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.