safety.

This project report covers Phase Three (Year Five) of the Intelligent Vehicle research program, beginning in early 2002. It focuses on northern Arizona's 2002-03 winter season, and it also describes the new direction in testing and research that was mandated after Phase Two(b) ended.

THE PROJECT NEED – THE COSTS OF WINTER TRAVEL

Crash statistics from the ADOT Traffic Records Section reveal the magnitude of the safety issues involved in winter travel across rural Arizona. Complete 2003 figures are not yet available, but the records for calendar year 2002 in Arizona show that 14 lives were lost and 539 persons were injured in crashes on roadway surfaces with snowy, slushy or icy conditions.

Table 1: Arizona "Snowy-and-Icy" Roadway Crashes: Calendar Year 2002

Description	2002
Total Crashes - Snowy or Icy Road Surface Conditions	1,243
Fatal Crashes - Snowy or Icy Conditions	12
Fatalities – Snowy or Icy Conditions	14
Injuries – Snowy or Icy Conditions	539
Property Damage Only Crashes – Snowy or Icy Conditions	909
Snowfall Days / Total Snowfall for <u>Calendar Year</u> 2002: Flagstaff	8 days / 30 inches
Total Estimated Economic Loss – Snowy or Icy Conditions: *Per National Safety Council 2002 Estimating Criteria*[4]	**$29,944,532**

Source: "Arizona Motor Vehicle Crash Facts 2002," ADOT Traffic Records Section [4]

In all of 2002, with regional snowfall only 30 percent of average, snowy or icy road conditions still were relevant factors in more than 1,200 crashes that took 14 lives across Arizona. National Weather Service records show that Flagstaff, for example, received only 8 days of significant snowfall (one inch or more) in calendar year 2002, for a total of 30 inches. Since records have been kept, the long-term average annual snowfall at Flagstaff's Pulliam Airport is 84 inches. For just the past six years of this research project, four years were above that average for Flagstaff, and the annual snowfall totals ranged from 30 inches to 131 inches.

The *estimated economic loss* to the State of Arizona from the more than 1,200 reported winter crashes on storm-impacted roadways was nearly $30,000,000 in 2002. These economic figures include estimates of lost personal earnings, medical costs, and property losses from crashes, but they do not assess the fiscal impacts to a time-sensitive economy of accident-related travel delays for commercial carriers and for the public. These vehicle crash cost figures are separate from any estimates of regional storm-related travel delays, and they do not include any snowplow crash repairs or operational costs to ADOT. Note also that these crash and weather statistics in Tables 1 and 2 are tabulated on a calendar year basis, not by the winter season.

Winter Storm Impacts on Highway Safety

Table 2 below shows the breakdown of winter storm-related crashes by county in Arizona for calendar year 2002. This table presents two sets of figures showing weather-related crash-event factors from police reports, the first being the road surface condition and the second being the observed weather at the time of the crash.

In Table 2, “weather condition” includes several classes of impaired visibility in winter storms, which is the critical concern for this research project. Rain-caused crashes and those on “wet” roads, however, are not included. The two key criteria, road surface and weather, are obviously not directly related, since icy roads in clear weather are a very frequent hazardous condition.

Table 2: Wintry Conditions in Crashes: Calendar Year 2002

2002 - Statewide Motor Vehicle Crash Summary - by Counties									
Winter Storm Conditions - *Snow, Ice, & Impaired Visibility*									
	Road Surface Condition				**Weather Condition**				
Crash Data - By Counties	Snow	Slush	Ice	*Sum*	Sleet / Hail	Snowing	Blowing Snow, Dust	Fog, Smoke	*Sum*
Apache	51	15	145	*211*	8	138	10	2	*158*
Cochise	4	2	33	*39*	7	20	5	1	*33*
Coconino	137	41	216	*394*	43	220	9	13	*285*
Gila	24	5	25	*54*	3	29	1	2	*35*
Graham	0	0	1	*1*	0	0	0	0	*0*
Greenlee	2	0	4	*6*	0	2	0	0	*2*
La Paz	0	0	1	*1*	0	0	2	0	*2*
Maricopa	5	14	37	*56*	131	7	61	13	*212*
Mohave	10	1	30	*41*	10	31	8	0	*49*
Navajo	59	6	192	*257*	19	149	9	24	*201*
Pima	2	6	68	*76*	67	13	24	9	*113*
Pinal	0	2	12	*14*	18	2	49	7	*76*
Santa Cruz	1	1	1	*3*	1	3	0	0	*4*
Yavapai	22	13	71	*106*	10	53	2	1	*66*
Yuma	0	3	0	*3*	4	1	9	3	*17*
Total Crashes	**317**	**109**	**836**	***1,262***	**321**	**668**	**189**	**75**	***1,253***
ATRC Note: Regional Snow Totals were only 30% of average in 2002									

Source: “Arizona Motor Vehicle Crash Facts 2002,” ADOT Traffic Records Section [4]

The road surface and weather factors tabulated above are observed conditions from crash reports, and may or may not be an actual causative factor in any of the crashes. There may also be local disparities in reporting of crash totals between counties, or from year to year. These figures are provided to indicate probable significant storm-related factors in winter crashes, and their distribution across the entire state.

The Project Need: Snowplow Accident Repair Costs

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. Even for this relatively mild winter of Year Five, between November 2002 and March 2003, records show a total of 16 snowplow vehicle damage incidents were entered into the ADOT equipment repair cost-tracking system.

These 16 incidents resulted in plow equipment repair costs for 2002-03 of more than $112,000, which does not include any possible property damage to roadside features such as guardrail, road signs and delineators. It also does not include any third party damage claims from snowplowing.

This figure also does not include any operating costs or ADOT internal costs for repairs or maintenance work that the district shop would consider as ordinary snowplowing wear and tear.

The following Table 3 illustrates the fluctuations in the number, type and severity of snowplow accident reports for the three most recent winters. For this summary, the weather statistics are reported by winter season, for the October to May time window. The winter snowfall totals are generally quite different from the calendar year totals, which combine two partial seasons, and the winter summary gives a truer picture of fleet attrition over a snowplowing season.

Table 3: Arizona Snowplow Accident Repairs by Winter Season

Description	Phase Two 2000-01	Phase Two(b) 2001-02	Phase Three 2002-03
*Snowfall Total by Winter Season at Flagstaff**	*125"*	*39"*	*55"*
Total Repair Cost for Snowplows - Statewide	$66,714	$49,852	$112,159
Total Incidents of Snowplow Damage	19	22	16
Damaged During Snowplowing Activity	15	8	16
- Struck or Struck By Other Vehicle	9	9	4
- Struck Fixed Object	6	6	12
- Other Incidents – Loading, Rigging, Transit	4	7	0
Average Repair Cost of Reported Accidents	$3,511	$2,266	$7,010
Storm Records courtesy of National Weather Service – Flagstaff			

Source: ADOT Equipment Services Group Records

Depending on the severity of the winter season, many or most of these damage reports would be for on-the-road snowplowing activity, as opposed to loading materials, rigging plow equipment, training or other causes. For the winters tabulated above, on average seven of these incidents involved collisions with other vehicles, and eight involved plows striking fixed objects.

For the 2002-03 winter, the accidents included three rollovers, which as indicated by the average repair cost for the year, were clearly a major cost element. In most crashes during snowplowing operations, roadway visibility would logically be a key factor, and this is an area where this advanced vehicles research project has made its most significant efforts over five winter seasons.

IV. ADVANCED SNOWPLOW RESEARCH IN ARIZONA

Highway travel in winter storm conditions is hazardous to all drivers, who face a combination of obscured visibility, blowing and drifting snow, high winds, slippery road surfaces, and erratic movements by other vehicles. The potential is significantly higher in these conditions for rear-end or sideswipe crashes, and in a storm, stalled or slow-moving vehicles are a further hazard.

In snowplowing operations, these specific dangers are much greater in the extreme low visibility of wind-blown snow and the “snow cloud” that the snowplow blade creates around the truck. Snow and ice that is thrown up by the plow blade builds up on the lights, windshield and mirrors, and the truck’s standard windshield wipers, washers and defrosters generally are not adequate for this service. Vision ahead, and to the rear and sides, becomes extremely limited.

The overall result is that in a heavy snowstorm, visibility is worse for snowplow operators than for any other drivers, especially those in the high cabs of tractor-trailer rigs. At the same time, these conditions are most likely to obscure stalled cars, fallen rocks or trees, animals, or people in and along the roadway. Vehicles in motion are another constant concern, especially for a nose plow and wing plow combination that clears both the lane and right shoulder at once. A greater challenge in whiteout conditions is staying in the proper lane, and even staying on the roadway.

For these reasons, and with strong interest and sponsorship from ADOT’s senior management, this research project was initiated in late 1997 with an early emphasis on snowplow operations. Over the four previous winters, two distinct phases of research into infrastructure-based snowplow guidance concepts were completed. Three previous reports have been published by the ATRC, which conducts this ADOT research program as an in-house effort.

This new report 473(4) describes Phase Three (Year Five) of the project, in which the research focus was shifted from roadway lane-guidance systems to commercial on-board driver warning technologies for winter maintenance.

PROJECT EVOLUTION

ADOT first became involved with Intelligent Vehicle (IV) research activity shortly after the National Automated Highway Systems Consortium (NAHSC) “Demo ’97” exhibition in San Diego, California. This landmark IV showcase for vehicle control concepts and fully automated highway systems (AHS) was a turning point in perceptions for many senior managers of ADOT.

ADOT and ATRC organized “smart car” tests and demonstrations for state leaders and the media in late 1997 and 1998. These local AHS and IV concept “demos” emphasized the potential of ITS technologies to improve safety, reduce congestion, and improve air quality. While perhaps less photogenic than the hands-off driving and fully automated platooning of AHS technologies, new ITS concepts for heavy vehicle operations were also being showcased at this time.

The key Phoenix-area AHS demonstrations included several prototype passenger cars employing both machine-vision and roadway-based guidance systems. The latter category included both the magnetic tape Lane Awareness System (LAS) developed by the 3M Company (3M) and the fully automated roadway magnet concept of the PATH (Partners for Advanced Transit and Highways) technology consortium between Caltrans and the California state university system. The PATH system was demonstrated on a closed course at Arizona State University in Tempe.

Despite the success of the Arizona demonstrations, ADOT soon realized that the infrastructure costs for AHS technology in the urban areas could not be balanced by congestion or air quality savings, nor was there any sign of near-term AHS initiatives by the major vehicle manufacturers.

Figure 4: Demonstration of Caltrans-PATH Concepts: Tempe, Arizona (1997)

In the post-Demo '97 time period, the national research emphasis gradually shifted to practical gains in safety and efficiency, an approach that pointed towards specialty vehicles. The transit, public safety and roadway maintenance fleets would become the primary focus of IV research and development. Around the country at this time, several research programs were being initiated that focused on snowplow driver-support systems in particular. ADOT and the ATRC also clearly recognized this need, and the program direction for this advanced vehicles research project began to crystallize.

Prior Phase One Research in 1997-2000

ADOT's Phase One research project, from 1997 to 2000, began with the "Arizona AHS Demos" in the Phoenix area, and with outreach to other key state agencies that were involved in vehicle research. The key project goals were to improve safety for both travelers and ADOT personnel, to defer more highway lane construction by maximizing the capacity of current roadways, and to improve regional air quality in Arizona.

While the original Phase One concept was to explore potential solutions for both urban and rural highway congestion problems, ADOT's senior management soon determined that the best near-term potential use of these new technologies was to improve the safety and efficiency of winter storm maintenance operations. Zero visibility conditions in snowstorms, together with heavy traffic on key route corridors, were issues that convinced ADOT to focus its research on evolving

ITS concepts that could significantly improve safety and efficiency for the snowplow operators and, as a result, for the traveling public.

Based on Demo '97 contacts, ADOT soon initiated a partnership with Caltrans, the California Department of Transportation, to field-test their prototype Advanced Snowplow (ASP) in Arizona. The Caltrans ASP utilized the PATH roadway magnets with specific coding to inform the snowplow of its position in the lane, and to predict the roadway curvature ahead. The ASP also employed an integrated collision warning radar system (CWS) prototype.

Figure 5: Caltrans RoadView ASP on US 180 in Arizona

The ATRC research project developed a six-mile test loop on US 180 at Kendrick Park near Flagstaff. This site allowed Caltrans to expand and diversify the research experience in different weather and terrain conditions, with a pool of Arizona snowplow operators. The California-PATH guidance system, installed on a 10-wheel Caltrans snowplow truck, was successfully tested in Arizona during the winters of 1998–99 (ASP-I) and 1999-2000 (ASP-II).

By the second winter season, however, the project sponsors realized that ADOT needed to obtain its own driver-assistance systems to effectively conduct full-winter, long-term testing. The ASP was an operational Caltrans snowplow, so the ADOT field-test period was limited to just four weeks, and technical issues further reduced the time it actually spent on the highway. These limitations led ADOT to expand its research into a new Phase Two, seeking to develop more hands-on experience than the Caltrans snowplow guidance partnership could provide.

This initial broadly-scoped research project, including the Arizona "smart-car demos" and the extensive partnering effort with Caltrans to establish an ASP test site on US 180 near Flagstaff, is described in detail in ATRC Final Report No. 473(1), *The Arizona Intelligent Vehicle Research Program – Phase One: 1997-2000*. [1]

Prior Phase Two Research in 2000-01

The Phase One research partnership with Caltrans was successful, but the results were clearly limited by the prototype status of the advanced snowplow system, and by the vagaries of winter weather. Just one month each winter with the Caltrans ASP in Arizona allowed for only limited testing, with limited results. For Phase Two, the third year of the project, the project's TAC mandated a new research effort to equip an ADOT snowplow with a roadway-magnet-based guidance system, to allow long-term concept evaluations in Arizona.

Figure 6: Arizona's Advanced Snowplow System: The ADOT-3M ASP

At this time, the Caltrans program did not have the staff resources to support a second ASP system outside of California. Also, the new RoadView[TM] snowplow, which superseded the earlier Caltrans ASP-II vehicle for 2000-01, was the sole developmental prototype. Many key RoadView components were not packaged systems, but were unique or even hand-built. ADOT therefore decided to procure a 3M Lane Awareness System (LAS), as well as five miles of 3M's magnetic striping tape. The tape was installed in mid-2000 at a site near Sunset Crater northeast of Flagstaff, between the layers of new pavement in a roadway reconstruction project on US 89.

The new Arizona research vehicle was designated as the ADOT-3M Advanced Snowplow (ASP). It was commissioned with the complete 3M Lane Awareness System (LAS), including a display screen, warning lights, and vibratory warnings. By placing the magnetic tape on the roadway centerline between the two traffic lanes, the per-lane cost of embedded infrastructure for the LAS was cut by half. The new ADOT-3M ASP was also equipped with standalone collision warning radar, and with an automatic vehicle location (AVL) system.

A new factor in ADOT's Phase Two research program was the need for a formal, unbiased analysis of the Arizona training and evaluation results for the 3M and Caltrans driver-assistance concepts. Flagstaff's Northern Arizona University (NAU) was assigned to monitor the training and testing, to develop third-party evaluation results, and to make recommendations for possible future implementation. The 3M Company also augmented the ATRC's evaluation effort with a parallel Arizona evaluation program that was conducted by the University of Iowa (U of I).

ADOT continued its long-term project commitment to Caltrans in Phase Two, with a new goal to compare both guidance systems operationally in similar weather and road conditions. However, Phase Two was not a complete success, primarily for technical reasons. Both ASP snowplows had various guidance and warning system issues that resulted in extensive diagnostic downtime. Additionally, the embedded tape at the 3M test site was not usable due to alignment problems with temporary lane striping that was placed on US 89 for the winter construction shutdown.

This project's second phase encountered a number of setbacks in the winter of 2000-01, as noted above, but the equipment tests and the driver training program for both systems proceeded as planned at the two regional test sites near Flagstaff. The ADOT-3M snowplow was able to conduct non-ASP field operations at intervals through the winter season, and the Caltrans ASP did conduct plowing operations to a lesser extent during its brief month in Arizona. The system failures were a significant disappointment because the Flagstaff area received 125 inches of snow through the winter, which would be the highest seasonal snowfall figure for the entire project.

Despite the setbacks, the Year Three effort was productive, as detailed in the ATRC's Final Report No. 473(2), *Arizona Intelligent Vehicle Research Program – Phase Two: 2000-2001*.[2] The key accomplishment was that Arizona had established the first advanced snowplow 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.

Prior Phase Two(b) Research in 2001-02

Phase Two(b) of Arizona's Intelligent Vehicle research program continued and evolved from the two earlier efforts. This was the fourth winter (2001-02) of ATRC's long-term research program to evaluate and compare state-of-the-art advanced snowplow systems in Arizona.

With Phase Two(b), the ADOT snowplow research project finally achieved a higher level of success. Guidance system evaluations were conducted with side-by-side field testing of the ADOT-3M magnetic tape and the Caltrans-PATH roadway magnet concepts. The same-day training program, field testing, and operator evaluations of the two low-visibility, low-speed guidance systems were quite successful.

Both the Caltrans RoadView and the ADOT-3M snowplows proved to be reliable and effective in their respective training, evaluation and operational phases. However, the Year Four (2001-02) winter brought less than half of the "normal" snowfall (39 inches) to northern Arizona. Worse yet, no snow at all fell in February during the fourth and last annual visit of the Caltrans RoadView snowplow to the Flagstaff test site.

At this point, the project's Technical Advisory Committee recognized that the economics of the infrastructure systems would continue to severely limit those applications in Arizona, and the project team began to steer the research toward new on-board concepts.

The fourth winter of the research project is described in the ATRC's Final Report No. 473(3), *Arizona Intelligent Vehicle Research Program – Phase Two(b): 2001-2002*.[3] This third report reviews the Year Four results, discusses the decision to change the basic ASP research concept, and introduces the ATRC's buildup for the crucial fifth and final year of the project.

CURRENT PHASE THREE RESEARCH: 2002-03

This new Phase Three project report describes the recently concluded final winter season of the Arizona Intelligent Vehicle research program, which continued and evolved from ATRC's previous efforts. Phase Three was the fifth winter (2002-03) of ADOT's long-term in-house research effort to evaluate and compare state-of-the-art driver-assistance systems for snowplow operations in Arizona. Phase Three of this research has evolved to on-board systems, focusing its efforts on deploying both collision warning radar and passive-infrared night vision systems.

The Arizona evaluation workplan for the current Phase Three evolved from the ATRC's long-term partnership with the Caltrans test program in California. However, with no infrastructure elements involved, the research plan would no longer conduct centralized orientations and driver training, nor was a third-party evaluator required. Over the previous four winters, report and survey formats had been developed and standardized as much as possible between the two ASP concepts. The ATRC plan for 2002-03 was to simplify and streamline the reporting process to reduce the drivers' paperwork burden, and then to follow up on the field operational results with periodic surveys and interviews.

The early chapters of this report provide background information on the earlier concepts and phases of the project, and on the transition to on-board warning system testing. From there, the report describes the concepts and the components for each of the commercial driver warning systems. It also describes the ADOT research plan, and discusses the results and conclusions for these two off-the-shelf, low-visibility guidance technologies.

The remaining chapters of the report review ATRC's Phase Three goals, challenges and results of the 2002-03 winter in Arizona, followed by the overall vehicle research program results and conclusions, and finally, the project team's recommendations for further advanced snowplow system implementation.

V. 2002-03: YEAR FIVE – A NEW BEGINNING

By early 2002, four years of complex intelligent-vehicle research activities had been conducted in Arizona, first with the California ASP-I, ASP-II, and RoadView^{TM} program, and then with the addition of the ADOT-3M commercial lane-awareness technology. Even before the fourth winter test cycle for these two systems in February, ADOT's project sponsors were concerned about the system and roadway infrastructure costs, and were looking in new directions. It was clear that ADOT needed a more realistic approach to provide effective support for its snowplow operators in the range of winter storm conditions that exist all across Arizona.

TECHNICAL ADVISORY COMMITTEE DECISIONS

The overall perspective of the project TAC, even when planning for the fourth winter season with the Caltrans and 3M systems in late 2001, was that the research had developed all of the information that ADOT needed. The TAC still hoped for a heavy winter to better evaluate both ASP concepts on a side-by-side basis, but the basic realities of each were already known.

Both magnet-based concepts were relatively high in their installation cost, and the overall durability of the embedded magnetic materials depends on the useful life of the pavement. The significant vehicle system costs were also a factor. It was clear that Arizona could not deploy either system, as the RoadView ASP was a prototype and 3M had left the market. It was also clear that the current roadway and on-board system costs were not realistic for ADOT.

A new direction was required. The project had developed good information on new advances in vehicle guidance. Rather than simply concluding the program with this knowledge, the TAC still felt the need to investigate other less costly concepts for snowplow operator support. ATRC and the TAC had already discussed many ideas, both internally and with the Caltrans research team. There were several directions that the project might take, but clear guidance was needed.

TAC Survey on Project Directions: Spring 2002

The project sponsors decided to conduct a survey of both the TAC and other key ADOT leaders at the state level. The survey was distributed to these stakeholders in early May. The questions on the key issues after four years included the perceived merits of each system as tested, their significance for ADOT, and what additional research efforts should be made from that point on:

<u>A. System Concepts – Pros And Cons? How Important To ADOT?</u>
- Caltrans roadway-magnet guidance system?
- 3M tape – Lane Awareness System?
- Eaton VORAD collision warning radar?
- GreyLink automatic vehicle logging/tracking (AVL) system?
- Bendix XVision night vision camera (testing proposed)?

<u>B. This Project's Future Directions? What's Your View?</u>
- What have we learned?
- What have we not learned yet?
- <u>What else</u> could the ITS snowplow project study effectively?
- Should this project do more <u>next winter</u>, and if so, where?

The results of the TAC survey dictated a clear change in the future direction of this research. Responses came from the departmental level, the partner districts and maintenance camps, and several of the project's Team Leader snowplow operators. After four years of evaluations, the stakeholder responses on *the future potential in Arizona* for the several guidance and warning systems can be summarized as follows:

Project TAC &Stakeholder Survey – Summer 2002

- Caltrans RoadView Guidance System - <u>Negative</u>
- 3M Lane Awareness System - <u>Neutral</u>
- Collision Warning Radar - <u>Positive</u>
- AVL Tracking System - <u>Negative</u>
- Infrared Night Vision (untested) – <u>Positive</u>

The following paragraphs summarize the stakeholder comments from the survey as well as from the subsequent TAC meeting discussions, which confirmed the new direction for the project.

- **Caltrans RoadView Guidance System** - The key to the TAC's negative rating is that this successful but costly prototype system does not have a deployment potential for ADOT in the near future. It is the more advanced driver-guidance system, but the costs of both the on-board system and the roadway magnets are quite high. The effect on pavement life, the magnet maintenance and durability concerns, and the lack of progress on reducing the installation costs are all negative factors; more testing was not recommended at this time.

- **3M Lane Awareness Guidance System -** The TAC opinions were evenly split on the 3M system, resulting in a neutral rating. It is simple and effective, but costly. It works well, but does not predict the road ahead. Technical support from 3M was very good, but there is no realistic potential to deploy it beyond the single US 89 site, since 3M has given up this market segment. The TAC recommended the continued use of the 3M LAS on US 89 in the following winter, for normal roadway maintenance operations.

- **Collision Warning Radar -** The EVT-300 collision warning radar had favorable ratings in the survey. Driver comments have been positive, but more winter testing is required. The TAC decided that the evaluation of this relatively low-cost, add-on system should continue in Year Five (2002-03). Adaptive cruise control (SmartCruise) will also be installed so that summer testing can be conducted, without the plow blade. This feature has the potential to reduce rear-end accidents year-round, for other vehicle types in the ADOT heavy truck fleet.

- **AVL Vehicle Tracking -** The survey indicated general disappointment with the GreyLink AVL system, and its cellular communications basis, although Caltrans had recommended this system. This was a valuable test overall, showing that the value of a cellular-based AVL system was limited in mountainous rural Arizona operations. The TAC recommended discontinuing the current GreyLink AVL system tests for the 2002-03 winter season.

- **Night Vision (untested)** – The survey response was positive about this low-cost, add-on system. Although procured for testing midway through the 2001-02 snow season, the Bendix XVision unit was not functional until May 2002, when night demonstrations were conducted for project stakeholders. The TAC recommended a full season of winter storm evaluation in 2002-03, to verify this system's potential for Arizona conditions and operating practices.

On-Board Warnings: Low Visibility vs. Zero Visibility

Arizona's extensive four-year test program had been sufficient to support future ADOT decisions on the low-visibility, low-speed operational potential of the two roadway-infrastructure guidance systems. Based on the original goal, to evaluate semi-automated vehicle systems for winter maintenance, both the 3M and Caltrans systems had been thoroughly tested, and while quite effective, their future deployment in Arizona did not appear practical. The experience gained over four winters with the primary and secondary ASP systems was clear enough to lead into a new phase of the project, with further tests of on-board driver-assistance concepts. These fully developed, low-cost, off-the-shelf commercial warning systems could directly benefit the ADOT snowplow operators, and therefore the public, during winter storms.

The ATRC was directed to deploy new on-board systems across the I-40 Corridor for the 2002-03 winter evaluation program. Based on the research project budget available after four winters, it was decided to supplement the CWS radar on ADOT-3M snowplow F342 with three more units, and to purchase two more XVision systems in addition to the one unit recently installed.

This budget-limited plan would deploy a total of seven on-board warning systems in the field. On this basis, with initial contacts already having been made, the ATRC initiated negotiations with both Eaton and Bendix.

SCOPE EXPANSION: THREE DISTRICTS

A long-standing problem with the ASP evaluations had been the inability to train snowplow operators in storm conditions, since trainees could only come to the Flagstaff test lanes during fair weather and in daylight. With the new on-board systems, the research would not depend on specific test sites, and there would be no need for group training in the coming 2002-03 season.

There were other potential issues in switching to on-board systems. A significant new challenge would be to retain the active participation of those project stakeholders who were being sidelined by the shift away from vehicle guidance systems.

With these issues in mind, the project TAC decided that a logical and practical new evaluation concept would be to deploy additional systems in other districts apart from just Flagstaff. This approach would expand the operator pool and increase both systems' exposure to local severe storms, as well as to statewide or regional storms. On that basis, therefore, the Holbrook and Kingman districts would each be allocated additional on-board systems for evaluation.

Each district, including Flagstaff, was asked to assess their own local conditions, and select a snowplow and a key route for testing with each of the new warning systems. The three districts assigned the evaluation systems to seven key snowplow routes, as highlighted in Figure 7 (Note: both Eaton VORAD and 3M systems are installed on the ADOT-3M snowplow).

For each project snowplow, the primary local route assignment is identified in Table 4. There would be three snowplows in the Flagstaff District with on-board systems for evaluation. The other partner districts, Kingman and Holbrook, each would deploy one EVT-300 radar system and one XVision infrared system. Most of the research plows were assigned to the I-40 Corridor, and the other test route segments connect with I-40. In a major regional winter storm, all of these snowplows would be fully engaged.

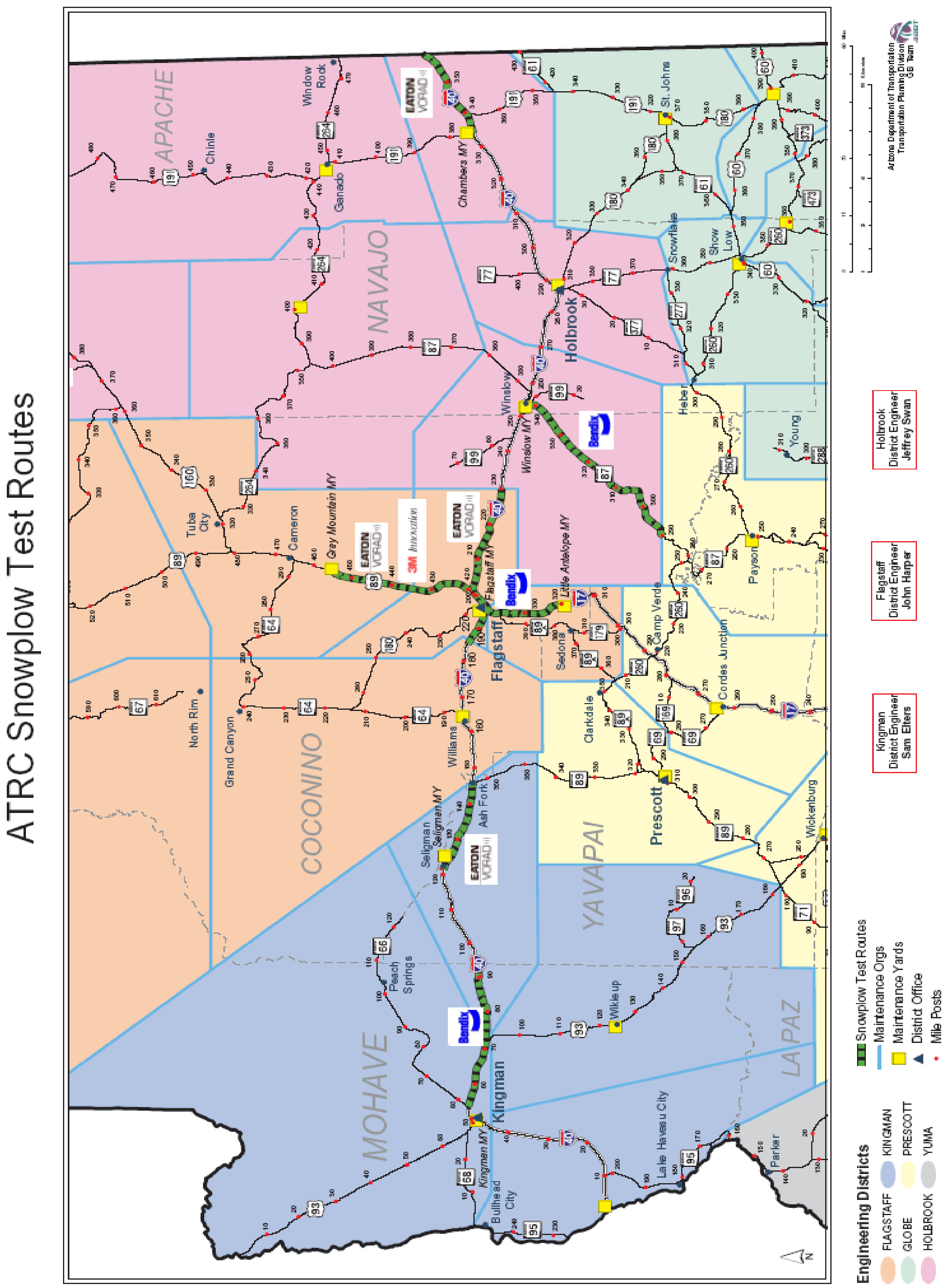


Figure 7: Seven On-Board Systems Evaluation Routes For 2002-03

Table 4: Route Assignments of Project Snowplows: Year Five

2002-03 - Research Snowplows with On-Board Systems					
Snowplow	Maintenance Camp / Yard	ADOT District	Route	Milepost Limits	System
F235	Little Antelope	Flagstaff	I-17	335 – 340 to 40/17 interchange	XVision
F269	Chambers	Holbrook	I-40	347 – 360	EV Radar
F277	Kingman	Kingman	I-40	54 – 72	XVision
F291	East Flagstaff / Green River	Flagstaff	I-40	185 – 230	EV Radar
F326	Seligman	Kingman	I-40	121 – 146	EV Radar
F340	Winslow	Holbrook	SR 87	317 – 290	XVision
F342	Gray Mountain	Flagstaff	US 89	420 - 440	EV Radar & 3M

The project had already gained extensive experience with collision warning radar systems. Since 1998, each evolution of the RoadView ASP had given ADOT more exposure to Eaton VORAD's technology as integrated and further refined by the Caltrans program team. Ultimately, the same EVT-300 commercial system had been chosen in late 2000 to equip the ADOT-3M plow, F342.

There was also stakeholder interest in night vision systems for both highway maintenance and for law enforcement. As early as mid-2001, Bendix marketed their XVision passive-infrared system to ADOT and to the Arizona Department of Public Safety (DPS).

Initially, XVision was considered to augment the radar system on the ADOT-3M snowplow, but combining the two was not practical due to truck cab space and system power limitations. By the time of the ATRC-TAC survey in mid-2002, however, a trial XVision system had already been demonstrated to the project stakeholders on Little Antelope Camp's snowplow F235, as indicated by the survey comments presented previously.

Phase Three Program Issues: Procurement, Costs, Budgets

The redirection of the Year Five project effort required the ATRC to establish relationships with two new suppliers to develop the research plan and evaluation approach. Both on-board systems were commercial products, but each was conceived as a driver-support system for long-haul transport fleets. The CWS radar system was already widely distributed, and the Eaton VORAD marketing program was not specifically focused on "niche markets" such as snowplowing. The Bendix infrared night vision system was just beginning to be widely marketed at that time, and their program was still exploring the potential for specialty vehicle applications.

A primary concern was to confirm the terms and procurement approach to obtain the two new systems for the research project. The ATRC faced a variety of procedural challenges with regard to procurement processes, as the ADOT commercial equipment sourcing requirements differed for the Eaton and Bendix suppliers. The XVision systems were procured through existing ADOT contracts with local Bendix equipment vendors, but a separate new contract was needed with Eaton Corporation to acquire the EVT-300 systems for evaluation.

ADOT-ATRC Experience with Eaton

ADOT had already gained considerable experience with the Eaton VORAD EVT-300 collision warning radar system (CWS), initially through the Caltrans RoadView ASP program. As noted in previous ATRC and AHMCT project reports, the Caltrans system used EVT-200 and –300 components for the forward warning feature of its integrated driver-vehicle interface (DVI). However, the Caltrans development team had extensively refined the collision warning system on the ASP, in order to provide more advanced target interpretation data and more specific warning information to the operators.

ATRC had also had procured an off-the-shelf commercial EVT-300 radar unit in mid-2000, as part of the initial development of F342, the ADOT-3M advanced snowplow. The ADOT-3M research plow was equipped with this CWS radar to approximate the suite of driver-assistance technologies used by the Caltrans snowplow.

The EVT-300 as installed on plow F342 was an off-the-shelf standard CWS unit, and it provided exactly the same features and warnings as the identical units already in use by numerous major trucking fleets across the country. However, it had to be installed on the cab roof in order to "see" clearly over the six-foot high ADOT snowplow blade.

ADOT-ATRC Experience with Bendix

As noted earlier, the ATRC and ADOT Equipment Services had already been in contact with Bendix Commercial Vehicle Systems in regard to their earlier testing of the XVision infrared night vision camera in other regions of North America. The caveat to testing in Arizona was that XVision was still in the final stages of development. However, this situation provided an early opportunity to evaluate the concept in a beta-test scenario, resolving ADOT's questions while supporting the further refinement of the system.

The ATRC approached Bendix in mid-2001, but the test plan could not be initiated until the next spring, too late for any snowplowing in the Flagstaff area. Bendix provided an initial evaluation unit to ADOT in January 2002, which was installed in February. No significant operations were carried out, however, due to unrelated truck problems. A night demonstration of XVision for the project TAC and partners was finally conducted in May at Rim Camp on US 89A near Sedona, and the stakeholder reactions were uniformly positive.

PHASE THREE PROGRAM VISION

For snowplow operators, restricted visibility in wind-blown drifting snow and the "snow cloud" that the snowplow blade generates around the truck are major hazards. In a heavy storm, on icy roadways, snowplow drivers have much worse visibility than any others, especially those in the high cabs of tractor-trailer rigs. At the same time, these conditions can hide moving cars, stalled cars, fallen rocks or trees, or animals or people in and along the roadway.

The project goal for Phase Three was to determine the key factors for successful implementation of commercial radar and night vision warning systems for snowplowing in rural states such as Arizona, and to determine the state of development, effectiveness, flexibility and reliability of each system in storm conditions.

The fundamental problem to be addressed by this ADOT research program is poor visibility for snowplow operators in severe winter storms. The new on-board warning systems do not provide predictive guidance abilities to keep the plow moving in very poor visibility, as do the 3M or Caltrans ASP concepts, but they do improve operator awareness of the conditions and potential obstacles in the road ahead.

The project TAC had directed that at least two snowplows in each of the partner district were to be equipped with either the EVT-300 radar system or the Bendix XVision system for 2002-03. The following chapters of this report describe each system, and its initial and wider deployment, in more detail.

VI. EATON VORAD EVT-300 WITH SMARTCRUISE: THE SYSTEM

SYSTEM CONCEPTS

The Eaton Corporation is one of the largest suppliers of truck and automotive components in the United States. A major growth initiative for the company over the past decade has been its safety electronics subsidiary, Eaton VORAD.

The EVT-300 Collision Warning System (CWS) was introduced by Eaton VORAD in 1994. Its key goal was to provide early warnings of obstacles ahead, to increase driver reaction times and to reduce the number of rear-end collisions regardless of weather and lighting conditions. The system is marketed by Eaton to serve as a driver aid in rain, sleet, snow, fog, dust and darkness. The key advantages of the CWS concept for the driver are: awareness of safe following distance, conditioning to evaluate road hazards, improved recognition of hazards in inclement weather, and continuous peak performance at all hours in all conditions.

Figure 8. EVT-300 Driver Display Module

The VORAD system (Vehicle On-board RADar) uses a patented monopulse radar design to warn drivers of potential hazards in the road ahead such as stopped or slow-moving vehicles. The system also provides side blind-spot warnings. Options with the EVT-300 include a vehicle information management system, accident reconstruction, and an adaptive cruise control feature.

Large trucks have very long stopping distances even in ideal conditions, and driver reaction and response times are a crucial factor in many if not most tractor-trailer crashes. The EVT-300 provides driver-alert warnings for overtaking and lane-change movements, and Eaton estimates that 40 percent of all heavy truck crashes are rear-ending or sideswiping events.

Highway travel in winter storms is extremely hazardous, with poor visibility from blowing and drifting snow, as well as frosted windshields and frozen wiper blades. Risks are higher for rear-end or sideswipe crashes, and in a storm, stalled or slow-moving vehicles are a constant menace.

The EVT-300 radar system was already deployed nationally with several major transport fleets. The primary market in terms of volume was for heavy commercial trucks, but the CWS concept was a natural enhancement for specialty fleets, including maintenance and emergency vehicles.

ADOT already had experience with the VORAD concept through the application of the system by Caltrans, as discussed in the following section. Also, an EVT-300 had been installed in 2000 on the ADOT-3M snowplow, for evaluation in year-round operations on US 89 near Flagstaff and for comparison with the enhanced Caltrans CWS components.

ADOT EXPERIENCE WITH THE CALTRANS ROADVIEW SYSTEM

From the beginning, the Caltrans advanced snowplow research program incorporated collision warning as an integral element of the driver support system. The evolution of the CWS element of the Caltrans advanced snowplow is described in detail in three ASP and RoadView reports by the lead contractor, the Advanced Highway Maintenance & Construction Technology (AHMCT) Research Center at UC Davis (*see Bibliography*). This ATRC project report includes a brief overview of the Caltrans program efforts, for perspective.

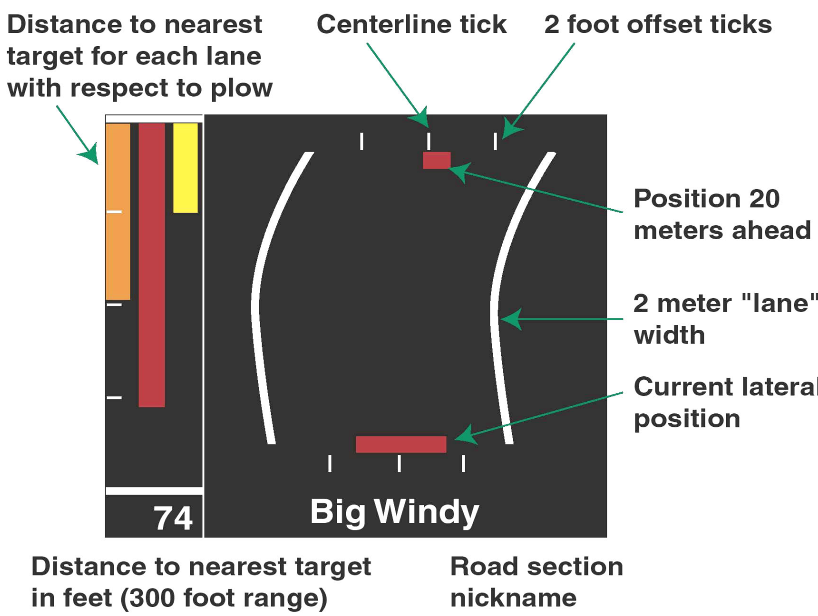


Figure 9. Caltrans RoadView Driver-Vehicle Interface Display

[Graphic courtesy of California PATH]

Caltrans initiated their advanced snowplow program as part of the preparations for the seminal San Diego Demo '97 activities. When ADOT-ATRC joined the ASP partnership in late 1997, discussions were still going on with regard to the best human-machine interface (HMI) approach for the original Caltrans ASP-I. Two ADOT snowplow operators participated with ATRC in a meeting with the Caltrans project team in Sacramento, to offer their perspectives on Arizona's operating practices, needs and constraints.

The ASP system design integrated collision warning radar into the HMI lane guidance display, using the left side of the screen to show the obstacle warning icons (Figure 9). As development progressed, the on-screen warning indicators evolved to moving tapes, or bars, ultimately showing target position, range, and rate of closure for up to three fixed or moving obstacles.

Off-the-shelf Eaton VORAD components were utilized to develop the CWS radar hardware used in the Caltrans system. Initially, the ASP-I had an EVT-200 antenna unit mounted at the center of the truck's radiator grille, positioned above the plow blade for a clear view of the roadway. Later on, the ASP-II and RoadView snowplow programs used twin EVT-300 antennas to provide binocular range and position data to the on-board system computer.

Constant development of this system by AHMCT over several years has focused on refining the accuracy and selectivity of the warnings. The goal was always to minimize the number of false or missed alerts and to maximize the consistency of timely, accurate target detections. Testing of the CWS in Arizona, as an integrated element of the ASP display, was a key program element in each winter of the joint evaluation program.

EVT-300 COLLISION WARNING SYSTEM DESIGN

The EVT-300 collision warning radar system employs an advanced Doppler radar design, operating at 24.725 Gigahertz, to monitor other vehicles and objects. The CWS system may be packaged at the customer's option with one or two side sensors to cover the driver's blind spots alongside the truck. Other options include the SmartCruise adaptive cruise control system, the Vehicle Information Management System, and an Accident Reconstruction data recording and recovery feature.

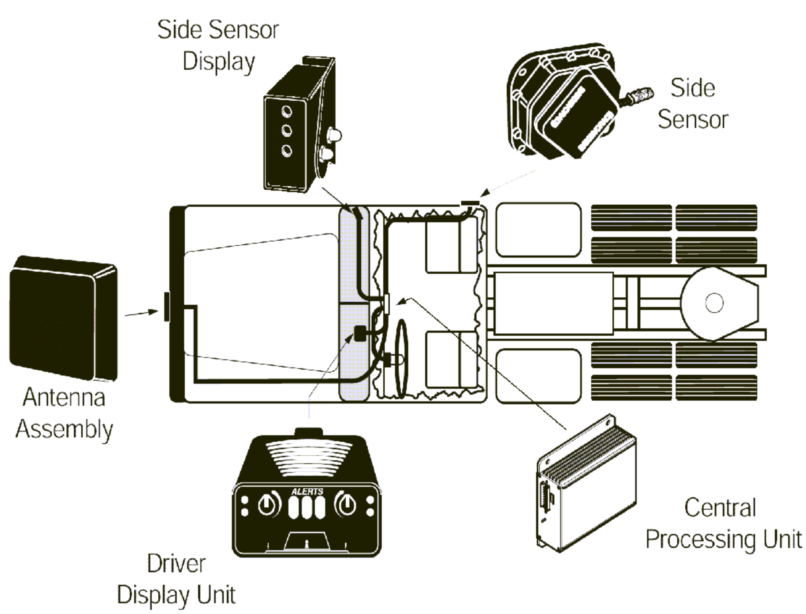


Figure 10. Schematic Diagram of the EVT-300 Collision Warning System

[Graphic by Eaton VORAD Technologies LLC]

The radar system has three major components, the antenna transceiver, the central processing unit, and the driver display unit. The optional side sensors have a separate display unit. The system employs monopulse radar technology with an effective range of 350 feet to accurately determine the distance, velocity and azimuth of multiple targets in the radar beam.

The primary antenna transceiver is normally mounted at bumper height on heavy trucks, and it transmits a flattened conical beam pattern that spreads five degrees vertically and twelve degrees horizontally. The added width of the beam accommodates roadway curvature. When traveling on a straight roadway, the processor filters out the warnings for objects that are outside of the 12 foot wide lane directly ahead of the vehicle. A gyroscope in the processor unit determines yaw rates relative to velocity as the vehicle moves through curves. With this turning rate data, the CWS processor can accurately shape the warning zone to the vehicle's curving trajectory. As forward motion returns to a straight path, the vehicle's yaw component becomes zero, and any new warnings are solely for the 12-foot travel lane straight ahead.

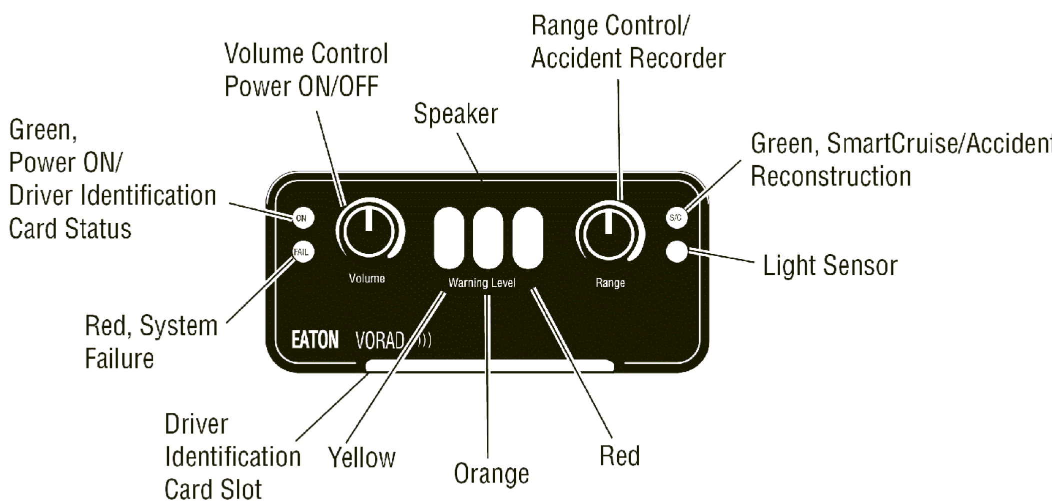


Figure 11. Driver Display Elements: EVT-300 Collision Warning System

[Graphic by Eaton VORAD Technologies LLC]

The EVT-300 employs a small driver display unit that is less than two inches high and four inches wide (Figures 8 and 11). It can be mounted on the dashboard, overhead, or as an integrated display. The optimal location is straight ahead of the driver, but different models of truck cabs have various space constraints. This driver display unit provides warnings with both colored lights and audible tones. As the distance to an obstacle decreases, three colored lights are progressively illuminated and multiple beeps or tones are sounded. Specific light and tone combinations also indicate system status.

The side sensor system option is equally sophisticated and will cover the critical blind spot(s) alongside a heavy truck. The side antenna transmits a conical 15-degree radar beam. The central processing unit filters the object warnings to just those between two and ten feet away, so as to cover only the lane next to the host vehicle. The side warning display unit is mounted on the windshield side pillar. It displays lights if objects are in range, but the audible tone is only given if the truck's turn signal is activated. In the ADOT research application, one side sensor for the right side of the snowplow was installed, just aft of the cab, as shown in Figure 10.

The SmartCruise adaptive cruise control feature takes proximity warnings to the next level, by automatically responding to slower vehicles ahead. For truck models that have implemented Eaton VORAD software for use with their engines, SmartCruise can maintain a fixed separation interval of from 2.25 to 3.25 seconds of travel time, with the factory cruise control system.

With the truck's cruise control engaged, the EVT-300 assesses the relative speed and position of vehicles ahead, or those that cut in after passing. If the host vehicle is overtaking, SmartCruise reacts progressively through the engine control software by reducing fuel, by engaging the engine retarder, and then by downshifting the automatic transmission. ADOT has tested this feature.

Another key option of the EVT-300 is the Accident Reconstruction feature. This system stores up to 10 minutes of vehicle dynamics information in the central processing unit. This recorded data includes speed, trajectory and deceleration for not only the host vehicle, but for any other vehicles in the radar beam pattern. This data allows for better analysis of a crash event and can support claims investigations. The accident reconstruction feature must be activated manually after the event to save the data. The unit then must be sent to Eaton VORAD to access the data and print the accident reconstruction report. ADOT has not tested this feature.

One other significant documentation option of the EVT-300 is Eaton's Vehicle Information Management System. This feature monitors and records numerous vehicle system data types including engine run time, driving time, fuel economy, average and peak speeds, hard braking, and time on brakes. It also can report from the radar data how much time the truck is following within one-half to three seconds of the vehicle ahead. This data is accessible by the fleet manager with Windows™-based software. ADOT has not tested this feature.

EVT-300 SYSTEM LIMITATIONS

The EVT-300 Driver Reference Manual contains a number of cautions for safe use of both the basic CWS and the SmartCruise. The systems are clearly defined as driving aids for the alert and conscientious professional driver. The primary factors in deploying the EVT-300 are training and commitment. When the system is properly installed and calibrated, a focused effort by the individual driver is required to learn to safely and efficiently use the system. The driver must be able to interpret the warnings confidently and correctly as to the urgency and type of hazard, and he must react quickly to the progressive series of warnings as shown in Figure 12.

Another concern is false warnings or missed alerts. The narrow twelve-foot lane warning zone allows situations where the radar response may be affected by gradual curves, dips and hills. There may also be inconsistencies at the transition from straight to curved roadway. Similarly, there may be false radar warnings from overhead signs or fixed objects near the shoulder.

Animals and pedestrians are an area of constant concern for drivers, and Eaton literature warns of possible missed alerts. The design focus of the system is for moving and/or stationary targets with some steel or aluminum present, such as the frame or chassis. The forward radar can detect people and animals if they are of the correct mass to reflect the Doppler radar signal, but it is not intended for that application.

Eaton VORAD states that there is no guarantee that the radar will see all people or animals, and it should not be used solely to detect animals in the roadway. Animals (elk, deer, etc.) moving perpendicular to the beam across the road at a fast rate of speed may not be consistently detected, as they are only in the radar beam detection zone for a brief period with no good reflection of the radar signal. The EVT-300 is designed to only warn of objects ahead within the 12 foot-wide travel path of the vehicle, to minimize false alerts.

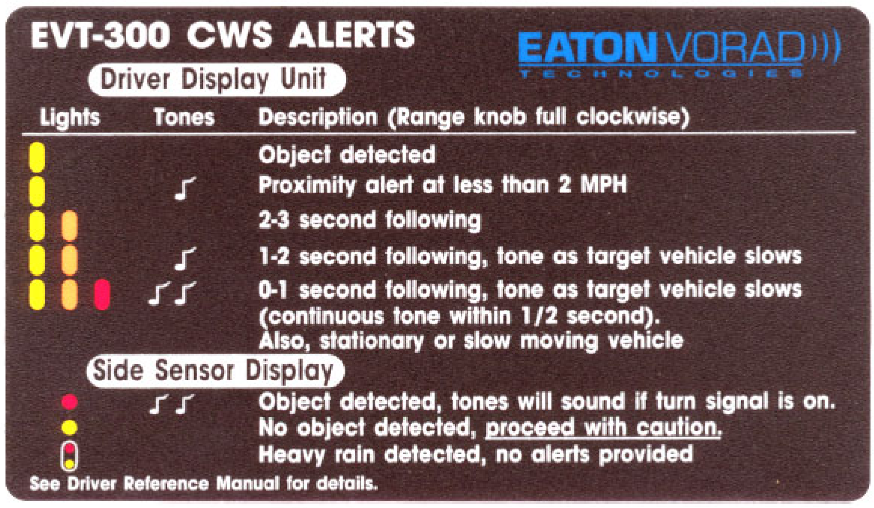


Figure 12. EVT-300 Collision Warning Alert Sequence

[Graphic by Eaton VORAD Technologies LLC]

Overall, a higher level of focus, training, practice and experience are required for drivers to rely fully on the EVT-300, and to interpret and respond quickly and properly in a warning situation.

EVT-300 SYSTEM COST DETAILS

The project acquired four of the collision warning radar system retrofit kits. The first unit was purchased in 2000, with three more in late 2002. The latter units, with one side sensor, were purchased directly from Eaton VORAD for approximately $2,400 each. There were also some Eaton technical support charges to help install and commission the three new systems on similar but not identical snowplows. ADOT shop charges averaged around $500 for each unit installed.

Originally, the first Eaton VORAD EVT-300 was installed on F342, the ADOT-3M research snowplow at Gray Mountain. This was the only snowplow that was considered for testing of the SmartCruise system. While that system upgrade had a cost of $250, ADOT also had to acquire and install a second bumper-mount antenna and wiring loom for summer tests with SmartCruise. There were also a number of issues to work out with Mack Truck to enable the engine control software to function correctly. These research-related costs are not relevant to a standard installation and so are not listed here. The project's cost for a standard system with one side sensor, as installed by ADOT shop crews, was approximately $3,000.

VII. EVT-300 COMMISSIONING

The EVT-300 CWS radar system is marketed primarily through heavy vehicle manufacturers for new truck deliveries, but it is also offered as an aftermarket system with options depending on the customer application. For the ADOT research snowplows, the aftermarket unit was the only possible approach. However, the off-the-shelf design would have to be modified due to the geometry of the snowplow equipment, and this became a long and complicated process.

ADOT's original Eaton VORAD EVT-300 unit was procured in Phase Two of this research for Gray Mountain's snowplow F342. As the ADOT-3M snowplow, this truck was set up to functionally duplicate the Caltrans ASP as much as possible so that trainee operators would have comparable driving experiences with both snowplows. Although the Caltrans design had integrated the CWS radar into the ASP's lane-position display, the goals and functions of the warning systems as installed on each snowplow were the same.

Unfortunately the ADOT-3M snowplow experienced commissioning problems soon after the CWS radar installation was completed in November 2000. The series of installation problems are detailed in the ATRC Phase Two project report. [2] This snowplow's forward radar system had hardware problems and was not functional in the first winter, although the side warning was effective. This unit was restored to full operation for the subsequent phases of the project, and the EVT-300 has performed effectively on snowplow F342 through the past two winters.

As described earlier, the research project focus was shifted to on-board systems in mid-2002, and three additional off-the-shelf Eaton VORAD units were assigned to regional maintenance yards at Seligman, Chambers, and Flagstaff.

EVT-300 COMMISSIONING ACTIVITY

The basic EVT-300 CWS radar system employs a single antenna that is normally mounted at bumper height to detect all objects and obstructions directly ahead of the vehicle. This antenna mounting position provides an unobstructed view down the roadway of any obstacle for the full range of the system. It is also the only position in which the SmartCruise adaptive cruise control feature can function effectively.

A different, non-standard mounting concept was required for snowplow trucks. In the case of the ADOT equipment design, the snowplow blade is nearly six feet above the road surface in the travel position, so a rooftop mounting was the only practical approach. This antenna location still left a minor blind spot in antenna coverage at the road surface for roughly 30 feet ahead of the snowplow blade, and Eaton VORAD initially had concerns about that gap (see Figure 13).

After some discussions, and based on the success of the initial mounting and CWS calibration, it was found that the system functioned completely effectively with the antenna in this position, where it approximates the driver's own field of view over the plow blade from the truck cab. The original Gray Mountain antenna unit was mounted on a standard light bar and worked well, while the three newer systems procured for Phase Three were mounted directly to the cab roof with a fabricated bracket.

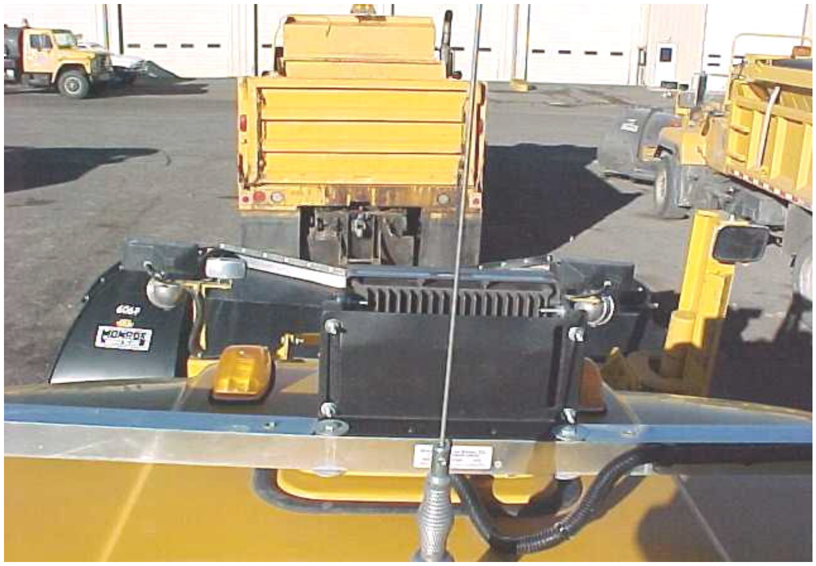


Figure 13. Radar Antenna on Bar: View of Roadway Over Snowplow Blade

With the successful installation of four EVT-300 units for the 2002-03 winter, ADOT was in a position at last to evaluate the collision warning radar concept across northern Arizona under winter storm conditions. The research snowplows were assigned to four routes, including two sites along I-40 in open wind-swept high desert terrain in both eastern and western Arizona. A third plow would patrol on I-40 in the forested areas both east and west of Flagstaff, and the fourth would plow US 89 over a 7,200-foot pass at Sunset Crater to the northeast of Flagstaff.

Installation Schedule

As noted elsewhere, the ADOT decision to conclude the Caltrans test program and shift to on-board systems was confirmed in TAC surveys and meetings in late July 2002. The procurement of the new commercial warning systems began in early August, in a complex internal process. With regard to the Eaton VORAD radars, there were issues as to vendor status, contract basis, ADOT plow truck compatibility, and factory installation support for the units.

The fiscal issues were resolved by October, and orders placed. Eaton VORAD's plant delivered the radar units in mid-November. As might be expected, scheduling the selected snowplows for two or three days of travel and installations in Flagstaff was not easy. While mid-December was the goal, January was the reality due to snowstorms, holidays, and limited staff resources.

Additionally, there were initial calibrations needed with Eaton field support for snowplow F342 to refine its performance and to provide a base case for installing the new CWS units. The three additional EVT-300s were actually installed between January 14 and February 4, 2003.

TRAINING & TESTING

The Eaton VORAD EVT-300 is a sophisticated warning system that has significant potential to improve driver safety year-round in darkness and conditions of poor visibility. As noted earlier, the Eaton system requires the driver to be fully informed and aware of the range of warning tones and lights, and what message each progressive warning conveys. With a radar range of approximately 350 feet, and with vehicle speeds of 100-plus feet per second in good weather, driver interpretation and action must be instinctive. For ADOT to consider employing CWS on its fleet units in the future, the system must prove itself to be effective, simple and reliable.

Eaton provides a wide range of EVT-300 technical and training materials to its customers. These resources include detailed installation, troubleshooting, and driver reference manuals and training aids, including an operator's video filmed in Arizona. For the ADOT snowplowing application and evaluation effort, the Eaton materials were effective and comprehensive.

The ATRC utilized these materials extensively to introduce new drivers to the EVT-300 system, beginning with previews and feedback from the project TAC members. Videos and operator's manuals were provided to each participating Org (local maintenance camp or yard) with the radar system, and to each district's Equipment Services shop as well. It was emphasized repeatedly that all snowplow drivers in each project-partner Org should be introduced to the system, in case they were assigned in mid-season to the research snowplow. The primary drivers were requested to make frequent dry-road familiarization runs on their assigned snowplow routes.

This extra effort would help develop driver confidence, and help identify any roadside features or conditions that might repeatedly produce false alarms or missed warnings. With foreknowledge of any problem sites, drivers could be more reactive to any other CWS warnings.

The ATRC's 2002-03 winter testing plan, due to the wide dispersal of the four test plows, was not based on group training and group evaluations. It depended instead on feedback at the local level using snowplow shift activity reports, system incident reports, and periodic driver surveys. The season's evaluation plan and results are detailed further in later sections of this report.

2002-03 CWS RADAR OPERATIONS

As noted above, all four project snowplows were equipped with operational EVT-300 radar units by early February. More than half of the season's snowfall was still yet to come, so valid field testing efforts in operational conditions were certainly still possible.

ADOT's in-house PECOS data management system allows the tracking of winter maintenance activities such as snowplowing, chemical or abrasive applications, and winter storm patrolling. Table 5 shows the extent of evaluation usage for the four project snowplows with Eaton's CWS, while Appendix D provides a complete summary of the storm-related operations and weather observations for both radar and night vision-equipped ADOT plows during the 2002-03 winter.

These figures show that through this winter evaluation activity, ADOT operators acquired more than 70 collective days of snowplow experience in nearly 18,000 miles of highway driving. Only one of the four plows was in commission before mid-January, so the total driving time could have been much higher for a full winter. From the time that all four plows were in service, the Flagstaff region received approximately half of the total snowfall for the season.

No significant performance problems were reported with the Eaton VORAD collision warning radar system during this 2002-03 winter operational testing program. However, the operators' acceptance of the system varied, and their shift activity reports were not consistently completed.

More detailed information on the EVT-300's performance, and on the operators' perceptions of the system, will be provided in later sections of this report.

Table 5. ADOT Winter Storm Activity with EVT-300 CWS Radar

Project 473 Winter 2002 – 2003				
PLOW DATA	F326	F342	F291	F269
MAINT ORG:	Seligman	Gray Mtn	Flagstaff	Chambers
Total Reports:	*13*	*61*	*33*	*16*
System:	Radar	Radar	Radar	Radar
Highway:	I-40	US 89	I-40	I-40
Mileposts:	121–146	420-440	185-230	347-360
Installed:	22-Jan-03	21-Sep-01	14-Jan-03	04-Feb-03
Dates / Miles Summary				
Sum of Miles:	1,830	8,484	4,452	3,021
Use-Days:	10	32	20	11

THE SMARTCRUISE OPTION

The SmartCruise adaptive cruise control feature was also of significant interest to ADOT for its ability to reduce the potential for rear-end crashes. This feature functions in addition to the proximity and closing rate warnings of the basic roof-mounted EVT-300. However, the EVT-300 cannot provide the SmartCruise functions with a rooftop antenna, due to its installation angle relative to the roadway, and the gap in radar coverage at ground level in front of the bumper.

To test SmartCruise on an ADOT snowplow, the project team developed a redundant on-board system with both roof and bumper antennas. The solution was to use one system control processor unit with two wiring harnesses, one for winter use of the rooftop antenna without SmartCruise, and another at bumper level for both collision warning and SmartCruise operation in summer, when the plow blade has been removed.

As described in prior reports, the EVT-300 radar system on F342 was installed in the 2000-01 winter, but the forward antenna was not operational for most of that initial season. The radar system was then repaired and it functioned effectively on the Gray Mountain plow routes through both winter 2001-02 and winter 2002-03, establishing a high level of confidence among the primary drivers. However, it was not until the end of the 2002-03 winter that ATRC and the Flagstaff Equipment Shop were finally able to resolve several key system issues and proceed with the upgrades required for SmartCruise phase of the evaluation later in the summer.

A variety of factors had stalled the full commissioning of the SmartCruise feature on plow F342. The original procurement had defined the basic engine and electrical specifications of this 1999 Mack snowplow truck, and there did not appear to be any problems with initiating the various modifications to the engine control system. When the three new EVT-300 units were purchased, Eaton VORAD provided technical support for those installations in Flagstaff. However, the initial tasks were to recalibrate the forward CWS on F342 as a baseline for the other units, install the required additional hardware, and fully commission the SmartCruise feature for testing.

The installations were to start in mid-December, but a series of storms and the holidays slowed the process. Modifying snowplow F342 with SmartCruise was the first objective, but numerous problems arose. ADOT had acquired diagnostic and calibration software from Eaton but did not have all of the needed system components to utilize it in the equipment shop. The project therefore acquired the necessary Eaton systems card for the shop's ProLink diagnostic system.

As the initial work progressed to install the second bumper-mounted antenna and wiring harness for SmartCruise on F342, further discoveries were made. The truck's engine had been upgraded earlier, but the vehicle computer and engine control computer, while functional, were not equally compatible with the VORAD system. This problem required extensive consultations between ADOT, Eaton, and Mack, and initially there was discussion of replacing the truck's camshaft and turbocharger. This process also delayed the installations of the other three systems into January and February.

Ultimately the Mack factory team determined that reprogramming of F342's engine computer software was possible, and advised ADOT through Eaton as to how to proceed. This was not the immediate resolution, however, as in the interim, ADOT had developed further concerns about doing modifications to individual truck engine control systems. This question was finally resolved in late February for the project snowplow, and the upgrades were completed by the Mack dealership.

From that point, the commissioning progressed and SmartCruise was operational at last on March 11, 2003; ATRC's evaluation of this feature is described in Chapter XIII.

VIII. BENDIX XVISION INFRARED CAMERA: THE SYSTEM

SYSTEM CONCEPTS

Bendix Commercial Vehicle Systems is a major source of truck and automotive components in the United States and overseas. While several other suppliers have concentrated on security-system markets such as law enforcement and the military for their low-light vision enhancement systems, Bendix has taken the initiative in marketing their XVision system to the heavy transport industry in the United States.

Commercial trucks and buses make up a large component of the traffic volume on the nation's highways, and at night the proportion of heavy vehicles on the road increases significantly. Bendix literature describes XVision as "the first infrared night vision system for commercial trucks and buses that allows drivers to see farther, react sooner and drive smarter."

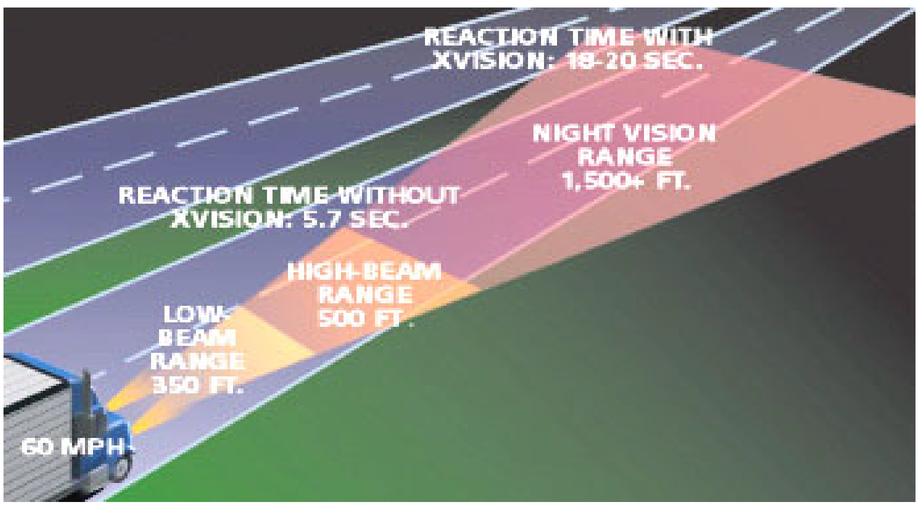


Figure 14. XVision Enhancement of Reaction Time to Roadway Hazards

[Graphic by Bendix Commercial Vehicle Systems LLC]

The Bendix XVision thermal imaging night vision system is a passive-infrared design, which requires no external light source. Passive-infrared technology reads the different heat signatures, or levels, of all objects in the camera's field of view and displays them as black-and-white images on a display screen. Every object, including the roadway, has a heat signature, and animate objects, such as deer and people, show up boldly as high-heat sources.

XVision is marketed not as a warning system but as collision avoidance information technology. As visibility is reduced, so are reaction times and overall road safety. The XVision system has the ability to extend the driver's range of vision far beyond his vehicle's headlights, which are only effective for 300 to 500 feet. Thermal imaging night vision can increase a driver's vision range to three to five times beyond the vehicle's headlights, out to 1500+ feet. With such an increase in effective vision at night, driver reaction time at 70 mph can increase from only five seconds with high beams to as much as 15 seconds with night vision, as shown in Figure 14.

The key advantages of the passive-infrared system are increased vision distance and improved recognition of road hazards. The design is most effective at night to detect and identify animals, pedestrians, work zones, turnouts, road debris, poorly lit vehicles and slow or stalled cars. The screen image is not affected by glare from oncoming headlights, allowing the driver to not only see farther, but see better.

The Bendix XVision system has been marketed nationally since 2001. A number of new features have been phased in during the past two years. The primary market for Bendix is seen to be heavy commercial trucks, but the night vision concept has extensive potential for specialty fleets, including emergency and highway maintenance vehicles such as snowplows.

ADOT EXPERIENCE WITH NIGHT VISION

ADOT had no real practical experience with passive-infrared night vision systems before the advanced snowplow project investigated the subject in mid-2001. Initially, the engineering team of ADOT's Equipment Services Group suggested that the concept be evaluated. Following up with supplier contacts, ATRC arranged for a presentation by the local Bendix representative. As a result of this meeting, the research TAC members agreed that the concept should be evaluated.

Figure 15. Original XVision Camera Installation on Snowplow F235

While an ADOT evaluation agreement and commercial pricing were generally established in late 2001, the XVision system was not completely ready for the market. Bendix could not provide a unit to ADOT before the 2001-02 winter was well along. The research project went ahead with the joint Caltrans ASP plans for Phase Two(b), with night vision remaining a secondary concern.

The XVision system was eventually delivered to ADOT in late January, and it was assigned to snowplow F235 at Little Antelope Camp on Interstate 17 in the Flagstaff District. XVision was finally installed on an ADOT snowplow in February 2002. However, commissioning problems delayed the first tests. Worse yet, shortly after the installation, this truck was taken out of service for unrelated equipment upgrades at the Phoenix shops, which were not finished until April.

As a result, no practical testing could be done with Bendix XVision until the following winter season began, in late 2002. However, as the system installation was refined over the spring, the project stakeholders maintained a high level of interest. In May, a demonstration was arranged for the TAC members with snowplow F235 at Rim Camp, on highway US 89A near Flagstaff.

THE BENDIX XVISION SYSTEM

XVision utilizes an externally mounted rooftop infrared camera, which senses relative heat levels of objects in the field of view. The camera can measure temperature differences as slight as 0.4 degrees Fahrenheit, and it processes the signals electronically to produce a virtual image on a flat-screen display mounted near the driver's line of sight. The system displays a thermal map of the forward view, with relatively warmer objects as brighter images, and cooler inanimate objects show in shades of gray (see Figure 18).

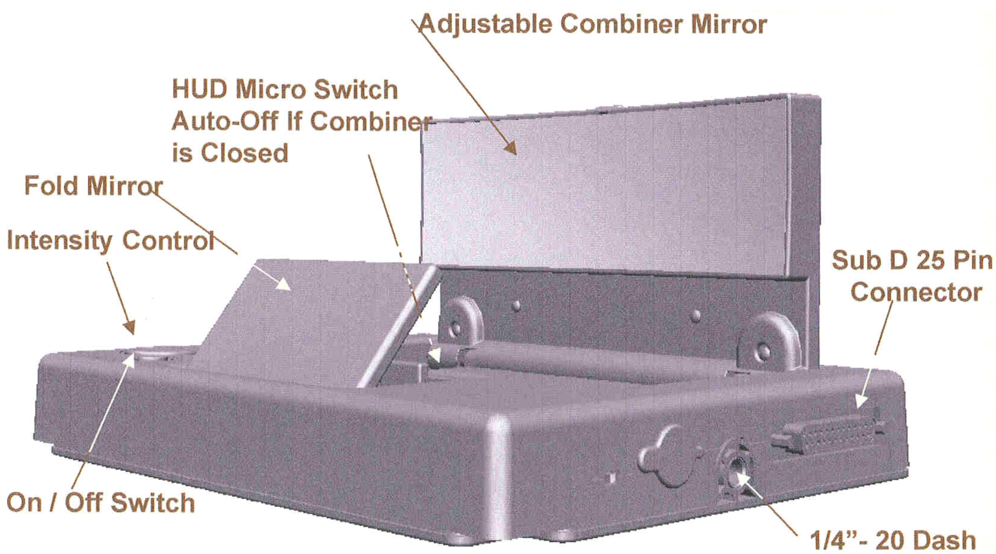


Figure 16. Original XVision Head-Up Display Unit (HUD)

[Graphic by Bendix Commercial Vehicle Systems LLC]

The Bendix XVision system was originally packaged with a head-up display unit (HUD) with folding mirrors. The infrared image is viewed on the combiner mirror (Figure 16). However, ADOT found that heavy vibration of the snowplow truck reduced the dual-mirror system's effectiveness. The current unit is sold either with the HUD unit shown above, or with a liquid-crystal display (LCD) flat-panel display screen (Figure 17). The driver needs to glance at the screen only occasionally, as a passenger car driver would glance at his rear-view mirror.

A significant option to enhance driver safety with XVision is a rear- or side-mounted low-light camera and microphone unit to monitor the blind spots around the vehicle. This camera shares the forward night vision camera's display screen, and the driver can easily toggle from one view to the other. Due to icing concerns, this feature was not considered by ADOT for snowplows.

Another option is a selection of protective shields for the XVision camera. ADOT has added a shield for each of the three research snowplows, in order to protect the camera's mounting and aiming hardware. As shown in several figures, the basic infrared camera, wiring harness and mounting system are exposed to damage from road debris and other hazards. The camera shields that later were developed by Bendix are not completely enclosed, but they do protect the camera unit (but not the lens window) against damage from the front and sides (see Figure 21).

PASSIVE-INFRARED SYSTEM DESIGN

The XVision camera and its original HUD display unit are a self-contained system. For the new flat-panel display, as upgraded by Bendix, a separate processor unit is required. The infrared camera itself is approximately 8 inches high, 10 inches wide and 6 inches deep. It bolts into the cab roof, and requires an additional one-inch hole for the data cable. The camera and brackets weigh 4.3 pounds. The camera's field of view is 11 degrees horizontal and 4 degrees vertical. The XVision system is capable of detecting temperature differentials as small as 0.4 degrees (F). The system's operational temperature range is from –40 to +140 degrees (F). This passive-infrared system detects electromagnetic energy in the 7-14 micron wavelength region.

Figure 17. Bendix Upgraded Flat Screen LCD Display: Dashboard Mounting

The original head-up display unit (Figure 16) weighs two pounds and is1.25 inches high, 9 inches wide and 7 inches deep. Because the space in truck cabs varies so widely, the unit is designed for either dashboard or headliner mounting. The HUD is mounted in the driver's line of sight, to provide the same relative perspective of objects as in his normal view.

The new optional Bendix flat-panel LCD display screen shown in Figure 17 (6.8-inch diagonal) has several mounting options, and due to its size, it may have to be offset more from the driver's line of sight. This display screen is eight inches wide, 5.25 inches high and 1.15 inches deep.

The key to functional success of the passive-infrared system is its ability to perform under a range of adverse conditions. The XVision concept depends on a clear field of vision. A camera window that is a 1.3 mm-thick silicon disk protects the infrared sensor system. This disk, which is transparent to infrared radiation, has a scratch-resistant coating to prolong its service life through frequent cleanings.

For winter operations, the XVision camera has an internal heating element that is designed to prevent gradual snow buildup on the lens itself (see Chapter XI, and Figure 24). This internal heater is in the lens bezel, not the silicon camera window, and it is intended to melt snow or ice within the inch-deep pocket formed by the lens bezel and the flat silicon disk. A thermostat activates the heater when the temperature drops below 40 degrees (F).

XVISION - ADVANTAGES AND LIMITATIONS

The advantages of night vision are quite clear, in particular for public safety and public service users in a variety of field conditions. For highway maintenance, one of the primary nighttime activities is winter storm operations. The simplicity of the system is a major advantage; it displays everything in the field of view and it triples the vision range beyond that of headlights. Unlike a CWS radar system such as the EVT-300, night vision requires no interpretation of warning chimes, tones, or lights, and it is not prone to false alarms or erratic detection.

Figure 18. XVision Thermal Imaging Display of Roadway Hazards

[Graphic by Bendix Commercial Vehicle Systems LLC]

There are limitations with the passive-infrared concept. XVision was designed and tested for service in all weather conditions but was not specifically enhanced to cope with severe weather. The nature of infrared detection is that the thermal differential of objects in view is reduced to some extent in fog, rain or snow, which falling at a uniform temperature can create a haze effect over the thermal images on the display screen. Under these conditions, interpretation of some thermal images may not be intuitive.

For operations by ADOT and its partner agencies, the infrared night vision concept is obviously a nighttime resource. The reality is that heavy ADOT vehicles are not operating on the road at night very frequently, except during storm-related maintenance operations. The night vision concept must therefore be justified by storm patrol and snowplowing activities alone.

XVISION SYSTEM - COST DETAILS

The first XVision system was provided to ADOT in a joint evaluation agreement with Bendix. The Bendix XVision commercial rollout took place in December 2001, after a series of pre-production refinements, and in January 2002 ADOT agreed to work as a developmental partner with Bendix on evaluating Arizona's first field unit prototype, and would test any future system upgrades as they were released.

Based on early impressions from the F235 installation, and the TAC demonstration in May 2002, the project initiated the purchase of two additional off-the-shelf units from Bendix for the 2002-03 winter test program, at which time the XVision system was commercially priced at $3,895. However, the value of the camera shields was roughly $100 each, and the average cost of the full system installations, at ADOT shop labor rates, was $800. Considering commissioning and shop troubleshooting labor charges, the average installed cost of each basic XVision system on the three ADOT snowplows was approximately $5,000.

As described later in this report, system performance was impaired in heavy snowstorms. ADOT and Bendix worked closely together through the 2002-03 winter with the three XVision units to develop and test solutions, some which are still being evaluated in the 2003-04 winter.

A number of ongoing cooperative efforts were made by ATRC and Bendix to refine the system and to improve its performance consistency, primarily dealing with camera lens-cleaning options. The installed cost to ADOT of this additional hardware as of late 2003 has been roughly $2,000 per vehicle. The washers have been functionally successful in field testing, and the overall value of these changes for night operations will be determined after the 2003-04 winter season.

IX. XVISION: COMMISSIONING

While the process required a great deal of time, the establishment of a working partnership with Bendix was a key aspect of the ADOT research project's new directions. The Bendix infrared night vision system was not yet being widely distributed in mid-2001, and the program was still exploring its potential for specialty vehicle applications.

The evaluation concept for the original XVision unit was straightforward, as worked out by the TAC, Bendix, and other ATRC partners. Bendix offered a night vision concept that was clear and intuitive; they therefore developed only limited training material and operating guidelines. Still, these materials were a necessity so that each driver would understand the abilities and limitations of the thermal imaging equipment.

The ATRC evaluation program was to utilize the standard operator shift reports from previous winters to detail the system operating conditions during plowing activity. ATRC also would work with Bendix on their specific needs, which were primarily for driver feedback on system performance. Bendix furnished an incident report form to describe any event when the system did or did not give a warning or influence the driver's decisions. The ATRC also adapted the Bendix report for the EVT-300 radar, to provide an evaluation tool that was consistent for both systems (Appendix F).

COMMISSIONING ACTIVITY

The Bendix XVision system was not quite ready for its market rollout in late 2001. Hoping to get early Arizona field results in the 2001-02 winter, Bendix offered an early-production XVision camera and HUD display to ADOT on an evaluation partnership basis. While this agreement was being worked out cooperatively, the key details at the field level were more of a challenge.

The first plan was to install the XVision camera side-by-side with the Eaton VORAD radar on the ADOT-3M snowplow F342 at Gray Mountain, to compare the two forward warning systems. However, this would have seriously overloaded both the electrical system and the plow operator. Also, this ADOT-3M snowplow was still scheduled for extensive joint training and evaluations with the Caltrans RoadView ASP in Year Four, and adding the night vision system would have complicated that side-by-side evaluation.

Another snowplow would therefore be needed to test the XVision system. The Flagstaff District in Year Four was providing basically all of the material and staff support to the research project, so it was clearly a decision for the local managers to resolve. By the fall of 2001, it was agreed to evaluate the XVision system on an ADOT snowplow stationed at Williams, west of Flagstaff.

This was a sound plan since the Williams crew patrolled both Interstate 40 and State Route 64 leading north towards the Grand Canyon. As a result, the project's 2001-02 research program workplan document listed snowplow F278 as the Bendix test plow, however, that was premature.

A variety of local issues in the fall prevented the XVision installation at Williams, in particular ADOT's procurement processes, but also a series of internal delays for Bendix. The system and the test unit were not fully ready for product delivery, and the XVision system was finally received by ADOT in the last week of January 2002. At that time, however, a decision was made to not use Williams as the test site after all. Instead, the Flagstaff District decided to assign a plow from Little Antelope Camp on I-17 for the XVision evaluation.

The first XVision system was finally installed on snowplow F235 in February. Commissioning problems delayed the initial field tests and shortly after the installation, this vehicle was taken off line for other scheduled snowplowing equipment upgrades to be performed at the Phoenix shops. There would be no more opportunities to field test the XVision system, as this mild winter was ending, and the snowplow was out of service until April.

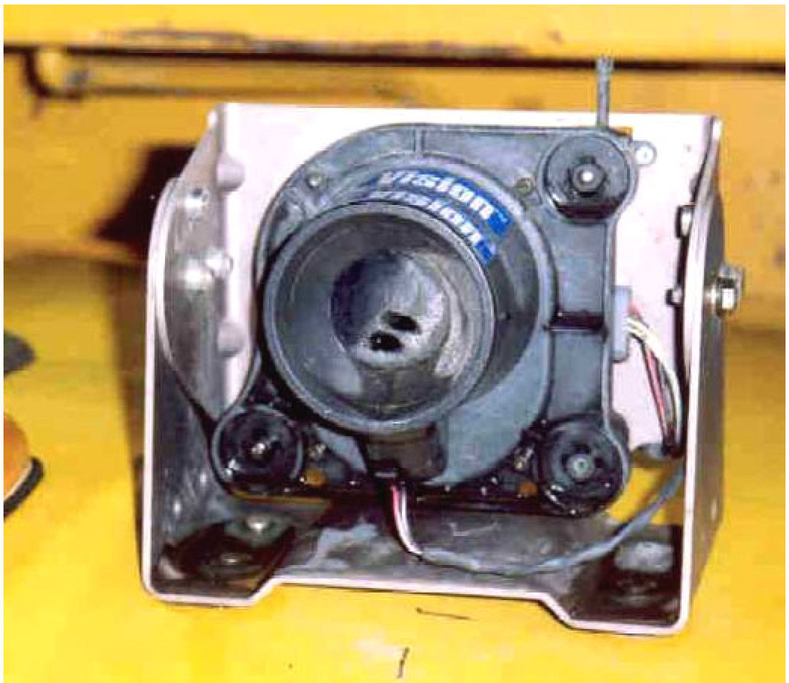


Figure 19. Basic XVision Mounting Exposed to Spray and Debris

When the truck was returned to Little Antelope, one longstanding issue remained for the XVision system. The two operators were initially enthusiastic about the system, but they found vibration to be a real issue for the system's HUD (Figure 16), which was mounted overhead. During the initial night familiarization runs, the Mack snowplow truck produced continuous vibrations in the two-mirror HUD projection system. The vibration problem prevented target identification during several storm patrols in spring rains and in low-lying fog along the I-17 corridor.

At this time, the only option that Bendix could offer was new mounting hardware. The HUD mirrors did not vibrate so badly on the softly sprung long-haul tractor-trailer rigs that were the primary market for XVision. In May, ATRC and Bendix took steps to identify an off-the-shelf LCD screen to be substituted for the tremor-prone mirrors of the head-up display unit. The XVision HUD unit did have output jacks for a secondary passenger-side screen, which had been provided for observation during the HUD development phase of the Bendix design program.

Locating a suitable LCD display screen was not a major problem, and it was obtained by ATRC from a Phoenix-area electronics supply house. Unfortunately the selected unit was imported from a developing nation, and its rudimentary wiring diagram forced a second screen purchase before the upgrade was finally successful (Figure 20). Later, a Bendix unit would be substituted.

May 2002 Stakeholders Preview

One key aspect of the XVision program for ADOT was to rekindle some of the enthusiasm in the districts and among the TAC members for the snowplow research effort. With the conclusion of the Caltrans partnership, the project was no longer focused on an intensive side-by-side guidance system evaluation program.

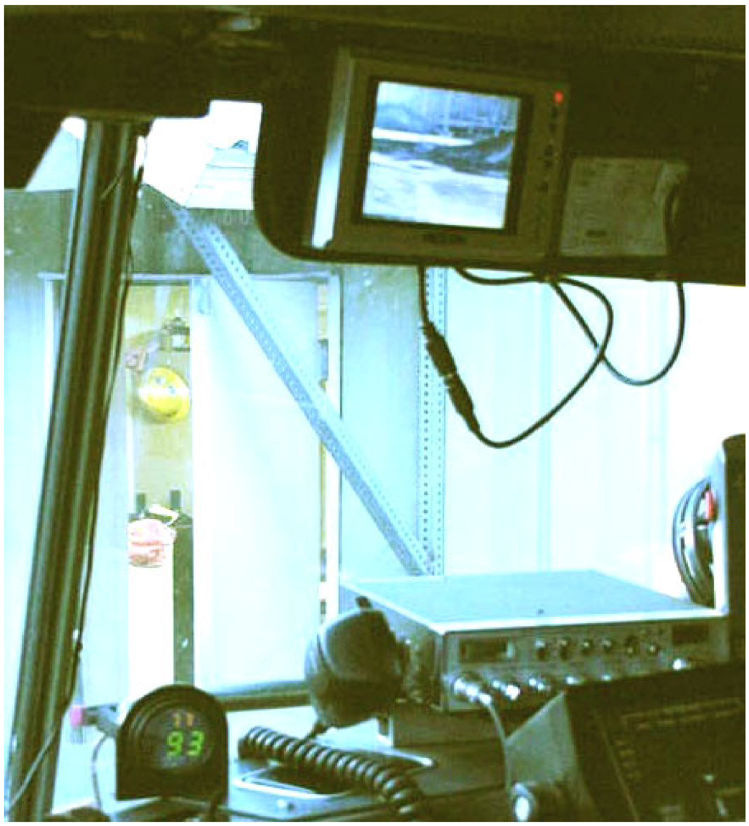


Figure 20. Visor-Mounted LCD Screen for May 2002 Demo

While the TAC had directed a new effort with on-board systems, not all TAC members were familiar with what other concepts might justify commitments in new directions. One aspect of bringing the program back into focus was to demonstrate the candidate on-board systems to the stakeholders, and night vision was a concept of real interest for many of the TAC members.

With the new LCD screen installed at last, the ATRC scheduled an XVision demonstration at the Flagstaff District's Rim Camp yard on US 89A. This "night demo" event took place on May 29, 2002, and a total of ten ADOT plow operators, supervisors and managers from three core TAC districts were on hand, as well as several project team members and visitors from Phoenix and Northern Arizona University. Most of the visitors were able to take 10-minute test rides, and they then filled out a brief opinion survey.

The TAC survey results from the brief initial test ride were favorable, and all testers rated the system on the positive side of the scale. More helpful were the open-ended comments that expressed a strong positive reaction to the extended vision range and to the clarity of the image. There were also a few concerns voiced about image size, mounting position and lack of clarity in some images. In general, however, all of those who witnessed the XVision demonstration rated it highly and were enthusiastic about real-world testing by ADOT in the next winter.

Installation of Additional Night Vision Units

As noted earlier, ATRC polled all of the TAC members on the overall direction of the research program following the May demonstration, and as anticipated, tests of on-board warning systems became the basic Year Five goal for the project. Along with the CWS radar systems, ATRC was also directed on July 30 to procure two additional Bendix XVision systems.

With this clear direction from the TAC, the new units were purchased for deployment on ADOT snowplows at Winslow and at Kingman. This plan provided for testing of three XVision units in diverse storm and terrain conditions that range from the I-17 corridor near Flagstaff, to US 87 south of Winslow in the forested Mogollon Rim area, and to I-40 where it rapidly climbs into the rugged Aquarius Mountains east of Kingman.

Procurement of these additional units was straightforward, with ADOT Equipment Services staff helping to overcome the traditional procurement obstacles. The new XVision units would now be furnished with a standard flat-screen display, and the original unit on F235 would also be retrofitted with the latest Bendix screen. Later on, new debris shields would also be provided if conditions required. The procurement effort, initiated in August, was completed in October.

Within a few more weeks the new systems were received, and all installations were finally completed by December 3, 2002. At this point the northern region of Arizona had only seen about three inches of snowfall so far, and the entire winter season remained for XVision testing.

TRAINING & TESTS

Bendix XVision is an extremely advanced passive-infrared system. One of its key advantages is that it is fundamentally intuitive for the driver. With the original HUD concept, the displayed image is at the proper scale and angle for the driver to instantly relate it to the visible scene directly ahead. However, as ADOT transitioned to the LCD display screen, mounted at the center of the dashboard, the driver's visual and interpretive efforts were slightly increased. Still, this was just an issue of driver familiarization and level of confidence in interpreting the image.

Bendix provided basic driver handout materials with XVision, along with a set of installation and marketing videotapes to illustrate the general concept and performance of the infrared system. The vendor did not develop extensive training materials because they were not considered necessary for successful adaptation to night driving with XVision.

The ATRC utilized the various Bendix materials to introduce drivers to the XVision system, after a preview and feedback session with the project TAC members. Copies of the videos, brochures and operator's guidelines were provided to each maintenance camp with the new system, and to each district Equipment Services shop as well.

Fundamentally, this approach was successful, although ADOT drivers sometimes encountered issues in troubleshooting system performance or malfunctions. There was occasional confusion as to expectations for the startup sequence, and concern about proper switch settings. Learning to interpret the infrared display was more challenging, especially at twilight, for example with a negative image on the screen of black sky and white trees ahead.

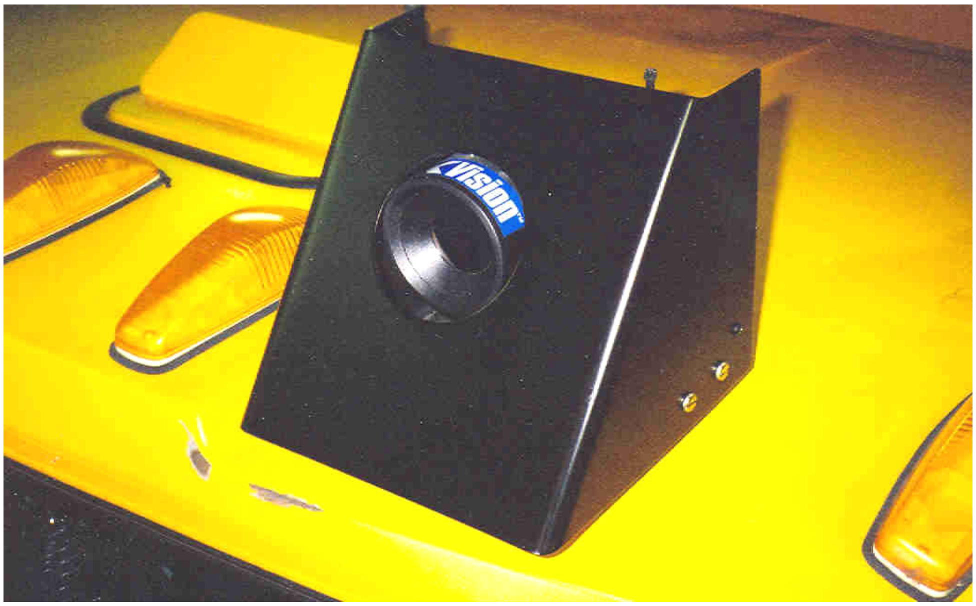


Figure 21. XVision Shield Added to ADOT Snowplow F235

The ATRC emphasized that all snowplow drivers in each participating Org should be briefed on the night vision system, in case they were assigned in mid-season to the research plow. The primary operators were also asked to make several night familiarization runs on their assigned snowplow routes before the first storm, to develop confidence with regard to interpreting the images, and to identify roadside features or conditions that might be confusing.

The drivers were generally quick to learn the idiosyncrasies of heat-based image intensity and the unique heat signatures of roadside objects such as guardrail, signs, rocks and trees. The general reaction of new drivers to the XVision's thermal imaging concept was that it was a tremendous improvement for night driving of heavy fleet vehicles, especially in hazardous environments.

The ATRC's 2002-03 winter testing plan, due to the wide dispersal of the three test snowplows, was not based on group training and evaluations. It depended instead on feedback at the local level using snowplow shift activity reports, system incident reports, and periodic driver surveys.

2002-03 INFRARED NIGHT VISION OPERATIONS

All three snowplows had been equipped with operational XVision systems by December 3, 2002. Most of the season's snowfall was yet to come, so a comprehensive and valid testing program was anticipated. ADOT's in-house PECOS data management system tracks winter maintenance activities such as plowing, chemical or abrasive applications, and winter storm patrolling.

Appendix D provides a complete summary of storm-related operations and weather observations for both radar and night vision-equipped snowplows during the 2002-03 winter, while Table 6 below shows the extent of evaluation usage for the three project plows with the Bendix XVision passive-infrared night vision technology.

Table 6. ADOT Winter Storm Activity with Bendix XVision

Project 473 Winter 2002 – 2003			
PLOW DATA	F277	F235	F340
MAINT ORG:	Kingman	Little Antelope	Winslow
Total Reports:	*12*	*72*	*40*
System:	XVision	XVision	XVision
Highway:	I - 40	I - 17	SR 87
Mileposts:	54 – 72	335-340	317-290
Installed:	3-Dec-02	7-Feb-02	3-Dec-02
Dates / Miles Summary			
Sum of Miles:	1,729	10,871	6,863
Use-Days:	6	39	22

These activity records show that during this winter evaluation activity, the project snowplows accumulated nearly 70 total days of on-the-road snowplow experience in almost 20,000 miles of highway driving. All three snowplows were fully operational by early December, and were in use for almost the entire 2002-03 winter. The Flagstaff region received all but three inches of its 55-inch snowfall total for the season after the date that all three night vision plows were in service.

The Bendix XVision units experienced some basic issues on the three test snowplows that affected the overall driver ratings for the 2002-03 winter. Expectations were very high in the fall, but as problems with snow buildup on the camera lens were observed, significant frustration and reduced levels of satisfaction developed for several of the project's snowplow operators.

As noted by Bendix initially, passive-infrared was not specifically designed for continual service in the high-moisture conditions that snowplow vehicles often experience. XVision was designed and tested as an all-weather system but was not developed specifically for severe storms. ADOT and Bendix worked continually through the Phase Three winter to develop solutions, and are still evaluating new approaches for 2003-04, including a third-party lens-washing system, to resolve the snow blockage problem for the camera lens.

More detailed information on the XVision performance, and on the ADOT operator perceptions of the system, will be found in the following sections on the 2002-03 research activities.

X. ON-BOARD SYSTEMS: ATRC RESEARCH PLAN

After four winters of snowplow guidance research, the ATRC'S survey of the TAC members and stakeholders resolved what new research would be the most valuable for ADOT after the end of the joint ASP evaluation program with California. As described earlier in Chapter V, the TAC survey results (Appendix J) mandated that commercial on-board driver-warning systems would be the new focus of an operational evaluation program in Phase Three.

RESEARCH ACTIVITIES FOR YEAR FIVE

The project TAC members and partner districts played a key role in determining the nature of the Phase Three research activities for 2002-03. Each district was asked to determine where the new systems could best be employed in their area of operations, and, to select a snowplow for the testing program. The only constraint was that all the plow trucks should be late-model Macks, similar to F342, the existing ADOT-3M advanced snowplow.

As detailed earlier in Chapter V, the results of the TAC survey directed the ATRC to conduct operational testing of three Bendix XVision units along the I-40 corridor in the 2002-03 winter. Additional Eaton VORAD collision warning radar systems were also acquired for evaluation at four other regional sites (see map, Figure 7, and Table 4).

Phase Three would be the first winter for ADOT to perform this snowplow research at the local rather than the regional level. The districts had to consider many factors in assigning radar or night vision to their local forces, such as the roadway classification, traffic volume, winter storm frequency, and total snowfall. Each district also had to consider the project's operational evaluation needs, which called for utilizing a variety of roadways, terrains and storm histories. There were several internal ADOT factors to consider in every case, including local plow truck route assignments, attitudes of the snowplow drivers on those routes, and perspectives of the local maintenance Org supervisors.

Org-Centered Research Plan

The ATRC's plan for Phase Three of the advanced snowplow research project was relatively simple and straightforward, especially compared to the complex procurement, construction, and joint agency partnering activities of the past four winters. This final Year Five of the project required a new approach at a different level of the ADOT organization. Additionally, it called for extensive coordination with the individual vehicle system suppliers.

With the new focus on self-contained on-board warning systems, and once the research vehicle assignments had been made, the key level of active participation for the project was no longer at the District level, but at the local maintenance Organizations, or Orgs. Each of the project's seven scattered maintenance Orgs would have a warning system installed on one snowplow. The local plow operators and supervisors would, in effect, perform the research and, hopefully, would document the system issues and performance through the 2002-03 winter. Therefore, the key activities of ATRC's Year Five snowplow research program would be Org-dependent.

The project was further dependent on ADOT's Equipment Services Section, first of all, to support the procurement effort by working with established system suppliers and the ADOT

Procurement Group. Secondly, ATRC relied on the district equipment shops to both install and later to support the new systems, and the Flagstaff Shop in particular would play a key role.

System commissioning was a critical issue for both on-board warning systems. ATRC, with TAC guidance, determined that all of the system installations should be performed at one location by one experienced team of technicians. The complexity of the installations and the variations between plow trucks required that one shop team should perform all system installations and calibrations. This role fell to the Flagstaff Shop, both for its prior experience with the Caltrans ASP and for its key role in developing the ADOT-3M advanced snowplow.

In the earlier winters of the project, the Caltrans plow had required frequent service in Flagstaff for numerous truck and ASP system maladies, including CWS radar problems. More recently, the ADOT-3M Advanced Snowplow F342 had been completely equipped in Flagstaff with the standard EVT-300 radar unit, with an Automatic Vehicle Location (AVL) tracking system, and with the complete 3M Lane Awareness System.

Figure 22. Installation of Vehicle Systems at Flagstaff Shop

There was no question that the Flagstaff Shop had the expertise for the new program, and the staff there was totally willing to support the new program. To ensure efficient future local support, as the system installations progressed in Flagstaff, equipment shop staff from the other partner districts also assisted with the work to commission their own plow trucks.

ATRC Shift Activity Reports

In the four previous winters of the advanced snowplow project, ATRC had collaborated with the Caltrans team, and later with 3M staff, to collect and share consistent research data and results. This meant utilizing a variety of report forms and survey questionnaires that would not only meet the data needs of the larger agency and industry research programs, but would support further ADOT research information needs and goals as well.

ATRC had developed its own driver survey forms for the side-by-side evaluations of the ADOT-3M plow, based primarily on the Caltrans program. The evaluation records for both systems could be shared and each party could extract and interpret the information that was significant to them. The project had also shared its driver survey results with 3M and the University of Iowa (U of I). ATRC utilized the results of the 3M surveys that had been conducted by the U of I, but did not attempt further interpretation of that data, as described in the project's Phase Two report.

In the four prior years, ATRC also developed a shift activity report that focused on operational evaluations of the ASP systems, rather than on the operator training activities. Only the Team Leader drivers utilized these shift reports. The key information requested of the drivers included road surface condition, weather, visibility, mileage, and system status. These shift reports were continually streamlined to reduce the paperwork effort for the operators at the end of a long shift of plowing in severe storm conditions and heavy traffic. For Year Five, the format and content of the shift activity reports were again reviewed and edited, and they were provided to the crews of the several new snowplows that were just joining the research program (Appendix E).

Incident Reports

While shift activity reports were basic to evaluating the operational performance of the on-board systems, a second type of information in more depth was also needed. This was an incident or event report form, intended to document any unusual situation where the radar or night vision system either helped or hindered the snowplowing operation. This form (Appendix F) asked for time and place information, a description of the event, and the outcome. This event record form was originally provided by Bendix to gather performance data for its XVision rollout, but the form was also adapted by ATRC to collect the same information for the CWS radar.

The already-burdened drivers were not expected to fill out an event report daily, but it was hoped that they would have reasonably frequent incidents and comments regarding the effectiveness of the systems. ATRC and the TAC sought both positive and negative anecdotal reports in this manner. As with many things, an "event" was subject to local interpretation over the winter.

Driver Surveys

Based on ADOT experience, no research activity in the snowplowing arena could be complete without administering driver opinion surveys. For Phase Three, with no outside partner actively involved in the evaluation, the ATRC administered several driver surveys (Appendixes G & H) at intervals through the winter season. This approach maintained the continuity of processes and expectations, but it also provided an excellent perspective of the drivers' reactions to each system as it was commissioned, and as it performed over time through the mild 2002-03 winter season.

The ATRC's extensive use of these surveys was quite productive. The surveys were developed from the resources of prior winters, but with a focus solely on the issues of greatest concern for the project TAC members and for ATRC. The survey addressed driver level of acceptance, likes and dislikes, perceived benefits, and driver recommendations. Over the initial winter deployment of the two on-board systems, these surveys revealed clear trends with regard to many aspects of the systems, and to the overall level of acceptance by the drivers. They also revealed a wide range of reactions to, and perceived needs for, these systems.

ATRC planned to conduct the surveys upon system introduction, at mid-season, and after the 2002-03 winter was over. This plan was followed, but the radar units were not commissioned until mid-winter. Therefore the XVision crews filled out three surveys at two-month intervals, but the CWS radar drivers took the survey only twice. Survey results for each system are discussed later in this section, and the full summaries are included as Appendixes G and H.

Ride-Alongs

The Phase Three research effort was completely decentralized in comparison with the previous winters, and the results would depend on coordination and follow-up at the local level. The ATRC workplan for the winter involved frequent staff contacts with the Org supervisors and the snowplow drivers, including visits to each local maintenance yard as time and weather would permit. This plan was reasonably successful, although the relatively mild winter reduced the opportunities to observe and document storm performance and to get real-time driver feedback.

One key aspect was "ride-along activity" by ATRC staff. This was intended to observe system performance and to engage the drivers in more discussion than the report forms could provide. ATRC staff ride-alongs this winter were limited to Little Antelope and Gray Mountain, but there were field visits to all of the project Orgs in support of the driver surveys, for storm debriefings, and in search of other project records.

ATRC DATA COLLECTION

By decentralizing the research activities to the field, a significant amount of data for the project also was decentralized. With seven snowplows and seven Org teams involved in the research for Year Five, new issues arose regarding consistency and thoroughness of data collection. During the winter, however, a variety of new resources, not always obvious, also were found to improve both the quality and quantity of information in support of the research process.

Fundamentally, the project was now much more exposed to the human factor, and this was especially true at the snowplow level. Of the various records needed to document the project, the daily shift reports and the incident reports were the most burdensome for some of the drivers. While most Orgs submitted good records, even the most consistent sources had shortfalls during severe storm periods. The results, and issues, are discussed in a later section of this report.

As mentioned above, ATRC staff conducted some snowplow ride-alongs as well as numerous visits to the field sites to discuss progress with drivers and supervisors. These meetings and driver feedback were very useful in filling in the gaps in activity and event reporting. With regard to the most basic operational data, however, more probing would be required.

ATRC eventually found that the shift reports were not complete enough to recreate the overall history of the 2002-03 winter for the project, as intended. Other resources existed, and it had been expected that those sources of information would be needed to confirm the field records. The only change in plan was that ATRC was obligated to rely on regional, not local, records to put together a complete overview of the winter season and the project snowplow activities.

Supplemental Data Resources

Because many of the shift activity reports were not always consistently completed and turned in, ATRC then resorted to the statewide central maintenance reporting system called PECOS. It was determined that the snowplow operators always filled out their vehicle logbooks and the maintenance record worksheets before going home from even the most arduous shift, but often the ATRC shift reports would be deferred and/or eventually lost.

Fortunately, ADOT's PECOS system captures the key maintenance activity information for each shift, including the operators' names, work shift hours, odometer readings, routes patrolled, and any noteworthy system problems. PECOS is sorted by activity code, and for snowplowing there are only a few key categories to be reviewed. These various task codes include plowing snow, applying abrasives or deicers, winter storm patrol, storm and rock patrol, and spot ice control. PECOS records also list manhours, equipment hours, materials quantities, and distance traveled.

ATRC found that once given on-line access to the PECOS logs, all records for specific activities and routes could be searched, identified and printed for review. Where gaps or overlaps were found in reviewing these records, the drivers' handwritten data entry sheets were also stored at the Orgs and could be crosschecked for specific dates.

This information filled many of the data gaps from the activity reports; it identified all days of plowing activity, and summarized the miles when the on-board systems were potentially in use. However, there were some areas of data that required follow-up, for example, the system reports did not isolate miles driven and other performance data for the project snowplows from the other trucks active on the same route during a storm shift.

The ATRC retrieved and reviewed all PECOS electronic work records for each project plow vehicle, but it was still necessary to visit each of the maintenance camps to review their hand-written records. This was also an opportunity to interview drivers and supervisors about their experiences over the winter.

A further information gap in the shift reports was the winter storm history, but with in-depth TAC support from the National Weather Service (NWS), this information also could be recovered. The ATRC met with NWS staff to identify the weather recording station that was most relevant to each of the seven project plow routes, and those observation records were copied from the regional office files at Bellemont, Arizona, near Flagstaff. As a result, ATRC was able to match the NWS winter storm date and snowfall records with the PECOS plowing activity records, working forward from the commissioning date for each of the seven project snowplows.

The results of these ATRC data recovery efforts are included in Appendixes A, B, C, and D, and the relevant storm history information is referenced throughout this report.

XI. ON-BOARD SYSTEMS: 2002-03 OPERATIONS

REAL-WORLD TESTING

The fundamental ATRC research approach described in the previous section called for the two driver-warning concepts to be deployed in the field as off-the-shelf aftermarket enhancements for the snowplowing environment. Both were relatively simple and durable systems that were available on the open market for commercial transport fleet use. The suitability of collision warning radar and of infrared night vision for snowplowing activities could only be established by a real-world field testing program.

Figure 23. XVision Snowplow F235 Refuels at Little Antelope Camp

The ADOT-ATRC evaluation program depended on achieving maximum exposure for as many snowplow operators as possible, during an entire winter in the high country of northern Arizona. The key features, baseline performance, and safety benefits of the two systems had been demonstrated, and were clear to all involved, but the systems' abilities and reliability had yet to be proven in Arizona's severe winter storms. This could only be done through the long-term deployment of the two warning systems in the hands of experienced ADOT operators, on the most challenging snow plow routes in each district.

Group familiarization, training and evaluation surveys had been practical in earlier winters for the Caltrans and 3M infrastructure-based guidance systems. This was not practical for the Year Five evaluation of on-board systems, due to the wide dispersal of the project plows and to the minimal level of orientation and training needed for driver-assistance systems in general.

As noted earlier, the CWS and IR systems did, in fact, require varying levels of warning display interpretation, and both therefore required some orientation, if not formal training. This was done at the Org level, with materials supplied by the vendors and ATRC, and for the primary operators it was generally effective. As a result, these units could be deployed as they came on line, and they were put into operation as the storm season required. In most cases, at least some familiarization runs were made by the drivers before the first use of the systems in winter storms.

Operational Usage

As was indicated in previous sections, the seven warning on-board systems deployed by ADOT across northern Arizona were given a thorough operational field trial, despite a below-average winter snowfall total. While the test units in some cases were not installed until January or even early February, the systems were in operation during snowplowing activities on 140 use-days of the winter, as summarized from the PECOS records in Table 7.

Table 7. Phase Three Activity Summary for Seven Research Snowplows

Intelligent Vehicles / Snowplow Guidance Research								
Project 473 Winter 2002 – 2003								
PLOW DATA	**F277**	**F326**	**F235**	**F342**	**F291**	**F340**	**F269**	**Sum**
MAINT ORG	Kingman	Seligman	Ltl Antelope	Gray Mtn	Flagstaff	Winslow	Chambers	
PECOS Reports	*12*	*13*	*72*	*61*	*33*	*40*	*16*	*247*
System	XVision	Radar	XVision	Radar	Radar	XVision	Radar	
Primary Route	I-40	I-40	I - 17	US 89	I-40	SR 87	I-40	
Mileposts	54 – 72	121–146	335-340	420-440	185-230	317-290	347-360	
Installed	03-Dec-02	22-Jan-03	07-Feb-02	21-Sep-01	14-Jan-03	03-Dec-02	04-Feb-03	
Plowing Activity Days & Miles Summary								
Total Miles	1,729	1,830	10,871	8,484	4,452	6,863	3,021	37,250
Total Use-Days	6	10	39	32	20	22	11	140

The total number of days of plowing activity usage, and the more than 37,000 miles driven with the warning systems in service, are very significant. The average utilization of the seven project snowplows was approximately 5,300 miles of operations. This activity reflects a season of tests involving some 15 primary operators, and perhaps a dozen more occasional drivers.

The field supervisors and the supporting shop technicians also gained significant experience and awareness of the two on-board warning technologies. For ADOT forces in northern Arizona, this degree of exposure to new concepts provided a positive preview of future vehicle enhancements for driver safety, even though not every expectation was met in the brief season of testing.

DEPLOYMENT PLAN CONCERNS

There were a certain number of issues that arose through the winter with regard to the project's system deployment and evaluation plan as formulated by ATRC and the research TAC. Some of these issues were beyond human control, such as the weather across northern Arizona. Others were in the hands of remote third parties, as some of the "off-the-shelf" commercial units were not available in a timely manner for a consistent rollout at the beginning of the 2002-03 winter. The ADOT procurement process, which involves both procedural and human factors, also impacted the orderly and timely execution of the deployment plan.

The incremental deployment of the units across the region had some impact on how consistently each group of drivers would be introduced to the system on their snowplow. In each case, the assignments of the warning systems were based on the typical visibility conditions encountered on the plow route, and on the type of truck and the experience level of the drivers assigned there.

The snowplow operators were the key individuals for the ADOT evaluation process, and their buy-in was essential. However, even if all of the other selection factors were in harmony, not every driver welcomed the opportunity for testing.

Even with seven snowplows in the field, the operator pool for the evaluation was very small. Generally each plow on a given route had two primary drivers assigned to it, with perhaps one or two others on a backup list. Because of the wide range of factors among operators as to their experience, training, age and attitude, the opinions and interest levels varied between the Orgs, and even in the cabs of individual plow trucks. In a few cases the day and night drivers were polar opposites in their attitudes toward the night vision or the radar.

Driver acceptance of each new system varied. Some saw the systems as ideal solutions to their low-visibility operating problem, but others felt that their attention was already overloaded with plow controls, instruments, radios, warning signals, and other distractions. The snowplow route location, traffic, terrain, weather, as well as personal attitude and level of confidence, all were factors in driver willingness to use the warning systems and to balance their safety advantages with their limitations. Some drivers already had concerns about the sensory overload in the crowded, noisy cab of a snowplow operating in near-zero visibility storms and heavy traffic.

For a few of the operators, the system performance was not consistent enough to trust it fully, and any doubt about the meaning or the urgency of the warning message was seen as a negative factor. This was true for the CWS radar, which required the driver to react quickly to the alarms and warning light display. The EVT-300 was prone to false warnings in specific situations such as bridge structures or roadside signs. It was also true for the infrared system, where the snow buildup on the camera lens caused fading of the screen image, which effectively reduced the XVision's warning functionality. In this case, the problem caused driver satisfaction ratings to drop significantly over the winter.

Operator acceptance of the two on-board systems was measured by ATRC in a series of surveys over the season. The drivers' views on their systems are discussed in the following section of this report, and the end-of-season survey results are included as Appendixes G and H.

XVision – Operational Issues

Based on the initial XVision installation on F235 at Little Antelope in February 2002, and the TAC stakeholder demonstration that followed in May, outlooks were positive and expectations were high for the coming winter. Over the summer, minor concerns arose in occasional night operations with plow F235 that became larger issues when the 2002-03 winter began and all three units were in operation.

Early comments on the XVision system were positive from all three districts. Drivers regularly reported sightings of animals, pedestrians, and even birds along the roadway, long before the headlights illuminated them, but reports were mixed with regard to rain, fog, and light snow. As noted previously, Bendix had initially warned that these factors would reduce the contrast and clarity of the thermal image as read by the infrared camera. But as operations progressed into the storm season, a basic concern with the system's winter performance began to grow.

A key challenge for winter applications is the system for lens heating to prevent snow buildup from obscuring the camera's view. Although tested extensively in the Bendix labs and in Canada, the heater was found to be vulnerable to extreme cold and wind chill factors.

As noted by Bendix in project planning discussions, passive-infrared is not specifically designed for continual service in high moisture conditions like snowplow vehicles can and do experience. The Bendix lens heater is a significant improvement but clearly is still not enough to overcome all the moisture scenarios that plow trucks encounter.

Figure 24. Freeze, Thaw, and Refreeze: the Camera Window Heating Element

The primary problem had to do with the lens heater element, as the single biggest complaint was snow being packed into the lens of the camera. While the drivers expected to clean the infrared camera whenever they stopped to clean their wipers and lights, they also expected the heater to be effective. On some plow routes there were few opportunities to pull off safely to clean the IR camera – which was masked by snow more rapidly than the driving lights and wiper blades.

With regard to the heater performance, the two new off-the-shelf XVision units did not seem to have problems as frequently as did the F235 prototype, for which Bendix exchanged several heating elements over the winter season. On occasion the lens temperature was measured at over 110 degrees (F), but at other times the drivers said it simply would not heat up to the touch. As shown in Figure 24, the heater did melt snow that built up within the recessed lens barrel, but it was unable to keep up with rapid accumulations. This picture also shows the threat of ice buildup to the exposed camera wiring.

The source of the problem was not identified, but it may have been the calibration of individual thermostats or the capacity of the heating element. The larger issue was the combination of cold, moisture and wind effects, which were more than the heater unit could effectively deal with. Driving into the wind in an oncoming storm aggravated the problem, and driving with the wind reduced it somewhat. The moisture level of the snow and the wind speed and direction were other significant factors. Slush spray from the plow blade was also a key problem area.

Other issues with the system were also generally related to the design of the camera window and lens barrel assembly. As Figures 19 and 24 show, the lens window is recessed, which creates a pocket for snow to quickly accumulate. Road film may also accumulate there; Figure 19 shows a gradual buildup of deicing chemical on the silicon disk of the lens window. The focal length of the XVision camera is approximately 80 feet, so dirt and bug parts do not block the image, but the lens pocket design seems to collect airborne material. ADOT drivers also reported problems in the rain; they experimented with commercial dispersant products but saw little improvement.

While the XVision camera mounting design seems exposed to damage, it is basically designed to be used by over-the-road transport tractors and so would usually be mounted within a cab fairing. Nonetheless, the lens itself has an exposure problem. Bendix worked with its contractors and was able to provide several shield options for truck cab rooftop applications, and ADOT selected one shield design, installed in January, for all three of the project snowplows (Figure 21).

As noted before, XVision was designed and tested by Bendix as an all-weather system but was not conceived specifically for severe storm use. It must be emphasized that while Bendix was never in a position to modify the basic design based on Arizona service observations, they have continually offered new approaches to solve perceived problems in the field. This support has included several replacement lens heater elements, the provision of camera shields, and the upgrading of F235's HUD with the new production LCD screen. There was frequent technical collaboration on display mounting hardware and on lens cleaning materials and techniques, and ADOT and Bendix continue to evaluate new approaches to the remaining issues.

EVT-300 – Operational Issues

The Eaton VORAD collision warning radar did not suffer from the snow-related problems that frustrated drivers of XVision-equipped snowplows during this Year Five winter of the project. On the other hand, the confidence issues discussed earlier were a concern for the EVT-300 test program. The level of familiarization and driver focus required to successfully utilize the CWS warnings in poor visibility was significantly greater than for the infrared display screen. This led some drivers to doubt and even to ignore the warnings; a few avoided using the system at all.

The training material for the EVT-300 system spelled out a number of key concerns, primarily in regard to the potential for false alarms or missed warnings. The system's narrow radar beam and its cutoff of warnings outside the predicted vehicle path provided sensitivity and accuracy only within that critical warning zone, and operators therefore had more confidence in the EVT-300 when it sounded an alert. However, some drivers, especially alternates, were unable to adjust to learning the predictable gaps in radar beam coverage for areas of hills, dips and curves. Nor were they comfortable with the predictable false warnings from overpasses, signs, and roadside features. The blind spot radar, while very popular, was also for a few drivers just one more source of uncertainty in stressful conditions and limited visibility.

There were a number of concerns about how well the Doppler radar would respond to specific targets ahead, such as animals or people, especially after a December 2002 incident when a tractor-trailer rig killed ten elk on I-17 just south of Flagstaff. Eaton and ATRC provided clarifications that the radar response to objects depends on body mass, metal content, position, and movement. For animals running across the 12-foot lane, the response window was too brief for the CWS, or even the human eye, to give a consistent warning.

Another significant driver concern was stationary objects in the roadway. Because of the warming system parameters, the EVT-300 is designed to respond immediately to a stationary object within a range of 220 feet. Considering the travel speed of the host vehicle, and the need to identify the target visually, Eaton's training material recommends reacting immediately to the characteristic double-tone warning for a stationary or very slow-moving vehicle, which would always be a dangerous situation. Reaction time is critical, even at slower snowplowing speeds.

The driving challenges, distractions, and stress factors varied on each plow route and for each individual. A few of the snowplow operators could not fully adjust to using the CWS concept under stressful low visibility conditions. Other crews with more experience using the EVT-300, such as snowplow F235 at Gray Mountain, were comfortable with the radar system and were willing to rely on it more.

SUMMARY OF 2002-03 OPERATIONS

The seven project snowplows accumulated 140 days of winter maintenance operations, and more than 37,000 miles of operational service in the Phase Three 2002-03 winter evaluation program. In this phase, at least two dozen snowplow operators and numerous support personnel received varying degrees of exposure to infrared night vision and collision warning radar.

As described in the preceding discussions of operational issues, individual driver preferences were significant in the evaluations of both the radar and the night vision warning systems. Sometimes two back-to-back primary operators on a snowplow were in complete disagreement. The judgments of the local Org supervisors and superintendents, based on all of their drivers' comments, may ultimately be the districts' primary decision basis for any further applications of these on-board warning systems.

It is noteworthy that while the I-40 Corridor received only about 55 inches of snow in the season, each of the test snowplows still was out on the road for an average of approximately 5,300 miles of operations. If all seven test units had been commissioned in October before the first storm, the research fleet would potentially have had 49 combined months of plowing activity; their actual combined activity total was roughly 33 months.

Projecting these on-the-road utilization figures to an "average winter," the normal combination of 100-plus inches of snowfall and full availability for the seven research snowplows could be expected to result in well over 100,000 miles of field service for the project's two commercial on-board warning system concepts.

XII. ON-BOARD SYSTEMS: ATRC RESEARCH ACTIVITY

PROJECT DATA COLLECTION

As described in Chapter X, the collection of research data for the on-board system evaluation in Year Five presented new challenges for the ATRC. There was no longer a third-party evaluation support consultant, since NAU had completed their workscope in the previous winter. With the seven test snowplows dispersed across northern Arizona, all of the field activity would take place in the truck cabs during the long season of patrolling and plowing the highways. These two accessory warning systems had no performance recording features, and the snowplow operators were responsible for observing, interpreting and reporting of operational activity and storm condition information.

The ATRC staff developed a variety of data collection methods and resources for the 2002-03 winter that were intended to not be too burdensome, requiring minimal extra effort from the real evaluation team, the 14 primary snowplow operators.

Operators' Shift Activity Reports

The most fundamental project reporting tool was ATRC's Shift Activity Report (Appendix E), which each driver was asked to complete after his 12-hour plowing shift was over. This form required mostly circles and check marks to record the conditions, with just a few key handwritten entries for date, name, Org, truck mileage and any warning-system concerns.

The overall response from the Orgs on ATRC's shift reports was quite poor, as they were the last piece of paperwork after all the other internal PECOS maintenance and vehicle logbook reports were filled out. Several Orgs submitted ATRC activity reports for up to 50 percent of the plow shifts recorded in the PECOS system, while one Org returned none. The return rate from the field was only 25 percent overall, but those reports provided valuable information on specific storm conditions that could be correlated to the storm data from the National Weather Service.

PECOS Maintenance Records

Fortunately, the proprietary PECOS data system, as the primary management tool for ADOT's entire winter maintenance program, was accessible to ATRC to document the full extent of the winter's snow-control activities. As discussed previously in Chapter X, this internal resource provided on-line verification of all shifts, full or partial, when any of the project snowplows were used on the roadway in winter maintenance activities. The various PECOS task codes include plowing snow, applying abrasives or deicers, winter storm patrol, storm debris and rock patrol, and spot ice control.

PECOS records also list manhours, equipment hours, materials quantities and distance traveled. Where gaps or overlaps were found in reviewing these records, the drivers' handwritten data entry sheets, which are also kept on file at the Orgs, were crosschecked for those specific dates. By searching the PECOS system records, ATRC staff were able to recover the key operational data that was needed to accurately document the utilization of all seven research snowplows for the Year Five winter.

PECOS records did not make ATRC's Shift Activity Reports redundant, as those forms included a variety of other significant observations on plowing activities, and on the roadway and weather conditions. The shift reports often captured driver comments, good or bad, which did not warrant filling out one of ATRC's Incident Reports. Driver comments frequently described how well or poorly the system was functioning in poor weather conditions including light and heavy fog, rain, and snow. Drivers also commented on having to stop to clean the camera lens or radar antenna. These comments were by far the most frequent, and one driver reported cleaning the night vision camera lens 18 times while plowing.

Driver Incident Reports

The second primary information resource that was provided to the project snowplow drivers was the ATRC Incident Report (Appendix F). These critical-event forms were requested initially by Bendix to collect real-word ADOT driver feedback, in order to refine their newly-introduced XVision system design and its marketing approach. Because of the relevance of the report for the ATRC's side-by-side evaluation of the two on-board warning systems, the form was also adapted for those plow drivers using the EVT-300 radar system.

The incident report form was provided to document any special situations where the on-board system did or did not perform as expected to help the driver respond to any roadway event. These reports were not limited to snowplowing, and especially in the case of the radar, feedback was requested for any unusual warning event in traffic. *The instructions to the drivers stated:*

"Incident" reports may be either positive or negative. They include:

- A warning of any object, stopped vehicle, person, or animal in the roadway.
- A warning you are rapidly overtaking a vehicle that you can't clearly see.
- Any observations of the road surface or other conditions affecting plowing.
- Any activity when you were able to plow more quickly, more precisely, or with fewer stops, due to visibility assistance information from the system.
- Any incident or situation when the system did not give accurate warnings.
- Any incident or situation when the system did not give any warnings.
- False warnings under specific weather or visibility conditions.
- Any other incident-specific safety or operational problems.
- Any other incident specific benefits to your safety and plowing efficiency.

Unfortunately, only a handful of these reports were submitted to ATRC during the relatively mild 2002-03 winter season. For the radar-equipped snowplows, only four "events" were reported on these forms. However, four other events were recorded on the shift activity reports. One of the four Orgs with CWS radar did not submit any reports – event or activity - over the entire winter.

Event reports on the night vision systems were slightly more complete, with ten events recorded. The operators' activity reports for XVision did not report any additional incidents. Comments on both systems as reported by the operators for events or incidents are summarized in Appendix F, together with similar comments that were sometimes recorded on the shift activity reports.

OPERATOR SURVEY RESULTS

The ATRC research plan called for periodic driver surveys through the winter, as the operators gained experience, and as the reliability of the two systems became more apparent with time.

This plan was successful despite the relatively mild winter season, and despite delays in the commissioning of several of the test snowplows.

As noted earlier, the three night vision systems were all operational by early December. The plow operators took the XVision survey three times, from pre-season to post-season, in December, February, and May. The potential time window of experience was shorter for the four EVT-300 CWS radar-equipped snowplows. In this case, only two surveys were conducted, first at mid-season and again in May, after the end of the winter.

The survey format utilized an opinion scale as to the basic plowing safety and efficiency factors of the warning systems, such as the driver's safety level, fatigue effects, and driving ability. The trends reported in the surveys reflect the overall level of satisfaction with each concept, and the level of confidence in the system as a benefit, rather than a burden, to the driver in a storm.

Both driver surveys were standardized to the greatest extent possible, but they did address the unique elements of each system. The final end-of-season surveys for both systems had an additional open-ended comments section, and the operators were asked for feedback on the potential for their warning systems to be deployed more widely in the future within ADOT. Driver responses to these surveys were generally complete and well expressed.

The complete summaries of the ATRC driver evaluation surveys are included as Appendix G for the radar system, and Appendix H for the night vision. A key aspect of these results, as noted above, is the comparison of comments and preferences from the beginning to the ending phase of the Year Five evaluation effort. In each Appendix, the rankings and the comments from the multiple iterations of the survey are listed together, to show how the drivers' opinions may have changed over the winter.

It should be observed that the very small pool of snowplow operators for each system allows for effective follow-up on individual comments, but it also allows extreme opinions at either end of the scale to stand out prominently. The ATRC, and the reader, must look within the summaries for the best overall sense of the operators' perspectives on each system being evaluated.

Collision Warning Radar Surveys (Appendix G)

For the radar system, most opinions (Part 1) did not change significantly over the winter; the initial impressions and driver expectations seemed to generally have stayed at about the same level through the season. There was some definite improvement shown as to effects on driver fatigue and distraction with the EVT-300 in use.

In Part 2 of the survey, the drivers commented on specific likes and dislikes about the system. As detailed in the Appendix, the forward warnings and the simplicity and reliability of the CWS system earned positive comments, but most drivers singled out the blind spot radar as the best feature. As to dislikes, false alarms at bridges and missed warnings were most significant for reducing confidence in the system. The display unit's mounting position was also criticized.

Open-ended questions made up Part 3 of the survey, and they dealt primarily with fatigue, range, warning preferences, and general advantages or disadvantages. Comments varied on the fatigue factors, but the system range and warning modes seemed to satisfy most of the drivers. A telling comment by one driver at season's end was that he "still had to use my own skills to do my job."

The post-season survey contained an added fourth section which asked the snowplow operators for their overall recommendations on the EVT-300 radar system. This is an area where many of the comments were well expressed and insightful; the drivers as a group put careful thought into their survey responses.

The first question in Part 4 of the final survey dealt with radar performance in a range of storm conditions. As shown in Appendix G, the operators generally indicated that the EVT-300 was effective in fog, rain, and light snow. As to heavy snow or whiteout conditions, most drivers responded that it worked well as long as snow did not build up heavily on the antenna.

The second question was especially crucial; it dealt with the usefulness of CWS radar for ADOT in any other non-plowing situations. The question was: “Is the system useful for you in any other operations apart from night plowing?” The drivers’ responses were:

- Useful in daytime driving and warns when you are coming upon a slow-moving vehicle.
- No, snow plowing is the only operation that the system is useful (three “no” replies).
- It works just as well when driving in heavy traffic.
- Works great for the passenger-side blind spot.
- City driving during snow, it helps with cars pulling in front of you.

Other questions dealt with whether other drivers had driven the test plow over the winter and their reactions, and, more significantly, whether other plow routes in their Org would benefit from the CWS radar. As to any additional routes, the Orgs on I-40 replied in the affirmative – except for Flagstaff.

The final Eaton VORAD radar survey question was perhaps the most significant. The question was: “Based on your experience with this research project, should ADOT purchase more of these systems for those snowplow routes where impaired visibility is a frequent and serious problem?” The various drivers’ responses are listed below:

- I think ADOT should put the systems in all snowplow trucks.
- ADOT should purchase additional systems where severe storms occur. The other additional places that might need this system are where there are high volume traffic areas.
- This product is very useful for over-the-road trucks. A plow truck has too many things in the way.
- The VORAD system would work better if used for summer driving.
- If it snowed more it would be useful but visibility (this season) has always been good.
- Yes, this system works without being too intrusive.
- Yes.
- No (two replies).

As can be seen from the various responses above, most of the ADOT plow operators found the EVT-300 to be a reliable and effective system overall, with four radar-equipped snowplows on the road for at least half of the 2002-03 winter season. The opinions expressed indicate a fairly high level of acceptance, tempered primarily by concerns over false and missed warnings. The project team’s perspective is that further experience in winter storm conditions, along with consistent training and familiarization for the primary drivers, would further improve the driver satisfaction levels. It would also increase the overall acceptance of collision warning radar for both snowplowing and other fleet operations.

Infrared Night Vision Surveys (Appendix H)

The Bendix XVision snowplow operators also participated in satisfaction surveys during the 2002-03 winter. As all three systems were operational by early December, three surveys were conducted at two-month intervals with drivers of the night vision research plows, in December, February, and May. Only six primary snowplow drivers took the surveys. There were a certain number of gaps in the responses to the three surveys over the winter, which should be considered as a factor in any future planning based on the responses described below.

For the XVision survey, several opinions in Part 1 did change significantly over the winter. Because of ongoing problems with lens cleaning, the mid-winter ratings dipped lower in most cases, but at the end of the season, some ratings for the entire winter rose slightly. A question on whether driving ability was improved by XVision went progressively from "agree" to "disagree" and finally to "neutral" in May. Responses on image quality, fatigue, and distraction all went down by one level from mid-season on. A key question, whether XVision significantly improved safety on the road, fell two steps from "strongly agree" to "neutral" from mid-season on.

In Part 2 of the survey, the drivers commented on specific likes and dislikes about the system. As detailed in the Appendix, the season summary of "likes" was focused on better vision in most nighttime conditions. As to "dislikes," every negative comment was about the extent of loss of vision in snow and rain.

Responses to the open-ended questions in Part 3 of the survey were mixed. There was consensus among the drivers that fatigue was not an issue and that the design elements of range and display characteristics were completely satisfactory. The miscellaneous comments in Part 3 were almost all negative, dealing with the heating and cleaning issues of snow and moisture on the lens.

An additional fourth section of the year-end night vision survey asked the plow operators for their overall recommendations on the Bendix XVision system. This is an area where many of the comments showed frustration, as expected, but most of the drivers provided insightful responses.

The first question in Part 4 dealt with night vision performance in a range of storm conditions. As shown in the comment summary in Appendix H, there was a general driver consensus that the XVision system was effective in fog and light snow. However, it was less useful in rain, and the results were inconclusive in heavy or wet snow, due in part to the scarcity of severe snowstorms and whiteout conditions in the 2002-03 winter (perceptions of "heavy snow" also varied by site).

The second question was significant with regard to the potential uses of night vision systems for ADOT in any other non-plowing situations. Based on their occasional non-plowing use of the XVision system, thermal imaging seemed to offer improved vision to the drivers in more general conditions. In answer to the question: "Is the system useful for you in any other operations apart from night plowing?" the drivers' responses were:

- You are able to see more what's on the shoulder and road, which I think makes it more safe.
- No.
- Daytime too, could see roadway better and objects clearer.
- All day.

Other questions dealt with whether other drivers had driven the test plow over the winter and their reactions, and, more significantly, whether other plow routes in their Org would benefit from the night vision system. As to use on other highways, Kingman suggested two other plow routes, while Winslow suggested more tests on Interstate 40 before making a recommendation.

The final Bendix XVision survey question was perhaps the most significant. The question was "Based on your experience with this research project, should ADOT purchase more of these systems for those snowplow routes where impaired visibility is a frequent and serious problem?" The six plow operators' responses are listed below:

- No (two replies plus one blank).
- Yes I do!!!!!!
- Yes – useful in winter weather.
- Sure!

As can be seen from the various responses above, ADOT snowplow operators found the Bendix XVision system to be very effective in many conditions, based on testing with three plow trucks through the entire 2002-03 winter season. However, the technology was not effective in the winter storm conditions for which it was being evaluated. The XVision system's performance in heavy snow and rain was not just reduced, but in almost all cases reported, was eliminated.

This survey's results are no surprise, coming from frustrated drivers who had to stop 10 to 15 times in a shift to clean out the camera lens. The ATRC and the project's TAC recognize that while further experience in winter storm conditions is desired, solutions must be found to enable the XVision system to perform effectively in snow. Only by solving this problem can the Bendix system gain acceptance from ADOT for winter maintenance as well as other fleet operations.

Other Project Records – Weather Data

The ATRC had to make a considerable effort to develop background information for Year Five of the project, in particular to effectively reference the various snowplowing activity reports with the weather records for the winter. To assess the evaluation efforts, the severity of the winter, and the performance of the project snowplows, complete summaries of the season's storms were required. With the Bellemont National Weather Service station represented on the project TAC, it was relatively simple for ATRC to obtain storm records for 2002-03 from the NWS archives.

Table 8. NWS Weather Observation Stations for Project Plow Routes

Snowplow Evaluation Routes – Weather Records				
ADOT Maint Yard	**Route**	**NWS Weather Site**	**At Hwy Milepost**	**02-03 Snowfall**
Kingman	I-40	Diamond M Ranch	91	12.7*
Seligman	I-40	Seligman	121	6.4
Little Antelope	I-17	Flagstaff Pulliam Airport	337	54.9
Gray Mountain	US 89	Sunset Crater	430	27.5
Flagstaff	I-40	Walnut Canyon	204	35.4
Winslow	SR 87	Blue Ridge	300	39.0*
Chambers	I-40	Sanders Port of Entry	339	0.0
Source: National Weather Service (NWS) Records				** Incomplete Data*

There were some complications to this process. ATRC and NWS collaborated on defining the most appropriate weather observation station for each snowplow route. The selected routes and weather sites are listed in Table 8. All of northern Arizona except Kingman is in the Bellemont-NWS area of operations. For Kingman, the weather records had to be sourced from Las Vegas.

The National Weather Service provided ATRC with eight months of weather observations for the seven project test sites. The NWS records are generally kept by local observers, at hundreds of locations scattered across the state. A standard Form B-91, Record of River and Climatological Observations, provides a wealth of information in the hands of conscientious observers, although some records occasionally were incomplete, and some datasets were more detailed than others.

Appendix B shows the NWS weather records of 2002-03 winter storms for the ATRC's project sites across northern Arizona. Unfortunately two sites have data gaps, which are denoted in the tables. One site record sheet was lost for December, a month with significant snowfall across the I-40 corridor. One other site, at Blue Ridge, generally did not record snowfall on weekends, and they also did not record data on several occasions when power was out. Apart from these gaps, the weather records provided a complete picture of the snowfall for the winter. These figures are tabulated in Appendix D, which correlates the extent of research snowplow operational activity relative to each area's snowfall totals.

Other Project Records – Crash Data

One other research area of real significance to the program is the history of winter storm-related crashes and their costs. The information presented in Chapter III of this report was assembled from key resources within ADOT, and represents the history of accidents and their human and financial costs. The primary resource is the 2002 annual edition of ADOT's *Motor Vehicle Crash Facts for Arizona*[(4)] from the Traffic Engineering Group's Traffic Records Section.

The 2002 annual report and several previous editions provided the primary statistics on crashes, including the lives lost and the injuries from crashes in winter roadway conditions in Arizona. These reports also provide the annually adjusted National Safety Council crash cost estimating figures, which are used to assess the economic impacts of these losses.

ADOT's Equipment Services and Risk Management sections provided other records on the costs to ADOT of snowplow repairs. These summaries of accidents and repair totals were utilized in Chapter III of this report also. As noted therein, the figures are not necessarily complete at the present time, due to unresolved claims and to delays in the distribution of internal charges.

It should be noted that during the five winters of this advanced snowplow field research, there have been no accidents involving the research snowplows during any project activities.

XIII. DEFERRED RESEARCH TASKS: RESOLUTIONS

OTHER GOALS: SMARTCRUISE BY EATON VORAD

As described earlier in Chapters VI and VII, one of the key elements of the EVT-300 collision warning radar system is its SmartCruise adaptive cruise-control feature. From the beginning, ADOT and ATRC intended to evaluate SmartCruise as a key element of the total radar-based driver safety package offered by Eaton VORAD.

ATRC's series of project reports have already discussed the various issues involved with the use of the CWS system, which required a rooftop mounting position for the antenna because of the height of the standard ADOT snowplow blade. The SmartCruise feature could not be tested during the previous or current winters of the project because the rooftop antenna and the plow blade prevent the use of the system as designed by Eaton VORAD.

The F342 snowplow from Gray Mountain was the original dedicated ADOT-3M-Eaton research vehicle, and logic and practicality dictated that SmartCruise be tested on this truck. This 1999 Mack was delivered with the factory cruise control system, so that the EVT-300 could be adapted to it. However, a variety of SmartCruise implementation issues arose with regard to the type of engine computer and the installed version of Mack's engine control software. The problems were ultimately worked out with close support from Eaton VORAD, Mack Truck, and both Flagstaff and Central ADOT Equipment Services, although it took considerable time to do so.

The first hands-on upgrades to F342 began in late December, but engine computer and diagnostic issues were immediate obstacles. Diagnostic issues and procedural concerns delayed the process further. The SmartCruise was fully commissioned in March 2003, with driver instruction and familiarization as the first step, followed by system testing.

SmartCruise Summer Evaluation Plan

With SmartCruise finally installed as part of the F342 CWS radar system, there were operational issues that precluded immediate training and testing. As the late winter progressed in northern Arizona, snowplowing activity continued through April, and basic roadway maintenance efforts were the initial focus at the Orgs after the plow blades were removed and stored for the summer.

The Gray Mountain plow operators were introduced to the SmartCruise functions in March when the feature was commissioned. They were asked to test it as opportunities arose during the early summer agenda of roadway maintenance operations in the area. With guidance from the project TAC, ATRC coordinated with Gray Mountain to conduct road tests of the system in mid-July.

The ATRC test plan involved both objective and subjective evaluations. The primary goals were to road-test the SmartCruise adaptive cruise control system in highway traffic, and to attempt to measure the consistency and accuracy of its performance. Although the EVT-300 system would monitor its own performance internally, checks on validity of the indicated performance figures were required. ATRC staff would ride with the plow operator for a series of test runs, taking measurements and recording observations. On a second level, the driver feedback and passenger observations would be documented.

ATRC developed a set of criteria to measure and monitor the SmartCruise system performance. The four primary objective criteria were:

- Preset speed control – accuracy.
- Following distance – consistency.
- Following distance – accuracy.
- Effect of vehicle sizes on following performance.

The subjective evaluation would involve a variety of observations on performance, as follows:

- Smoothness – engagement and disengagement.
- Positive driver overrides – brake & accelerator.
- Operation in curves.
- Operation on grades.
- False warnings from roadside objects.
- Response to vehicles suddenly cutting in (consistent & appropriate).
- Effect of vehicle size on system response when cutting in.
- Effects of inclement weather – dust, fog, rain, snow, mud, heat, cold.
- Warnings – type and intensity.
- Operator confidence level.
- Operator fatigue factors.
- Overall satisfaction – suitability for driving tasks.

With cooperation from the Flagstaff Equipment Shop and the Gray Mountain Org, the ATRC's SmartCruise evaluation was conducted on July 17. The test plan was to initially calibrate all of the EVT-300 system elements at the shop, and then to take the snowplow out on Interstate 40.

ATRC staff received valuable support from TAC members for the tests, including the Flagstaff District of the DPS, which provided a Stalker speed radar gun to verify both the snowplow and target vehicle travel speeds. ATRC obtained a Bushnell Lytespeed 400 Infrared rangefinder from ADOT Natural Resources to confirm the target distances.

The Flagstaff Shop provided its ProLink portable diagnostic system as the primary in-cab tool to display real-time SmartCruise performance data from the EVT-300's onboard computer. The hand-held systems provided crucial backup data when the ProLink unit failed during the testing.

SmartCruise Testing Results

After confirming system functionality, F342 made several round trips on a 25-mile stretch of I-40 east of Flagstaff, between Walnut Canyon and Two Guns. This section gradually rises in elevation, with a series of long grades in rolling hills as I-40 climbs west towards Flagstaff.

During multiple runs in both directions, the snowplow was run on its Mack cruise control system at speeds of 55 to 65 miles per hour, and the SmartCruise was tested both by overtaking and then tracking slower vehicles, and by "locking on" to faster vehicles that passed. A series of four test runs were made, during which several targets were acquired and followed for five to ten miles.

The ATRC used the ProLink display to record the EVT-300's speed and distance measurements, and also confirmed them with the hand-held radar gun and rangefinder. This was eminently successful in two ways; on initial runs the two sources of data provided nearly identical readings. After two runs, when the ProLink failed, the tests were therefore able to continue using the hand-held units with a high degree of confidence.

Overall, both the objective and subjective results were considered to be a complete success by the plow operator, by the Flagstaff Shop and by ATRC. The ProLink diagnostic tool showed that while the EVT-300 might register a brief target loss when entering a curve, as expected, the SmartCruise held smoothly to the acquired target. There were no problems with false warnings of roadside objects on the Interstate. The system also worked very well on both upgrades and downgrades. Speed changes occurred while following vehicles on hills, but the following distance remained consistent while the target vehicle changed its speed. There was no observed problem regarding vehicle size, as several vehicles were tracked with equal results.

Figure 25. SmartCruise Antenna and Hand-Held Test Equipment

As noted above, the evaluation included four test runs during which SmartCruise tracked target vehicles of varying sizes, types and speeds. In each situation, the four primary objective criteria were met, as described below.

- Preset speed control – accuracy: The Mack cruise control was effective in holding speeds within 1 mph, with a slight variation on grades. Plow F342, with a manual transmission, was able to hold speed accurately on its factory cruise control. There was no apparent loss of accuracy with the VORAD SmartCruise engaged to acquire and follow a target vehicle.

- Following distance – consistency: Following distance varied from 250 to 310 feet, as based on travel speed and the system's following-time interval setting. Ranges fluctuated by 10 to 15 feet. The system follows at a set separation interval in seconds, based on travel speed. Even in hilly terrain the SmartCruise maintained a fixed following (time and) distance relative to targets.

- Following distance – accuracy: The ProLink speed readings displayed error rates of only +/- 0.2 to 0.5 mph. These rates increased up to +/- 1.5 mph on grades. Range errors displayed were only +/- 15 feet. The ProLink and hand-held figures corresponded very well.

- Effect of vehicle sizes on following performance: No significant issues were identified, and consistent results were observed with several vehicle types. Vehicles tracked included a compact sedan, a compact pickup, and two tractor-trailer rigs – a cargo trailer and a tanker.

Subjective evaluations of SmartCruise were also positive. For the snowplow driver, there were no issues with the system acquiring a target vehicle or disconnecting. Driver overrides also were basically seamless. As a result of the day's test runs, the operator responded positively to most aspects of the system. While he had not previously tried the SmartCruise more than a few times, the test driver said that he was impressed and felt comfortable using it after the day's activities. He also said that it was likely to improve his safety and driving performance on the highway.

Appendix I contains the testing and observation records of the July 17 testing on I-40, and the complete evaluation activity results for the EVT-300 SmartCruise feature as discussed here.

OTHER GOALS – TECHNOLOGY TRANSFER

Figure 26. Gray Mountain and Kingman Plows: ADOT Equipment Roadeo

With the conclusion of the 2002-03 winter season, there was a great deal of interest in the project results, both among TAC members and for other agency partners and stakeholders. With all seven installed systems fully functional and with no snow in the forecasts, the TAC's attention turned to planning for the next winter. This focus also included disseminating more information to interested partners on the concepts and benefits of the two low-cost warning systems.

As recommended by the TAC membership, the ATRC displayed the project's concepts at two significant events in the fall of 2003. The first of these stakeholder outreach events was ADOT's annual Arizona Equipment Partnering Safety Roadeo. This exhibition includes safety training, operator competitions, and equipment displays. The event was held in September at the Arizona State Fairgrounds, and the ATRC participated with a display table and literature.

Two of the project's research snowplows were also exhibited during the Roadeo, as shown in Figure 26. Snowplow F277 was driven down from Kingman to display the XVision system. The second plow was F342 from Gray Mountain, equipped with both the EVT-300 radar and the 3M tape guidance system. ATRC also laid out 80 feet of magnetic tape to illustrate Lane Awareness System concepts to the event visitors.

The statewide Equipment Roadeo was a valuable opportunity to display both on-board systems and to market their advantages to hundreds of maintenance personnel from other ADOT districts around the state, as well as maintenance and equipment services managers in the Phoenix area. Other interested Roadeo visitors included a contingent of transportation department personnel from New Mexico.

Figure 27. Chambers and Winslow Plows: Four Corners Conference

The second significant outreach event was the annual Four Corners Maintenance Conference, held in Cortez, Colorado in early November. The ADOT Holbrook District was the conference host for 2003. As a core partner in this research project, the district provided its two research snowplows for the event. These were F269 from Chambers, with the Eaton VORAD CWS radar system, and F340 from Winslow, with the Bendix night vision system.

About one hundred maintenance personnel attended this event from Colorado, New Mexico, Utah and Arizona. The ATRC project staff made a brief slide presentation, and also assisted the ADOT plow operators with a display table at the outdoor exhibit area.

Both of these well-attended maintenance-oriented events involved operations staff, equipment operators, and senior managers. For the research project and its sponsors, they were both excellent opportunities to display the new warning system concepts, and to showcase Arizona's commitment to improving safety for its snowplow operators and the public.

OTHER GOALS: SURVEY ON LOW-VISIBILITY PLOW ROUTE MILES

One of the project's long-range goals was to develop a consistent estimate of the areas of the state highway system that regularly experience severe visibility problems in winter storms. There are numerous highway corridors in Arizona where visibility frequently is obscured due to blowing and drifting snow in winter, or in fog and heavy rain year-round. Based on terrain, elevation, and prevailing weather patterns, highways in certain areas may be restricted or closed frequently in severe winters. These low-visibility areas are a major challenge for the ADOT snowplow operators, and any road closure in bad weather also creates severe problems both for the public and for public safety agencies.

This research project, guided by the TAC members, first initiated an impaired-visibility survey as part of the effort to determine deployment factors for the costly infrastructure-based Caltrans and 3M snowplow guidance systems. Because of the high cost of the roadway magnetic media, it was clear that only the worst whiteout or low-visibility areas might justify the installation of systems that required embedded roadway materials.

One of the program tasks that were assigned to Northern Arizona University in the project's third winter (2000-01) was to conduct a comprehensive survey of ADOT senior managers as to the potential to deploy the two guidance systems under evaluation at that time. This survey effort addressed winter maintenance problems and perceptions across ADOT management ranks. One of the key goals in that survey was to identify all of the low-visibility and whiteout areas on the state highway system.

The NAU survey effort, while extensively involving the TAC members, was more difficult than expected. The NAU team found that there were several related measurements used by ADOT in winter maintenance planning and budgeting, and local perceptions varied across the state as to what measure was most significant. The research project's definitions of impaired and whiteout visibility levels, as developed by the TAC, were also subject to regional semantic debate.

The districts had different perspectives on the severity and frequency of visibility impairment, and of plowing difficulties. Other local or regional factors were also involved, such as long-term average winter snowfall totals, frequency and severity of storms, types of plowing equipment in use, and the experience level and turnover rate of the local snowplow operator pool.

The NAU project team worked extensively with the TAC, in particular the Flagstaff maintenance staff, but the first survey results were inconclusive, as described in the 2000-01 project report. [2] As a result, the visibility survey was reformatted and the parameters were redefined. It was sent out only to the ADOT District Maintenance Engineers, in order to achieve more consistent results. Despite these and other follow-up efforts by NAU, the project's TAC members found the results of the second survey were still not consistent, as described in the 2001-02 report. [3]

Visibility Survey Resolution

Finally, the ATRC made a third attempt to resolve the survey issue, as the project wound down after completing the on-board system evaluations in the 2002-03 winter. Since NAU was no longer on the project team, the ATRC and the TAC agreed to focus the survey differently. The definitions of whiteout and impaired visibility, however, were not changed. One clarification was that on-board systems will apply to entire snowplow routes, not just to extreme whiteout areas that might extend for only a mile or two, where magnets or 3M tape might be considered.

Each district was surveyed on the basis of milepost distances along route corridors. Because infrastructure cost is not an issue for CWS radar or for night vision, the length of the highway corridors with impaired visibility and the number of plow routes with visibility problems are the key decision factors for possible future deployments. The real issue at the local level would be how many snowplows might need these types of warning systems.

Table 9. Final Results of the Statewide Winter Visibility Survey

ADOT Winter Visibility Survey: Highway Corridor (Milepost) Distances

ADOT Maintenance District	Whiteout Visibility Miles Total[1]	Reduced Visibility Miles Total[1]	Total Extent w/ Impaired Visibility	Total of Plow Route Miles in District	Total of All Highway Miles in District	Impaired Percent of Plow Route Miles	Impaired Percent of All Route Miles
Flagstaff	63	97	160	776	776	21%	21%
Globe	117	179	296	804	919	37%	32%
Holbrook	130	215	345	833	833	41%	41%
Kingman	100	140	240	385	530	62%	45%
Phoenix	6	0	6	20	379	30%	2%
Prescott	146	78	224	387	572	58%	39%
Safford	47	48	95	675	804	14%	12%
Tucson	11	18	29	112	840	26%	3%
Yuma	0	0	0	0	562	0%	0%
State-wide Totals	*620*	*775*	*1,395*	*3,992*	*6,216*	35%	22%

[1] **Whiteout Visibility Conditions**: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

[2] **Reduced Visibility Conditions**: Plows have to slow significantly, even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

Notes - Route or Corridor miles are the total length of the low- or zero-visibility section of the corridor, as defined by the starting and ending mileposts. Plow Route miles are the normal patrol route segments where plows are always assigned for an exp

Survey data updated & verified by ATRC during months of June-August 2003. Rev: 08-15-03

Another significant change to the survey was to identify not only the extent and distribution of the two impaired visibility roadway categories, but also the total extent of the assigned snowplow routes in each district. The goal was to identify the proportion of snowplowing routes for each district and for the entire state highway system, and to also determine the extent of the impaired or whiteout zones on those snowplow routes. Winter storm patterns and severity are relatively fixed in the long term, and these results will support winter maintenance planning at all levels.

The key information sources were still the district maintenance managers. ATRC presented the new survey to all of the districts at a maintenance retreat in mid-June and expressed the need for consistent responses. By providing worksheet files and large paper maps for each district, the ATRC ensured that the information could be verified as it was received, and then summarized.

This approach was successful, and the ATRC had received and reconciled all of the responses by the end of July. As shown in Table 9, the third project survey found that nearly 4,000 miles, or

60 percent, of the 6,216-mile state system are designated as snowplow routes for major winter storms. Based on this locally-sourced information, almost 1,400 miles of highway have impaired visibility in a typical snowstorm, which is more than 20 percent of the entire state system. More than half of those sections will experience whiteout conditions.

It should be noted that there will always be possible inconsistencies among the individual district perspectives on how they define impaired visibility plow routes, but each district has its own local circumstances and challenges to assess. The research project's goal has been to develop information on the potential of the two on-board driver warning systems (as well as for the roadway-based systems) so that each district maintenance team can determine whether, and where, these concepts would be of real value to them.

As noted above, each district was given large maps to help work out their impaired and whiteout visibility zones on each highway corridor in their area. These maps supported the tabulation of the milepost limits for each low-visibility route segment, and the color-coding clearly showed regional trends based on terrain or storm weather patterns as well.

While the scale reduces its clarity, a statewide map (Figure 28) was created to illustrate the extent of the visibility problems for the ADOT snowplow operators across Arizona.

The complete tabular and graphic results of the project's snowplow impaired-visibility survey are included in Appendix K of this report. Both a visibility classification map and a route summary table are provided for each of the ADOT maintenance districts.

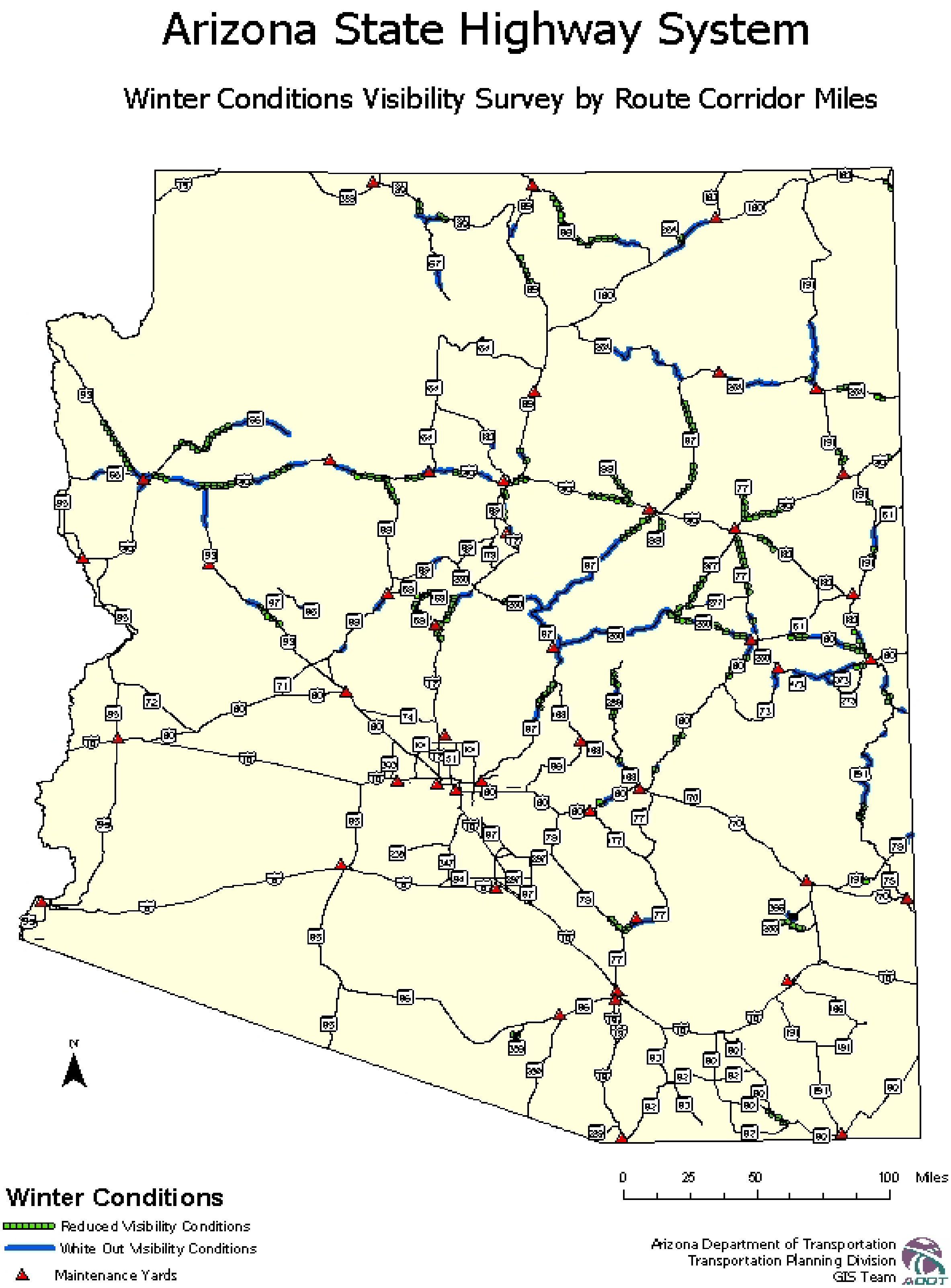


Figure 28. Impaired Visibility Snowplow Routes

XIV. PHASE THREE RESULTS AND CONCLUSIONS: 2002-03

ON-BOARD SYSTEMS PROJECT SUMMARY: YEAR FIVE

The goal of the Phase Three research effort was to evaluate on-board warning systems to support ADOT's snowplowing operations. This new project goal for 2002-03 followed four years of testing of two different lane guidance systems that each employed an embedded-magnet roadway infrastructure. Due to the overall cost, complexity, and life-cycle concerns of those systems, the project efforts were redirected to an evaluation of commercial off-the-shelf radar and night vision systems. The new on-board warning systems were installed and tested on a regional basis, with seven project snowplows in service for Year Five of the project.

Figure 29. An Early Winter Storm Slows I-17 Traffic

As described in the preceding chapters, this research effort had goals on two levels for 2002-03. The primary level was the new direction as set by the project's Technical Advisory Committee. The ATRC was to expand on the initial field demonstration to fully evaluate the Bendix XVision passive-infrared night vision camera, and also to further evaluate the Eaton VORAD EVT-300 collision warning radar system that was already in use on the ADOT-3M advanced snowplow.

A second level of effort, as resources allowed, was to reconcile earlier efforts from previous winters, which for both external and internal reasons had not been successfully completed. The first of the deferred tasks was to evaluate the SmartCruise adaptive cruise control feature of the Eaton VORAD radar system, which could not be done during the winter season. A second deferred research effort was to complete a consistent statewide survey of highways where visibility was frequently, consistently, and severely impaired in winter storms each year.

2002-03 RESEARCH ACTIVITIES

The primary research effort for the two commercial warning systems called for a wide dispersal of the test units across northern Arizona. This was done in order to involve all three of ADOT's I-40 Corridor maintenance districts, and to improve the likelihood of the project snowplows being actively engaged in every winter storm that passed over the region. On that basis, seven snowplows were selected from the three partner districts, with seven diverse snowplow routes identified for the Year Five research effort.

Most of the test routes were on interstate or other divided highways, but two plow routes were on mostly two-lane highways. Three ADOT snowplows, one in each district, were outfitted with the XVision infrared system, and all were in service by December. Three others were equipped with the EVT-300 collision warning radar by February, in addition to the CWS unit on the existing ADOT-3M advanced snowplow.

The Year Five research approach was simple, but it required a high level of field involvement. Unlike four previous winters, the project now had no test site infrastructure, and no clear central focal point. The vagaries of winter weather could shift the focus of the evaluation to any area of northern Arizona. The project plan therefore was Org-dependent, in that the assigned snowplow operators and supervisors at the seven scattered maintenance camps would be the ones to monitor performance, and to report to the ATRC on any issues.

Despite the delays in completing installations, and the mild winter across northern Arizona, the concept was sound and the plan was basically successful. Added paperwork for the drivers was not welcome, but it was the only way to record field information on system performance under the decentralized evaluation plan. The ATRC's basic daily Shift Activity Report was the key record, along with an Incident Report form for events where the on-board system was a factor. The ATRC also developed a driver survey on system performance, features and reliability.

Vendor support throughout the winter was excellent, both for commissioning the systems in Flagstaff, and for troubleshooting over the winter. Both Eaton and Bendix provided training materials, and made site visits during commissioning and for system upgrades. ATRC staff also frequently visited the partner Orgs to discuss the on-board systems and to resolve any issues.

The primary research activities, the operational testing and evaluations, were successful, and the TAC's recommendation to diversify the research across three ADOT districts was validated. The operational evaluation covered nearly 40,000 miles of snowplowing and patrolling activity by the seven project snowplows over the 2002-03 winter.

RESEARCH RESULTS

Bendix XVision System: 2002-03 Results

Maintenance crews from Kingman, Winslow, and Little Antelope tested the XVision infrared night vision system. A consistent and thorough operational evaluation was the basic project goal. As discussed in Chapter XI, and as detailed in the Appendices, the three night vision snowplow crews accumulated nearly 20,000 miles of driving experience over the winter in their 67 days of plowing activities among the three evaluation sites. More than 120 PECOS activity reports were posted for these three units.

Overall, results were mixed for the Bendix night vision program in its first winter, with enhanced driver visibility but with numerous snow buildup problems. On the positive side, some of the post-season operator survey comments were clearly enthusiastic about XVision in most driving conditions. However, ADOT's goal for the evaluation was to determine whether the system was effective for snowplowing operations. It was clear to the TAC sponsors and to the operators that, in field conditions, the aftermarket warning system did not fully address ADOT's needs in conditions of wet, driving snow, or in the rain.

The current XVision system did not meet the project's high expectations for Year Five, which were based on early night demonstrations and field tests in dry weather. This result was clear at the end of the winter, despite excellent efforts from the Bendix team to support the project with hardware enhancements and technical support. As is discussed in the following section on the project's "Lessons," the three XVision units remain operational and will be evaluated further in the next winter. ADOT and ATRC have sought other means to improve XVision performance, and the snow buildup problem may still be resolved.

Bendix XVision System: Lessons and Limitations

The Bendix XVision infrared camera system can be a valuable resource for many nighttime highway maintenance and operational activities. Its ability to lift the veil of darkness far beyond the range of snowplow headlights is unquestionably remarkable. The plow operators found many pre- and post-storm roadway maintenance situations, day or night, where the system may enhance performance and safety. They found that in any night operations, XVision performed ably while spreading chemicals and abrasives and while patrolling after storms for rockslides, fallen trees, disabled vehicles, and roadway flooding. However, there was less driver satisfaction with regard to snowplowing operations.

Because of the lens barrel and heater design, the XVision camera lens suffered from snow buildup, which masked the thermal images from the roadway ahead. While the camera and the lens heater generally performed well in light snow, or with calm or following winds, the system was overwhelmed when heavier wind-driven snow and roadway slush would fill the recessed lens housing. This level of performance under the most critical snowplowing conditions was a major disappointment to the operators over the winter.

There were no significant training issues, as noted earlier, since the system effectively served as a window in the darkness for the driver, extending visibility out to a quarter-mile or more ahead of the snowplow in most weather conditions. There were some early concerns about accurate interpretation of thermal images for objects such as various vehicle and trailer types, and some questions as to the variations in heat retention between dusk and dawn for terrain features, roadside hardware, and the road surface itself. While Bendix training material in these areas was minimal, the drivers still were able to quickly adapt to the screen images and to correctly respond to any situation revealed by XVision.

Bendix technical support was always prompt and responsive to ADOT's requests, in particular by supplying upgraded XVision camera accessories as they were developed, including lens heaters, shields, display screens, and more. However, there were areas of concern that Bendix could not directly respond to, such as additional engineering to solve the lens icing problems. When the ATRC located third-party sourcing for a lens washer system (Figure 30), Bendix encouraged the tests and also procured the same hardware for their own testing efforts. Other potential refinements were discussed with Bendix, but they were not considered to be feasible design changes in the current project time frame.

As ATRC's interim and post-season surveys show, most drivers started the evaluation program with real enthusiasm for night vision, but at the end of the winter many were at best only neutral as to the XVision system's performance and capabilities. The Bendix system's foul-weather limitations led to a clear loss of support among the snowplow operators on the three test routes.

Figure 30. Monroe Prototype Camera Lens Washer System

In its first winter of evaluation, the XVision system did not perform consistently in the variety of winter storm conditions that ADOT snowplows must face. This determination was a goal of the evaluation program, however, this result is not considered final yet. The prototype lens washing system recently developed by Monroe Truck Equipment may be a practical solution, and it will be thoroughly tested on the project's three XVision snowplows in the 2003-04 winter.

Eaton VORAD EVT-300 Radar: 2002-03 Results

The EVT-300 collision warning radar system from Eaton VORAD was more widely marketed in 2002 than the newer Bendix night vision system, and it is less costly. ADOT also had previous experience with the system from the ATRC's Caltrans and 3M evaluation program.

The EVT-300 was tested on four snowplows dispersed across the state, at Seligman, Flagstaff, Gray Mountain and Chambers. As with the night vision concept, a consistent and thorough operational evaluation was the basic project goal. The four CWS-equipped research snowplows accumulated a total of nearly 20,000 miles of activity in just the last three months of the winter. More than 70 days of plowing-related activity were logged among the four test sites, and more than 120 PECOS activity reports were posted for the four CWS-equipped snowplows.

The Phase Three results for the Eaton VORAD evaluation were good overall, but there were mixed reports from some operators, and as noted earlier, one plow crew with CWS radar did not submit any reports during the evaluation. Based on the survey responses, and as discussed in "Lessons" below, one key factor in driver acceptance was the individual's willingness and ability to devote the extra efforts required to learn the system's limitations, and to interpret the sequence of progressive warnings when obstacles are detected.

ADOT's basic goal for the Org-centered testing program was to determine whether the EVT-300 was effective for snowplowing operations. At the end of the 2002-03 winter season, it was clear that this collision warning radar system was effective, robust and reliable in all weather, day or night. Key features such as the blind-spot warning and the SmartCruise also earned positive comments. However, the issue of individual driver commitment is a greater concern for CWS radar than for the simpler infrared night vision concept.

EVT-300 System: Lessons and Limitations

The Eaton VORAD system is a fully developed, sophisticated yet robust commercial driver-assistance tool to improve the performance and safe operation of all fleet vehicles. It is not limited to daytime or to seasonal operation, nor is it significantly impacted by foul weather conditions. It is simple in concept but it has important options and features that are complex. Extra focus and effort is required for the driver to use the system to its full potential.

The EVT-300 Driver Reference Manual contains a number of cautions for safe use of both the basic CWS and the SmartCruise. The systems are clearly defined as driving aids for the alert and conscientious professional driver. The key factors in deploying the EVT-300 are training and commitment. The system requires dedication by the individual driver to review his training materials, in order to safely and efficiently use the system. While the warnings are sequential, the driver must interpret them correctly as to the urgency and the threat level, and he must react reflexively to the most critical warnings.

Another issue is recognition and interpretation of both false warnings and missed alerts. Due chiefly to the narrow single-lane field of focus, there are situations where the radar might miss a target on gradual curves or on hills, or in moving from straight to curved sections of roadway. There also may be false radar warnings from overhead signs, in roadway dips, or from objects near the shoulder.

The operating climate in a snowplow cab during a snowstorm is far from tranquil. For the plow operators, even the best warning system can be perceived as a burden if it is not consistent, or if it requires too much interpretation effort. Only training, practice, and experience with the system will allow drivers to respond properly in a critical warning situation. Generally, Eaton VORAD training materials are both thorough and consistent, and their technical support was responsive and supportive on any ADOT requests.

A committed snowplow operator can readily learn the system's responses along his assigned route after a few baselining runs, so that an unexpected warning in a storm will be immediately recognized as a probable hazard ahead. For each test snowplow route, the distractions and stress factors were different. Some of the drivers, as noted earlier, were simply not comfortable with the CWS concept. Other operators with more EVT-300 experience, such as the F235 crew at Gray Mountain, were comfortable with the system and were willing to rely on it more, as reflected in the end-of-season surveys. As the ATRC surveys show, most of the drivers involved in the testing were positive about the EVT-300 system's performance and capabilities.

Eaton VORAD SmartCruise: Evaluation Results

The long-delayed installation and commissioning of the SmartCruise feature of the EVT-300 finally took place in mid-2003. A day of operational testing with snowplow F342 on Interstate 40 effectively demonstrated the performance of this system. This adaptive cruise control feature readily acquired and followed several targets at consistent ranges and speeds, and it effectively decelerated the plow truck when overtaking slower vehicles in cruise control. The SmartCruise system was effective and consistent, and its function was not affected by grades or curves.

This is a system that offers increased safety for long-haul trucking operations, and this is relevant to some elements of the ADOT equipment fleet. It functions as intended with the factory cruise control to reduce truck speed when overtaking slow-moving vehicles, and it may reduce rear-end accidents and near misses.

Low Visibility Route Survey Results

The project's third effort at a statewide low-visibility survey was a significant accomplishment, despite delays in earlier phases. When finally refined and completed by ATRC in mid-2003, the resulting database and maps effectively showed the areas of impaired visibility for snowplows across the entire state, as submitted by each district with detailed input from the local Orgs. This information, and in particular the resulting maps, will be a valuable winter maintenance planning resource for each of ADOT's districts and Orgs, as well as for Central Maintenance.

BENEFITS AND COSTS

From the snowplow research activity for the winter of 2002-03, it is clear that the deployment of seven test units across northern Arizona was a successful approach regardless of the results at any individual Org. Because of the design constraints and observed limitations of the two on-board warning systems evaluated in Phase Three of this project, it is premature to predict any specific quantifiable benefits with regard to the wider deployment of either system by ADOT.

Resolving the cost side of the equation is not complicated, as commercial system pricing is clearly defined, but addressing the associated internal costs is also a significant factor. Presently the four ADOT snowplow installations of an EVT-300 forward and side radar system have an average installed cost of approximately $3,000, without the SmartCruise feature.

The installed cost of each XVision system, with labor by ADOT shop crews, averaged $5,000. However, the prototype Monroe camera washers newly installed for 2003-04 add $2,000 to the system cost, mostly in labor. With price increases announced, and possibly with a future lens washer option from Bendix, the full cost of an enhanced XVision system may approach $7,500.

The warning system costs must be balanced against the current cost of a new ADOT snowplow. Initially, even $7,500 to add an effective on-board warning system would be minor compared to the $175,000 cost in 2003 of a typically equipped new ADOT plow truck. Providing XVision infrared cameras for ADOT's entire fleet of 250 snowplows would cost less than $2,000,000, and to provide the same number of EVT-300 CWS radars would only cost about $750,000.

The cost of either system for just the few most critical plow routes in any one ADOT district would certainly be minimal. The cost is also minor relative to the costs of crashes while plowing the highways in a severe storm. Further potential benefits can be estimated in regard to traveler crashes, injuries, and fatalities, as well as lost user time on the highway - an important cost factor for commercial transport fleets.

The economic impact of a single life lost, according to the National Safety Council (NSC), was almost $1.1 million dollars in 2002, the year that this on-board warning system evaluation began.

During 2002 in Arizona, 14 persons were killed in crashes on snowy or icy roadways. *For the six winters since this research project began, that total is 68 deaths and 3600 injuries*.

The NSC economic impact estimates for 2002 are $6,200 for a property damage crash, and an average of more than $16,000 for an injury accident. The costs of a single severe crash would provide for several on-board warning systems. If longer-term operational trials show that either system will improve the safety and efficiency of ADOT's snowplowing operations, then their continued deployment may effectively reduce the number of crashes in future winters.

There is no way to predict how many crashes might be avoided by equipping snowplows with collision warning radar or night vision, but in many situations, these systems can enhance the ability of ADOT drivers to plow more consistently, effectively, and safely, with better awareness of storm conditions and potential obstacles along their routes. As a result, all highway users will experience better road conditions, and have a better chance to reach their destinations safely.

ON-BOARD SYSTEMS: 2002-03 CONCLUSIONS

Either radar or night vision may reveal any number of night-time driving hazards in the roadway, such as stalled cars, pedestrians, deer and elk, damaged guardrail or signs, and rocks and debris. The infrared night vision system, with a quarter-mile range, also can effectively show hazards along the roadside. It can even show plow operators where road-surface deicers are or are not working. The CWS radar has less range, but it is also much less affected by heavy snow or rain.

Neither system alone, as tested, can completely solve the visibility problems that are a constant hazard for ADOT snowplowing crews. Both systems were effective in some conditions, and both have design constraints and inherent technical limitations. On that basis, each must be used primarily as an aid for an alert, skilled snowplow operator in restricted visibility, but not as a guidance system in whiteout storm conditions.

Driver acceptance is a significant factor with both on-board warning systems. Individual snowplow operators and supervisors must provide a local voice in deciding where to deploy future systems, or they may not be accepted and used consistently at the field level.

As a result of the Phase Three evaluation program, the project team recommends a gradually wider implementation of these systems in Arizona, based on local district needs. This project's assessments and recommendations for implementation of on-board warning systems in future winters, as listed below, represent the overall perspective of the Technical Advisory Committee:

- As evaluated in northern Arizona, Eaton VORAD's EVT-300 collision warning radar system is effective with the proper driver training, familiarization, and personal commitment. It offers significant safety benefits at a low cost, and the EVT-300 CWS should be deployed more widely on both new and existing trucks in the ADOT snowplow fleet. The system's integral SmartCruise feature also performed well in field tests, and it should be considered for any of the state's transport fleet applications.

- The performance of the Bendix XVision passive-infrared camera system was promising but problematic in its current off-the-shelf package. The key issue of snow buildup in winter storms may be resolved in the coming season with the addition of a camera washer system. While XVision can be recommended now for many low-light, low-visibility applications, its suitability and benefits for ADOT's snowplow fleet will be determined by evaluation of the washer systems to be installed for 2003-04. The project recommends that any wider snowplow deployment of XVision should be decided by the overall results of the next winter season; however, design refinements by Bendix could also solve the snow buildup problem.

FUTURE OPERATIONAL EVALUATION: ADOT DISTRICTS

The future plans for the research project are as limited as its budget. The goal of evaluating the two commercial on-board systems was reached, and the deployed equipment is now operational on seven ADOT snowplows. The success of these systems in the districts in future winters will resolve the practical applications for either concept, and ATRC will monitor the operational experience of the project snowplows. Certainly the field evaluation of the XVision camera washers will be of great interest to all parties.

ATRC will continue to support the local operations as required, will act as liaison with system vendors, and will solicit feedback from the local level. After the 2003-04 winter, a follow-up survey will be distributed to the drivers who used the on-board warning systems, and the ATRC will then prepare a summary memorandum for the TAC members and key project partners.

XV. ADOT ADVANCED VEHICLE RESEARCH PROGRAM: 1997–2003

In June 2003, Under Secretary Jeffrey Shane of the U.S. Department of Transportation addressed a national meeting of Intelligent Vehicle Initiative (IVI) partners in Washington D.C. Having just witnessed IVI-advanced safety system demonstrations, he said, “These are powerful, elegant technologies, and they have the potential to help us save thousands of lives.” He further noted that, “Vehicle-only systems have already proven highly effective in a number of applications.”

This long-term ATRC in-house research project was mandated by the ADOT Research Council and by senior management in late 1997 to explore advanced vehicle technologies for Arizona. The research soon became focused on snowplows, and for five winters, the project has evaluated both infrastructure-based and on-board driver-assistance concepts. The fundamental research goal has been to improve the safety of ADOT’s snowplow operators and the public, and to increase the effectiveness of the state’s snowplow fleet.

Arizona is geographically a large area, with a relatively small population. Several key Interstate highway corridors carry very large traffic volumes across the state, and the “land bridge” concept of coast-to-coast cargo delivery is a crucial aspect of the nation’s economy. In winter, transport traffic may also be diverted southward from other route corridors, so severe storms in northern Arizona quickly cause extensive regional problems with congestion, delays, and crash losses.

PROJECT SUMMARY: ADVANCED SNOWPLOW RESEARCH

The 6,216-mile Arizona State Highway System includes 3,992 miles that are designated ADOT snowplow routes, and 1,395 miles of those routes have frequent storm visibility issues. Winter conditions in the higher elevations are generally severe, although during the life of this project, the winter snowfall average fell significantly below the 30-year historical figure. Recent mild winter seasons constrained comprehensive operational evaluations of this project’s IV concepts.

Table 10. Flagstaff Winter Storm Summary: 1997-2003

Winter Season (October to May)	Storm Events*	Snowfall: Inches**	ATRC Project: Research Phase
1997-98	27	108”	*Pre-Planning Stage*
1998-99	13	72”	Caltrans
1999-2000	18	74”	Caltrans
2000-01	25	125”	Caltrans & 3M
2001-02	10	39”	Caltrans & 3M
2002-03	14	55”	Bendix & Eaton VORAD
*6-Year Seasonal Average:	18	79”	
Historical Avg of Storm Events (30 yrs)	22.5	107”	*(1973-2003)*
Historical Avg since 1898 (105 yrs)		84”	*(1898-present)*
*Storms Greater than One Inch of Snow at Flagstaff **Seasonal total snowfall recorded at Pulliam Airport / WX Observation Station			

Source: National Weather Service records

As noted earlier in this report, the winter storm records vary dramatically between calendar year snowfall totals and those for the October to May winter season. The 2001-02 winter season had only 39 inches of snow at Flagstaff from November to March, while the calendar year totals were 131 inches in 2001, followed by 30 inches in 2002. Appendix A lists the past 30 years of Flagstaff-area snowfall records, which provide an indication of the relative severity of the regional winters across northern and eastern Arizona.

It is noteworthy that the advanced-snowplow focus of this research project was developed during the 1997-98 winter, when the snow total for the season was a "nearly normal" 108 inches, but since 1998, the Arizona winters have seldom been described as "normal."

Traffic Accident History: Wintry Conditions

The winter-season snowfall statistics are most directly relevant to the annual operational testing of advanced snowplow technologies, but calendar year summaries are normally used to generate the long-term historical averages. ADOT's crash statistics are also based on calendar year totals, so the total annual snowfall, not the seasonal figure, is the relevant statistic used in Table 11 to correlate crash and fatality/injury records to winter weather across Arizona.

Table 11. Arizona "Snowy and Icy" Crash Records: Six Winters

Statewide Motor Vehicle Crash Histories By Calendar Year							
Life of Project: 1997 - 2002							
Statewide Crash Data	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**6 Years: Average**
Total "Snowy & Icy" Crashes	1,768	1,855	647	1,292	2,073	1,243	1,480
Snowy & Icy: Fatal Crashes	7	12	5	8	14	12	10
Snowy & Icy: Injury Crashes	371	453	206	318	518	322	365
Snowy & Icy: PDO Crashes	1,390	1,390	436	966	1,541	909	1,105
Total "Snowy & Icy" Fatalities	7	14	5	14	14	14	11
Total "Snowy & Icy" Injured	581	763	322	567	818	539	598
(PDO is: Property Damage Only)							
Total Snow- Flagstaff- Cal. Year:	*113*	*123*	*56*	*101*	*131*	*30*	*92" Avg*
Days more than 1 inch of snow:	*17*	*26*	*9*	*24*	*27*	*8*	*18.5 Avg*

Source: "Motor Vehicle Crash Facts" Annual Reports (various), ADOT Traffic Records Section

Table 11 shows crash records for six calendar years of the research project (2003 crash records were not yet available for this report). The Flagstaff weather records for this period show that the average number of storm days was 18.5, with a 92-inch average snowfall. These figures reveal a significant short-term decrease in the severity of recent winters, compared with 30-year records (Appendix A) showing 22.5 storms per winter on average, and 107 inches of snowfall.

The table shows a relationship for six calendar years between Flagstaff snow records and the Arizona crash history figures. Assuming that Flagstaff's figures provide some measure of the severity of winters across the state, then the "total crashes" in "snowy and icy conditions" do appear to vary generally with the storm records, both for total snow accumulation and recorded days of snowfall.

Figure 31. Storm Cleanup: An Icy Highway In Northern Arizona

The winter crash records are not extensive enough to be statistically significant, but they do imply the economic, social, and personal costs of every crash on a wintry roadway. Every crash record involves personal trauma and loss, increases the demands on emergency services and snowplow crews, compounds the storm-caused congestion, and has real economic impacts.

ATRC does not have sufficient performance data on the new advanced snowplow technologies for this project to quantify any specific benefits to ADOT of installing these systems in its fleet. If these systems could reduce the toll of winter highway crashes, the benefits to the state and its citizens would be tremendous. At a cost of between $3,000 and $7,500, any ADOT snowplow can be equipped with an advanced on-board warning system. In comparison, the National Safety Council estimates the economic loss from a single non-injury vehicle crash to be $6,200.

1997-2003 PROGRAM RESULTS: ADVANCED VEHICLE SYSTEMS

The key result of five winters of ADOT's snowplow evaluation project is the confirmation that effective and reliable driver-assistance systems exist that, if deployed, may over time provide significant benefits to Arizona and to other states for maintenance operations in severe winter storm conditions. These potential benefits include enhanced safety for snowplow operators and also for the public, as ADOT clears the highways with more efficient plowing operations.

Infrastructure-Based Systems: Years One to Four

Extensive evaluations were conducted of the two primary concepts for roadway-based vehicle guidance systems during four winters, from 1998 through 2002. The magnet-based Caltrans RoadView advanced snowplow was evaluated as it evolved over four winters, and ADOT also deployed the magnetic tape-based 3M Lane Awareness System for side-by-side testing during two of those seasons. Three previous ATRC reports describe those advanced-vehicle concepts, costs, and the Arizona evaluations in detail.

This project has validated the roadway-based vehicle guidance concepts developed by 3M and by the Caltrans program, but they are not the best solution for Arizona at their current cost levels. Overall, both systems proved their effectiveness and reliability, but it was also clear to ADOT that the cost of either system's infrastructure was prohibitive. Research was then redirected to commercial on-board warning systems in 2002-03, at a much more practical level of cost.

On-Board Systems: Year Five

The basic goal for the Org-based evaluation program was to determine whether either on-board system was effective and reliable in snowplowing operations. At the end of the winter, it was clear that neither collision warning radar nor infrared night vision, as tested, can solve all of the visibility problems for ADOT's snowplow crews.

The Bendix infrared night vision system worked effectively overall, but it had frequent snow buildup problems. The current model of this warning system did not fully meet ADOT's Year Five expectations in wet, wind-driven snow, or in rain.

The EVT-300 collision warning radar was effective, robust and reliable in all weather, day or night. The blind-spot warning and the SmartCruise were also key features. A critical factor in operator acceptance is the willingness to learn the system's strengths and weaknesses. Driver commitment is a greater factor for the CWS radar system than for the simpler infrared night vision concept.

Both systems were effective in some conditions, and both have design constraints and inherent technical limitations; they must primarily be considered as aids for an alert driver in impaired visibility, but not as a guidance system in whiteout storm conditions. Both systems should be evaluated further in the next winter season.

Project Implementation and Deployment

This research project has established the potential in ADOT fleet operations for on-board collision warning radar units and night vision cameras. These commercial on-board warning systems do not offer predictive guidance abilities to keep moving in very poor visibility, but they do improve the operator's awareness of the conditions and the potential obstacles in the road ahead. Further operational use of each system to gain additional field experience is expected to support further deployment decisions.

The near-term recommendation is to maintain the current deployment of the seven on-board warning systems for 2003-04 and into the future. This includes three XVision systems and four EVT-300 radar units. The ADOT-3M advanced snowplow is one of the radar units, and it will also continue operations indefinitely with the magnetic tape-based 3M Lane Awareness System.

The three XVision units will remain operational, with refinements (Figure 30), and will be evaluated further in the next winter. ADOT, ATRC, and Bendix have sought other approaches to improve XVision performance, and the lens cleaning problems may still be resolved. The EVT-300 deployment will continue in the next winter, and further installations of on-board collision warning radar systems are recommended.

Issues remain about full winter storm functionality, but both on-board warning systems are operationally effective and reliable at a cost that is minor with regard to equipping a new snowplow vehicle. Any lingering concerns from Phase Three as to the winter maintenance applications of either system should be answered in the 2003-04 winter season.

The research project has achieved its goals and has expended its budget. This project report, the fourth, concludes the series. The ATRC will continue to assist with local testing as required, will act as a liaison with system vendors, and will solicit feedback from the local level. At the end of the 2003-04 winter, a follow-up survey will be distributed to those Orgs that are utilizing the two on-board warning systems. The ATRC will then prepare a summary memorandum for the TAC and its key project partners.

Program Vision

The vision of the ITS America organization was recently refined as follows: "A future where people and goods are transported without delay, injury, or fatality by integrated systems that are built and operated to be safe, cost effective, efficient and secure." Through five winters, the ADOT advanced snowplow research program has evaluated both infrastructure-based and on-board systems to meet such goals and to improve the operation of the state highway system.

This project's results indicate that on-board warning systems have the potential to improve snowplowing safety and efficiency on Arizona's highways. Now, the Department will have to make implementation decisions based on the research records, on a second full winter of operational deployment, and ultimately on the recommendations of rural district managers.

The transition from roadway-based to on-board systems may alter the deployment process for ADOT. The low cost of the two recommended aftermarket warning systems potentially allows the purchase decisions to be made at the district level, rather than centrally at the agency level.

On the other hand, an internal decision could be made to add these systems to the specifications for new snowplow trucks, but that process would make the deployment more gradual. This is an internal question for the agency, which the research project has not addressed.

APPENDIX A

FLAGSTAFF REGIONAL WINTER STORM HISTORY

WINTER STORM SUMMARY – FLAGSTAFF
SIX PROJECT WINTERS: 1997 - 2003

Winter Season (October - May)	Storm Events	Seasonal Snowfall - Inches	*Snow In Caltrans-3M Tests*	ATRC Research Project Phases
1997-98	27	**108”**	-	*Pre-Planning Stage*
1998-99	13	**72”**	*5.4”*	Caltrans
1999-2000	18	**74”**	*16.8”*	Caltrans
2000-01	25	**125”**	*30.6”*	Caltrans & 3M
2001-02	10	**39”**	*None*	Caltrans & 3M
2002-03	14	**55”**	-	Bendix & Eaton VORAD
Six Year Average Winter Season:	***18***	***79”***		
**Flagstaff 30 Year Historical Average:*		***107”***		*(1997-2003)*
**Flagstaff 105 Year Historical Average:*		***84”***		*(1898-present)*

- Storms Greater than One Inch of Snow at Flagstaff
- Recorded at Pulliam Airport / WX Observation Station

NUMBER OF DAYS SNOWFALL EXCEEDED 1 INCH FOR FLAGSTAFF

Calendar Year	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec	Total Days	Total Snow
1997	6	2	0	4	0	0	1	4	**17**	**113**
1998	4	8	7	3	0	0	2	2	**26**	**123**
1999	1	1	2	5	0	0	0	0	**9**	**56**
2000	3	5	9	1	0	2	3	1	**24**	**101**
2001	7	5	2	5	0	0	2	6	**27**	**131**
2002	0	0	2	0	0	0	1	5	**8**	**30**
2003	0	3	4	1	0	0	0	0	**8**	**33**
7 Cal Yr Average	**3.0**	**3.4**	**3.7**	**2.7**	**0.0**	**0.3**	**1.3**	**2.6**	**17.0**	**84**

**Full Calendar Year averages - through December 2003.*

Courtesy of National Weather Service, Flagstaff

FLAGSTAFF REGIONAL WINTER STORM HISTORY: 1973-2003

Number of Days Snowfall Exceeded 1 inch for Flagstaff, AZ

Year	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec	Total
1973	6	9	15	4	1	0	4	1	**40**
1974	5	0	2	1	0	3	1	4	**16**
1975	7	6	8	6	2	0	3	5	**37**
1976	1	4	3	5	1	0	0	2	**16**
1977	3	2	2	2	1	0	1	1	**12**
1978	8	7	8	3	1	0	4	4	**35**
1979	10	4	5	1	1	0	1	3	**25**
1980	8	7	9	2	0	2	0	3	**31**
1981	3	3	10	2	0	0	3	1	**22**
1982	7	7	7	1	0	0	3	7	**32**
1983	3	5	8	4	0	0	4	2	**26**
1984	1	1	0	2	0	0	3	11	**18**
1985	6	5	7	2	0	0	5	1	**26**
1986	0	6	5	1	0	0	1	3	**16**
1987	7	5	4	0	0	0	1	6	**23**
1988	4	2	1	5	0	0	4	3	**19**
1989	3	2	4	0	0	0	0	1	**10**
1990	6	7	4	2	1	0	2	6	**28**
1991	1	2	11	0	0	1	4	5	**24**
1992	6	5	8	1	0	0	1	7	**28**
1993	15	11	3	1	0	0	5	3	**38**
1994	1	5	3	6	0	1	4	2	**22**
1995	7	1	2	5	1	0	0	3	**19**
1996	1	3	1	0	0	5	4	0	**14**
1997	6	2	0	4	0	0	1	4	**17**
1998	4	8	7	3	0	0	2	2	**26**
1999	1	1	2	5	0	0	0	0	**9**
2000	3	5	9	1	0	2	3	1	**24**
2001	7	5	2	5	0	0	2	6	**27**
2002	0	0	2	0	0	0	1	5	**8**
2003	0	3	4	1	0	0	0	0	**8**
Average	**4.3**	**4.3**	**5.0**	**2.4**	**0.3**	**0.5**	**2.2**	**3.3**	**22.5**

Courtesy of National Weather Service, Flagstaff

APPENDIX B

I-40 CORRIDOR SNOWFALL BY DATE: WINTER 2002-03

Intelligent Vehicles / ADOT Snowplow Research

Daily Snowfall - Winter 2002 – 2003

Plow No.	**F277**	**F326**	**F235**	**F342**	**F291**	**F340**	**F269**	***Notes***
ORG	Kingman	Seligman	Ltl Antelope	Gray Mtn	Flagstaff	Winslow	Chambers	*ADOT Maint Site*
WEATHER SITE	**Diamond M Ranch**	**Seligman**	**Pulliam Airport**	**Sunset Crater**	**Walnut Canyon**	**Blue Ridge**	**Sanders POE**	*WX Site Loc'n*
ROUTE	I-40	I-40	I-17	S 89	I-40	SR 87	I-40	
MP Loc'n	*91*	*121*	*337*	*430*	*204*	*300*	*339*	*WX Site Approx MP Loc'n*
			Summary of Dates w/ Snowfall Total					
10/02/02		R			R			R - Rain
10/03/02	R	R		T	R	R		T - Trace Snow to 0.5"
10/04/02					R			Snowfall > 0.5"
10/16/02							R	
10/17/02		R		R	R	R	R	
10/18/02	R			R	R			
10/21/02					R			
10/22/02	R					R		
10/23/02	R	R		R	R			
10/24/02				R	R	R		
10/25/02				R	R			
10/26/02	R							
10/27/02	R	R	0.3	R	R			
10/28/02	R			R	R	R		
11/08/02	R							
11/09/02		R		R	R			
11/10/02				R	R			
11/12/02						R		
11/26/02	R		3.0		R			
11/30/02	R	R		R	R			
12/01/02	*(missing Dec)*	R		R	R			
12/02/02						R		
12/03/02							R	
12/04/02				R				
12/08/02				0.5				
12/17/02		R	4.3	3.0	3.0	2.0		
12/18/02		T	7.2	1.5	4.0	3.0		
12/19/02			0.3	T	T	T		
12/20/02		1.7						
12/21/02			2.5	0.5	2.0			
12/23/02				3.0	2.5			
12/24/02			2.7	1.0	2.8			
12/29/02		R						
12/30/02			2.6	1.5	2.0			
01/01/03			T					
01/03/03	T							
01/06/03		R	0.5	10.0	4.0	1.0		
01/07/03				0.3				
01/08/03	R	R						
01/09/03	R			R	R			
01/11/03				R				
01/19/03							R	
01/20/03							R	
01/21/03		R			R			
ORG	Kingman	Seligman	Ltl Antelope	Gray Mtn	Flagstaff	Winslow	Chambers	
02/08/03			T	0.5				
02/09/03			1.0	R	0.9	2.0		
02/10/03						2.0		
02/12/03	R			R				
02/13/03	R	R		R	R	R		
02/14/03	R	R		R	R	R	R	
02/15/03				R	R			
02/16/03					R			
02/18/03			T			R		
02/25/03	R	R	T	0.3	T	R	R	
02/26/03	2.5	1.0	5.0	0.5	1.0	4.0	R	
02/27/03	T	1.4	2.0	T	2.0	3.0	R	
02/28/03	4.0	R	9.0	0.6	5.0	10.0	R	
03/01/03	T	1.1	1.0	0.3	T		R	
03/02/03	3.0	0.5	5.2	1.0	1.5		R	
03/03/03	T			0.3		R		
03/04/03						1.0		
03/05/03	1.2		2.0		0.5	1.0		
03/06/03			1.0					
03/16/03	R	R	T	R	R			
03/17/03	R	0.2	1.3	R	0.7	7.0		
03/18/03	R	R	2.0	0.3	T	R	R	
03/19/03				0.3				
03/21/03	R		T	0.3		1.0		
04/06/03			T	T	R			
04/15/03	2.0	0.5	2.0	1.0	3.5	2.0		
04/16/03	R			0.5	T			
04/19/03	T	R	T	0.3				
04/20/03			T					
04/22/03						R		
04/23/03	R		T	T	R			
04/24/03				T				
SUM	***12.7***	**6.4**	**54.9**	**27.5**	**35.4**	***39.0***	**0.0**	Snow Totals - Season
WEATHER SITE	Diamond M Ranch	Seligman	Pulliam Airport	Sunset Crater	Walnut Canyon	Blue Ridge	Sanders POE	*NOTE: Daily records from 12AM to 12AM*
ROUTE	I-40	I-40	I-17	S 89	I-40	SR 87	I-40	*Shaded Dates Missing*

APPENDIX C

SNOWPLOW ACTIVITY BY WINTER STORM CODES: ALL SITES

Snowplow Activity: Winter Storm Codes – All Sites								
Project 473 Winter 2002 – 2003								
PECOS DATA	**F277**	**F326**	**F235**	**F342**	**F291**	**F340**	**F269**	**Notes**
MAINT ORG:	Kingman	Seligman	Ltl Antelope	Gray Mtn	Flagstaff	Winslow	Chambers	Activities: 171,172,173, 1607
Reports	*12*	*13*	*72*	*61*	*33*	*40*	*16*	*247*
System:	XVision	Radar	XVision	Radar	Radar	XVision	Radar	
Std Hwy	I-40	I-40	I - 17	US 89	I-40	SR 87	I-40	
MP's	54 – 72	121–146	335-340	420-440	185-230	317-290	347-360	
Installed	03-Dec-02	22-Jan-03	07-Feb-02	21-Sep-01	14-Jan-03	03-Dec-02	04-Feb-03	
Dates / Miles Summary								
10/26/02			141					
10/27/02			25					
11/25/02			305					
11/26/02			193					
11/30/02			134					
12/01/02			149					
12/07/02				49				
12/08/02				140				All XVision opn'l
12/17/02						284		
12/18/02			269	321		348		
12/19/02			323	404		257		
12/20/02	356		232	253		153		
12/21/02	249		307	285		182		
12/22/02			244	196		315		
12/23/02			671	764		604		
12/24/02			321	325		328		
12/29/02			231	277		124		
12/30/02			333	275		352		Odo failed F342
01/06/03			349	BO		182		
01/08/03			51	130				
01/09/03			71					
01/10/03				63				
01/11/03				111				
02/08/03			589		162	411	31	All radars opn'l
02/09/03			182			118	165	
02/11/03				50				
02/12/03			109	297	72			
02/13/03			260	281	87	268		
02/14/03		116		117	68	104		
02/15/03					95			
02/16/03					266			
02/18/03							150	
02/24/03			67	55	73			
02/25/03	143	143	523	562	235	425		
02/26/03	269	377	714	350	288	604	717	
02/27/03	320	249	686	602	608	656	344	
02/28/02	392	128	658	363	706	463	414	Dash short F340
03/01/03		266	353	658	431		404	
03/02/03		172	363	248	147	163	303	
03/04/03			290	217	151		125	
03/05/03		28	267	92	144	139		
03/16/03			283	121	236			
03/17/03		123	101	398	305	383	186	
03/18/03				221	147		182	
03/20/03			56	114				
03/21/03			17	145				
04/15/03		228	354		103			
04/18/03			278					
04/22/03			132					
04/23/03			240		128			
SUM	1,729	1,830	10,871	8,484	4,452	6,863	3,021	37,250
Use-Days:	6	10	39	32	20	22	11	
	F277	**F326**	**F235**	**F342**	**F291**	**F340**	**F269**	
ORG	Kingman	Seligman	Ltl Antelope	Gray Mtn	Flagstaff	Winslow	Chambers	

APPENDIX D

SNOWPLOW ACTIVITY BY SNOWFALL DATES: ALL SITES

Intelligent Vehicles / Snowplow Guidance Research

Project 473 Winter 2002 – 2003

	F277		F326		F235		F342		F291		F340		F269		Notes
MAINT ORG:	Kingman		Seligman		Ltl Antelope		Gray Mtn		Flagstaff		Winslow		Chambers		Activities: 171,172,173, 1607
WEATHER SITE:	**Diamond M Ranch**		**Seligman**		**Pulliam Airport**		**Sunset Crater**		**Walnut Canyon**		**Blue Ridge**		**Sanders POE**		
System:	XVision		Radar		XVision		Radar		Radar		XVision		Radar		*Shading:*
Std Hwy	I-40		I-40		I - 17		US 89		I-40		SR 87		I-40		*RAIN*
MP's	54 – 72		121–146		335-340		420-440		185-230		317-290		347-360		*LT SNOW*
Installed	03-Dec-02		22-Jan-03		07-Feb-02		21-Sep-01		14-Jan-03		03-Dec-02		04-Feb-03		***HVY SNOW***
Dates / Miles / Snowfall Summary : PECOS															
10/26/02		*R*			141							*			
10/27/02		*R*		*R*	25	*0.3*		*R*		*R*		*			
10/28/02		*R*						*R*		*R*		*R*			
11/08/02		*R*													
11/09/02				*R*				*R*		*R*		*			
11/10/02								*R*		*R*		*			
11/12/02												*R*			
11/25/02					305										
11/26/02		*R*			193	***3.0***				*R*					
11/30/02		*R*		*R*	134			*R*		*R*		*			
12/01/02	*(No Dec WX)*			*R*	149			*R*		*R*		*			
12/02/03		*										*R*			
12/03/03		*												*R*	All XVision opn'l
12/04/03		*						*R*							
12/07/02		*					49					*			
12/08/02		*					140	*0.5*				*			
12/17/02		*		*R*		***4.3***		***3.0***		***3.0***	284	***2.0***			
12/18/02		*		*T*	269	***7.2***	321	***1.5***		***4.0***	348	***3.0***			
12/19/02		*			323	*0.3*	404	*T*		*T*	257	*T*			
12/20/02	356	*		***1.7***	232		253				153	*			
12/21/02	249	*			307	***2.5***	285	*0.5*		***2.0***	182	*			
12/22/02		*			244		196				315	*			
12/23/02		*			671		764	***3.0***		***2.5***	604	*			
12/24/02		*			321	***2.7***	325	***1.0***		***2.8***	328				
12/29/02		*		*R*	231		277				124	*			
12/30/02	*(No Dec WX)*				333	***2.6***	275	***1.5***		***2.0***	352	*			Odo failed F342
01/01/03						*T*						*			
01/03/03		*T*													
01/06/03				*R*	349	*0.5*	BO	***10.0***		***4.0***	182	***1.0***			
01/07/03								*0.3*							
01/08/03		*R*		*R*	51		130								
01/09/03		*R*			71			*R*		*R*					
01/10/03							63								
01/11/03							111	*R*				*			
01/19/03												*		*R*	
01/20/03												*		*R*	
01/21/03				*R*						*R*					
ORG	Kingman		Seligman		Ltl Antelope		Gray Mtn		Flagstaff		Winslow		Chambers		
02/08/03					589	*T*		*0.5*	162		411	*	31		All radars opn'l
02/09/03					182	***1.0***		*R*		***0.9***	118	***2.0***	165		
02/10/03												***2.0***			
02/11/03							50								
02/12/03		*R*			109		297	*R*	72						
02/13/03		*R*		*R*	260		281	*R*	87	*R*	268	*R*			
02/14/03		*R*	116	*R*			117	*R*	68	*R*	104	*R*		*R*	
02/15/03								*R*	95	*R*		*			
02/16/03									266	*R*					
02/18/03						*T*						*R*	150		
02/24/03					67		55		73						
02/25/03	143	*R*	143	***R***	523	*T*	562	*0.3*	235	*T*	425	*R*		*R*	
02/26/03	269	***2.5***	377	***1.0***	714	***5.0***	350	*0.5*	288	***1.0***	604	***4.0***	717	*R*	
02/27/03	320	*T*	249	***1.4***	686	***2.0***	602	*T*	608	***2.0***	656	***3.0***	344	*R*	
02/28/03	392	***4.0***	128	*R*	658	***9.0***	363	***0.6***	706	***5.0***	463	***10.0***	414	*R*	Dash short F340
03/01/03		*T*	266	***1.1***	353	***1.0***	658	*0.3*	431	*T*		*	404	*R*	
03/02/03		***3.0***	172	*0.5*	363	***5.2***	248	***1.0***	147	***1.5***	163	*	303	*R*	
03/03/03		*T*						*0.3*				*R*			
03/04/03					290		217		151			***1.0***	125		
03/05/03		***1.2***	28		267	***2.0***	92		144	*0.5*	139	***1.0***			
03/06/03						***1.0***									
03/16/03		*R*		*R*	283	*T*	121	*R*	236	*R*		*			
03/17/03		*R*	123	*0.2*	101	***1.3***	398	*R*	305	***0.7***	383	***7.0***	186		
03/18/03		*R*		*R*		***2.0***	221	*0.3*	147	*T*		*R*	182	*R*	
03/19/03								*0.3*							
03/20/03					56		114								
03/21/03		*R*			17	*T*	145	*0.3*				***1.0***			
04/06/03						*T*		*T*		*R*		*			
04/15/03		***2.0***	228	*0.5*	354	***2.0***		***1.0***	103	***3.5***		***2.0***			
04/16/03		*R*						*0.5*		*T*					
04/18/03					278							*			
04/19/03		*T*		*R*		*T*		*0.3*				*			
04/20/03						*T*									
04/22/03					132							*R*			
04/23/03		*R*			240	*T*		*T*	128	*R*					
04/24/03								*T*							
MILES:	**1,729**		**1,830**		**10,871**		**8,484**		**4,452**		**6,863**		**3,021**		**37,250**
Use-Days:	6		10		39		32		20		22		11		140
WX SITE w/ Snow Total	Diamond M Ranch	***12.7***	Seligman	***6.4***	Pulliam Airport	***54.9***	Sunset Crater	***27.5***	Walnut Canyon	***35.4***	Blue Ridge	***39.0***	Sanders POE	***0.0***	
ORG	8650		8651		8553		8552		8550		8751		8755		* Missing WX

APPENDIX E

ADOT-ATRC DAILY ACTIVITY REPORT

SNOWPLOW RESEARCH '02-'03

DAILY ACTIVITY REPORTS

CHAMBERS / WINSLOW / FLAGSTAFF GRAY MOUNTAIN / LITTLE ANTELOPE SELIGMAN / KINGMAN

ADOT TEAM LEADER - OPERATORS:

Please fill out one activity report after each shift of operation on the roadway with the Advanced Snowplow Systems in use. These activities may include:

- Radar / Xvision / Guidance / AVL system installs, tests and calibrations,
- Operator training, evaluations and demonstrations, and,
- All normal winter maintenance operations on your route.

These shift reports are needed to record the time and distance logged using the advanced snowplow systems, the weather and surface conditions, and problems. This is very valuable data to analyze the performance and value to ADOT of the several technologies being tested in this study.

These reports should take less than a minute to complete after a normal shift. But, if there is a problem with any of the systems on the snowplow, please take the time to fully describe the problem and when, where and how it occurred.

**The Org operating the Advanced Snowplow should copy these reports for the ATRC (MailDrop 075R) and keep the originals in a binder.

SAMPLE

Rev 09-18-02

ADOT SNOWPLOW RESEARCH 2002-2003

DAILY ACTIVITY REPORT

ADOT OPERATIONAL TESTING

Date: __________ **Time Start:** _________ **Time End:** __________ **System:** *Eaton Vorad Rada*

Operator's Name: ____________________ **Snowplow:** ____*F342*___ **Org No:** ____*8552*____

* * * *CONDITIONS WHILE PLOWING* * * *

Highway Number:	Primary Route: US 89	*Other Route:*	*Other Route:*	
Route Mileposts:	420 - 440			
CONDITIONS: *(check or circle)*				
Windy?	Yes - No	Yes - No	Yes - No	
Wind Speed	Low – Med – High	Low – Med – High	Low – Med – High	
Wind From Direction	N - S - E - W	N - S - E - W	N - S - E - W	
Snowfall?	No – Lt - Med -Hvy	No – Lt - Med -Hvy	No – Lt - Med -Hvy	
Sunny?	Sunny	Sunny	Sunny	
Cloudy?	Cloudy	Cloudy	Cloudy	
Day or Night	Day - Night	Day - Night	Day - Night	
		VISIBILITY (circle):		
	Zero	Zero	Zero	
	50 feet	50 feet	50 feet	
	100	100	100	
	200	200	200	
	300	300	300	
	> 300 ft	> 300 ft	> 300 ft	
		ROADWAY (circle):		
	Icy	Icy	Icy	
	Snowpack	Snowpack	Snowpack	
	Slush	Slush	Slush	
	Clear	Clear	Clear	
		ACTIVITY (circle):		
	Plowing	Plowing	Plowing	
	Spread Sand / Chemical	Spread Sand / Chemical	Spread Sand / Chemical	
	Test Runs	Test Runs	Test Runs	
	Operator Training	Operator Training	Operator Training	

Odometer Start of Shift Mileage: _________ **End of Shift Mileage:** _________

Truck Status (*check one*): **Good?** _______ **Problems?** ______ **(Note below)**

System Status (*check one*): **Good?** _______ **Problems?** ______ **(Note below)**

Problems and / or Comments: ____

____

____

____

ADOT TL DayRpt-All *Return a copy of this form to ATRC at Maildrop 075R.*

APPENDIX F

ADOT - ATRC INCIDENT REPORT

SNOWPLOW RESEARCH ‘02-‘03

WARNING SYSTEM INCIDENT REPORTS

** ** ** ** ** **

CHAMBERS - WINSLOW - FLAGSTAFF - SELIGMAN KINGMAN - GRAY MOUNTAIN - LITTLE ANTELOPE

ADOT TEAM LEADER - OPERATORS:

Please fill out a Warning Systems Incident Report for any shift of operation on the roadway in which the Advanced Warning System on your snowplow made a difference in the safety and efficiency of your work. These reports are very important to ADOT, and to the system suppliers, to determine their value for future winters.

Your “incident” reports may be either positive or negative. They include:

- A warning of any object, stopped vehicle, person, or animal in the roadway.
- A warning you are rapidly overtaking a vehicle that you can’t clearly see.
- Any observations of the road surface or other conditions affecting plowing.
- Any activity when you were able to plow more quickly, more precisely, or with fewer stops, due to visibility assistance information from the system.
- Any incident or situation when the system did not give accurate warnings.
- Any incident or situation when the system did not give any warnings.
- False warnings under specific weather or visibility conditions.
- Any other incident-specific safety or operational problems.
- Any other incident specific benefits to your safety and plowing efficiency.

These reports should only take a few minutes to complete after a normal shift. But, if there is a problem with any of the systems on the snowplow, please take the time to fully describe the problem and when, where and how it occurred. Please inform your Equipment Services contacts and the ATRC of any significant system problems.

Please copy the reports for ATRC (MailDrop 075R) and keep the originals in a binder.

Questions or problems? Call Steve Owen, ATRC, 602-712-6910

EVT-300 RADAR SYSTEM – ADOT COMMENT SHEET FOR INCIDENTS

PLEASE TAKE A FEW MINUTES TO DESCIBE ANY SITUATIONS THAT AROSE WHILE DRIVING THAT COULD HAVE BEEN SERIOUS WITHOUT THE **EATON-VORAD RADAR SYSTEM**. *RECORD ANY POTENTIAL COLLISIONS OR NEAR MISS SITUATIONS* WITH ANIMALS, AUTOS, PEDESTRIANS, ETC. COMMENT ON SYSTEM WARNINGS, WEATHER CONDITIONS, INCIDENT AND WHETHER OR NOT IT WAS AN EMERGENCY. THANK YOU!

DRIVER:__________ PLOW TRUCK: __________ ROUTE: __________ MILEPOST: __________

DATE	INCIDENT DESCRIPTION	EMERGENCY	NON – EMERGENCY	OUTCOME AND COMMENTS	TIME OF DAY	WEATHER CONDITIONS

ADDITIONAL COMMENTS: *(Return a copy of this form to ATRC at Maildrop 075R)*

EATON VORAD

XVISION COMMENT SHEET for Situations - ADOT

PLEASE TAKE A FEW MINUTES TO RELATE ANY SITUATIONS THAT AROSE WHILE DRIVING THAT COULD HAVE BEEN SERIOUS WITHOUT THE **BENDIX XVISION SYSTEM**. *RECORD ANY POTENTIAL COLLISIONS OR NEAR MISS SITUATIONS* WITH ANIMALS, AUTOS, PEDESTRIANS, ETC. COMMENT ON SCREEN POSITION, WEATHER CONDITIONS, INCIDENT AND WHETHER OR NOT IT WAS AN EMERGENCY. THANK YOU!

ADOT DRIVER: ____________ PLOW TRUCK ________ ROUTE __________ SCREEN POSITION: DASH / VISOR

DATE	INCIDENT DESCRIPTION	EMERGENCY	NON – EMERGENCY	OUTCOME /COMMENTS	TIME OF OCCURANCE	WEATHER CONDITIONS

ADDITIONAL COMMENTS: *(Return a copy of this form to ATRC at Maildrop 075R)*

Bendix

DRIVERS' EVENT & ACTIVITY REPORT COMMENTS

1. EVT-300 radar comments submitted by four Eaton VORAD project snowplow crews.

Date	Incident Description	Outcome & Comments	Time of Day	Weather Conditions
1-29-03	Drove truck to Phoenix	System worked good	Day shift	Fair
2-25-03	Overtook one vehicle in fog, radar responded normally	Radar works well in fog	Night shift	Moderate to heavy ground fog
2-26-03	Came up on a semi truck in very low visibility and heavy snowfall. (Radar) did not pick up the vehicle.	Radar started picked up objects again until it stopped snowing.	Midnight	Heavy snowfall and very low visibility.
2-26-03	Alerts from roadside in fog	Radar gave alerts from bridge and off-ramp sign	Night shift	Medium to heavy fog, visibility 50 ft to 300 ft.
2-28-03	Picked up semi trucks, bridges, and vehicles	OK	Day shift	Snowing off & on, plowing slush
3-01-03	Picked up semi trucks, overpass,vehicles	OK	Day shift	Snowing off & on, slush on road
3-01-03	Emergency - Traffic Accident	Radar picked up a pedestrian in the dark before I had seen him.	7:15 PM	Medium snowfall, snowpacked & icy
3-01-03	Lost some detection range	Caused by snow buildup on antenna	3:00 – 9:00 PM	Medium snowfall, slush & snowpack
4-15-03	Warnings in dips on SR 89	Radar does alarm in deep dips, sems to work OK in light fog.	Day shift	Medium snow, slushy roadway

2. Bendix night vision comments submitted by three XVision project snowplow crews.

Date	Incident Description	Outcome & Comments	Time of Day	Weather Conditions
10-26-02	Person walking at side of roadway	Able to see with night vision before headlights	10:15 PM	Partly cloudy
11-25-02	Iced up within a mile, in snowfall, cleaned it 5 times.	(Lens heater) Never cleaned itself.	7:00 PM	Medium to heavy snow, visibility 50-100 ft
11-30-02	Icy road, sanding, no visibility in fog	Heavy fog, could not see anything.	Night shift	Thick fog, zero visibility
12-17-02	Night owl flying; coyote in middle of road 200 feet ahead	Able to see with night vision before with the headlights.	7:30 & 8:15 PM	Partly cloudy
12-18-02	Working well	Worked great – lens hot!	Night shift	Light snowfall
12-22-02	With XVision I could see wheel paths from oncoming traffic		8:30 PM	Medium snowfall

Date	Incident Description	Outcome & Comments	Time of Day	Weather Conditions
12-22-02	While it was snowing I could see better where I had already plowed		8:30 PM	Medium snowfall
12-22-02	Erratic heater, road film baked on hot lens	½ time lens too hot to touch, ½ time ice cold.	Night shift	Light-medium snow, snowpack
12-23-02	When snowing, I could see elk at the side of the shoulder better		1:30 AM	Light flurries
12-23-02	Saw elk eating on side of roadway	System is working	9:00 PM	Light snow
12-24-02	When doing cleanup of roadway, can see where you just plowed	Still need a good storm	1:00 AM	Light snow
12-29-02	Saw a rabbit	Saw it ahead of (lights)	9:00 PM	Light snow
1-06-03	Snow packed in lens		Day shift	Med snow, slush
2-08-03	Jackrabbit, elk & coyote	Could see them running across road	10-12 PM	Clear
2-09-03	Fog	Could see a lot better ahead; lens iced up on day shift		Clear
2-13-03	Rain	XVision fuzzy when raining hard.	1:00 AM	Rain
2-13-03	Rain & Fog	Light rain & fog; can still see good.	4:30 AM	Rain & fog
2-25-03	Ice, slush – plowing	Stop twice to clean lens	Night shift	Medium snow – 50 ft visibility
2-25-03	Iced up – air temp 34	Ice formed on lens, no heat apparent	Day shift	Light snow, 200 ft
2-26-03	Snowpack – plowing	Clean the lens 5 times	Day shift	Medium snow – 200 ft visibility
2-26-03	Iced up, turned off	Would not restart	Day shift	Medium snow & 50 ft vis
2-26-03	Ice, slush – plowing	Clean lens three times	Night shift	Med snow – 200 ft
2-27-03	Snowpack, slush - plowing	Clean XVision 18 times	Day shift	Heavy snow – 50 ft visibility
2-27-03	Snowpack, slush - worked great	No problems plowing	11:00 AM - 1:00 PM	Heavy snow, & 200 ft visibility
2-27-03	Storm patrol, clear roads, fog & rain	System worked excellent in foggy conditions; poor screen image when raining	Night shift	Some fog, and rain
2-28-03	Snowpack, slush, windy - plowing	Clean lens 3 times	Night shift	Light snow, 200 ft
4-15-03	Plowing, slush & medium snow	Lens was snowpacked all day	Day shift	Med. Snow, 100 foot visibility

APPENDIX G

ADOT - ATRC DRIVER SURVEYS: RADAR

EATON VORAD EVT-300 RADAR - Long-Term Evaluation Response Summary
2002-03

Overview:

This survey was administered twice to most of the project snowplow drivers – in mid-winter and at the end of the season. All four Eaton VORAD systems were installed by 04 February 2003.

Because of the very limited number of participants, the responses and scores are listed for each topic, and also averaged. Individual field sites are not identified. Not all of the same drivers took both surveys. All responses below are grouped into mid-winter (March) and end-of-winter (June) perspectives.

Part 1.

The statements listed below address key evaluation goals for the EVT-300 system. Each plow operator has marked the numeric scale as best represents his opinion of the system, and any comments to explain the ratings are shown also. With 4 as the scale's midpoint, scores from 3.6 to 4.4 show a *Neutral* rating.

Example: I could more effectively complete my driving tasks.

Strongly Disagree	*Disagree*			*Agree*	*Strongly agree*		
1	*2*	*3*	*4*	*5*	*6*	*7*	N/A

1. I would buy an EVT-300 radar system, if I owned my own truck.
- a. Mid-winter: 2, 4.5, 4, 5, 4, 5, 3, 2.5, 3.5 = Avg 3.7 - *Neutral*
- b. Post-season: 4, 3, 4, 4, 1, 3, 1, 6, 1 = Avg 3.0 - *Disagree*

2. My safety on the road is significantly improved when I use the EVT-300 radar.
- a. Mid-winter: 2, 4, 4, 5, 4, 5, 3, 2.5, 4.5 = Avg 3.8 - *Neutral*
- b. Post-season: 4, 3.5, 5, 4, 3, 1, 2, 6, 4 = Avg 3.6 - *Neutral*

3. I feel my ability to detect and react to objects in the road is significantly improved with the EVT-300 radar system.
- a. Mid-winter: 3.5, 5, 5, 5, 4, 5, 3, 4, 4.5 = Avg 4.3 - *Neutral*
- b. Post-season: 4, 3.5, 5, 4, 3, 2, 2, 6, 4 = Avg 3.7 - *Neutral*

4. I feel my overall driving ability is significantly improved with the EVT-300 radar system.
- a. Mid-winter: 4, 5, 4, 4, 4, 5, 3, 2.5, 4.5 = Avg 4.0 - *Neutral*
- b. Post-season: 4, 4.5, 4, 4, 3, 3, 1, 5, 5 = Avg 3.7 - *Neutral*

5. I feel my ability to use the EVT-300 radar system is significantly <u>reduced</u> by noise in the cab, from other systems, rough road conditions or when the truck vibrates.
- a. Mid-winter: N/A, 5.5, 5, N/A, N/A, 3, N/A, N/A = Avg 4.5 - *Agree*
- b. Post-season: N/A, 4, N/A, N/A, 3, N/A, 1, 2, 4 = Avg 2.8 - *Disagree*

6. After the long night of driving with the EVT-300 radar system, I felt that fatigue significantly <u>reduced</u> my driving ability.
- a. Mid-winter: N/A, N/A, 4, 4, 3, 1, 3, 3.5, 3.5 = Avg 3.1 - *Disagree*
- b. Post-season: 4, 5, 5, 5, 6, 3, 1, 2, 5 = Avg 4.0 - *Neutral*

7. I feel the EVT-300 system warnings are clear and effective for object detection.
- a. Mid-winter: 3.5, 4.5, 5, 5, 5, 5, 4, 4.5, 4 = Avg 4.5 - *Agree*
- b. Post-season: 4, 5, 5, 5, 3, 4, 2, 6, 4 = Avg 4.2 - *Neutral*

8. I could easily focus on the road without becoming distracted by the EVT-300

a. Mid-winter: 3.5, 5, 4, 5.5, 5, 5, 4, 3.5, 4.5 = Avg 4.4 - *Neutral*
b. Post-season: 5, 5, 5, 5, 3, 4, 5, 6, 7 = Avg 5.0 - *Agree*

Part 2. General Preferences

1. List the two things you liked most about the EVT-300 radar, and describe why.

a. Mid-winter:

- Beeps when someone is in front of you.
- Radar was helpful when I was plowing the fast lane – vehicles would at times be in a blind spot alongside the plow.
- It detects vehicles on your right side (blind spot).
- Not obtrusive; warning bells do make you alert.
- When plowing in the left lane, the side sensor helps to let you know when a vehicle is passing or is in your blind spot.

b. Post-season:

- The right side sensor is pretty handy – alerts you when vehicle is in your blind spot on right side.
- It alerts you when coming upon a slow-moving vehicle.
- The detection of vehicles or other objects along the right side.
- Ease of operation – always on when using the truck.
- Low maintenance – just keep sensors clean and check wires.
- I was not using the equipment as much as expected.
- The advance warning.
- The ability to see cars in the blind spot on the right side of the truck.

2. List the two things you disliked most the EVT-300 radar, and describe why.

a. Mid-winter:

- Hard to see warning lights during daytime.
- System display mounted behind steering wheel.
- System picked up bridge columns causing me to focus ahead quickly, which took my eye off the traffic behind me.
- Mounting on dash – would like to have display mounted above windshield, more in line of sight.
- When it sounds off it's very alarming and startles you most of the time.

b. Post-season:

- The beeper goes off when going under bridges; you begin to ignore the system.
- The mounting of the sensor display unit is in the wrong place. The steering wheel is in the way, and you can't see the lights until it beeps.
- The detection of bridge columns.
- Main display location would be better mounted at top of windshield, more normal driving view.
- Will startle you.
- Warning system doesn't come on soon enough.
- It gives false signals both by going off when there is nothing there, and not going off when an object is ahead of you.

Part 3. Open-ended Questions

1. With regard to fatigue, describe how you felt at the end of your shift. Do you feel your state (tiredness, attention span) was affected for better or worse by using EVT-300 radar? Do you feel that fatigue affected your performance?

a. Mid-winter:
- Attention span (divided between) roadway and system.
- I was not very tired after using the radar because the beeping it produced kept me more alert.
- No change from normal.
- It does help keep me more alert watching the contact distances.
- No difference.

b. Post-season:
- My overall state was not affected and my performance was not affected by the EVT-300.
- At the end of my shift I didn't feel tired, this is probably due to the system. When the system was activated, I was ready to slow down.
- It was about the same.
- I feel that in hard-to-see conditions the EVT-300 did help out considerably.
- Fatigue always affects your abilities, the radar does not change this.
- The time I spent on the truck was not sufficient to answer.
- Worse, all the false alarms make it hard to drive.
- I felt the same as without it, but it did help when my attention span was low.
- Fatigue has not been a factor because we have had no real snow.

2. Preferred radar range. Do you feel the current range is acceptable? If not, how far out in front of the truck would you like the system to "see"?

a. Mid-winter:
- Right now it's 300 feet – change to 500 feet.
- Radar range is okay. Many times passing trucks would move back into the driving lane and the radar would beep.
- Range is acceptable at 310 feet but the alarm needs to be set when the red light first comes on.
- So far the range seems to be OK.
- No, it needs to warn you further out.

b. Post-season:
- The system range is acceptable.
- The radar range is far enough. At times vehicles passing will turn back into the travel lane and will activate the system.
- The range seems to be good right now.
- Yes – acceptable.
- 500 feet would be better.
- No, not acceptable.
- The range is good. If it went out any further it would be going off too much.
- I really agree with the range.

c. Preferred system warnings. Was the audible or the visual alarm more effective for target warning information? Did any of the system elements interfere with your driving? Would you have preferred more adjust in the setting?

a. Mid-winter:
- Audible warning was effective. The only interference was the false warning of bridge columns.
- The alarm comes on a little too late. May need to adjust where the alarm comes on earlier.
- The two alarms together are working well.
- Audible is more noticeable, but when you're tired it is startling.

b. Post-season:
- Everything is OK, but the mounting for the visual alarm needs to be relocated.
- The alarms seem to be effective in getting the warning across.
- Both warnings seem to work well. There has been no interference, the settings work fine.

- I feel it did fine.
- No interference, and no more adjustments.
- Both together work good.
- Settings are good.

4. Please make <u>any further comments</u> regarding advantages and disadvantages of the EVT-300 radar system below.

a. Mid-winter:
- I have not needed the system currently as visibility is pretty good; the least is about ½ mile.
- So far the system seems to be working well.

b. Post-season:
- Still had to use my own skills to do my job.

<u>Part 4. Your Overall Recommendations – Post-Season:</u>

1. Your summary of storm experience <u>on average for the entire winter</u> - how useful was the Eaton VORAD EVT-300 for you in:

a. Fog?
- Good warning.
- Worked well.
- Helped out in hard-to-see conditions.

b. Rain?
- Good warning.
- Worked well.

c. Light Snow?
- Average.
- Good warning.
- Worked well.

d. Heavy Snow / Whiteouts?
- Sometimes useful and sometimes not.
- Warning slightly altered because of buildup of snow on system (antenna).
- Worked well, as long as buildup is not severe.
- Worked good.
- Worked well in all aspects of weather; you just need to clean the radar antenna in heavy snow.

2. Is the system useful for you in any other operations apart from night plowing? Please describe:
- It is useful in daytime driving and warns you when you are coming upon a slow-moving vehicle.
- No, snow plowing is the only operation that the system is useful (3 “no” replies).
- It works just as well when driving in heavy traffic.
- Works great for the passenger-side blind spot.
- City driving during snow, it helps with cars pulling in front of you.

3. How many other snowplow operators in your Org have driven or ridden in your truck? What comments on the system did they have?
- (Chambers) Two other drivers, with no comments.
- (Seligman) One other - did not like the alarms; he did not understand what all it was telling him.
- (Flagstaff) None.
- (Gray Mountain) Four or five people. No comments as they didn’t use the system.

4. Are there any other plow routes in your Org where this system would also be useful? If so, how many plow trucks, and roughly how many plow route miles?

- (Chambers) There are other routes all along I-40 that should have this system or a similar system installed.
- (Seligman) All seven routes, about 620 plow miles.
- (Flagstaff) Not really; N/A.
- (Gray Mountain) This system would not work for snow activities elsewhere in our area.

5. Based on your experience with this research project, should ADOT purchase more of these systems for those snowplow routes where impaired visibility is a frequent and serious problem?

- I think ADOT should put the systems in all snowplow trucks.
- ADOT should purchase additional systems where severe storms occur. The other additional places that might need this system are where there are high volume traffic areas.
- This product is very useful for over-the-road trucks. A plow truck has too many things in the way.
- The VORAD system would work better if used for summer driving.
- If it snowed more it would be useful but visibility (this season) has always been good.
- Yes, this system works without being too intrusive.
- Yes.
- No (2 replies).

<u>*NOTES:*</u>

- Not all of the nine primary operators completed Part 4 of the survey.
- The final survey included one new driver with very limited training.
- The four EVT-300 snowplows were normally in use on SR 89 and I-40.
- The number of shifts using the system that 7 drivers reported were 7, 6, 6, 5, 2, 30, and 2.
- Due to install dates and varying weather conditions, maintenance and weather records indicate that the EVT-300 system was actively in use over the winter for plowing and storm patrol as follows:

  - Seligman – 9 days, with 6.4 total inches of snow on the assigned plow route.
  - Flagstaff – 20 days, with 35 inches of snow on the route (Walnut Canyon weather site).
  - Gray Mountain – 32 days, with 27.5 inches of snow on the route (Sunset Crater).
  - Chambers – 12 days, with no snow recorded on the route (Sanders POE).

APPENDIX H

ADOT - ATRC DRIVER SURVEYS: NIGHT VISION

BENDIX XVISION - Long-Term Evaluation Response Summary
2002-03

Overview:

This survey was administered as many as three times to the drivers – in early winter, mid-winter and at the end of the season. All XVision systems were installed by 03 December 2002.

Due to the very limited number of participants, the responses and scores are listed for each topic, and also averaged. Individual field sites are not identified. Not all of the same drivers took both surveys. Responses are grouped into pre-, mid- , and end-of-winter perspectives (December, February, & May).

Part 1.

The statements listed below address key evaluation goals for the XVision system. Each plow operator has marked the numeric scale as best represents his opinion of the system, and any comments to explain the ratings are shown also. With 4 as the scale's midpoint, scores from 3.6 to 4.4 show a *Neutral* rating.

> Example: I could more effectively complete my driving tasks.
>
> *Strongly Disagree* *Disagree* *Agree* *Strongly agree*
> □ ——— ○ ——— □ N/A
> *1 2 3 4 5 6 7*

1. I would buy an XVision system, if I owned my own truck.

a. Pre-winter (December '02): 4, 7, 4, 6, 7, 6 = Avg 5.7 - *Agree*
- I really enjoy seeing all objects both on and off the highway.

b. Mid-winter (February '03): 7, 5, 7, 4.5, 1, 6 = Avg 5.1 - *Agree*

c. Post-season (May '03): 4, 7, 1, 7, 4.5, 6 = Avg 4.9 - *Agree*

2. My safety on the road is significantly improved when I used the XVision system.

a. Pre-winter: 5, 5, 5.5, 6, 7, 7 = Avg 5.9 - *Agree strongly*
- I really like the system, especially seeing around curves.

b. Mid-winter: 7, 3, 5, 4.5, 1, 6 = Avg 4.4 - *Neutral*
- Except in snow.

c. Post-season: 6, 2.5, 6, 1, 5, 3 = Avg 3.9 - *Neutral*

3. My ability to detect and react to objects in the road is significantly improved with the XVision system.

a. Pre-winter: 6, 4, 6, 5.5, 6, 7 = Avg 5.8 - *Agree*

b. Mid-winter: 4, 3, 5, 5, 1, 7 = Avg 4.2 - *Neutral*

c. Post-season: 3, 6, 1, 7, 5.5, 6 = Avg 4.75 - *Agree*

4. My overall driving ability is significantly improved with the XVision system.

a. Pre-winter: 7, 6, 4, 5, 5, 5.5 = Avg 5.4 - *Agree*
- I don't think Xvision could improve my driving – just make me more aware of surroundings.

b. Mid-winter: 1, 2, 3, 4.5, 1, 6 = Avg 2.9 – *Disagree*
- Not in snow.

c. Post-season: 3, 5, 1, 6, 1.5, 5 = Avg 3.6 – *Neutral*

5. I feel my ability to use the XVision system is significantly reduced on rough road conditions or when the truck vibrates.

a. Pre-winter: 6, 4, 2, N/A, 3, 3 = Avg 3.6 - *Neutral*
- The LCD screen is very stationary, and does not move.

b. Mid-winter: N/A, 2, 3, N/A, 3, 5 = Avg 3.25 - *Disagree*
c. Post-season: 3, 4, N/A, 6, 3.5, 4 = Avg 4.1 - *Neutral*

6. After a long shift of driving with the XVision system, I felt that eye fatigue significantly <u>reduced</u> my driving ability.

a. Pre-winter: N/A, 4, 2, 4, 5, 1 = Avg 3.2 - *Disagree*
b. Mid-winter: N/A, 3, 3, 4.5, 5, 4 = Avg 3.9 - *Neutral*
c. Post-season: 4, 6, N/A, 5, 2.5, 4 = Avg 4.3 - *Neutral*

7. I feel the image resolution was adequate for object detection.

a. Pre-winter: 7, 7, 4, 4, 4, 6 = Avg 5.3 - *Agree*
b. Mid-winter: N/A, 3, 5, 4.5, 1, 6 = Avg 3.9 - *Neutral*
c. Post-season: 4, 4.5, 6, 1, 6, 3 = Avg 4.1 - *Neutral*

8. I feel I could easily focus on the road without becoming distracted by the XVision system.

a. Pre-winter: 7, 7, 7, 4, 3, 5 = Avg 5.5 – *Agree*
- I barely have to adjust my sight to see the screen where it is located.

b. Mid-winter: N/A, 3, 6, 4.5, 1, 6 = Avg 4.1 - *Neutral*
c. Post-season: 3, 6, 1, 3, 6, 5 = Avg 4.0 - *Neutral*

<u>Part 2. General Preferences</u>

1. List the two things you <u>liked</u> most about the XVision system, and describe why.

a. Pre-winter:
- Seeing around curves.
- See better.
- See roadway better, and curves and trees.
- See a long way down the road.
- Seeing people, animals and cars.
- Safety.
- Helps you see more of what's ahead of you.
- Picks up anything with a heat source.

b. Mid-winter:
- Still could see objects in fog; see around curves.
- Detects objects on shoulder of road.
- Could see better at night - see animals a lot better.

c. Post-season:
- Helps seeing things at night a lot better.
- See around curves; see through fog.
- See better generally, especially see objects better in roadway.
- Able to see elk hazards; able to see cars and people.
- When it was not snowing I could pick out objects .

2. List the two things you <u>disliked</u> most the XVision system, and describe why.

a. Pre-winter:
- The lens plugs up.
- Ice build-up around the lens.
- Need better adjustments on unit to see more clearly – for LCD display contrast.
- Ices up all the time in snow conditions and salt buildup, both make it unusable.
- Sunset – screen was blurred.
- Vehicles changing lanes in front of me look closer than they are.

b. Mid-winter:

- Iced up.
- Rain conditions – blurred screen.
- Screen not clear, fuzzy most of the time.
- Camera lens cover when wet, you can't see or focus on objects on screen.
- I do not like it - hard to see; snow packs on the camera.
- When it's raining it gets fuzzy.
- The XVision should move with the roadway.

c. Post-season:

- It always plugs up when it's snowing.
- Did not work in snow!!
- Snow on the system – hard to see.
- Cleaning the lens during winter storms.
- Fuzzy when raining a lot.
- Rain conditions.
- Too fuzzy on the screen – needs to be more clear.

Part 3. Open-ended Questions

1. With regard to fatigue, describe how you felt at the end of your typical plow shift. Do you feel your state (tiredness, attention span) was compounded by using XVision? Do you feel fatigue affected your performance?

a. Pre-winter:

- N / A
- At first, but now I've gotten used to the system
- It gave me something to look at when I wanted to see way up the road, I lookeed at the screen and didn't have to strain my eyes.
- With headlamps of oncoming cars, I can look at the screen and have less eyestrain.
- Some eye fatigue after 10 to 12 hours of driving.

b. Mid-winter:

- No fatigue, no effect on performance (2 replies).
- After a 12-hour shift at my age (59) I am tired, but with regard to the XVision, I do not see any more fatigue due to this system.

c. Post-season:

- Tired & fatigued after 12-hour shifts, but not from XVision.
- I feel the XVision had nothing to do with tiredness. Fatigue did not affect my performance.
- When I first used the system I felt fatigue, but when I got used to it I felt better using the system.
- The same as any (other) shift.
- No, I could watch the screen and then the road. I didn't have to stare just at the road.

2. Preferred camera range. Is the current range acceptable? Is the field of view (side to side, up and down) acceptable? If not, what changes would improve the usefulness of the system to "see"?

a. Pre-winter:

- Yes (2)
- I love the way my lens is set.
- I feel the camera range is great.

b. Mid-winter:

- Yes, everything is good.
- For myself the current range is acceptable.

- Yes (2 replies).

c. Post-season:
- Yes – acceptable (2 replies).
- Current range is great.
- Range is just fine – view just right for distance, and up and down too.
- Need more side-to-side range.

3. Preferred screen contrast and brightness level. Was the adjustment range on the units adequate for target detection? Did it interfere with your driving?

a. Pre-winter
- Contrast setting was a great help; adjusted for my preference. Nothing interfered with my driving.
- Contrast was adequate, no interference, no need to adjust settings.
- Prefer being able to adjust settings somewhat.
- Contrast setting was good.

b. Mid-winter:
- No – no interference (3replies).
- Yes, adequate contrast, no interference.
- Need adjustments for this setting, and any others.

c. Post-season:
- Most of the time, did not interfere with my driving.
- Yes (adequate), did not interfere with driving.
- It was just fine – did not interfere (2 replies).
- It was very adequate.

4. Please make any further comments regarding advantages and disadvantages of the XVision system.

a. Pre-winter:
- A washer system would be a lot better for melting ice buildup, on or around the lens housing, wiring, etc. – need to try different deicer fluids if not corrosive to lens.
- Need more time with the unit to comment more on it.
- I think XVision is better than (other tests with) radar and Caltrans system (magnet guidance).
- Let's get the heater situation worked out and you should have a great system.
- I think it will help greatly, and am glad to have the opportunity to run it.

b. Mid-winter:
- Everything good for now.
- Disadvantage when wet, can't make out what's on the screen.

c. Post-season:
- Need good heating system on the camera.
- Wish it would have worked during snow.
- Hard to focus on it.
- Snow gets on the camera and you cannot see.
- Very pleased with the system, but snow blowback from the plow dirties the lens a lot.
- When wet, raining or wet snow, hard to make out what's on screen because of wetness.
- The system is a great help – I look forward to next year.

Part 4. Your Overall Recommendations – Post-Season:

1. Your summary of storm experience on average for the entire winter - how useful was XVision for you in:

a. Fog?
- N/A (2)
- Was OK.
- Excellent.

b. Rain?
- N/A
- It was fuzzy.
- Poor.
- Not very useful when wet.

c. Light Snow?
- As long as lens didn't get wet, XVision was most useful.
- Excellent.
- Worked really good.

d. Heavy Snow / Whiteouts?
- Did not have any whiteouts.
- Excellent.
- We didn't get much snow here this year – about two storms only.

2. Is the system useful for you in any other operations apart from night plowing? Please describe:
- You are able to see more what's on the shoulder and road, which I think makes it more safe.
- No.
- Daytime too, could see roadway better and objects clearer.
- All day.

3. How many other snowplow operators in your Org have driven or ridden in your truck? What comments on the system did they have?
- (Little Antelope) One other – no comments noted.
- (Winslow) One other – he doesn't like the system too much.
- (Kingman) One other – had about the same comments as I did (positive except rain issues).

4. Are there any other plow-routes in your Org where this system would also be useful? If so, how many plow trucks, and roughly how many plow-route miles?
- (Kingman) It would be useful on US 93, and SR 66 (57–123); that would mean two more trucks.
- (Winslow) Need to try system on I-40 to see how it works with more <u>traffic</u> and <u>slideoffs.</u>

5. Based on your experience with this research project, should ADOT purchase more of these systems for those snowplow routes where impaired visibility is a frequent and serious problem?
- No (2 replies plus 1 blank).
- Yes I do!!!!!!
- Yes – useful in winter weather.
- Sure!

<u>NOTES:</u>
- Not all six primary operators responded to Part 4 of the survey.
- The plows were normally in use on I-17, SR 87, and I-40.
- The number of shifts that four drivers reported using the system were: 10, 25+, 15, and 20.
- Due to install dates and varying weather conditions, maintenance and weather records indicate that XVision was actively in use over the winter as follows:
  - Kingman – 5 days, with 13 total inches of snow on the assigned plow route.
  - Little Antelope – 37 days, with 55 inches of snow on the route.
  - Winslow – 22 days, with 39 inches of snow on the route.

APPENDIX I

EATON VORAD SMARTCRUISE EVALUATION RESULTS

EVT-300 RADAR SYSTEM – SMARTCRUISE EVALUATION

PART 1 – OBJECTIVE

Criteria	Measurements	Notes & Comments
Preset Speed Control – Accuracy	The Mack cruise control was effective in holding speeds within 1 mph, slight variation on grades. (SmartCruise will override factory cruise control)	Plow F342, with manual transmission, was able to hold speed accurately on its factory cruise control. There was no apparent loss of accuracy with the VORAD SmartCruise engaged to "hook up" with and follow the target vehicle.
Following Distance – Consistency	Following distance varied from 250 ft to 310 ft, as based on travel speed vs the time interval setting. Ranges varied slightly, +/- 10 to 15 ft, while tracking a target vehicle.	SmartCruise will follow at from 2.25 to 3.25 seconds separation, based on real-time speed of the vehicles. Even in hilly terrain, SmartCruise did maintain a fixed following distance for long periods. Any variations seemed to be primarily due to speed fluctuations of the target vehicle.
Following Speed and Distance – Accuracy	Normal ProLink readings consistently differed by only +/- 0.2 to 0.5 mph . Readings varied more, up to +/-1.5 mph, on grades. Ranges varied +/- 15 ft.	The ProLink diagnostic tool with VORAD card produced excellent following-speed results. Larger variations in hilly areas indicate that the target vehicle probably could not exactly maintain a steady speed, even if they had cruise control.
Effect Of Vehicle Sizes – Following	No significant issues – had consistent results with several different vehicle types.	Vehicles tracked included a Ford Contour sedan, a Chevy S-10 pickup, and two 18 wheelers – a cargo trailer and a gas tanker.

EVT-300 RADAR SYSTEM – SMARTCRUISE EVALUATION

PART 2 – SUBJECTIVE

Criteria	Notes & Comments
Smoothness – Engagement / Disengagement	The operator reported no problems with SmartCruise engaging the normal Mack cruise control. It engaged smoothly to both accelerate and decelerate the truck to “hook up” with the target vehicle. Application or cutting back of the throttle and engine brake were apparent but not obtrusive.
Positive Driver Overrides – Brake & Accelerator	Any overrides simply acted on the basic Mack cruise control system, and were not a problem for the driver. The SmartCruise is transparent in this aspect.
Operation In Curves	The ProLink often showed a brief target loss of one to two seconds when entering a curve. This is the normal timeframe for the yaw sensor to read the curve and adjust the beam pattern. The driver did not perceive a loss of cruise control in curves , however, as the system recaptured the target immediately.
Operation On Grades	The effect of Interstate-standard grades on the Mack cruise control was minor. Some target vehicles, especially those without cruise, showed variations, which the SmartCruise was able to deal with.
False Warnings From Roadside Objects	On the I-40 test route, no problems were noted.
Response To Vehicle Cutting In	Vehicles generally cut in at least 120 feet ahead, and were immediately acquired by the system. If they continued at a faster pace, the SmartCruise did not respond but the warning lights did. If they cut in and slowed, the SmartCruise acted to decelerate.
Effect Of Vehicle Size – Cutting In	The vehicle size did not seem to be a factor in warning response or in the SmartCruise tracking & following performance.
Effects Of Inclement Weather - Dust / Fog / Rain / Snow / Mud / Heat / Cold	Not tested in this case.
Warnings – Type and Intensity	The system performed normally in testing. The operator was familiar with all warning modes and had no problems or concerns.
Operator Confidence Level	This operator had not used SmartCruise on a regular basis since the installation on March 10th-11th. At the end of the test session, he was comfortable with the system. He felt confident that it was working as designed and did improve performance and safety.
Operator Fatigue Factors	The SmartCruise should provide real safety benefits for long-haul trips where driver fatigue, inattention and distraction can be factors.
Overall Satisfaction – Suitability for Driving Tasks	Based on the test performance and the consistent results, the SmartCruise appears to be a valuable safety feature for long trips.

EVT-300 RADAR SYSTEM – SMARTCRUISE EVALUATION

Snowplow: *F342*
Site: *I-40: MP 204-230*

Test Instruments:

- *ProLink Engine Diagnostic System*
  With Eaton VORAD system cartridge
- *Stalker Speed Radar Gun*
- *Bushnell Lytespeed 400 Infrared Rangefinder*

Test Runs	Test Conditions	ProLink – VORAD Diagnostics	Rangefinder & Speed Radar
1	Target: Red S-10 Pickup Speedometer: 55 mph EB gradual downgrade	Speed: 55 +/- 0.5 mph Distance: 265 ft +/- 10 ft	Speed: 55 +/- 1 mph Distance: 93 yd / 279 ft
2	Target: 18 wheel cargo Speedometer: 65 mph WB gradual upgrade	Speed: 65 +/- 1.5 mph Distance: 300 ft +/- 10 ft (target dropped to 55 mph) (distance: 255 ft +/- 5 ft)	Speed: 63 mph Distance: 100 yd / 300 ft (distance 93 yd / 279 ft)
3	Target: 18 wheel tanker Speedometer: 65 mph EB gradual downgrade	Lost ProLink Connection	Speed: 64 mph Distance: 107 yd / 321 ft
4	Target: Ford Contour Speedometer: 65 mph WB gradual upgrade	Lost ProLink Connection	Speed: 65 mph Distance: 98 yd / 294 ft

NOTES:

1. SmartCruise can be set for 2.25 to 3.25 seconds of separation at any cruise speed:

   Design Following Distance - 55 mph: 182 to 262 feet
   Design Following Distance - 60 mph: 198 to 286 feet
   Design Following Distance - 65 mph: 214 to 309 feet

2. The maximum range for both cruise target capture and obstacle warning is 350 feet.
3. Hand-held readings provided a check on the ProLink, but were less precise.

APPENDIX J

TECHNICAL ADVISORY COMMITTEE

PROJECT OPINION SURVEY RESULTS: JUNE 2002

(NEW PROJECT DIRECTION FOR PHASE THREE – 2002-03)

Final 23 Jul 02

IVI / SNOWPLOW GUIDANCE RESEARCH PROJECT No. 473 TECHNICAL ADVISORY COMMITTEE

TAC OPINION SURVEY RESULTS: JUNE 2002
PROJECT RESULTS & PROJECT DIRECTION

Introduction – Since late 1997 this project has studied advanced vehicle topics, to identify the advantages of ITS to help ADOT improve the function and safety of the state highway system. ADOT has installed magnetic media in two Arizona highways, and has acquired new systems to the point that we now have access to three Advanced Snowplows in the Flagstaff area.

After four years of field research, we have answered some basic questions, and learned a great deal about some ITS systems. And, we have just begun to work with others. Now, ATRC has surveyed the TAC members on where ADOT and partners should go with this research project.

This short survey asked for the TAC's views on each major ITS system that the project has deployed for testing and evaluation. It also asked what the TAC feels has been achieved, and what the project can practically do next, with our budget and available ADOT resources.

* * * * * *

BACKGROUND – CURRENT PROJECT STATUS:

3M – Magnetic Tape is in place for 5 miles of US 89 (10 lane miles) at Sunset Crater.
Since 2000 (3M Corp. is on hold, but will still provide new mat'ls and repairs).
Truck System installed and supported (off warranty - repairs at ADOT's cost).

Caltrans – Magnets are in place for 6 lane-miles of US 180 at Kendrick Park.
Since 1998 (the IGA is open for another year, to June 03).
ASP System is available to ADOT for future winter evaluations (*radio required).

F342 3M and Collision Warning Radar – Both Installed and operating, over the past winter.
Support by 3M for repairs has been prompt and efficient – *our costs from now on.
Radar tech support & service has been spotty / Eaton hasn't invoiced, nor been paid.

F235 Night vision System – Installed & functional on I-17 plow route / truck cab issues.
Evaluation agreement at no cost / no tests or demos done yet / need different truck?

AVL GreyLink Vehicle Tracking System – two units – F342 and portable - both functional.
Flagstaff Snow Desk workstation / needs dedicated phone line, modem, and PC.
Problem areas: phone service / cell coverage / shared line / training materials.

*** Responses – 14 – TAC Members and Snowplow Operators-Team Leaders ***

A. SYSTEM CONCEPT PROS AND CONS? HOW IMPORTANT TO ADOT?

- **Caltrans Roadway-Magnet Guidance System?**

Position	Org	Comments
State Manager	Phoenix	I think this is an interesting technology. I think it might have merit for further deployment. Unfortunately, given budget shortfalls, this will not be a high priority in the near future. We are doing good right now just to keep snowplows running.
State Manager	Phoenix	Issue is cost / versus benefit to the state.
State Eqpt Mgr	Phoenix	This appears to be old technology relative to progress in other areas.
Maint Engineer	I-40 Dist	The infrastructure (embedded magnets) appears impractical for use on rural asphaltic concrete roadways. Application seems appropriate for PCCP. Low importance for ADOT.
Maint / District Engineer	I-40 Dist	The best system for guidance, but most labor intensive to install. Not fully developed to point of production. Most favored by drivers.
District Engineer	I-40 Dist	Pro: it is a positive control system with the magnets, truck system seems a little complicated but may be possible to modify to meet local needs in the future. Con: expensive to install in both roadway and truck, magnet life may be limited by future maintenance actions on the paved surface, system may be only limited to those areas that require the positive control, is dedicating truck to the one site reasonable?
Superintendent	I-40 Dist	N / C
Superintendent	I-40 Dist	The system seems to work well but it can only be tested when we have the Caltrans truck plus it would be unrealistic to try and install this type of system for at a large scale.
Dist Eqpt Mgr	I-40 Dist	Very interesting, however I feel we will never have the resources to purchase and install this elaborate a system.
Org Supervisor	I-40 Dist	The system has proven itself, with some changes – it all depends on money.
Org Supervisor	I-40 Dist	According to my crew, it's a little different from F342 (3M) but agree with magnet system and would help them out during snowstorms.
Operator	I-40 Dist	Fairly good idea. But cost and installation is too much to think about a longer area.
Operator	I-40 Dist	Some places we do need it.
Operator	I-40 Dist	Will work good during whiteouts.
ATRC		Caltrans says the 3 RoadView plows are successful, but the data is too poor to support more deployments now. Will work to improve hardware, but focus will be on rotary plows. Only Alaska and AZ have partnered. Caltrans plow available next winter.

- **3M Tape – Lane Awareness System?**

Position	Org	Comments
State Manager	Phoenix	I think this is an interesting technology. I think it might have merit for further deployment. Unfortunately, given budget shortfalls, this will not be a high priority in the near future. We are doing good right now just to keep snow plows running.
State Manager	Phoenix	Cost / installation. Maintenance of the tape ?
State Eqpt Mgr	Phoenix	A good product but the business failed. Practical where it can be overlaid one or more times.
Maint Engineer	I-40 Dist	Good potential due to concept and ability to sustain function after rehabilitation (overlays). Concern over product availability. Importance to ADOT – Moderate.
Maint / District Engineer	I-40 Dist	Good basic system. Concerns over lack of support from 3M due to them getting out of the business.
District Engineer	I-40 Dist	Pro: another positive control system with the tape, truck system seems a little less complicated then the magnet system Con: similar to the magnet system with the exception that the limitation on the number of trucks equipped to read the system may not apply.
Superintendent	I-40 Dist	Seems like this is a dying product.
Superintendent	I-40 Dist	This system seems to also work well and is more feasible to set up in a larger scale.
Dist Eqpt Mgr	I-40 Dist	If we were to pursue any system, this appears to be the one most compatible with our limited resources.
Org Supervisor	I-40 Dist	Is very costly and has some concerns on other pavement jobs going over the top.
Org Supervisor	I-40 Dist	My crew sure likes it. If only they had put 3M tape on both lanes, going southbound too.
Operator	I-40 Dist	The use of this is fairly simple. Everyone that I trained on it could run it their first try. Tape was a good idea but now that it is no longer made what good is it to keep testing unless we combine the different systems pros, to create a new system that works for everyone. But cost is an issue.
Operator	I-40 Dist	Works good.
Operator	I-40 Dist	Works good but tape goes on too small a section of road – need southbound 89 also.
ATRC		3M reports that there is no corporate interest in reopening the marketing of the tape product, although more material or hardware can be obtained. This snowplow is fully operational as regards the 3M system, US 89 NB.

- **Eaton VORAD Collision Warning Radar?**

Position	Org	Comments
State Manager	Phoenix	This has merit for warning snowplow operators of potential problems. As we begin to purchase new snowplows, we should consider including this as a standard item.
State Manager	Phoenix	I think this is more important than above items
State Eqpt Mgr	Phoenix	Good product that is soon to be OEM on more heavy trucks.
Maint Engineer	I-40 Dist	Not familiar with details of performance. Importance of application – high.
Maint / District Engineer	I-40 Dist	Great concept, but am not convinced that we have sold the idea to the drivers.
District Engineer	I-40 Dist	Pro: interesting concept that could help even in clear and dry weather in the future Con: I'm not sure we know where we're headed at this point and that Eaton has been somewhat non-responsive to our questions.
Superintendent	I-40 Dist	N / C
Superintendent	I-40 Dist	Most operators seem to like this system but it kind of gives you false impression of the obstacles that are out there.
Dist Eqpt Mgr	I-40 Dist	Let's take it to its limits before we judge.
Org Supervisor	I-40 Dist	Very helpful and can be used any time other than winter – Good Deal.
Org Supervisor	I-40 Dist	According to my operators the radar is a good system, it really helps when you need it. The question is will it really work during a whiteout snowstorm.
Operator	I-40 Dist	I like every part of this because we ,the operators, can use this all year round. I have used this and found that it increases the time for you to avoid a collision with an object that is in front of you. It also has the capabilities to record 20 seconds of an accident, that could be used in court or for equipment services.
Operator	I-40 Dist	Gives warnings ahead of you.
Operator	I-40 Dist	Warning system works good, we could use it.
ATRC		Radar worked well, within its design limits, in the second winter, but without snow. Several storms are needed for a valid test. The plan to test the SmartCruise feature should proceed, we have the funds and the vendor is interested in doing this.

- **GreyLink Automatic Vehicle Logging/Tracking (AVL) System?**

Position	Org	Comments
State Manager	Phoenix	Additional research should be done in the area of AVL. The technology seems to be catching on throughout the US, but Arizona does not have a lot of experience with this technology. AVL is more prevalent in the emergency services industry.
State Manager	Phoenix	Low priority
State Eqpt Mgr	Phoenix	A good resource for management, operational responsibility always lies with the driver.
Maint Engineer	I-40 Dist	Not satisfied with benefits or intention of utilization; concern with liability aspects. Importance to ADOT – low.
Maint / District Engineer	I-40 Dist	The AVL concept is good. However from what I have seen so far, the Greylink product is less than what I had envisioned and hoped it would accomplish. We need a system that an end user can operate easily, with little or no training and data is easily read and understood.
District Engineer	I-40 Dist	Pro: this is another system that would help during not only winter storms but during the clear and dry weather as well; system has possibilities in monitoring material usage, etc. in the future. Con: I'm not sure we totally know what technology infrastructure is required and how the way we do business fits with this device.
Superintendent	I-40 Dist	May need to go to satellite phone system for truck.
Superintendent	I-40 Dist	I don't see us using this system much until we have a more reliable phone system. It makes more sense trying to get the operators equipment that will make it safer for them to operate the equipment, than in tracking them with the limited funds we have.
Dist Eqpt Mgr	I-40 Dist	No real feel for this – no comment.
Org Supervisor	I-40 Dist	This can be very good for quick response to incidents, and if the truck needs help.
Org Supervisor	I-40 Dist	I've seen some papers on the tracking system (AVL). I agree with the research going on.
Operator	I-40 Dist	This is some what of a good idea but with being hooked up to a cell phone doesn't really give us a reliable way of communicating between that computer and AVL. There are other AVL that can be accessed through the internet that could be easier to communicate.
Operator	I-40 Dist	Works good, would use it.
ATRC		The concept of AVL seems very valuable to local & state fleet managers. This system, and support, has improved since the purchase, but is not so rural-user-friendly. Combined with phone and modem problems it has not proven out yet. Research can fund better hardware for SnowDesk, can upgrade the software again, and get more training. A test of this AVL or a different system in Phoenix may also answer our questions.

- **Bendix X-Vision Night vision Camera?**

Position	Org	Comments
State Manager	Phoenix	Could use some additional testing and demonstrations.
State Manager	Phoenix	Important – especially in those blizzard type of situations
State Eqpt Mgr	Phoenix	A good product, no chance to use it yet.
Maint Engineer	I-40 Dist	Potential for deployment is high – but mounting location and vibration concerns need more work.
Maint / District Engineer	I-40 Dist	This could be as important to ADOT as the snowplow guidance system, although I'll be the first to admit that I only know a little about the concept – that's all - don't know enough to comment.
District Engineer	I-40 Dist	Pro: It's really nice to know what is ahead of you before your headlights find it. Con: Do we really need it?
Superintendent	I-40 Dist	Need to do the tests and demo. Use existing truck if we can and new one if necessary.
Superintendent	I-40 Dist	I am hoping this will provide the operators with better vision of what they can't see with their eyes thus making it safer for the operators to perform their work.
Dist Eqpt Mgr	I-40 Dist	We need to fully test this, then evaluate.
Org Supervisor	I-40 Dist	N / C
Org Supervisor	I-40 Dist	My people said they really like it. They agree with the night vision system, it should help them during snowstorms.
Operator	I-40 Dist	This system is still new. I have used it during dry conditions and I thought it worked great but I would like to see how it would work under snow or rainy conditions.
Operator	I-40 Dist	Great distance vision.
Operator	I-40 Dist	Works good, I would use it.
ATRC		This unit deserves a full winter's testing to determine how it performs in various storm conditions. A summer partner is unlikely now, and snow is the key issue. We could move this to other snowplows every month or six weeks, to get a better cross-section of users and conditions.

B. THIS PROJECT'S FUTURE DIRECTIONS?

- **WHAT HAVE WE LEARNED?**

Position	Org	Comments
State Manager	Phoenix	The technology has potential benefits. There are still many issues around who will market this technology, and what is the business case?
State Manager	Phoenix	Not sure… delegated to others at district – thus do not feel comfortable answering this
State Eqpt Mgr	Phoenix	N / C
Maint Engineer	I-40 Dist	In my opinion, the 3M guidance, Bendix, and Vorad should be considered for expansion. The 3M system needs additional testing in a heavy winter.
Maint / District Engineer	I-40 Dist	We learned a lot about teamwork. We've learned a lot about 2 different guidance systems. We're received a lot of feedback on other things we should be studying. We've also learned that funding is a big issue and overshadows much of what we want to do. We learned a little about AVL.
District Engineer	I-40 Dist	The positive control systems have potential despite the initial costs in saving on equipment accidents, etc. There is a high cost in constructing positive control systems. There might be greater opportunities in focusing on the individual vehicle systems that are not totally tied to some hardwired or positive control systems.
Superintendent	I-40 Dist	There are a lot of things out there technically that should make it safer for the operators to perform their work It is not feasible to implement some of the new systems.
Dist Eqpt Mgr	I-40 Dist	3M System works, radar works but not fully tested, the night vision works but value uncertain.
Org Supervisor	I-40 Dist	That it takes a lot of time and effort to research all all that has been done. We have learned a lot about vendors that are out there, materials, and ways to use them.
Org Supervisor	I-40 Dist	My crew are saying IF only it would snow really bad to see if the systems really would help them.
Operator	I-40 Dist	We have learned that there are ways of keeping us and the public safe during a snow storm. But also we have found out the cost of that and it is more than people are willing to spend.
Operator	I-40 Dist	More safety on the road at night.
Operator	I-40 Dist	Need more snow and whiteouts to use the systems.
ATRC		We have learned a lot about the state of the art in guidance and warning systems. We've learned that rural AZ conditions, even in a mild winter, can limit the use of some of these systems. We have also learned what ITS systems may be most valuable, considering ADOT's slim resources. We have learned the costs, benefits, and limits, of both guidance systems.

- **WHAT HAVE WE NOT LEARNED YET?**

Position	Org	Comments
State Manager	Phoenix	Would be nice to have more time and experience in live winter conditions.
State Manager	Phoenix	N / C
State Eqpt Mgr	Phoenix	What is the ideal snowplow (blade system) design? What is the ideal snowplow truck, and, what is feasible?
Maint Engineer	I-40 Dist	N / A
Maint / District Engineer	I-40 Dist	Implementation plan. Night vision. Other AVL product possibilities.
District Engineer	I-40 Dist	The cost/benefit of the different systems, mainly due to the fact that we have not been able to compare data of accidents, closures, delays due to plow downtime that these systems would impact. How the data collected will inter-relate with the data from the free agent vehicle systems to provide choices between hardwired and free agent approaches.
Superintendent	I-40 Dist	N / C
Superintendent	I-40 Dist	How to provide more vision for our operators through wipers/lighting.
Dist Eqpt Mgr	I-40 Dist	Radar and night vision – usefulness.
Org Supervisor	I-40 Dist	How to get things at a lower price. Are there other vendors out there?
Org Supervisor	I-40 Dist	Don't know at this time, but what information we have should help us.
Operator	I-40 Dist	We have to learn how to make things safe with out increasing the cost that people are willing to spend.
Operator	I-40 Dist	N/C
Operator	I-40 Dist	N/C
ATRC		We have not learned <u>how much</u> any specific system can help our plow operators and supervisors. We can't measure improvements or benefits, especially in mild winters. We know costs and driver satisfaction levels, but not the specific benefits on the roadway or at the District office. We still have specific on-board systems waiting to be evaluated.

- **<u>WHAT ELSE</u> COULD THE I.T.S. SNOWPLOW PROJECT STUDY EFFECTIVELY?**

Position	Org	Comments
State Manager	Phoenix	More work on AVL and night vision would be a good idea. Also, more work on cost benefit analysis.
State Manager	Phoenix	N / C
State Eqpt Mgr	Phoenix	N / C
Maint Engineer	I-40 Dist	No new concepts with this study.
Maint / District Engineer	I-40 Dist	Two-way communication between the plow and the 'Central office'. Would probably require satellite communications. Could tie AVL and a number of other concepts and functions for data collection. GPS Guidance could be studied.
District Engineer	I-40 Dist	Cost/benefit possibilities to determine what system should be used. Can this research be tied to the individual vehicle telematics being developed in private industry? How can this research be applied to the way ADOT does business?
Superintendent	I-40 Dist	GrayLink with satellite phone
Superintendent	I-40 Dist	We need to see what the night vision system does and what is out there, that will help all the operators see better at night, and when you have white outs.
Org Supervisor	I-40 Dist	Collision radar and night vision.
Org Supervisor	I-40 Dist	I think we have enough equipment to work with at this time. I don't know about the cost.
Operator	I-40 Dist	I think lighting on plows, wipers, and plow sizes could be a good start. I think studying the use of training personnel to see if it also increases safety.
Operator	I-40 Dist	N/C
Operator	I-40 Dist	Lights on snowplows.
ATRC		This effort can coordinate with Maintenance Research, which has been funded in the past for lighting, visibility and AVL studies. This project has pretty limited resources for the next winter, depending on TAC decisions regarding Caltrans and also NAU.

- **SHOULD THIS PROJECT DO MORE <u>NEXT WINTER</u>, AND IF SO, WHERE?**

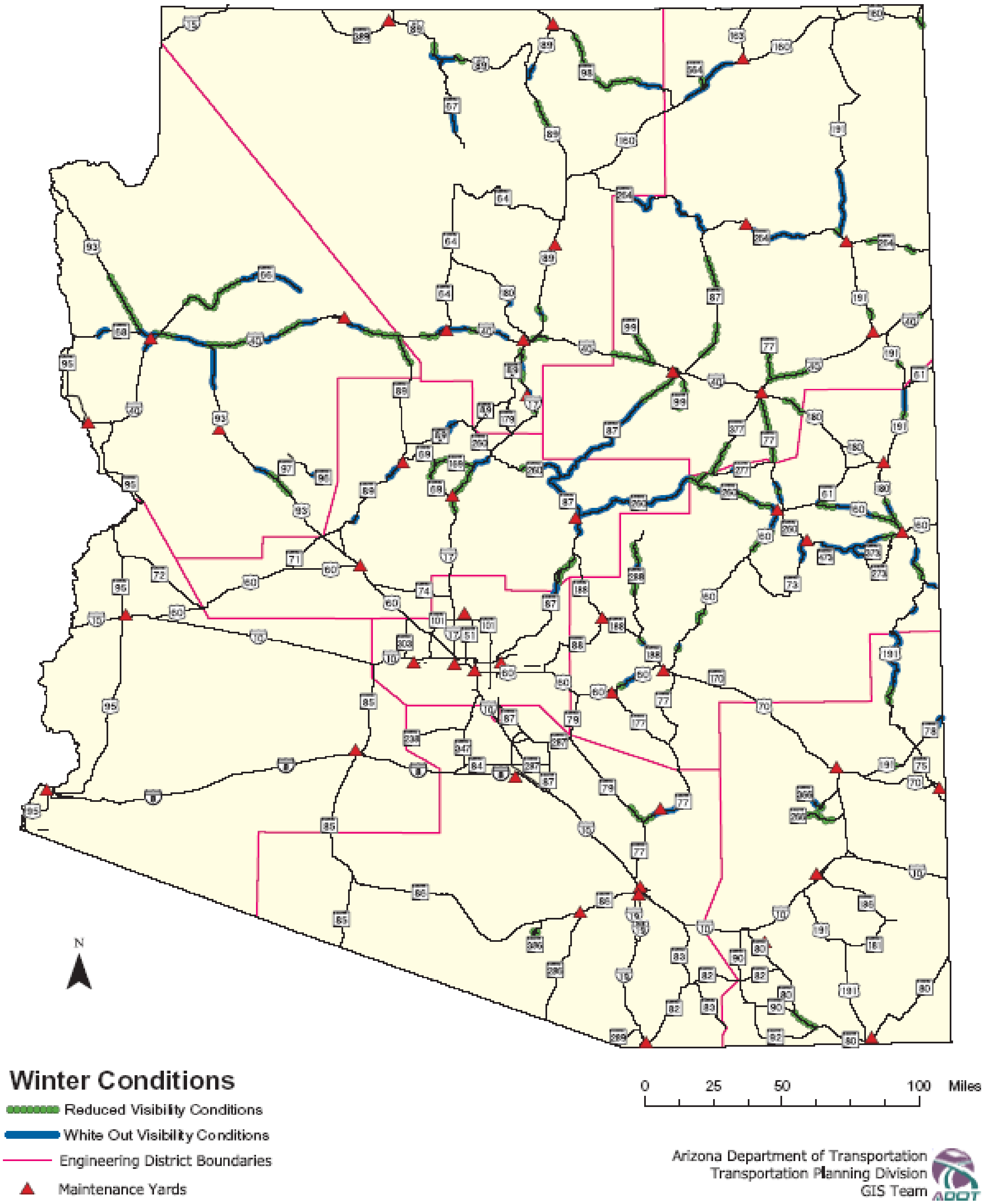
Position	Org	Comments
State Manager	Phoenix	Given the need to better assess live winter conditions, I think it is very important that additional work be done next year.
State Manager	Phoenix	No – I think the focus now should be – what does Maint. want – in regards to safety features, enhancements to their vehicles to support them
State Eqpt Mgr	Phoenix	Yes, on specific on-board systems.
Maint Engineer	I-40 Dist	Additional 3M testing, CalTrans plow does not need to return
Maint / District Engineer	I-40 Dist	I think there are at least 2 ways to approach this: 1. See what kind of support you receive from the District to continue. Without it, we are not going to go very far and it will be very frustrating. 2. Discuss the results with the TAC for input. You may get the same or differing opinions between 1 and 2. Do we have enough data to finish up the snowplow guidance portion of the study? If not, what is left undone that needs follow up next winter season? The answers to these questions are essential to being able to determine an answer to your question above. I believe you will find that the District, most likely, thinks we squeezed out all we can regarding the snowplow guidance system beyond finding the funding to implement and fine tune the system. So if there are things left undone that you need to study, then we need to make that case to the District.
District Engineer	I-40 Dist	We should reach out and possibly start introducing the technology in the Prescott, Globe, and Holbrook Districts, starting with the introduction of some of the individual vehicle devices rather than the positive control systems.
Superintendent	I-40 Dist	Finish test on the night vision.
Superintendent	I-40 Dist	We probably should not do anymore with the Magnets, 3M tape or AVL but we should see what the night vision is going to do and what else is out there that can help the operator see at night and when it is snowing.
Org Supervisor	I-40 Dist	Collision radar and night vision.
Org Supervisor	I-40 Dist	I think it is working now, we should wait until we have a good snowstorm.
Operator	I-40 Dist	With the state budget the way it is I think that we should look into the cost of bringing the plow from Cal Trans to see if we have enough information to make a good enough project analysis from it. I feel as some of the operators are not into the different projects and don't want to continue writing all the reports and taking time out their work schedule to train the different people on the equipment. I feel it should be up to the managers to see if there is money and time to keep up the different projects. The 3M project can keep going on next year since there is really no cost in using the equipment because it is already going to be out on the road.
Operator	I-40 Dist	Yes
Operator	I-40 Dist	Yes
ATRC		We have big gaps in our knowledge of our new systems in severe winter weather. Primarily these are night vision, collision radar, & 3M performance. As to training, there are not any new aspects of the 3M or Caltrans systems.

APPENDIX K

ARIZONA WINTER VISIBILITY SURVEY BY ROUTE MILES: 2003

ADOT Engineering Districts

Winter Conditions Visibility Survey by Route Corridor Miles



ADOT Winter Visibility Survey: Highway Corridor (Milepost) Distances

ADOT Maintenance District	White-Out Visibility Miles Total(1)	Reduced Visibility Miles Total(1)	Total Extent w/ Impaired Visibility	Total of Plow Route Miles in District	Total of All Highway Miles in District	Impaired Percent of Plow Route Miles	Impaired Percent of All Route Miles
Flagstaff	63	97	160	776	776	21%	21%
Globe	117	179	296	804	919	37%	32%
Holbrook	130	215	345	833	833	41%	41%
Kingman	100	140	240	385	530	62%	45%
Phoenix	6	0	6	20	379	30%	2%
Prescott	146	78	224	387	572	58%	39%
Safford	47	48	95	675	804	14%	12%
Tucson	11	18	29	112	840	26%	3%
Yuma	0	0	0	0	562	0%	0%
State-wide Totals	*620*	*775*	*1,395*	*3,992*	*6,216*	35%	22%

(1) **White-Out Visibility Conditions**: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

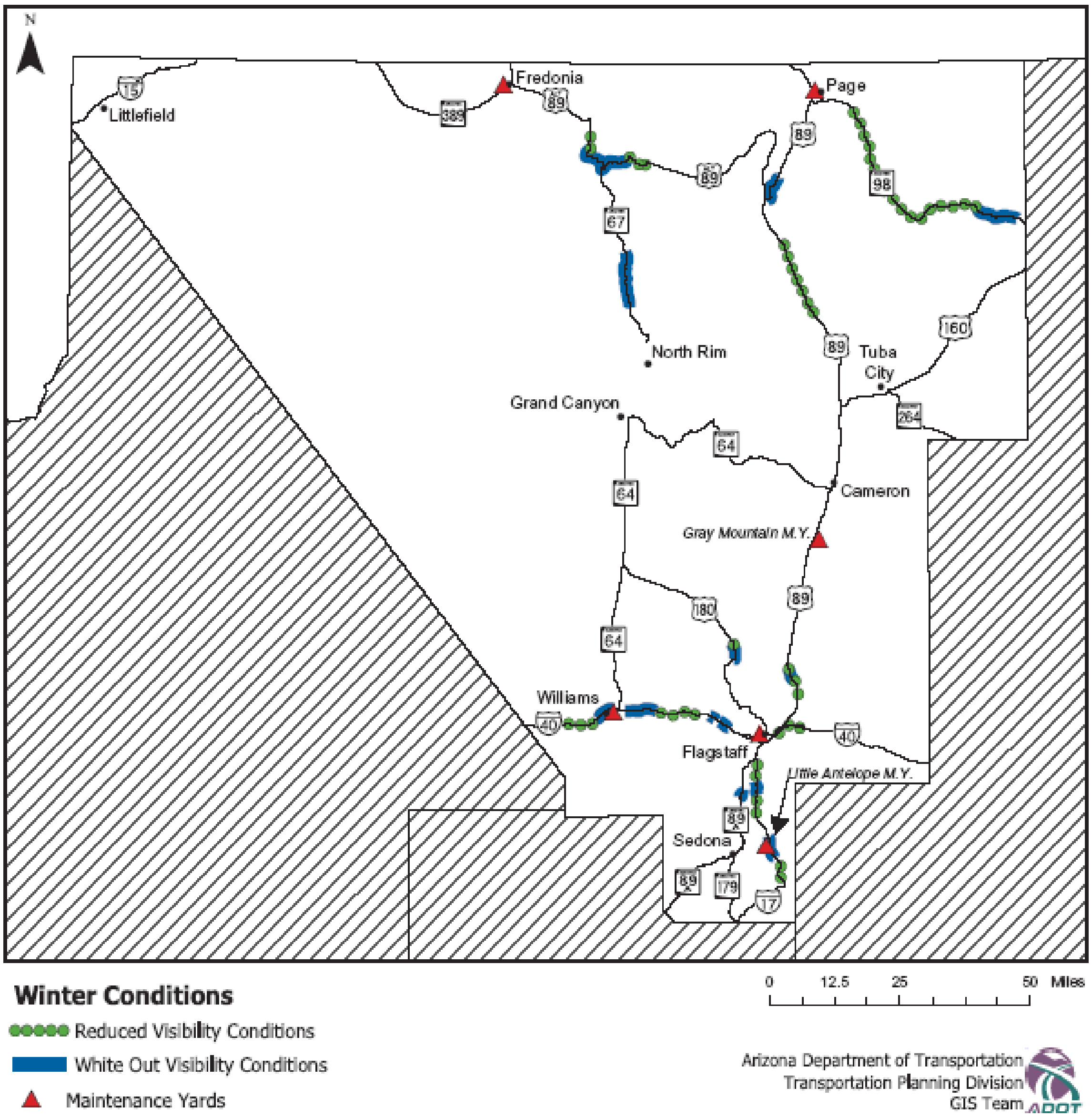
(2) **Reduced Visibility Conditions**: Plows have to slow significantly, even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

Notes - Route or Corridor miles are the total length of the low- or zero-visibility section of the corridor, as defined by the starting and ending mileposts. Plow Route miles are the normal patrol route segments where plows are always assigned for an expected storm.

Survey data was updated & verified by ATRC during the months of June & August 2003. Rev: 08-15-03

Flagstaff District

Winter Conditions Visibility Survey by Route Corridor Miles



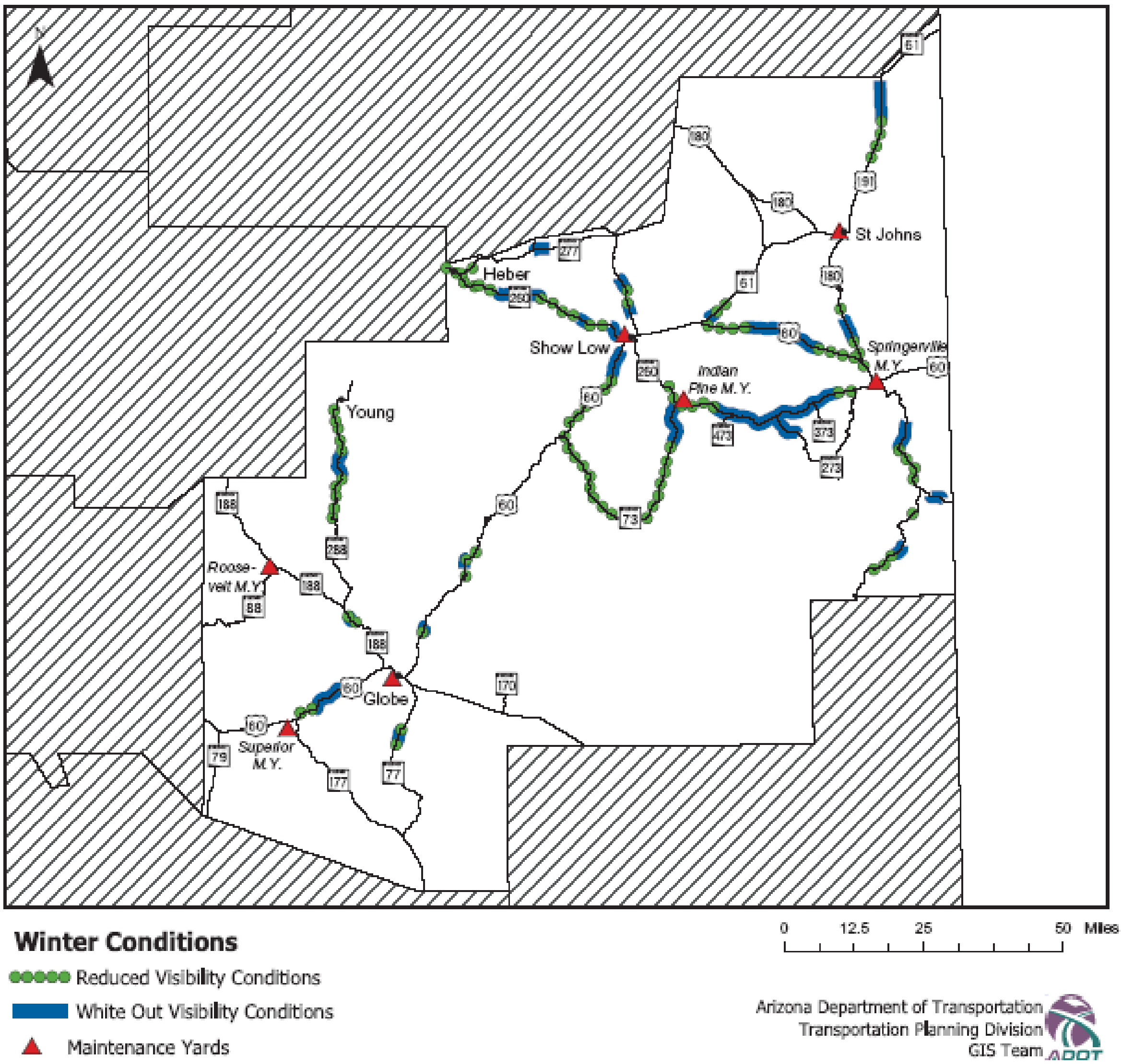
FLAGSTAFF District								
Winter Conditions Visibility Survey by Route Corridor Miles								
JUNE 2003								
	A - White-Out Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	Flagstaff	Williams	Gray Mtn	Ltl Antelope	Page	Fredonia		
Org Number-->	**8550**	**8551**	**8552**	**8553**	**8554**	**8555**		
Route & Location							**Lanes**	**Check:Ln-Mi*
I40, MP 186-188	2						4	*8*
I40, MP 167-173		6					4	*24*
I40, MP 184-185		1					4	*4*
I40, MP 161-165		4					4	*16*
I17, MP 317-321				4			4	*16*
I17, MP 330-332				2			4	*8*
89A, MP 389-391				2			2	*4*
89, MP 428 to 430			2				4	*8*
89, MP 525-530					5		2	*10*
98, MP 342-350					8		2	*16*
SR 67, 599-610						11	2	*22*
89A, MP 573-586						13	2	*26*
180, MP 235-238	3						2	*6*
Org Totals-->	**5**	**11**	**2**	**8**	**13**	**24**		*(Sum L-M)*
District Total for White-out Conditions (corridor route miles)-->						***63.00***		*168*
	B - Reduced Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	Flagstaff	Williams	Gray Mtn	Ltl Antelope	Page	Fredonia		
Org Number-->	**8550**	**8551**	**8552**	**8553**	**8554**	**8555**		
Route & Location							**Lanes**	**Check:Ln-Mi*
I40, MP 199-204	5						4	*20*
I40, MP 155-160		5					4	*20*
I40, MP 174-181		7					4	*28*
I17, MP 312-315				3			4	*12*
I17, MP 333-337				4			4	*16*
I17, MP 326-330				4			4	*16*
89, MP 425 to 428			3				4	*12*
89, MP 430-432			2				4	*8*
89, MP 500-514					14		2	*28*
98, MP 304-342					38		2	*76*
89A, MP 567-573						6	2	*12*
89A, MP 586-590						4	2	*8*
180, MP 238-240	2						2	*4*
Org Totals-->	**7**	**12**	**5**	**11**	**52**	**10**		*(Sum L-M)*
District Total for Reduced Visibility Conditions (corridor route miles)-->						***97.00***		*260*
								(Sum L-M)
District Total for Both Impaired-Visiblity Conditions (corridor route miles)-->						***160.00***		*428*
ALL Plow Route Miles in Org-->	***106.78***	***107.33***	***154.24***	***102.39***	***165.01***	***139.91***		
*Source: Meeting w/ Danny Russell	***Total of Plow Route Miles in District-->***					***775.66***		
ALL Milepost Distance Miles in Org-->	***106.78***	***107.33***	***154.24***	***102.39***	***165.01***	***139.91***		
*Source: Org Boundary Log	***Total of ALL Highway Miles in District-->***					***775.66***		

A - White-Out Visibility Conditions: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

B - Reduced Visibility Conditions: Plows have to slow down significantly, and even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

Globe District

Winter Conditions Visibility Survey by Route Corridor Miles



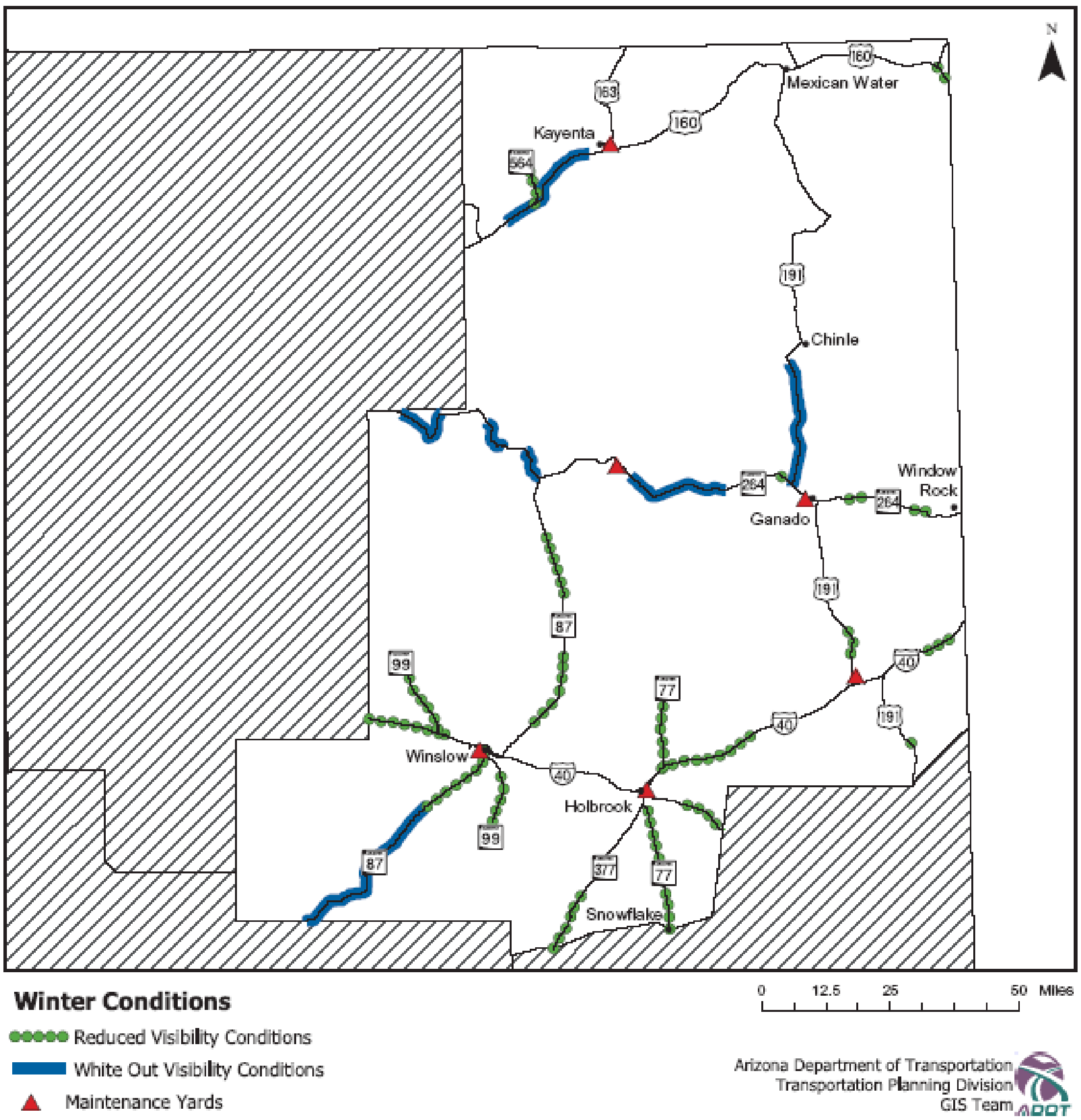
GLOBE District
Winter Conditions Visibility Survey by Route Corridor Miles
JUNE 2003

	A - White-Out Visibility Conditions								
	Route Corridor Miles - Milepost Distances								
Orgs-->	Globe	Roosevelt	Superior	Show Low	St Johns	Springerville	Indian Pine		
Org Number-->	**8350**	**8352**	**8353**	**8354**	**8355**	**8356**	**8357**		
Route & Location								**Lanes**	**Check:Ln-Mi*
US 60, MP 261.5 - 262.5	1							3	*3*
US 60, MP 279.5-281.5	2							2	*4*
SR 77, MP 160-162	2							2	*4*
SR 288, MP 290-295		5						2	*10*
SR 188, MP 227-228		1						2	*2*
US 60, MP 231.5-238.5			7					3	*21*
US 60, MP 333-338				5				2	*10*
SR 77, MP 346-348				2				2	*4*
SR 77, MP351-353				2				4	*8*
SR 260, MP 314-322				8				2	*16*
SR 260, MP 330-332				2				2	*4*
SR 260, MP 336-338				2				4	*8*
SR 277, MP 321-324				3				2	*6*
SR 61, MP 355-357					2			2	*4*
US 180, MP 386-390					4			2	*8*
US 191, MP 337-344					7			2	*14*
US 60, MP 362-376						14		2	*28*
US 180, MP 412-417						5		2	*10*
US 180, MP 429-431						2		2	*4*
SR 260, MP 377.4-390						12.6		2	*25.2*
US 191, MP 238.3-240.4						2.1		2	*4.2*
SR 260, MP 365-378.7							13.7	3	*41.1*
SR 73, MP 350-357.7							7.7	3	*23.1*
SR 273, MP 377.8-383							5.2	2	*10.4*
Org Totals-->	**5**	**6**	**7**	**24**	**13**	**35.7**	**26.6**		*(Sum L-M)*
		District Total for White-out Conditions (corridor route miles)-->					***117.3***		*272*

	B - Reduced Visibility Conditions								
	Route Corridor Miles - Milepost Distances								
Orgs-->	Globe	Roosevelt	Superior	Show Low	St Johns	Springerville	Indian Pine		
Org Number-->	**8350**	**8352**	**8353**	**8354**	**8355**	**8356**	**8357**		
Route & Location								**Lanes**	**Check:Ln-Mi*
US 60, MP 261-261.5 & 262.5-263	1							3	*3*
US 60, MP 278-279.5 & 281.5-284	4							2	*8*
SR 77, MP 159-160 & 162-163	2							2	*4*
SR 288, MP 280-290 & 295-305		20						2	*40*
SR 188, MP 226-227 & 228-229		2						2	*4*
US 60, MP 228-231.5 & 238.5-242			7					3	*21*
US 60, MP 321-333				12				3	*36*
SR 77, MP 348-351				3				2	*6*
SR 260, MP 302.7-310				7.3				4	*29.2*
SR 260, MP 310-314				4				4	*16*
SR 260, MP 322-330 & 332-336				12				2	*24*
SR 277, MP 306-310				4				2	*8*
SR 61, MP 357-360					3			2	*6*
US 180, MP 384-386 & 390-394					6			2	*12*
US 191, MP 330-337					7			2	*14*
US 60, MP 355-362						7		2	*14*
US 60, MP 376-387						11		2	*22*
US 180, MP 417-425						8		2	*16*
SR 260, MP 390-394						4		2	*8*
SR 373, MP 388-390.2						2.2		2	*4.4*
US 191, MP 233-238.3						5.3		2	*10.6*
US 191, MP 248-249						1		2	*2*
SR 260, MP 354-365							11	2	*22*
SR 73, MP 335-350							15	3	*45*
SR 73, MP 310-330							20	2	*40*
Org Totals-->	**7**	**22**	**7**	**42.3**	**16**	**38.5**	**46**		*(Sum L-M)*
	District Total for Reduced Visibility Conditions (corridor route miles)-->						***178.8***		*415.2*
									(Sum L-M)
	District Total for Both Impaired-Visiblity Conditions (corridor route miles)-->						***296.1***		*687.2*

Holbrook District

Winter Conditions Visibility Survey by Route Corridor Miles



HOLBROOK District
Winter Conditions Visibility Survey by Route Corridor Miles
JUNE 2003

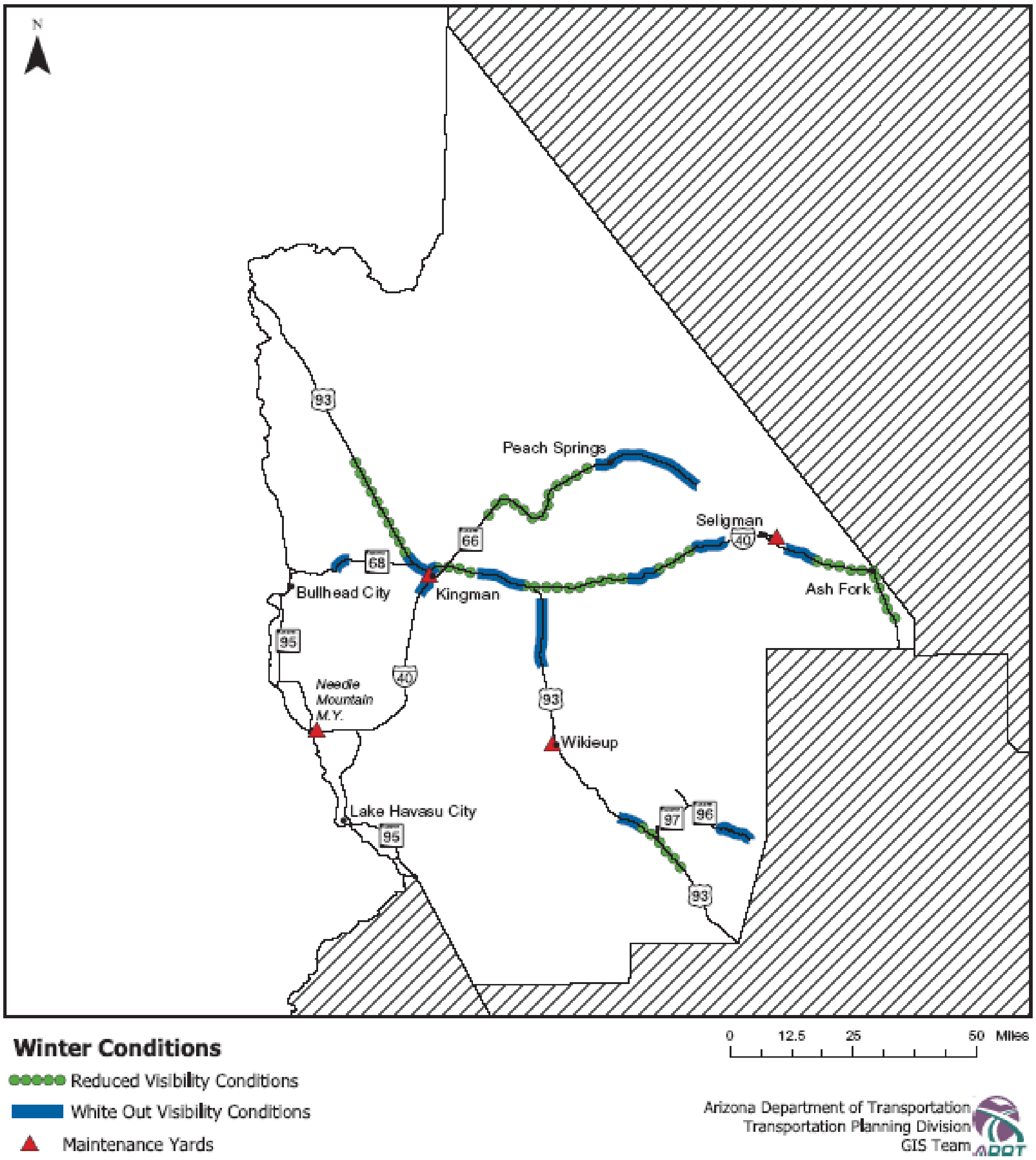
	A - White-Out Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	**Holbrook**	**Winslow**	**Kayenta**	**Keams Canyon**	**Ganado**	**Chambers**		
Org Number-->	**8750**	**8751**	**8752**	**8753**	**8754**	**8755**		
Route & Location							**Lanes**	**Check:Ln-Mi*
SR 87, MP 290.5-326		35.5					2	*71*
US 160, MP 368-390			22				2	*44*
US 191, MP 418-442					24		2	*48*
SR 264, MP 342-355, 365-372, 377-384, 405-426				48			2	*96*
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
Org Totals-->	**0**	**35.5**	**22**	**48**	**24**	**0**		*(Sum L-M)*
	District Total for White-out Conditions (corridor route miles)-->					***129.50***		*259*
	B - Reduced Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	**Holbrook**	**Winslow**	**Kayenta**	**Keams Canyon**	**Ganado**	**Chambers**		
Org Number-->	**8750**	**8751**	**8752**	**8753**	**8754**	**8755**		
Route & Location							**Lanes**	**Check:Ln-Mi*
I-40, MP 230-245		15					4	*60*
I-40, MP 292-312	20						4	*80*
I-40, MP 350-355						5	4	*20*
US 64, MP 465-470			5				2	*10*
SR 77, MP 361-386, 395-408	38						2	*76*
SR 87, MP 326-342, 355-362		23					2	*46*
SR87, MP 363-370, 382-395				20			2	*40*
SR 99, MP 27-38, 52-72		31					2	*62*
US 180, MP 316-325	9						2	*18*
US 191, MP 353-355, 380-385						7	2	*14*
SR 264, MP 438-440, 453-456					15		2	*30*
SR 264, MP 466-470					4		4	*16*
SR 377, MP 0-13	13						2	*26*
SR 564, MP 374-384			10				2	*20*
								0
								0
								0
								0
Org Totals-->	**80**	**69**	**15**	**20**	**19**	**12**		*(Sum L-M)*
	District Total for Reduced Visibility Conditions (corridor route miles)-->					***215.00***		*518*
								(Sum L-M)
	District Total for Both Impaired-Visiblity Conditions (corridor route miles)-->					***344.50***		*777*
****Fill Out For Each ORG:***								
ALL Plow Route Miles in Org-->	***142.89***	***149.76***	***168.27***	***130.08***	***155.5***	***86.98***		
*Source: Meeting w/ Dave Sikes			***Total of Plow Route Miles in District-->***			***833.48***		
ALL Milepost Distance Miles in Org-->	***142.89***	***149.76***	***168.27***	***130.08***	***155.5***	***86.98***		
*Source: Org Boundary Log			***Total of ALL Highway Miles in District-->***			***833.48***		

A - White-Out Visibility Conditions: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

B - Reduced Visibility Conditions: Plows have to slow down significantly, and even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

Kingman District

Winter Conditions Visibility Survey by Route Corridor Miles



KINGMAN District

Winter Conditions Visibility Survey by Route Corridor Miles

JUNE 2003

A - White-Out Visibility Conditions

	Route Corridor Miles - Milepost Distances							
Orgs-->	**Kingman**	**Seligman**	**Needle Mtn**	**Wikieup**				
Org Number-->	**8650**	**8651**	**8652**	**8653**				
Route & Location							**Lanes**	**Check:Ln-Mi*
I40, M.P. 44-51 & 60-70	17						4	*68*
U.S. 66, M.P. 100-123.2	23.2						2	*46.4*
US 93,M.P. 65-70	5						4	*20*
SR 68,M.P. 10-14	4						4	*16*
I40,M.P. 92-99 & 108-114 & 127-134		20					4	*80*
US 93,M.P. 94-108				14			2	*28*
US 93, M.P. 146-151				5			4	*20*
SR 96, M.P. 0-4 & 14-22				12			2	*24*
								0
								0
								0
								0
								0
Org Totals-->	**49.2**	**20**	**0**	**31**				*(Sum L-M)*
District Total for White-out Conditions (corridor route miles)-->						***100.20***		*302.4*

B - Reduced Visibility Conditions

	Route Corridor Miles - Milepost Distances							
Orgs-->	**Kingman**	**Seligman**	**Needle Mtn**	**Wikieup**				
Org Number-->	**8650**	**8651**	**8652**	**8653**				
Route & Location							**Lanes**	**Check:Ln-Mi*
I40, M.P. 51-60	9						4	*36*
I40, M.P. 70-72	2						4	*8*
US 66, M.P. 70-100	30						2	*60*
US 93, M.P. 43-65	22						4	*88*
I40, M.P. 72-92 & 99-108 & 114-127 & 134-146		54					4	*216*
SR 89, M.P. 353-363.8		10.8					2	*21.6*
US 93, M.P. 151-163				12			2	*24*
								0
								0
								0
								0
								0
Org Totals-->	**63**	**64.8**	**0**	**12**	**0**	**0**		*(Sum L-M)*
District Total for Reduced Visibility Conditions (corridor route miles)-->						***139.80***		*453.6*
								(Sum L-M)
District Total for Both Impaired-Visiblity Conditions (corridor route miles)-->						***240.00***		*756*

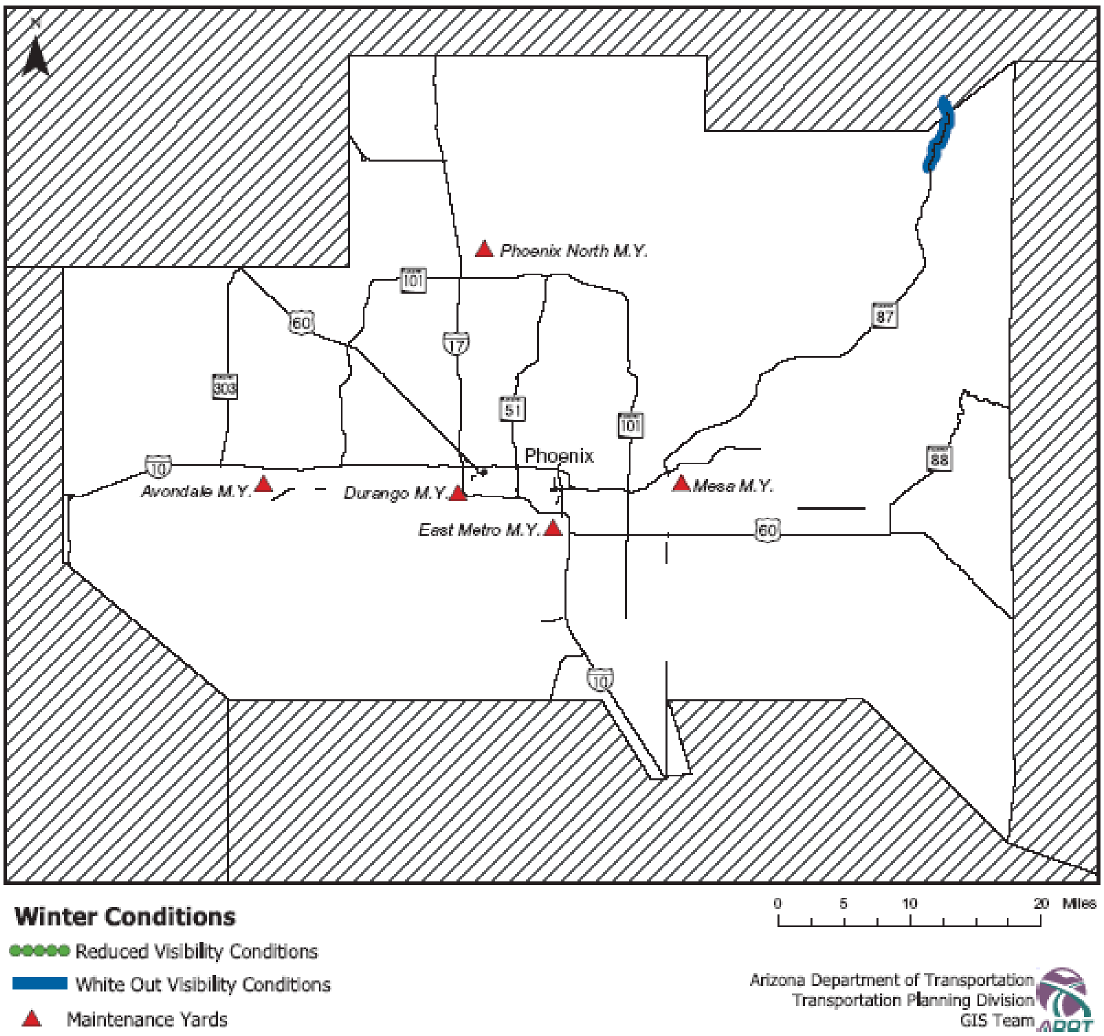
****Fill Out For Each ORG:***						
ALL Plow Route Miles in Org-->	***183***	***97.81***	***0***	***104***		
*Source: Meeting w/ Rance Spurlock		***Total of Plow Route Miles in District-->***				***384.81***
ALL Milepost Distance Miles in Org-->	***195.8***	***97.81***	***110.62***	***125.33***		
*Source: Org Boundary Log		***Total of ALL Highway Miles in District-->***				***529.56***

A - White-Out Visibility Conditions: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

B - Reduced Visibility Conditions: Plows have to slow down significantly, and even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

Phoenix District

Winter Conditions Visibility Survey by Route Corridor Miles



PHOENIX District
Winter Conditions Visibility Survey by Route Corridor Miles
JUNE 2003

A - White-Out Visibility Conditions

	Route Corridor Miles - Milepost Distances							
Orgs-->	Avondale	Phx North	Phx East	Mesa	Durango North			
Org Number-->	7871	7872	7873	7874	7875			
Route & Location							Lanes	Check:Ln-M
SR 87, MP 212 - 218				6			4	24
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
Org Totals-->	0	0	0	6	0			(Sum L-M)
District Total for White-out Conditions (corridor route miles)-->						6.00		24

B - Reduced Visibility Conditions

	Route Corridor Miles - Milepost Distances							
Orgs-->	Avondale	Phx North	Phx East	Mesa	Durango North			
Org Number-->	7871	7872	7873	7874	7875			
Route & Location							Lanes	Check:Ln-M
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
Org Totals-->	0	0	0	0	0			(Sum L-M)
District Total for Reduced Visibility Conditions (corridor route miles)-->						0.00		0
								(Sum L-M)
District Total for Both Impaired-Visiblity Conditions (corridor route miles)-->						6.00		24

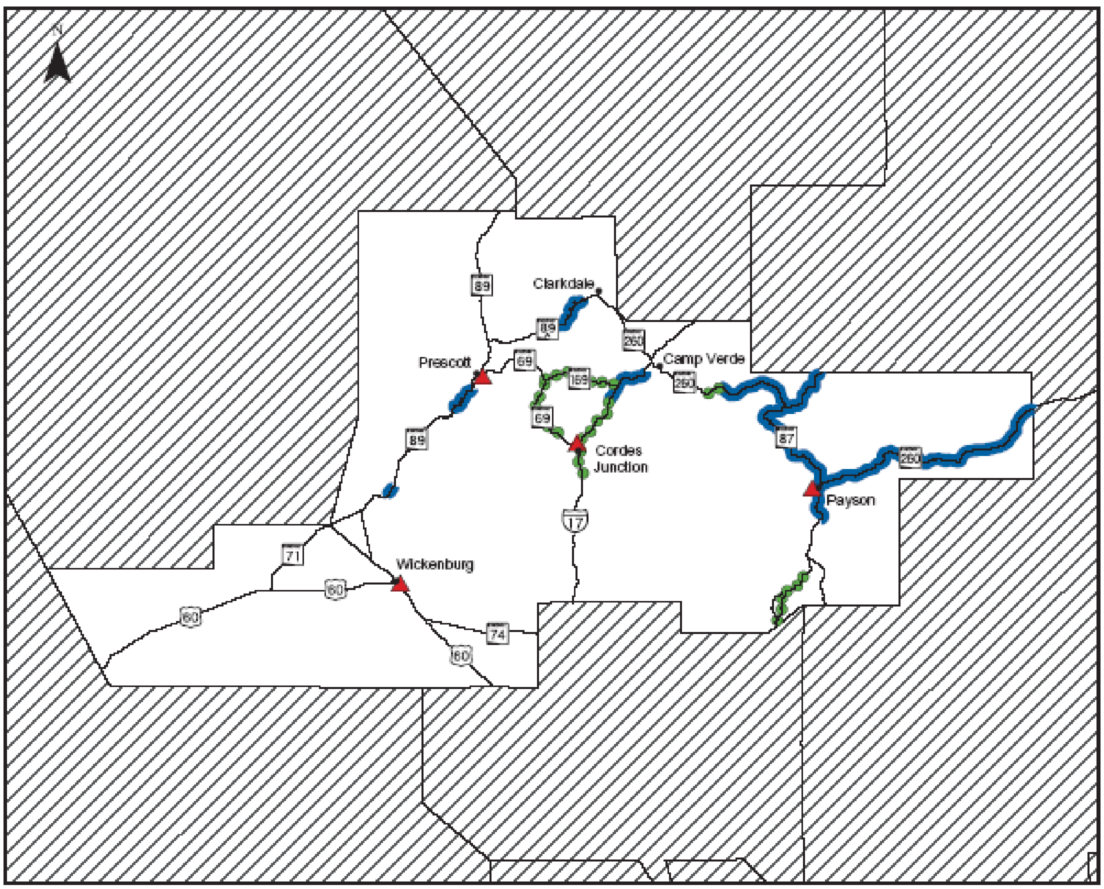
*Fill Out For Each ORG:						
ALL Plow Route Miles in Org-->	0	0	0	20	0	
*Source: MSLT followup w/ Craig Cornwell	Total of Plow Route Miles in District-->					20.00
ALL Milepost Distance Miles in Org-->	72.88	67.61	56.92	133.01	48.54	
*Source: Org Boundary Log	Total of ALL Highway Miles in District-->					378.96

A - White-Out Visibility Conditions: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

B - Reduced Visibility Conditions: Plows have to slow down significantly, and even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

Prescott District

Winter Conditions Visibility Survey by Route Corridor Miles



Winter Conditions

Reduced Visibility Conditions

White Out Visibility Conditions

Maintenance Yards

Arizona Department of Transportation
Transportation Planning Division
GIS Team

PRESCOTT District

Winter Conditions Visibility Survey by Route Corridor Miles

JUNE 2003

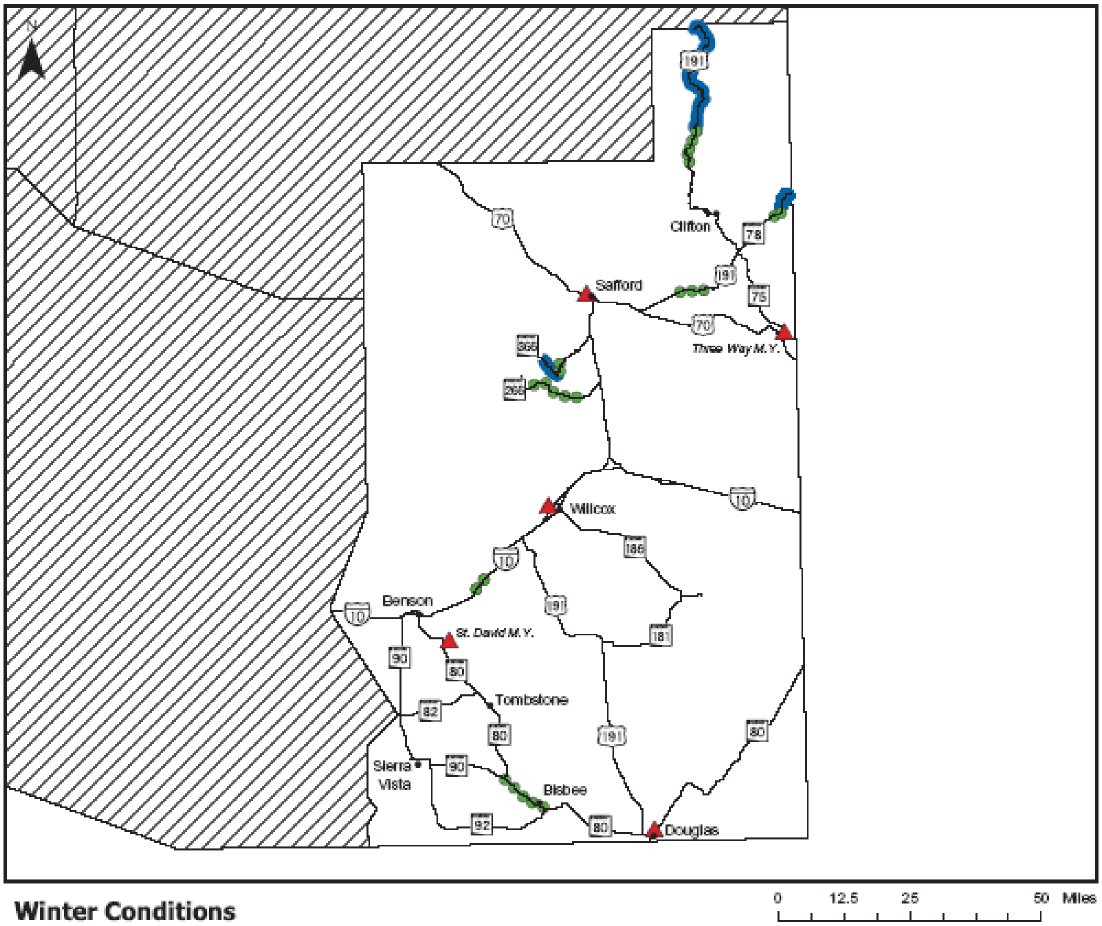
	A - White-Out Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	**Prescott Valley**	**Cordes Jct**	**Wickenburg**	**Payson**				
Org Number-->	**8850**	**8851**	**8852**	**8853**				
Route & Location							**Lanes**	*Check:Ln-M*
I-17 MP 275 - 285		10					4	*40*
SR 87 MP 244 - 254				10			4	*40*
SR 87 MP 254 - 290				36			2	*72*
SR 89 MP 276 - 278			2				4	*8*
SR 89 MP 300 - 308	8						2	*16*
SR 89A MP 331 - 344	13						2	*26*
SR 260 MP 236 - 243		7					2	*14*
SR 260 MP 243 - 282				39			4	*156*
SR 260 MP 282 - 303				21			2	*42*
								0
								0
								0
								0
Org Totals-->	**21**	**17**	**2**	**106**				*(Sum L-M)*
	District Total for White-out Conditions (corridor route miles)-->					***146.00***		*414*
	B - Reducd Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	**Prescott Valley**	**Cordes Jct**	**Wickenburg**	**Payson**				
Org Number-->	**8850**	**8851**	**8852**	**8853**				
Route & Location							**Lanes**	*Check:Ln-M*
I-17 MP 258 - 275		17					4	*68*
SR 69 MP 268 - 281		13					4	*52*
SR 69 MP 281 - 296	15						4	*60*
SR 87 MP 218 - 233				15			4	*60*
SR 169 MP 0 - 15		15					2	*30*
SR 260 MP 233 - 236		3					2	*6*
								0
								0
								0
								0
								0
								0
								0
Org Totals-->	**15**	**48**	**0**	**15**				*(Sum L-M)*
	District Total for Reduced Visibility Conditions (corridor route miles)-->					***78.00***		*276*
								(Sum L-M)
	District Total for Both Impaired-Visiblity Conditions (corridor route miles)-->					***224.00***		*690*
****Fill Out For Each ORG:***								
ALL Plow Route Miles in Org-->	***122***	***117***	***3***	***145***				
*Source: MSLT file edits: Bob Lajeunesse		***Total of Plow Route Miles in District-->***				***387.00***		
ALL Milepost Distance Miles in Org-->	***120.65***	***136.69***	***170.68***	***144.34***				
*Source: Org Boundary Log		***Total of ALL Highway Miles in District-->***				***572.36***		

A - White-Out Visibility Conditions: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

B - Reduced Visibility Conditions: Plows have to slow down significantly, and even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

Safford District

Winter Conditions Visibility Survey by Route Corridor Miles



Winter Conditions

Reduced Visibility Conditions

White Out Visibility Conditions

Maintenance Yards

Arizona Department of Transportation
Transportation Planning Division
GIS Team

SAFFORD District
Winter Conditions Visibility Survey by Route Corridor Miles
JUNE 2003

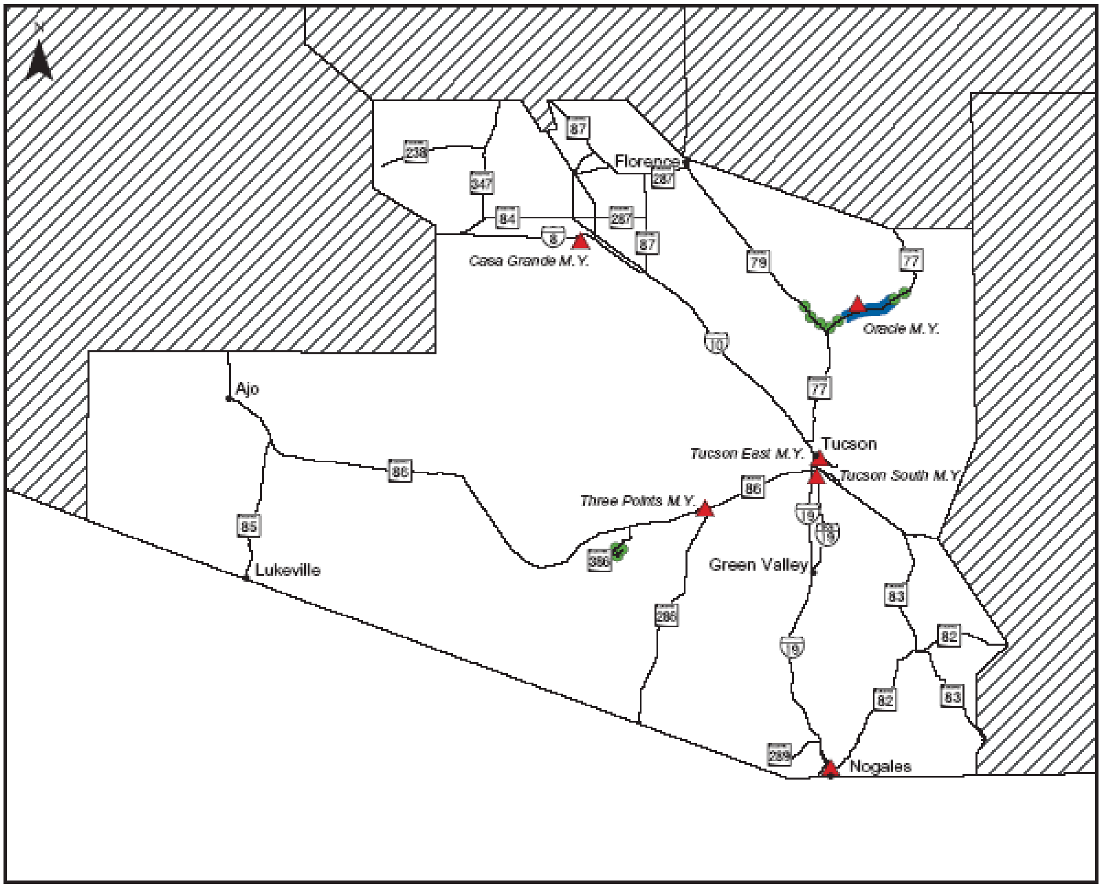
	A - White-Out Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	**Safford**	**3-Way**	**Willcox**	**St. David**	**Douglas**			
Org Number-->	**8450**	**8451**	**8452**	**8453**	**8454**			
Route & Location							**Lanes**	**Check:Ln-Mi*
SR 366, MP 130.0 - 137.0	7						2	*14*
US 191, MP 190.0 - 225.0		35					2	*70*
SR 78, MP 169.0 - 174.0		5					2	*10*
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
Org Totals-->	**7**	**40**	**0**	**0**	**0**			*(Sum L-M)*
District Total for White-out Conditions (corridor route miles)-->						***47.00***		*94*
	B - Reduced Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	**Safford**	**3-Way**	**Willcox**	**St. David**	**Douglas**			
Org Number-->	**8450**	**8451**	**8452**	**8453**	**8454**			
Route & Location							**Lanes**	**Check:Ln-Mi*
I-10, MP 318.0 - 322.0				4			4	*16*
SR 366, MP 125.0 - 130.0	5						2	*10*
SR 266, MP 110.0 - 120.0	10						2	*20*
US 191, MP 139.0 - 144.0	5						2	*10*
SR 78, MP 166.0 - 169.0		3					2	*6*
US 191, MP 180.0 - 190.0		10					2	*20*
SR 80, MP 333.0 - 344.0					11		2	*22*
								0
								0
								0
								0
								0
								0
Org Totals-->	**20**	**13**	**0**	**4**	**11**			*(Sum L-M)*
District Total for Reduced Visibility Conditions (corridor route miles)-->						***48.00***		*104*
								(Sum L-M)
District Total for Both Impaired-Visiblity Conditions (corridor route miles)-->						***95.00***		*198*
****Fill Out For Each ORG:***								
ALL Plow Route Miles in Org-->	***140***	***95***	***237***	***83***	***120***			
*Source: MSLT file edits from Steve Puzas	***Total of Plow Route Miles in District-->***					***675.00***		
ALL Milepost Distance Miles in Org-->	***184.57***	***151.28***	***171.35***	***149.24***	***147.37***			
*Source: Org Boundary Log	***Total of ALL Highway Miles in District-->***					***803.81***		

A - White-Out Visibility Conditions: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

B - Reduced Visibility Conditions: Plows have to slow down significantly, and even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

Tucson District

Winter Conditions Visibility Survey by Route Corridor Miles



Winter Conditions

Reduced Visibility Conditions

White Out Visibility Conditions

Maintenance Yards

0 12.5 25 50 Miles

Arizona Department of Transportation
Transportation Planning Division
GIS Team

TUCSON District

Winter Conditions Visibility Survey by Route Corridor Miles

JUNE 2003

A - White-Out Visibility Conditions

Route Corridor Miles - Milepost Distances

Orgs-->	Tucson W.	Tucson E.	3 Points	Nogales	Oracle	Casa Grande		
Org Number-->	8150	8151	8152	8153	8154	8155		
Route & Location							**Lanes**	**Check:Ln-Mi*
								0
SR 77: MP 96 - 107					11		2	22
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
								0
Org Totals-->	0	0	0	0	11	0		(Sum L-M)
District Total for White-out Conditions (corridor route miles)-->						11.00		22

B - Reduced Visibility Conditions

Route Corridor Miles - Milepost Distances

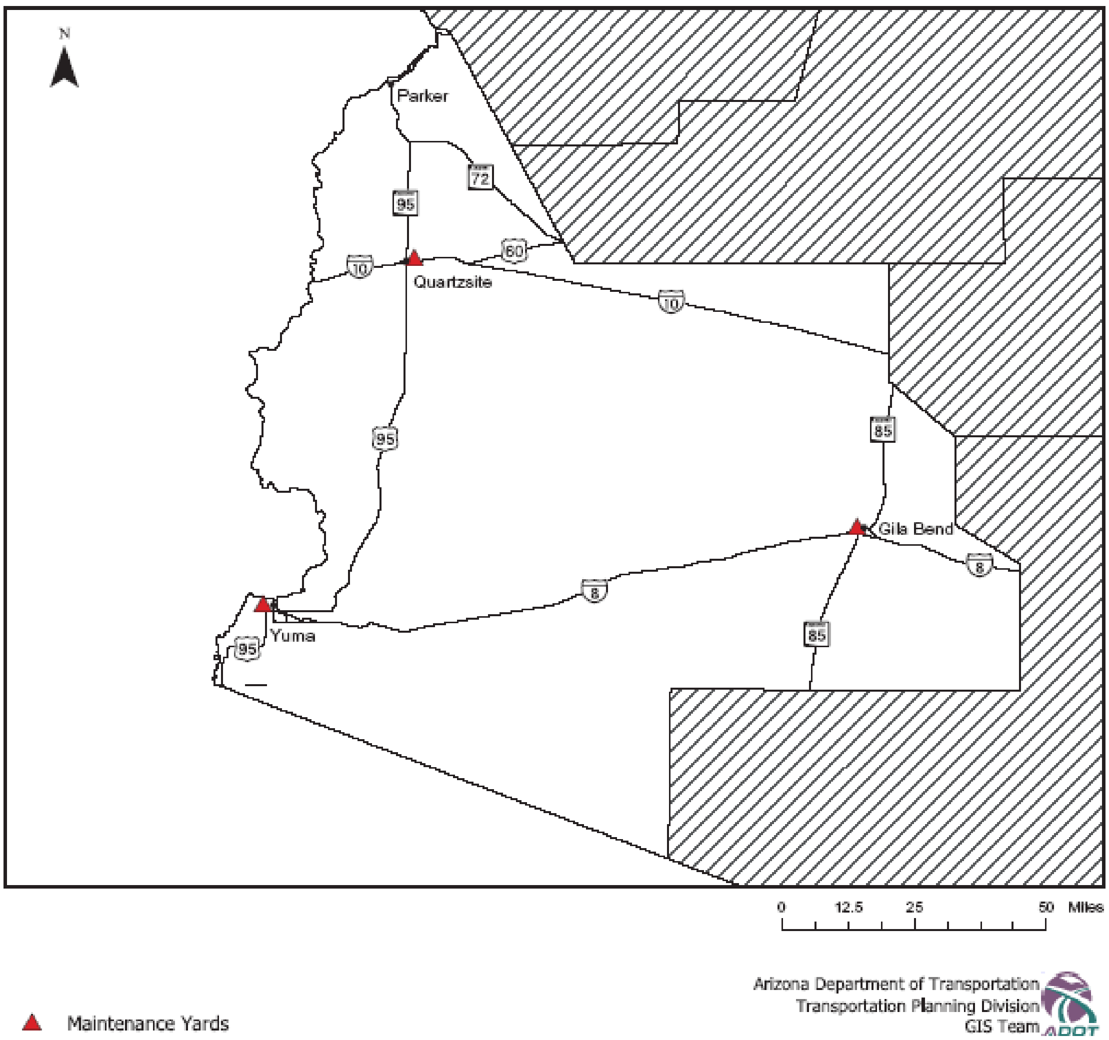
Orgs-->	Tucson W.	Tucson E.	3 Points	Nogales	Oracle	Casa Grande		
Org Number-->	8150	8151	8152	8153	8154	8155		
Route & Location							**Lanes**	**Check:Ln-Mi*
								0
SR 386: MP 7 - 12			5				2	10
SR 77: MP 92 - 96					4		2	8
SR 77: MP 107 - 110					3		2	6
SR 79: MP 93 - 99					6		2	12
								0
								0
								0
								0
								0
								0
								0
								0
Org Totals-->	0	0	5	0	13	0		(Sum L-M)
District Total for Reduced Visibility Conditions (corridor route miles)-->						18.00		36
								(Sum L-M)
District Total for Both Impaired-Visiblity Conditions (corridor route miles)-->						29.00		58
**Fill Out For Each ORG:*								
ALL Plow Route Miles in Org-->	12	15	15	25	45	0		
*Source: MSLT followup w/ Cliff Riley		*Total of Plow Route Miles in District-->*				112.00		
ALL Milepost Distance Miles in Org-->	62.68	94.17	209.82	155.74	157.49	160.3		
*Source: Org Boundary Log		*Total of ALL Highway Miles in District-->*				840.20		

A - White-Out Visibility Conditions: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

B - Reduced Visibility Conditions: Plows have to slow down significantly, and even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

Yuma District

Winter Conditions Visibility Survey by Route Corridor Miles



YUMA District

Winter Conditions Visibility Survey by Route Corridor Miles

JUNE 2003

	A - White-Out Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	**Quartzsite**	**Gila Bend**	**Yuma**					
Org Number-->	**8251**	**8252**	**8253**					
Route & Location							**Lanes**	*Check:Ln-M*
I-10 0.00-70.76	0							*0*
US 95 70.00-161.73	0							*0*
US 60 31.26-49.56	0							*0*
S 72 13.11-49.91	0							*0*
I-8 79.86- 147.60		0						*0*
I-10 70.77-112.20		0						*0*
S 85 0.00-32.51		0						*0*
S 85 120.32-149.10		0						*0*
I-8 0.00-79.86			0					*0*
US 95 0.00-70.00			0					*0*
								0
								0
								0
Org Totals-->	**0**	**0**	**0**					*(Sum L-M)*
District Total for White-out Conditions (corridor route miles)-->						***0.00***		*0*
	B - Reduced Visibility Conditions							
	Route Corridor Miles - Milepost Distances							
Orgs-->	**Quartzsite**	**Gila Bend**	**Yuma**					
Org Number-->	**8251**	**8252**	**8253**					
Route & Location							**Lanes**	*Check:Ln-M*
I-10 0.00-70.76 (70.76)	0							*0*
US 95 70.00-161.73 (91.73)	0							*0*
US 60 31.26-49.56 (18.30)	0							*0*
S 72 13.11-49.91 (36.80)	0							*0*
I-8 79.86-147.60 (67.74)		0						*0*
I-10 70.77-112.20 (41.43)		0						*0*
S 85 0.00-32.51 (32.51)		0						*0*
S85 120.32 - 149.10 (28.78)		0						*0*
I-8 0.00-79.86 (79.86)			0					*0*
US 95 0.00-70.00 (70.00)			0					*0*
								0
								0
								0
Org Totals-->	**0**	**0**	**0**					*(Sum L-M)*
District Total for Reduced Visibility Conditions (corridor route miles)-->						***0.00***		*0*
								(Sum L-M)
District Total for Both Impaired-Visiblity Conditions (corridor route miles)-->						***0.00***		*0*
****Fill Out For Each ORG:***								
ALL Plow Route Miles in Org-->	***0***	***0***	***0***					
*Source: MSLT file edits from Frank Felix	***Total of Plow Route Miles in District-->***					***0.00***		
ALL Milepost Distance Miles in Org-->	***223.56***	***175.48***	***163.06***					
*Source: Org Boundary Log	***Total of ALL Highway Miles in District-->***					***562.10***		

A - White-Out Visibility Conditions: Unable to continue plowing; cannot see beyond the hood or make out any surroundings. May last 15 to 20 minutes or more. Occurs 3 or more times each winter season: Oct 15 - Apr 15.

B - Reduced Visibility Conditions: Plows have to slow down significantly, and even occasionally stop. May last 15 to 20 minutes or more, but is not bad enough to be considered a "white-out". Occurs 3 or more times each winter season: Oct 15 - Apr 15.

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