

Report No. CDOT-DTD-R-2005-19
Final Report

A SYNTHESIS TO IMPROVE THE DESIGN AND CONSTRUCTION OF COLORADO'S BRIDGE ANTI-ICING SYSTEMS

Gordon T. Bell, Bell Enterprises, LLC
Wilfrid A. Nixon, Ph.D., P.E., Asset Insight Technologies, LLC
Robert D. Stowe, P.E., Asset Insight Technologies, LLC



April 2006

**COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH**

The contents of this report reflect the views of the author(s), who is (are) responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Use of the information contained in the report is at the sole discretion of the user.

A SYNTHESIS TO IMPROVE THE DESIGN AND CONSTRUCTION OF COLORADO'S BRIDGE ANTI-ICING SYSTEMS

Gordon T. Bell
Wilfrid A Nixon, Ph.D., P.E.
Robert D. Stowe, P.E.

Report No. CDOT-DTD-R-2005-19

Prepared by
Bell Enterprises, LLC, 7127 E. Concord Place, Highlands Ranch, CO 80310
Asset Insight Technologies, LLC, 85051 Winesap Road, Milton-Freewater, OR 97862

Sponsored by the
Colorado Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

April 2006

Colorado Department of Transportation
Research Branch
4201 E. Arkansas Ave.
Denver, CO 80222
(303) 757-9506

ACKNOWLEDGEMENTS

Andrew Pott, CDOT Staff Bridge
Dr. Naser Abu-Hejleh, CDOT Research Branch
Dick Osmun, CDOT Staff Bridge
Wayne Lupton, CDOT Staff Maintenance
Phillip Anderle, CDOT Region 4 Maintenance
Al Roys, CDOT Region 4 Maintenance
Don Miller, CDOT Region 1 Maintenance
Delmon French, CDOT Region 3 Maintenance
Roy Smith, CDOT Region 6 Maintenance
Joseph Crichton, CDOT Region 6 Maintenance
Matt Greer, FHWA

EXECUTIVE SUMMARY

Fixed Automated Spray Technology (FAST) is a relatively recent development used by maintenance organizations to provide anti-icing liquids to remote locations, key structures, and high hazard locations during winter weather events. Anti-icing materials are applied at a specific site using an automated system consisting of pumps, piping and nozzles.

This synthesis study was recommended to generate proper, cost-effective and uniform bridge anti-icing system specifications and to provide the optimal system for the Colorado Department of Transportation (CDOT). The research was conducted using a literature review along with a survey of transportation agencies and system suppliers. The literature review and survey results are discussed in the report and highlight the positive and negative issues encountered with various systems.

Failures and successes are documented in reports from transportation agencies and were instrumental in the development of the specification guideline criteria. The research highlighted some key facts; these systems are not “off the shelf” or “plug and play” technology. They are sophisticated installations that can provide reliable operation if designed, installed and maintained properly. The type of structure selected to store the pump, anti-icing material, and electronic equipment for automatic detection and activation play a key role in a successful FAST system.

Road Weather Information Systems (RWIS) play an equally important role in the success of automated FAST systems. RWIS is an established technology consisting of atmospheric and surface instrumentation used to provide weather data to the user and the FAST system for automated or manual spray control. Surface and atmospheric data are used to determine the activation and frequency of applications of anti-icing chemicals to the surface of the target area. RWIS provides surface temperature, wet/dry status, percent of chemical detected at the surface sensors, freeze point temperature, etc., along with air temperature, dew point temperature, precipitation type and rate, visibility, and wind speed and direction. This information is critical for the accurate automated operation of the FAST systems.

This research has provided the guideline criteria for a uniform specification for CDOT that will allow each region a platform to secure the best, most reliable RWIS and FAST system utilizing the latest information in design and technology. CDOT maintenance was identified as the principal user of these systems and they will use the criteria to create a uniform specification based on CDOT preferences and practices. This specification should be considered a “living document” and should be updated continually as the technology develops.

IMPLEMENTATION STATEMENT

This report provides detailed recommendations on how to improve the design and construction of Colorado's bridge anti-icing systems. The research and recommendations in the report provide details for the planning, design, installation and testing for future FAST system projects. This report should serve as an important resource to Staff Maintenance personnel for both consideration and implementation of new FAST sites.

TABLE OF CONTENTS

CHAPTER ONE	INTRODUCTION	2
	General Description of a FAST System	2
CHAPTER TWO	LITERATURE REVIEW	5
CHAPTER THREE	SURVEY OF AGENCIES AND MANUFACTURERS	15
	Overview	15
	Survey Design	15
	Survey Results	17
CHAPTER FOUR	REQUIREMENTS FOR MODEL GENERIC SPECIFICATIONS	28
	Storage Device	28
	System Pump	30
	Pipes, Valves, and Other Delivery System Components	30
	Nozzles	31
	Triggering Mechanism and Associated Systems	32
CHAPTER FIVE	BENEFIT COST METHOD FOR SITE PRIORITIZATION	34
CHAPTER SIX	CONCLUSION AND RECOMMENDATIONS	38
REFERENCES		42
APPENDIX A	MODEL SPECIFICATIONS FOR A FAST SYSTEM	A-1
APPENDIX B	SURVEY INSTRUMENTS	B-1
APPENDIX C	SURVEY RESPONSES	C-1
APPENDIX D	BENEFIT COST WORKSHEET	D-1
APPENDIX E	STUDY PROPOSAL	E-1
APPENDIX F	PROBLEMS DOCUMENTED BY CDOT	F-1
APPENDIX G	LOCATIONS OF CDOT FIXED ANTI-ICING EQUIPMENT	G-1

LIST OF FIGURES

Figure 1. The “key lessons learned” from the FreezeFree Evaluation (CERF 2005).	6
Figure 2. Present value of benefits.	36
Figure 3. Present value of annual operation and maintenance costs.	37
Figure 4. Present value of salvage.	37

LIST OF TABLES

Table A. Respondent’s FAST installations.	17
Table B. Respondent’s systems by manufacturer.	18
Table C. Choosing a manufacturer.	18
Table D. Quality and performance rating.	19
Table E. Chemicals used in respondent’s systems.	26
Table F. Calculating the estimated annual rate of crash reduction.	35
Table G. Calculating the annual benefit of crash reduction.	35

INTRODUCTION

The purpose of this study has been the development of a set of model specifications for Fixed Anti-Icing Spray Technology (FAST) systems. The specifications include the best practices for such systems as determined by a survey of the literature and a survey of agencies currently using such systems.

This report presents a general description of a FAST system, together with a literature review. The literature surveyed has been copied and presented in a separate volume. A survey of system owners and of system suppliers was also conducted. The survey details are presented together with the results obtained from the surveys. The requirements gleaned from the literature and the surveys are then presented and discussed, in the context of a set of specifications for a FAST system. The appendices to this report contain the model specification, and a listing of all the literature referenced in the report.

General Description of a FAST System

The purpose of a FAST system is to deliver ice control chemicals in a controlled manner to a segment of road by means of a pump and nozzle system. While many FAST systems are located on bridge structures, their use is not limited to such structures, and as discussed in the next section, there are a number of significant uses of FAST systems that are not located on bridges. FAST systems are of course only considered for deployment in areas subject to winter weather, with the associated degradation of safe travel that such weather can bring.

There seem to be three major reasons for deploying FAST systems. One reason is that the structure or stretch of highway that is in particular need of ice control chemicals is very remote from the location of vehicles that can deliver such chemicals. If it takes two or three hours to reach a structure and apply ice control chemicals to that structure (followed by a return journey of similar length) then the use of an automated system may have significant benefits.

A second reason for deployment of FAST systems occurs when a road has very high traffic volumes and is also subject to winter weather. Under such circumstances, it is quite common for these highways to suffer congestion, especially during winter weather. The congestion creates a significant barrier to effective winter maintenance, because the plow trucks that are seeking to deploy ice control chemicals are prevented from doing so by the congestion. Thus road conditions on the congested stretch of highway worsen, making the congestion even worse. The use of an automated system under such circumstances ensures the delivery of ice control chemicals regardless of the traffic levels on the road or structure.

Safety can also be a reason for using a FAST system. If certain segments of highway are particularly prone to winter accidents, it may be worthwhile to use an automated system for ice control chemical delivery so that chemicals are always provided in a timely and appropriate manner.

Thus, the three main reasons for using or considering the use of a FAST system may be summarized as: remoteness of location, high levels of traffic volume and significant congestion, and major safety concerns in winter weather. Of course, a given site may be justified on the basis of some combination of these three reasons, rather than merely on the basis of one sole reason.

The primary components of a FAST system are a storage system to store an appropriate amount of ice control chemical, a pump system to deliver this chemical through the piping of the system, a system of pipes and valves that deliver the ice control chemical to various points along the structure, and a system of nozzles that spray that liquid onto the road surface in an appropriate manner. In addition, some sort of triggering device is required. Some systems are triggered manually – that is, an individual must send a signal to the system indicating that chemical should be delivered. Almost always this signal can be sent from a remote location rather than at the structure itself. The signal can be delivered in a variety of ways – via cell phone, via text messaging, via computer and modem, and so forth. Alternatively, the system may include an option for automatic triggering in addition to manual triggering. In such cases,

the system needs to be able to determine the condition of the road surface or bridge deck (with respect to ice and snow cover) and when certain conditions are met, the system is triggered. Thus such a system will include a number of weather and temperature sensors, together with a computer that has an algorithm to determine when adverse conditions have occurred and when ice control chemicals need to be applied.

It should be noted that while the concept of FAST systems seems relatively simple and straightforward (basically, apply a liquid ice control chemical to a well defined stretch of highway in controlled amounts, at specific times and under certain conditions) the realization of this concept is far from simple or straightforward. Simply put, there are many ways in which such a system can fail. This report will examine how these systems can fail and suggest, by way of a model specification, ways in which such failure can be minimized. While this means that the report will inevitably concentrate on the weak point of such systems, the authors wish to point out their belief that such systems, in the correct locations, and appropriately specified, are a very valuable tool in winter maintenance.

LITERATURE REVIEW

The literature that is reviewed in this report was obtained, primarily, in one of two ways. First, the TRIS literature database was searched to find as much general literature as possible. This literature was then supplemented by the authors' knowledge of the field and by making use of personal connections. While it is possible that some papers or reports have been missed, the literature reviewed here is likely to comprise a significant and representative portion of all literature on this topic.

In reviewing the literature the authors have not attempted to determine if any given piece of literature is more "valuable" than another. Rather, the literature has been searched for indications on what aspects of FAST systems are most critical, where problems are most likely to be encountered, and what steps have been taken to address those problems. These factors are the most pertinent to consider, in the context of developing a model specification that will provide the optimal systems for the Colorado DOT.

A relatively large comparative study was completed by the Highway Innovative Technology Evaluation Center in April 2005, entitled "Evaluation of the FreezeFree Anti-Icing System" (CERF, 2005). This report examines six different installations of one vendor's system (the FreezeFree system, a product of Energy Absorption Systems Inc.) in six different locations. A seventh location was initially to be part of the study, but could not be installed in time for data from that site to be included in the report. The report studies issues related to the installation, operation, and maintenance of the six installations (two in Wisconsin, and one each in Maryland, Minnesota, North Dakota, and Oregon).

Each of the installations was unique in terms of the type of system installed. The uniqueness existed in terms of "type of system such as Basic, Automated, or Nitro, type of sensor (active or passive), type of nozzles, and so forth." (CERF, 2005). The systems underwent essentially continuous repairs and upgrades during the test periods. Ratings of the installation, operation, and maintenance of the six systems were based on a five point Likert type scale, with ratings

of poor, below satisfactory, satisfactory, above satisfactory, and good. The qualitative nature of this rating system and the lack of consistent definitions of the five rating terms used does not allow for meaningful numerical comparisons between the six installations. Accordingly, the most valuable information in the report is the anecdotal reports about areas in which systems performed well, and those in which the systems did not perform well. Such data will be useful in developing a model specification.

Six “key lessons learned” were reported in this study (CERF, 2005; section 7.1.7). These are shown in Figure 1.

The key lessons learned from this evaluation study include:

1. The FreezeFree system is not an off-the-shelf system that can be purchased and installed right away at any given site. It requires customization of the installation at each site after studying the site requirements and conditions, and designing a specific system and its installation to meet those requirements.
2. Selection of the proper site for the installation of the system is key to obtaining the maximum benefit out of the system. The site should have unique characteristics like high crash history, remote location away from the regular maintenance routine, etc.
3. The type and quality of the anti-icing liquid used can significantly affect the performance of the system.
4. The system can be most effective under frost conditions. It should not be expected to enhance safety under moderate to heavy snow conditions.
5. The installation and maintenance of the system is fairly simple. Apart from some isolated problems that have been documented in this report, the installation and maintenance requirements generally met the expectations of the users.
6. There were a number of problems that were experienced in the operation of the system. Some sites reported erratic response to the spray logic, which includes firing of the system when not required (6% of all events), and not firing when required (7% of all events), as observed at the North Dakota test site. There needs to be more work done in order to eliminate or significantly reduce this problem to get maximum safety and economic benefits, and to increase the overall reliability of the system.

Figure 1. The “key lessons learned” from the FreezeFree Evaluation (CERF 2005).

Of these lessons learned, numbers two and four do not relate specifically to specification development, but are nonetheless pertinent, and bear out the literature elsewhere. It is clear that FAST systems are most effective when used to treat frost or black ice type situations. Further, FAST is not an appropriate solution for the whole road network, but rather should be applied in those areas where it will present the greatest benefit.

Lessons one, three, five, and six are extremely pertinent to this study. Lesson one is very important to bear in mind – no FAST system is an “off the shelf” product and thus each system will require site specific design and installation requirements. Such specificity must be allowed for in the specifications. The selection of the liquid used in the system is of great import – a major concern here is corrosion of system components, and this issue is discussed in more detail below. By and large for the six sites in this study, installation was not a problem, although in some cases it took a year to get the systems fully operational. Finally, system operation in these six cases was problematic, especially when some sort of automated triggering was used. The report notes the need for further work to improve the reliability of the automated system operation. It appears the logic for triggering an application of liquid through the system is complex and not easy to manage.

Thus the FreezeFree study includes some very useful experience that informs the process of system selection.

FAST systems have been used extensively in Europe. Perhaps the largest such system is on the A9 Lausanne bypass, in Switzerland. A FAST system was installed over 8.15 kilometers of this highway (a little more than 5 miles) in 1997 (Zambelli, 1998). The highway has three lanes in each direction, and carries (in 1998) about 70,000 vehicles per day. The system can be operated in both manual and automatic mode, with the latter being triggered when the ice detection system detects ice or gives advanced warning of ice formation. The system uses salt brine as the ice control chemical, and has four main storage tanks with capacities of approximately 3,300 gallons and eight intermediate storage tanks each with a capacity of approximately 550 gallons. A cost benefit analysis conducted prior to installation considered capital, interest, and depreciation costs as well as material costs, savings due to accidents

avoided and work crew call outs also avoided. The analysis indicated a benefit cost ratio of 1.45 with interest costs included (or 1.98 without), indicating that for every dollar (or in this case Swiss Franc) spent, \$1.45 (or \$1.98) would be saved. Such analyses should be a feature of every decision to deploy a FAST system. When the report was given in 1998, the system had been most successful.

An analysis conducted by the Federal Highway Research Institute of Germany (Moritz, 1998) considered the various FAST systems that had been deployed on the Federal road system in Germany up to that time. Some of these systems have been in operation since 1983, and so considerable experience in their use and operation has been gathered. The cost benefit analysis presented in this report indicates a benefit cost ratio of 1.9, which compares with that found by Zambelli (1998).

Another example from Europe is the Buthier viaduct (Christillin et al., 1998), located on the E27 International Highway that connects Italy and Switzerland through the Great St. Bernard Tunnel. This viaduct is located a significant distance from the maintenance center and frost control in a timely manner is both difficult and expensive to achieve in such a way as to ensure traffic safety. The Buthier viaduct lies between two tunnels (the Cote de Sorreley and the Signayes tunnels, 2.9 and 1.3 miles long respectively) and is an open stretch of 1,485 feet of which 660 feet is an open viaduct. The location of the viaduct is such that it is highly prone to frost formation events. A salt brine was the liquid used in the system, and deck mounted nozzles were also used. Again, operation could be manually or automatically triggered. The system comprises 58 spraying units, connected in pairs to 29 pressure accumulators. Spraying units are mounted approximately 30 feet apart. Storage includes 2 main tanks of about 2,200 gallons capacity. No cost benefit analysis was reported for this system, perhaps because one of the major factors governing its deployment was the remoteness of a relatively short stretch of highway that needed service to avoid ice formation. Nonetheless, a similar benefit cost ratio could be implied from other studies.

Another factor noted in the report by Christillin et al. (1998) is that FAST systems had been used for some twenty years at the time of their report, from 1978 onwards. The experience

gained with these systems must now be considered extensive, and as such, they should not be considered experimental technology, but rather a proven technology, that has a well demonstrated benefit cost ratio when placed in appropriate locations. Further, the systems clearly can operate in both automatic and manual mode – none of the European reports cited indicate any problems with operation in automatic mode, in contrast with the CERF (2005) report. The implication of this is that U.S. agencies should not have to settle for systems that fail to provide fully automated operation, if that is a needed requirement. Such systems exist and work.

A report by Keranen (1998) details the experiences of Minnesota DOT with two automated systems. One, a traditional FAST system, was located on Highway 169, near Hibbing in Northern Minnesota. A second system, which uniquely supplied solid material, was located on US Highway 10 about 10 miles north of St. Cloud. Both systems were actuated by sensors located in the bridge decks (i.e., they were designed to operate in an automatic mode, as well as by some manual trigger, which could be set remotely by cell phone, for example). The study was intended to examine both the performance of the systems, as well as their economic benefits, if any. The report notes that the automated system was not tested during the first winter of operation, but that during that winter, the remote triggering mechanism was tested for both structures and appeared to work in a satisfactory manner. An economic analysis based on actual accident data could not be performed, but a conceptual study indicated that eliminating even one accident a year at each of the bridge locations would provide a benefit cost ratio greater than one.

A number of reports by major agencies (either State Departments of Transportation or Canadian Provincial Ministries of Transportation) have examined the installation and operation of FAST systems. These reports provide extremely useful information, as they tend to be written by those who will be using the system in the long run, and as such they are strongly focused on the realities of operating such systems. One of these reports is by Minnesota DOT (Johnson, 2001). This report provides an operational evaluation of a FAST system installed on I-35W on a bridge over the Mississippi River. The system, designed, manufactured, and installed by Boschung, included 8 parapet-mounted nozzles, and 68 flush

mounted disk spray nozzles. There was a 3100-gallon storage tank for the chemical used, which was potassium acetate. Thirty-eight valve units controlled chemical flow, with two nozzles assigned to each valve. The report compares the operational performance of the system during the 2000-01 winter, with data on the 1996-97 winter, determined to be the closest winter climatologically to the winter of the test.

The operational test gathered a great deal of information, and allowed a number of observations to be made. From the point of view of the current study, the following findings are the most pertinent.

- All parapet nozzles were consistently blocked by snow during snow plowing operations.
- The flush mounted nozzles occasionally became plugged, resulting in less than 100% coverage of the lanes, but this blocking was temporary and usually cleared during the second spray of any blocked unit.
- Traffic flow was not significantly impacted by the spraying.
- The original in-line filter at the pump house failed (resulting in a 50 gallon spill of ice control chemical) but this problem was solved with a redesign of the line filter.
- The software exhibited one error in spring 2001, and was not easy to edit or to use to access real-time or historical data.
- The pump house performed poorly and the containment area did not contain the fluid that spilled (see above).
- The size of the storage tank was too small, since the chemical was delivered in batches of 4,400 gallons. Thus the tank should have been sized to store at least one delivered load.
- The chemical used in the system (potassium acetate, specifically the Cryotech CF7 product) performed well, and worked in low temperatures.
- However, the CF7 appeared to react with galvanized metals in the pump house. Cleaning the metal in question stopped the chemical reaction.
- The particular product (CF7) has a potential for hydrogen gas build up, thus it is critical that the pump house be properly vented.

In addition to the operational concerns listed above, a comparison of accident data between the 2000-01 winter and the comparable 1996-97 winter indicated a reduction in accidents of approximately 68% from the earlier winter to the later winter. Given how comparable the two winters were, it seems reasonable to assume that the reduction was at least in part due to the FAST system.

Roosevelt (2004) reports on a pilot installation of a FAST system for the Virginia DOT. The project goals were to evaluate the effectiveness of the various options available for FAST systems, and to become familiar with the construction, maintenance, and operational issues involved with such systems. The study was conducted in the context of using the system as a preventative measure for the formation of ice and for the bonding of snow to the pavement. It is clearly noted in the study that the use of a FAST system is not a substitute for plowing snow.

The site chosen for the pilot study was a bridge on the ramp from Route 7 eastbound to I-66 westbound in Fairfax County Virginia. The structure is 30 feet wide, and serves as a single-lane, one-way roadway, with a marked travel lane that is 16 feet wide. The system selected for this installation was an Odin System. The chemical used was magnesium chloride brine. Three nozzle mounting schemes were used in the pilot installation: parapet mounted, in-deck lane mounted, and in-deck centerline mounted. The Environmental Sensor Station (ESS) for the installation was provided and installed by VDOT, and was used to automatically activate the FAST system. This report discusses the logic used for automated operation in some detail and provides significant insight into the triggering mechanism. Evaluation data for the system were collected over two winters: 1998-99 and 1999-2000.

The findings of this study are of great value in terms of developing a model specification. The study notes that a FAST system is in fact two interacting sub-systems. One sub-system senses various weather and surface condition parameters, and the second sub-system delivers chemical onto the structure via pumps, valves, pipes and nozzles. It was noted that the sensor sub-system was not able to determine the concentration of brine on the structure, and was thus

unable to accurately determine at what temperature the bridge was going to begin to ice. This in effect means that the automated triggering system could not work.

The system appeared, with the assistance of vehicle tracking, to provide a sufficiently uniform spread of chemical over the protected structure, provided chemical is placed in areas where the traffic runs. The quantity of chemical supplied by the system was clearly adequate for the treatment the system was designed to provide. Some difficulties were encountered during the construction of the system that appear to be related primarily to the use of conduits in the bridge deck. The need for a clearly detailed preventive maintenance program was stressed. The nature of the study was such that a detailed cost benefit analysis could not be performed due to lack of pertinent data.

Barrett and Pigman (2001) evaluated a FAST system deployed on a bridge on southbound Interstate 75, and north interchange to Corbin, Kentucky. The system was an Odin system, using spray nozzles mounted on the bridge wall and the bridge rail. The bridge being protected was approximately 600 feet in length and three lanes wide. The system used calcium chloride brine as the anti-icing chemical. For this installation, the only means of operation was remotely by means of a dial-up connection. After four winters, the performance of the system was evaluated.

During the four-year evaluation period, the system was only used about 10 to 12 times, and as such was probably not located at an optimal site. Some problems were encountered with nozzles, with pump operation due to overly high amperage, and with the video camera used to remotely view the bridge site. All of these problems were fixed. In addition, there is concern that relatively few personnel were trained in the use and maintenance of the system and so in a relatively short time there will be nobody on staff to handle maintenance and operational issues. Further, it was recommended that future placement of such FAST systems be in locations that were more susceptible to freezing situations.

Pinet et al. (2001) describe the installation and performance of the first FAST system in Canada, deployed on the northbound 416/401-interchange structure, in Ontario. The structure

is approximately 550 ft in length, is super-elevated, and serves as a high speed, freeway to freeway ramp with AADT of 3000, and a design speed of approximately 80 mph. The selected chemical for the system was potassium acetate. The installed system had two modes of operation. In the first, sensors at the site detected a potentially dangerous condition, provided an alarm to a designated person, who then had the option to remotely trigger the system. In the second mode, the system detected dangerous conditions, and also triggered the system based on algorithmic relationships that had been previously determined. In this latter mode of operation, all pertinent data in the system were recorded.

The paper by Pinet et al. (2001) lists a number of important “lessons learned” on the project. These include the requirement for a feasibility study prior to deciding on a FAST system, the fact that project costs were more typical for an Information Technology project than for a typical roadway infrastructure project, that getting utilities to remote sites can be a challenge, that a storage reservoir for chemicals on site is an absolute requirement, and this reservoir must be adequately sized for the season. In addition, the upper edge of super-elevated structures must be cleared of snow, to avoid it melting, running across the structure and causing an unnecessary firing of the system. Further, there were a number of issues with regard to the system software, in terms of compatibility with various operating systems, limited numbers of licenses for the system owner, and challenges with accessing the FAST server when needed. Nonetheless, the system appears to have functioned very well, and since installation there have been no winter weather related accidents on the protected structure. As a result, the Ontario Ministry of Transportation is examining other locations at which FAST installations may be of benefit.

Friar and Decker (1999) report on the installation of a “home built” FAST system on an interchange/overpass on I-215 in Salt Lake City, Utah. The system protected the northbound side of the structure, with the southbound lanes being left in an unchanged state. Their study reports a significant reduction in the number of winter weather related accidents on the protected structure, in comparison with the five previous winters. No data are presented regarding any operational issues with the system.

Lipnick (2001) reports on a system installed by the Maryland DOT State Highway Administration in the 1998-99 winter season, on a bridge on I-68, over Street Road, in Allegany County, Maryland. The system was installed by SSI, with Odin Systems International as a subcontractor. The ice control product selected for the system was CMAK, a mixture of calcium magnesium acetate and potassium acetate sold by Cryotech. The system experienced some installation issues such as plugged nozzles and pipelines, loose fittings and software issues. However, these were all addressed prior to the 1999-2000 winter season to the satisfaction of the State Highway Administration (SHA). After this first season of operation, SHA met with all vendors (SSI, Odin, and Cryotech) to discuss the system operation during that winter and how it could be improved. As a result of that meeting a few changes were made in the system, including a low level warning on the storage tank, and the replacement of the initial video camera with a wide angle camera that allowed both eastbound and westbound bridge decks to be viewed simultaneously. In terms of benefits experienced by SHA due to the system, about \$16,000 of savings were identified due to avoiding winter callouts, and accidents on the bridge were reduced by approximately 40%. The final conclusion in the report is that "WMTET and the LaVale Shop managers and engineers unanimously agree the system is a major success."

Stowe (2001) presented an effective and detailed methodology for determining the benefit/cost ratio for a proposed FAST installation. His methodology used as an example a section on I-90 termed the "Vantage Curves." The value of the paper lies in the detailed and thorough manner in which it explains how to determine a benefit cost ratio for such an installation, based primarily on accident reduction. Stowe assumed a 60% reduction in accidents once the system was installed. While this figure can certainly be challenged, it does lie within the ranges observed and reported, and thus has significant validity. The analysis showed that the proposed installation would have a benefit/cost ratio of 2.36.

To summarize the literature presented here, it appears that FAST installations can exhibit high benefit/cost ratios, if their location is chosen carefully. Literature also indicates that installing a FAST system is complex, and difficulties seem to be expected. Particular areas that exhibit problems often include software, triggering process, pumping system, and storage tanks.

SURVEY OF AGENCIES AND MANUFACTURERS

Overview

Three surveys of individuals familiar with the design and operation of FAST systems were conducted. Each survey targeted a specific knowledge group. The three knowledge groups were representatives from transportation agencies that have deployed FAST systems, manufacturers of FAST systems, and CDOT staff. Twenty-five representatives from transportation agencies, four manufacturers, and three CDOT staff were surveyed.

Written survey questions were mailed to agency representatives and manufacturers. Survey questions differed significantly between the two knowledge groups due to their respective roles in FAST technology. Agency representatives were surveyed for their knowledge regarding design, contracting, operation, and maintenance of FAST systems. Manufacturers were surveyed for their knowledge regarding design, features, service, and problem areas. A survey of CDOT staff was conducted by oral interviews. They were surveyed for their views regarding the operations of existing FAST systems operated by CDOT.

Ten agency representatives responded to the survey for a 40 percent response rate. Two of the four manufacturers responded to the survey. The oral interview process collected responses from all CDOT staff in the survey. The response rate is respectable for survey processes. However, given the small population of organizations operating and manufacturing FAST systems, a greater response rate was preferred. The consultants conducted follow up calls to encourage more responses. This effort yielded a single additional response from agency representatives.

Survey Design

Survey questions were developed to collect information relating to research tasks defined in this project. In addition, questions were included to encourage respondents to document their

views and preferences, based on experience, of FAST systems. Specific topics covered by survey questions are listed below:

- System manufacturer
- Types of pavement sensors
- Hardware and software compatibility
- Weather station requirements
- Camera hosting capability
- Type and location of spray nozzles
- Pump system specifications
- Pump house and storage facilities
- Availability of parts and service
- Operation triggering capabilities
- Chemicals used in systems
- Corrosion problems
- Operational problems and successes
- System component cost
- Advancements and emerging technology

Question format included yes or no responses, select a response from a list of options, filling out tables with information, and essay questions. Most were essay questions. The extensive breadth of the subject matter resulted in a 55-question survey for agency representatives and 38 questions for manufacturers. Respondents likely spent up to an hour to complete the survey due to the format and number of questions. It should be noted that most respondents provided complete and detailed answers, which represents a significant investment of time on their part. Questions for CDOT staff interviews covered general topics. Questions were designed to encourage CDOT staff to express their views and experiences without limitations to specific subject matter. The intent of this format was to identify issues from their perspective and their general preferences regarding those issues.

Survey Results

System Selection, Features, and Design

Survey responses from transportation agencies represent twenty systems from four FAST manufacturers (Table A). A survey was sent to All Weather, Inc., Boschung, Odin, and Quixote. A representative from All Weather replied that the company is no longer manufacturing FAST systems. Quixote and Odin did not respond to the survey. Boschung was the only manufacturer to return a completed survey. The consultant could find no indication that Odin was currently manufacturing FAST systems. Although Quixote representatives did not respond to the survey or follow up contacts, the company is certainly an active FAST manufacturer. The discussion of system features and design focuses on the two active manufacturers; Boschung and Quixote. Distribution of manufacturers among surveyed transportation agencies is shown in Table B. The numbers shown are not presumed to represent all FAST systems under the jurisdiction of an agency, but represent the systems rated by survey respondents.

Table A. Respondent's FAST installations.

Manufacturer	Number of systems represented by survey	Date range when systems placed in operation	Respondent's comments
Boschung	4	1999-03	1. Fully automated, very reliable. 2. Problem with software, vendor availability medium, equipment good.
Odin	4	1997-02	1. System no longer being used. 2. Problem with software, vendor availability poor, equipment OK. 3. Pilot test-never managed by field operations.
All Weather (Qualmetrics)	2	2002	No comments.
Quixote (Numetrics or Freeze Free)	10	2000-04	1. Both locations need more adjustments and calibration. 2. System has been plagued with problems for two years.

Table B. Respondent's systems by manufacturer.

Agency	Total Number of Systems	Boschung	Odin	All Weather (Qualmetrics)	Quixote (Numetrics or Freeze Free)
Colorado	4				4
Wisconsin	3		1		2
Washington	2			2	
Ontario, CN	5	2			3
Nebraska	3	1	2		
Minnesota	1	1			
Iowa	1				1
Virginia	1		1		

FAST systems are complex. A FAST system integrates sensing technology, fluid mechanics, data processing, and communication technology with the concrete and asphalt of a highway facility. Few, if any, transportation agencies are able to design a FAST system from components. Agencies must depend on a FAST manufacturer to design a system for a given application. Such dependence on a manufacturer means selecting the right manufacturer is crucial to success of a FAST project. Most survey respondents named performance and quality the most important criteria for selecting a FAST manufacturer (Table C.).

Table C. Choosing a manufacturer.

Agency	Manufacturer Selection Criteria Used				Preferences	
	Performance	History	Quality	Low Bid	Most Important Criteria	Preferred Vendor
Colorado	No	No	Yes	No	Performance	N/C
Wisconsin	No	No	Yes	No	Quality	Quixote
Washington	No	No	No	Yes	History	Boschung
Ontario, CN	Yes	Yes	Yes	No	Low Bid	N/C
Nebraska	Yes	Yes	Yes	Yes	Low Bid	Boschung
Minnesota	Yes	No	Yes	Yes	Quality and Performance	Boschung
Iowa	No	No	No	Yes	Quality	N/C
Virginia	No	No	No	Yes	Performance	Boschung

Among survey respondents, Boschung is rated highest for quality and performance. All respondents with Boschung systems rate them high quality and 75 percent indicate system performance is satisfactory. Respondents rate 20 percent of Quixote systems high quality and 60 percent medium quality. Half the respondents rate Quixote system performance satisfactory (Table D).

Table D. Quality and performance rating.

Manufacturer	System quality rating				Met user's expectations	
	High	Medium	Low	Not rated	Yes	No
Boschung	4	0	0	0	3	1
Odin	0	2	2	0	0	4
All Weather (Qualmetrics)	0	0	0	2	0	2
Quixote (Numetrics or Freeze Free)	2	6	0	2	5	5
Column total	6	8	2	4	8	12

Indications of performance and quality may be gained from the history of a given manufacturer's prior FAST installations. A sufficient number of Boschung and Quixote systems are in operation to learn something about their performance and quality. Users of both systems have experienced problems. Conversely, both systems have advocates among respondents who appear quite satisfied with performance and quality. Boschung appears to have greater appeal among respondents. Boschung has manufactured FAST systems for a longer period and has had ample opportunity to work out problem areas. Quixote has less experience and appears to be working through design problems. It should be remembered that FAST systems are made of complex hardware and software. Even proven systems experience problems. The history of a manufacturer's systems demonstrates how well the manufacturer is able to resolve the inevitable problems that arise. Companies that are unwilling or unable to resolve design and operational problems eventually leave the market.

In today's market, selecting a manufacturer means choosing either Boschung or Quixote. Performance and quality, as demonstrated by product history, are the preferred selection

criteria indicated by survey respondents. Bid price is the third criteria indicated by respondents. When low quality or poorly performing systems are in the market, bid price should be a less important selection criterion. However, the current market consists solely of two manufacturers with proven systems. Bid price should have considerable weight in the selection process.

The most consistent responses among respondents are found in the system features and design sections of the survey. A strong consensus exists for the following features to be a part of each FAST installation:

- Full RWIS instrumentation
- Full automatic detection and activation
- Active and passive roadway sensors
- Data recording (for archiving)
 - Atmospheric conditions
 - Road surface conditions
 - System functions
- Automatic, manual on site, and manual remote activation
- Alarm notification for system activation and system functions (i.e., leaks, pump failure, activation failure, low chemical, etc.)

CDOT staff indicates a preference for a system that is capable of accommodating multiple firing and time cycles, flow control monitoring with leak protection, NTCIP compatibility, and communications that can accommodate PTZ cameras and multiple equipment arrays.

Other desirable system features include:

- Nozzle group isolation, which allows a single nozzle group to shut down without affecting firing at remaining nozzles.
- Full chemical recovery from distribution lines into storage tank without dilution.
- Remote reading of chemical tank level on demand.
- FAST system RWIS integration with agency RWIS network.

All respondents indicated using the manufacturer's activation and firing parameters. Some adjustments were made after observing operations. System design should allow the operators to easily adjust firing sequences and chemical volume.

The focus of this survey is on fully automatic FAST systems. Manufacturers are bringing less expensive, pre-fabricated, and manually operated systems to the market. These systems can be desirable because they are less complex and more affordable. A survey respondent commented on manually operating a FAST system. The respondent noted that manually operating the system requires deciphering conditions to fire the system. The respondent is referring to data from the sensor array that must be analyzed before determining whether to fire the system. This indicates a system operator requires a certain level of training and knowledge at reading RWIS data and drawing a conclusion of current roadway conditions what conditions are likely to occur in the future. The operator must know how anti-icing chemicals work, specifically what chemicals are capable of doing once applied to a roadway. To successfully deploy manually operated systems, transportation agencies should plan to provide nearly constant monitoring of site conditions by staff with a high degree of expertise utilizing RWIS and anti-icing practices.

Pump House and Storage Features

When CDOT staff was asked, "What are the major disappointments with your existing systems?" their collective response focused on underground pump houses. CDOT staff cites maintenance and operational issues and confined space entry as major problems. Their recommendation is to construct aboveground pump house and storage facilities at all new FAST installation sites. They also recommend that facilities should be designed for ease of maintenance where all pump house hardware may be installed or removed without specialized equipment. This theme was echoed by survey respondents from other transportation agencies. Although underground pump houses have created problems for CDOT staff the option should remain open when other types of facilities are not practical or esthetically acceptable. CDOT has two installations using direct buried tanks separate from the underground pump vault with the liquid being piped to the system supply pump. This type of installation minimizes the problem of tank leakage inside the equipment vault causing problems with the operating

equipment for the FAST System. While this can be advantageous it creates issues for tank inspection, possible tank failures, vault and buried supply line leakage leading to ground contamination, and requires confined entry regulations. General CDOT opinion is that direct buried tanks will not be used because of these potential problems.

All respondents reported using aboveground pump houses. One respondent indicated both above and belowground facilities were in use at his agency. The respondents agreed in their perspective of the advantages and disadvantages of both facility designs. Unsightly appearance and opportunity for vandalism were cited as disadvantages for aboveground facilities, while advantages were ease of access and less costly to construct. Poor access and high cost were disadvantages and aesthetic appearance was an advantage for underground facilities. Boschung America, LLC weighed in on the issue of aesthetics. The Boschung representative stated, “Pump houses can include any aesthetic options the owner desires as long as it is sized to properly match the needs of the system.”

Several respondents correctly identified chemical storage requirements as the primary criteria for sizing pump houses. Responding to a question about sizing chemical tanks, Boschung’s representative stated, “We use a formula that takes into account number of disks, length of system, and average expected firing of system per season. We also factor in quantity discounts available when ordering chemicals to make capacity more economical for the owner.” Survey responses reveal two issues regarding tank sizing. First is that storage tanks, typically located inside pump houses, drive the size and, therefore, the cost of the facility. The second issue is that re-supply costs and/or the needs of system operations determine the site storage capacity. A FAST system with few nozzles may function the entire season with a single tank full of chemical, thus reducing costs to construct the storage facility and tanker access requirements. Larger FAST systems, which require re-supply during the season, must have more chemical storage capacity. Tanks large enough to accept a full tanker load, while still retaining enough chemical in reserve to operate the system, may be most economical even considering higher pump house construction costs. CDOT currently stores the anti-icing liquid in a central regional facility with larger capacity tanks and then delivers smaller loads

themselves to the individual anti-icing installations. For this supply scenario, larger storage capacity at the individual sites may not be warranted. CDOT should develop a standard procedure, utilizing “in-house” expertise, for the sizing of chemical product and delivery amounts based on the information contained in this report and site specific criteria.

The survey responses show a strong preference for pump house and storage facilities that are maintenance friendly. Any organization installing a FAST system should carefully consider the needs and preferences of staff that are charged with operating and maintaining the system. FAST technology is new and complex and, most of all, challenging to operate. Every effort should be made to make the task of maintaining a system as simple and straightforward as possible. The Consultant recommends that CDOT strongly consider the staff preference for aboveground facilities. Recognizing that aesthetics is the primary reason for constructing underground facilities, challenge FAST manufacturers to design a facility that is aesthetically pleasing and blends with characteristics of the site. Survey respondents also recommend constructing a paved area for tanker access to storage tanks and add an exterior light that is on when the system firing sequence is in operation.

Spray Nozzles

Spray nozzle related questions were intended to identify nozzle placement preferences and any problems associated with nozzle operation. CDOT staff was asked, “What type of equipment is necessary for optimal operation of your FAST site?” Their response named nozzle placement and spray operations. CDOT staff prefers nozzles mounted flush with the roadway surface. They recommend using side or barrier mounted nozzles only where flush nozzles are not practical. CDOT staff desires reliable and versatile spray operations. They suggest flow control monitoring to detect line, valve, or tank leakage. They also suggest the system be capable of utilizing multiple fire and time cycles for various surface and weather conditions as determined by the on-site RWIS.

All respondents reported using flush mounted spray nozzles. Five agencies use both flush and side mounted nozzles. There was unanimous agreement among respondents that flush mounted nozzles worked best. Respondents commented that side mounted nozzles can get

obstructed by snow against the barrier and flush mounted nozzles have better coverage, are less susceptible to wind, and spray does not hit the side of passing vehicles. Flush mounted nozzles were most commonly placed between driving lanes. Two respondents reported placing nozzles at the roadway shoulder and one used both shoulder and lane placement. Recommended nozzle spacing ranged from 20 feet to 60 feet. Chemical distribution is very dependent on tracking by passing vehicles. Important design considerations for spacing include roadway profile grade, super-elevation, and traffic volume.

The survey asked if spray nozzles were placed beyond the limits of a bridge. Five agencies placed nozzles off bridges and three placed them only on the bridge. Rationale for placing nozzles before a bridge is to provide chemical tracking onto the bridge and treat bridge approaches with chemical. When the adjacent roadway receives a different treatment than that provided by the FAST system, nozzle placement off the bridge allows the agency to manage the transition point. One respondent commented his agency placed nozzles well beyond bridge limits in an attempt to prevent or reduce chloride tracking onto the bridge.

Only one respondent reported experiencing no problems with spray nozzles. Three reported problems with nozzle pressure and three reported problems with the firing sequence. Two reported corrosion problems at nozzles. Other problems included making spray adjustments and software compatibility. None of the manufacturers systems represented by the respondents were trouble free regarding spraying operations. Owners should consider specifications that hold manufacturers responsible for resolving problems before released from their contractual obligations. One consideration may be a performance bond to insure the manufacturer's system operates as intended, particularly with respect to hardware/software compatibility.

Chemicals

Potassium acetate is the most widely used chemical in FAST systems represented by the survey. Table E shows the agency and chemical of choice. Two agencies use magnesium chloride and one uses both magnesium chloride and potassium acetate. Two agencies once used calcium chloride or sodium chloride but both have switched to potassium acetate. One

agency switched from potassium acetate to magnesium chloride. Boschung America, LLC states their system does not have any limitations regarding selection of anti-icing chemical as long as the liquid is free of solids, which may clog the system, and the liquid does not thicken in cold temperatures.

Respondents reported corrosion problems with both potassium acetate and magnesium chloride. In each incident, the problem was corrected. Based on survey responses, no indication is present that potassium acetate is less corrosive to FAST system hardware than magnesium chloride. Six of eight agencies represented in the survey reported the occurrence of corrosion at the pump, pump house, nozzles, or valves. All reported corrosion problems were resolved or, as in one case, was determined to be the result of poor preventive maintenance practices.

Table E. Chemicals used in respondent's systems.

Agency	Chemical Used in System(s)	Corrosion at Pump or Pump House	Corrosion at Nozzles or Valves	Comments
Colorado	Potassium Acetate NC3000 MgCl ₂ cold Temp Modified	No	No	NC-3000 brand of KAc reported to leave a residue on roadway sensor preventing communication with controller.
Wisconsin	Magnesium Chloride	No	Yes	KAc not worth higher costs, switched to MgCl ₂ . Corrosion at nozzle valves with MgCl ₂ , corrected by vendor.
Washington	Potassium Acetate	No	No	N/C
Ontario, CN	Potassium Acetate	No	Yes	N/C
Nebraska	Potassium Acetate and Magnesium Chloride	No	No	N/C
Minnesota	Potassium Acetate	Yes	No	Galvanized steel floor grating corroded with KAc. Nozzles are plastic and valves are stainless steel.
Iowa	Potassium Acetate	No	Yes	Repositioned valve boxes to aboveground which stopped corrosion problem. Tried sodium chloride but it froze in the lines.
Virginia	Magnesium Chloride	Yes	No	Pump corrosion due to lack of preventive maintenance.

It must be noted that some reports of corrosion at valves referred to the Quixote Freeze Free system. In a discussion with a Quixote representative, the Consultant was informed that valve corrosion was at first the result of a chemical reaction with valve material. This condition was corrected by changing materials. However, corrosion continued to be a problem. The second problem was discovered to be the result of manufacturing process error that compromised the

protective coating on valve parts. The Quixote representative stated that the error was corrected and corrosion was no longer a problem.

Other chemical issues noted by respondents were problems with chemical residue interfering with the operations of roadway sensors and one report of sodium chloride brine freezing in the lines.

Survey results challenge the common perception that non-corrosive, non-chloride chemicals should be used in FAST systems. It is apparent that FAST system manufacturers, Boschung and Quixote, construct their systems from high quality materials that are either not susceptible to corrosion or have protective coatings to prevent corrosion from chloride based anti-icing chemicals.

Conclusion

A resounding theme from survey respondents is that FAST systems are not turnkey technology. None of the systems represented were constructed and placed in operation without significant problem solving by the owner and manufacturer. Some systems do not operate as intended after years of adjustment and repair. Transportation agencies should not expect a FAST system to operate as planned upon completion of construction activities. Agencies should expect, and foster, a close and ongoing relationship with the manufacturer, for the demands of problem solving system operations and maintenance issues requires the manufacturer's expertise. Operations and maintenance programs and procedures appear to be a low priority to most of the agencies responding to the survey. This trend seems incongruous given the complexity of FAST systems. It is likely that at least some of the operational issues plaguing FAST systems could be mitigated with good preventive maintenance procedures. As challenging as the systems are, the technology is expanding because they deliver results. FAST systems reduce vehicle accidents. And this is why survey respondents are looking for more successful FAST installations regardless of the challenges and disappointments they have experienced.

REQUIREMENTS FOR MODEL GENERIC SPECIFICATIONS

The data collected and reviewed during this project indicate that there are various areas or parts of a FAST installation that are particularly prone to failure, and thus need to be specified very carefully. In this section of the report, these areas or components will be identified, and the specific needs or issues associated with them will be addressed.

As noted in the introduction to this report: “The primary components of a FAST system are a storage system to store an appropriate amount of ice control chemical, a pump system to deliver this chemical through the piping of the system, a system of pipes and valves that deliver the ice control chemical to various points along the structure, and a system of nozzles that spray that liquid onto the road surface in an appropriate manner. In addition, some sort of triggering device is required.” Thus this section will consider the following five components of a FAST system: the storage device, the pump, the pipes, valves and other associated delivery equipment, the nozzles, and the triggering mechanism or device. For each of these components, issues identified in the literature and the surveys will be presented and potential solutions discussed. In addition, the selection of the ice control chemical to be used in the system will be discussed.

Storage Device

The primary concern with the storage device is that it should be sufficiently large to hold enough chemical that it does not need to be refilled too often. A secondary but related concern is that when the quantity of chemical drops to a level at which more chemical must be ordered, there should be sufficient storage available in the storage device to accommodate a full load of chemical (i.e., one truck full). Some sort of low level (of chemical in the storage vessel) warning system is a requirement to ensure the system does not run dry during the winter season. In the ideal, the level should be capable of being monitored remotely, but this may be an unnecessary feature, depending on the location of the whole system.

The sizing of the chemical storage tank may be undertaken in one of two ways. The CDOT engineer may design the tank size or the specification may require that the vendor include the design of the storage size in their bid. If tank size is to be determined by the CDOT engineer, then that design must consider the following factors:

- Quantity of material used in each anti-icing cycle
- Quantity of material delivered in one shipment by chemical supplier
- Remoteness of the site, and thus the difficulty associated with refilling the storage tank from a central location
- The expected frequency at which the anti-icing cycle will be triggered
- Other factors that may be pertinent depending on the specific structure to be protected.

In addition to the sizing issue, a number of other concerns about the storage system were expressed by users. Spill containment must be addressed in the storage area, and the pertinent environmental regulations relating to spills must be met. Venting in the pump house is a concern, especially if potassium acetate is the chosen chemical, since this chemical may cause a hydrogen gas build up. If storage facilities are placed underground, then the whole facility will likely be termed an enclosed space, which will make working in the facility potentially hazardous. Thus, if at all possible, such underground storage should not be used. In any case, electrical shutoff should be provided outside the storage facility. Also, grab bars should be placed above grade to allow for easier access. Steps should be taken to ensure security of the facility and to minimize possibilities for vandalism and graffiti. Depending on the details of the system, a sump pump will likely be required and the floor should be sloped to the sump. All concrete floors and walls should be monolithic pours to minimize any possibility for surrounding contamination due to leakage at poured joints. The issue of the need for heaters in the storage area was raised, and certainly heaters should only be used if required. Roof access should be able to be achieved in such a way that special lifting gear is not required, and should provide a watertight seal. Any other external joints in the vault should also have watertight seals, as should all fittings inside the vault. The storage tank should be capable of being filled from outside the storage vault, with appropriate valves and controls on the outside wall. The use of a three-way valve to aid in the removal of deicing liquid for decommissioning the system is recommended. Finally, appropriate steps should be taken to

ensure, as far as possible, that the design of the storage facility is in keeping with the bridge design, and does not prove to be a visual distraction.

System Pump

In selecting the pump, care must be taken to ensure that it has sufficient capacity to pressurize the system and ensure adequate flow to the pipe and nozzle sub-system. The selection of filters must be carefully made in conjunction with the anti-icing chemical selection, so that undue clogging of filters is not a problem. The pump itself must be compatible with the ice control chemical that is selected for the system. In particular, the chemical must not cause any corrosion problems, and if there is a possibility of corrosion occurring, the vulnerable parts of the pump must be specified to be of a material that is not corroded by the selected chemical. Additionally, the pump must be capable of automated and remote operation. Specifically, it must be capable of being switched on and off under the control of a computer with appropriate electronic interface systems. Ideally, the pump should be located in the storage facility in such a way as to allow for easy servicing. A number of comments suggested mounting pumps on the wall of the storage facility, so that if breakage occurs, the pumps will not be flooded. Its location must also be secure from vandalism and other similar types of damage. The pump and pumping system must have the capability to pump material from the storage tank into a mobile tank. Finally, the expected lifetime of the pump should be the same as that for the whole system.

Pipes, Valves, and Other Delivery System Components

The piping for a FAST system can be fairly complex, so care should be taken in a number of ways to ensure that the piping and valves are not a point of weakness in the system. There is some indication that flexible piping can be very valuable during installation, simplifying this process considerably. Concerns about corrosion imply that stainless steel connectors should

be used throughout the delivery system, and care should be taken to ensure that the selected ice control chemical does not corrode the materials used in the valves.

There have been some reports of nozzles blocking, but the blockages appear to be temporary and self-clearing. A judicious combination of filtering at the pump and careful selection of nozzle size should minimize this issue as an operational concern. Nozzles can be located either in the deck or on the bridge parapet. Of these two options, the deck location is far preferable in terms of system operation (although this will lead to a more complex installation process).

Nozzles

There were a number of concerns expressed about the nozzles used in various installations. The first of these was that many pavement-mounted nozzles were mounted slightly above grade and as such were damaged by snowplows. Nozzles should be recessed a suitable distance whether mounted in pavement or on parapets. If mounted in the pavement, care should be taken to ensure that subsequent maintenance operations (e.g., re-surfacing, or milling of the surface) do not render the nozzles useless. The height of the nozzles in the pavement should thus be adjustable to some degree. The use of non-metallic and non-mechanical nozzles seems to be acceptable.

One of the major concerns expressed was that the pattern of nozzles was insufficient to provide chemical coverage to the whole of the structure being covered. Such coverage is a function not only of the structure itself but also of traffic levels, since much of the liquid coverage on a structure is obtained by vehicular “tracking” of the chemical across the structure. Certainly, every effort must be made during the design phase to ensure adequate coverage, and this particularly applies to the nozzle height for parapet-mounted nozzles. Ideally, the pattern of delivery should be presented to the state maintenance engineer for review and approval.

Triggering Mechanism and Associated Systems

There is considerable desire in having a system that can be triggered in a number of different ways. These include triggering by a button placed outside the vault, activation by phone, activation by a remote (that can be triggered by a passing vehicle, e.g., a snow plow) and activation by a computer from a Windows or Web based PC software.

Concerns were expressed about some sensor performance. It appears that in some cases, water was ponding around the sensors, causing them to indicate a condition that required an application of chemical (when in fact no such application was required). To avoid this, the asphalt around the sensors needs to be appropriately sealed.

Some problems were, or appeared to be, associated with “dirty power,” i.e., brown outs, line interruption, etc. The possibility of noisy power causing system problems certainly exists, and specifications should ensure that appropriate steps are taken by the contactor to provide “clean power” that is unlikely to trigger the systems inappropriately, i.e., separate line feed, battery or standby generator backup. Each site should be evaluated for back up power either by battery or generator with a warning alarm at the central computer location. In general, it appears that in most cases the automated functioning of the system was not operating well, if at all. This is of course the most difficult aspect of the system to function, yet it is precisely this automated operation that is most appealing about FAST installations. While such systems still have significant value if operated by phone, remote, or manually, the specifications need to address the issue of automated operation in detail, to ensure that, if desired (and in most cases, it would be) the automated operation of the system does actually operate, as it should.

To the extent that computer equipment is located on site, care should be taken to ensure that the equipment is protected from dust, dirt, water, and ice control chemicals. This may involve storing the equipment in some sort of watertight enclosure. However, the equipment should also be located in such a way that on-site use of the computer and other related equipment does not require contortions, but instead can be done easily and ergonomically.

In addition to the recommendations made herein, several resources exist regarding the siting of RWIS systems and sensor accuracy.

CDOT may opt to use the Siting Guide document provided by SCIOP at www.sicop.net/ess05.pdf.

Excerpts from the Scope are below:

1.1 Scope

This document provides guidelines for siting a Road Weather Information System (RWIS) Environmental Sensor Station (ESS) and its associated environmental sensors.

The document is designed to provide siting criteria that satisfy as many road weather monitoring, detection, and prediction requirements as possible. The criteria are based on an analysis of published documents on the siting of weather and pavement sensors, and the results of interviews conducted with nearly two dozen road weather experts representing State Departments of Transportation (DOT), equipment suppliers, and consultants.

CDOT may opt to use the data from the Aurora Program report regarding sensor testing and accuracy at :

http://www.aurora-program.org/pdf/pavement_sensor_rpt.pdf

The project overview is below:

Project Overview

This report presents the methods, results and conclusions of the *Laboratory and Field Studies of Pavement Temperature Sensors* evaluation sponsored by the Aurora Consortium. The objective of this project was to conduct both laboratory and field studies to evaluate the pavement surface temperature reporting performance of various models of in-pavement (contact) and mobile (noncontact) pavement temperature sensors in varying environmental conditions.

BENEFIT COST METHOD FOR SITE PRIORITIZATION

The goal of winter highway maintenance is to provide for safe and efficient transportation of people and goods during periods when roads are susceptible to ice and snow conditions. Ice and snow causes reduced friction on roadway surfacing resulting in travel delays and vehicle crashes. Good winter maintenance strategies reduce travel delays and crashes.

A capital expense accompanies any new winter maintenance strategy. Benefit cost comparisons help managers evaluate proposed strategies. Benefits of winter maintenance operations can be measured in terms of delay and crash reduction. Measuring travel delay is difficult, but measuring crash reduction is relatively simple. This fact provides a straightforward method of determining some of the benefit, in dollars, of highway improvements such as FAST systems.

Tracking vehicle crashes by highway location, road condition, and severity identifies problem areas where slick road crashes most occur. FAST systems are, quite often, a viable solution to these problem areas, particularly at bridges and intersections. However, deploying expensive strategies, such as FAST systems, is prohibitive due to limited resources. Benefit cost analysis is a method of prioritizing candidate sites for FAST installations. The ratio of the value of benefits (crash reduction) to the cost of constructing, maintaining, and operating a FAST system identifies locations that gain the greatest benefit from a capital expenditure.

To calculate a benefit cost ratio, first select a bridge, intersection, or other site where accident data shows a high frequency of vehicle crashes. Analyze the data to determine which crashes are related to ice or snow on the roadway. Table F shows an example in which 36 ice or snow crashes are identified over a 5 year period, as well as the outcome of the crashes (fatality, injury, or property damage only). Annual crash rate for each type is calculated by dividing total crashes by the number of years of data included in the count. FAST systems are proven to reduce crashes and in this example a system is expected to eliminate 75 percent of all ice or

snow related crashes. The estimated number of crashes reduced annually is 75 percent of the calculated annual crash rate.

Table F. Calculating the estimated annual rate of crash reduction.

Crash Type	Column A Total Crashes ¹	Column B Years of Crash Data	Column C Annual Crash Rate (A)/(B)	Column D Estimated Crash Reduction ²	Estimated Annual Crash Reduction (C)X(D)
Fatality	1	5	0.2	75%	0.15
Injury	10	5	2	75%	1.5
Property Damage Only	25	5	5	75%	3.75

1. Total number of crashes with ice or snow present on the roadway.
2. Estimated percentage of crashes reduced by FAST system.

The annual benefit of crash reduction is equal to the annual rate of crash reduction times the cost of crashes. Table G shows the annual benefit for this example. The total annual benefit of crash reduction expected from the FAST system is \$506,250.

Table G. Calculating the annual benefit of crash reduction.

Crash Type	Cost per Crash ¹	Estimated Annual Crash Reduction	Annual Benefit of Crash Reduction
Fatality	\$2,500,000	0.15	\$375,000
Injury	\$75,000	1.5	\$112,500
Property Damage Only	\$5,000	3.75	\$18,750

1. Costs for demonstration purposes only. Use AASHTO or Agency assigned costs.

Once the site for a FAST system is selected, the cost of design and construction can be estimated and the annual operations and maintenance costs can be determined. The final data

needed to calculate a benefit cost ratio is the service life of the system, the salvage value at the end of its service life, and an annual interest rate. Service life is the period the system operates before requiring a major overhaul. Salvage value could be the difference in cost between overhauling the system and replacing it. Interest rate could be estimated from the rate the Agency pays on bonds it sells to generate construction capital. The following values are selected for this example:

- Project cost, $I = \$800,000$
- Annual operating and maintenance cost, $OM = \$40,000$
- Service life, $n = 10$ years
- Salvage value, $S = \$75,000$
- Annual interest rate, $i = 4\%$ expressed as a decimal 0.04
- Total annual benefit of crash reduction, $B = \$506,250$

The data assembled is a mixture of one-time costs and annual costs and benefits. These must be processed in a way that equates all costs and benefits in the same time frame. This is accomplished by converting all costs and benefits to present value. A benefit cost ratio is calculated by dividing the present value of benefits by the present value of costs.

Present value of benefits (PV_B) is the present value of the annual benefit of crash reduction over the ten-year service life of the system. It is calculated using the equation in Figure 2 and substituting the values above for B , n , and i .

$$PV_B = B \left(\frac{1 - \frac{1}{(1+i)^n}}{i} \right) = \$4,106,141$$

Figure 2. Present value of benefits.

Present value of costs (PV_C) is the sum of the project cost (I) and the present value annual operation and maintenance costs (PV_{OM}) less the present value of the salvage value (PV_S). The

present value of annual operation and maintenance costs and salvage value is calculated using the equations in Figure 3 and Figure 4, and substituting the values above for OM , S , n , and i .

$$PV_{OM} = OM \left(\frac{1 - \frac{1}{(1+i)^n}}{i} \right) = \$324,436$$

Figure 3. Present value of annual operation and maintenance costs.

$$PV_s = S \left(\frac{1}{1+i} \right)^n = \$50,667$$

Figure 4. Present value of salvage.

Present value of costs is:

$$PV_C = I + PV_{OM} - PV_s = \$1,073,769$$

And, the benefit cost ratio is:

$$B/C = PV_B / PV_C = \$4,106,141 / \$1,073,769 = 3.82$$

Benefit cost and present value calculations are greatly simplified by using an Excel spreadsheet. These calculations, when automated in a spreadsheet, provide a reasonably simple and quick method of comparing and prioritizing sites under consideration for FAST systems. A sample spreadsheet is shown in Appendix D. The sample demonstrates a layout and equations that will calculate a benefit cost ratio. With additional formatting for appearance, the spreadsheet would be appropriate for inclusion in written reports.

CDOT should consider the use of safety funds for the installation of future sites.

CONCLUSION AND RECOMMENDATIONS

This study has reviewed the literature pertaining to FAST installations, including a number of studies that report on the successes and failures of these installations, and made specific recommendations for their improvement. In addition, the study has included a survey of agencies who currently use such systems, and of the vendors who make and sell such systems. Finally, a number of interviews of CDOT personnel have been made, with the specific intent of determining what has and has not worked in their experience with FAST installations. On the basis of this, the study has led to the preparation of a model specification for such systems, together with four specific observations. These observations and associated recommendations are listed below:

Observation One

It is clear from all the experience with FAST installations that these are in no way to be considered “off the shelf” or “plug and play” systems. Each site has unique characteristics, and presents unique challenges to achieving long term success with these installations. Given this, CDOT will need to establish long term relationships with vendors to ensure that their FAST installations function as intended and for the period of time intended. The installation of a FAST system is an ongoing commitment, not a one-time event. A particular aspect of concern in this regard is the automated operation of such systems. There are clearly significant challenges in achieving fully automated operation of a FAST installation, and the information reviewed in this study strongly indicates that those challenges have not yet been met. Accordingly, if such automated performance is a requirement for a given site, there should be an expectation of significant work in the deployment phase to achieve full functionality.

Observation Two

On the basis of the feedback received through the various survey instruments and interviews, there does not appear to be a compelling reason to use a particular ice control chemical in FAST installation. A perceived wisdom had been that potassium acetate should be used to avoid problems with corrosion, but experience with other chemicals indicates that, if suitable care is taken to keep equipment clean, corrosion is not an issue. Accordingly, the chemical used in a given installation should be chosen primarily on the basis of its ability to perform over the likely range of road temperatures to be experienced during precipitation or frost events at that location.

Observation Three

A common feature of the majority of FAST sites was that preventive maintenance was not conducted, apart from an annual draining and flushing of the system at the start of the summer. A more aggressive preventive maintenance program should be developed for each FAST installation, and actions taken under this program should be carefully documented and archived. It is evident by the information in this report that CDOT should undertake an aggressive position in developing and supporting, with “in-house” and vendor expertise, a preventative maintenance program for existing and future FAST sites.

Observation Four

A major concern expressed in interviews was the difficulty of working with underground storage facilities. Accordingly it is recommended that all facilities should be aboveground.

The implementation of these conclusions and recommendations, together with the use of the model specification included in Appendix A, will result in a much more efficient and effective installation and operation of FAST systems in the State of Colorado.

Observation Five

During the informational meetings with CDOT personnel, it was discovered that Staff Bridge had major involvement in the revision of the anti-icing specification currently in use by CDOT. Staff Maintenance is the primary user and maintainer of these systems and has greater knowledge and experience with the RWIS and other required components of the system. Accordingly it is recommended that Staff Maintenance should have primary control of this specification and its revisions. They should seek necessary assistance and expertise for the implementation of the final specification, e.g., structural consultant for structural considerations, architectural consultant for architectural considerations, etc.

To implement the findings of this report, the following steps are recommended:

1. Staff Maintenance to hire consultants to verify/expand portions of Guideline Criteria in Appendix A that need amplification or insertion of maintenance preferences and create a standard Anti-Icing Project Special Provision (architectural, structural, electrical, mechanical, environmental, instrumentation).
2. Staff Maintenance to hire consultants to develop a design/build specification for designs, which are different for completely belowground and completely aboveground.
3. Staff Maintenance to develop minimum CDOT requirements for aboveground installation, i.e., dimensions of building (height, width, depth), door requirements (double doors, rolling doors, etc.).
4. Staff Maintenance to hire consultants to verify requirements for underground installation drawings (mechanical, architectural, electrical, environmental).

5. Staff Maintenance to develop a procedure/checklist for selecting and designing Anti-Icing units, for example:

- Is anti-icing required?
- Will installation be standard aboveground or belowground?
- Will standard specification work on this installation?
- Is in-house expertise available and timely or will design/installation be completely per design/build contract?”

REFERENCES

Barrett, M. L. and Pigman, J. G. (2001). "Evaluation of Automated Bridge Deck Anti-Icing System, Kentucky Transportation Cabinet Research Report # KTC-01-26/KH36-97-1F, December, 2001.

CERF, (2005). "Evaluation of the FreezeFree Anti-Icing System," funded by FHWA under NAVFAC Contract No. N47408-03-D-8402, Final Report by CERF (Civil Engineering Research Foundation), April 22, 2005.

Christillin, M., Ardemagni, C., and Trombella, G. (1998). "The Buthier Viaduct – A Different Approach to Road Network Maintenance in Winter," Proc. Xth PIARC International Winter Road Congress, Vol. 2, pp. 297-306, Lulea, Sweden, March, 1998.

Friar, S. and Decker, R. (1999). "Evaluation of a Fixed Anti-Icing Spray System," Transportation Research Record No. 1672, Paper # 99-0839, Transportation Research Board, Washington, D.C.

Johnson, C. (2001). "I-35W And Mississippi River Bridge Anti-Icing Project: Operational Evaluation Report," Minnesota Department of Transportation, Report # 2001-22, Office of Metro Maintenance Operations.

Keranen, P.F. (1998). "Automated Bridge Deicers for Increased Safety and Decreased Salt Use in Minnesota," Proc. Xth PIARC International Winter Road Congress, Vol. 2, pp. 487-497, Lulea, Sweden, March, 1998

Lipnick, M. (2001). "Automated Bridge Anti-Icing System Interstate 68 over Street Road Allegany County, Maryland," report published by Winter Materials and Technologies Evaluation Team, State Highway Administration, Maryland Department of Transportation, July, 2001.

Moritz, K., (1998). "Effectivity and Economy of De-icing Agent Spraying Systems," Proc. Xth PIARC International Winter Road Congress, Vol. 2, pp. 307-315, Lulea, Sweden, March, 1998

Pinet, M., Comfort, T., and Griff, M. (2001). "Anti-Icing on Structures Using Fixed Automated Spray Technology (FAST)," Paper presented at the Annual Conference of the Transportation Association of Canada, May 1, 2001, Halifax, Nova Scotia.
<http://www.mto.gov.on.ca/english/engineering/anti_ice/anti_ice.htm#service> October 17, 2005.

Roosevelt, D. S. (2004). "A Bridge Deck Anti-Icing System in Virginia: Lessons Learned from a Pilot Study," Virginia Transportation Research Council Report # 04-R26, June 2004.

Stowe, R. (2001). "A Benefit/Cost Analysis of Intelligent Transportation System Applications for Winter Maintenance," Paper # 01-0158, presented at the 80th Annual Meeting of the Transportation Research Board, January 7-11, 2001, Washington, D.C.

Zambelli, M. (1998). "Implementation of a Steady Plant for Automatically Spraying Chemical De-Icer on the Lausanne Bypass," Proc. Xth PIARC International Winter Road Congress, Vol. 2, pp. 447-458, Lulea, Sweden, March, 1998

APPENDIX A

Guideline Criteria for a Fixed Anti-Icing Spray System

For use in the Revision of Section 614 – Anti-icing System

Note: The purpose of these guidelines and sample drawings is to provide information for CDOT Maintenance in establishing their needs and desires for minimum requirements of each FAST/RWIS site-specific installation. These guidelines are a suggested starting point for developing those specifications, based on documentation of successes and failures gathered from CDOT and other agencies listed in the report, and should not be construed as a final specification. Italicized portions need to be examined and revised by qualified consultants per CDOT requirements and/or preferences. CDOT Maintenance will need to review non-italicized portions to verify compliance with CDOT practices. Desired modes of operation (automatic, manual, etc.) will affect the type of equipment required such as RWIS equipment.

Note: Sample plan sheets attached are for “minimum requirements”.

Design Considerations

The design, construction and installation of FAST/RWIS Systems require specific professional design skills and CDOT should consider utilizing outside resources if in-house expertise is not available. These disciplines should be considered when selecting a successful vendor for FAST/RWIS sites.

- Architectural design
- Structural design
- Electrical design
- Mechanical design
- Environmental compliance
- Weather and Surface instrumentation

General Description

This work provides guidelines to develop specifications for the design, installation and testing of a fixed automated anti-icing system (FAST) for each new, rehabilitated or existing structure that calls for such a system on the project plans. If applicable, the Contractor shall

utilize the infrastructure previously installed, as indicated in the design plan sheets included as part of this specification. The Contractor shall be responsible for all additional conduit, hardware, storage tanks, pump house design and construction, plumbing, electrical wiring and connections, AC power source and connections and phone/communications source and connections capable of pan, tilt, zoom (PTZ) video for a fully operational state of the art Road Weather Information Weather System (RWIS) FAST/RWIS System. It shall be the responsibility of the Contractor to review the attached plans and design the layout of the FAST/RWIS system to incorporate/utilize the existing conduit and hardware installed to date. Aesthetics are a key part in all CDOT construction projects and the project engineer prior to construction shall approve each component of the System design for compliance with aesthetic requirements. Design of the systems shall be the responsibility of the Contractor. The anti-icing system is a fixed automated system that allows automatic treatment of the traffic lanes and other targeted areas. The anti-icing system dispenses a liquid anti-icing agent by pumping the chemicals selected by CDOT through a series of solenoid-controlled valves to nozzles mounted in the roadway and bridge deck.

The purpose of the system is to deliver anti-icing liquid to the roadway under a specified set of conditions. When those conditions are met, the system must be capable of activating automatically. Upon activation, a remote processing unit (RPU) controller opens solenoid valves in an automated sequence to spray the anti-icing liquid over the targeted area. This sequence is termed the anti-icing cycle. The anti-icing cycle shall be initiated automatically, requiring no human activation, based on information provided by active and passive sensors mounted in the bridge deck or non invasive sensors located above the roadway or bridge deck, and atmospheric sensors. The anti-icing cycle shall also be capable of initiation by remote telephone call (or in some other, equivalent, manner) using data or voice transmission, by a remote pushbutton switch from a CDOT vehicle, or by manual activation from the pump house. The system shall be capable of dispensing varying quantities of liquid anti-icing agent in variable spray sequences depending on road surface conditions at the site, for example, black ice, snow, or freezing rain.

FAST/RWIS Components

By definition, anti-icing systems operate in a harsh winter environment and have long periods of inactivity and must still be in a condition of readiness to meet mission critical demands. Therefore, the materials, components and control circuitry must meet stringent specifications and performance standards. The following criteria should be used to establish the minimum acceptable standards and each criterion must be met.

Pump House - (if required)

The Contractor shall design and erect a pre-cast concrete, concrete, or masonry pump house building at the site as shown in the plans. Walls and roof shall be insulated to a rating of R-8 or greater. All reinforcing steel in the structural walls, floors and ceilings shall be epoxy-coated in accordance with section 602 of the Standard Specifications. The walls and ceilings shall be designed and constructed in a manner that will prevent any moisture or rodents from entering the building along the roof or walls. The building shall have adequate ventilation to prevent any buildup of toxic or flammable gases and adequate heating to prevent freezing of piping or clear water storage. The roof shall be capable of withstanding vertical loading per (insert any Building Code, BOCA National Building Code or Structural Codes required by CDOT or State Code), and the structure shall be capable of withstanding 100 mph wind loading or as required by (insert any Building Code, BOCA National Building Code or Structural Codes required by CDOT or State Code. The double steel doors shall be of heavy-duty industrial grade construction using end-grain balsa wood as core material. Paper honeycomb core materials are not acceptable. Doorplates shall be 0.12 inch thick resin reinforced with hand-laid glass fiber mat, and molded in one continuous piece. Door edges shall consist of at least three layers of glass fiber reinforced resin with a nominal thickness of 0.4 inch and shall be machine tooled. Doors shall be 1.77 inches thick and shall have an insulating value of R-11. Doors shall have a smooth gloss surface with a minimum value of 88 in accordance with ASTM D 523 – “Standard Test Method for Specular Gloss”. Color shall be specified on the plans or approved by the Engineer and shall be a permanent pigment that runs throughout the entire material thickness. The doors shall have an opening of adequate size to service and/or replace any equipment or storage tanks required for system operation. The nominal dimensions of the pump house shall be of adequate size to house two (2)

separate chemical tanks. The storage tanks should be sized as described in the storage section of this specification. The floor of the pump house shall be perfectly level and constructed to support the weight of the filled chemical tanks. The cast-in-place floor design shall serve as a containment area and incorporate a liner, if required, to prevent leakage of chemical outside the structure. All construction joints shall be caulked using a Type A Silicone Sealant or equal approved by the Engineer.

The Contractor shall provide to the Engineer for review, design plans for the pump house that are sealed by a Colorado Registered Professional Engineer. The plan shall be provided to the Engineer four weeks prior to commencement of construction of the pump house. The Engineer will review and provide comments within two weeks after receipt of the plans.

The Contractor shall be responsible for a foundation investigation and foundation design for the pump house. A Colorado Registered Professional Engineer shall approve the foundation investigation and design. (insert any Building Code, BOCA National Building Code or Structural Codes required by CDOT or State Code).

Note: Alternate pump house construction may be considered as approved by the Engineer. Specifications for exterior treatment of concrete construction i.e., aesthetic treatment of wall sections (exposed aggregate, color, etc.) should be added if required.

Buried Mechanical and Electrical Vault – (if required)

The Contractor shall design and erect a pre-cast concrete or concrete vault at the site as shown in the plans to house the chemical pump, electrical controller and anti-icing chemicals. All reinforcing steel in the structural walls, floors and ceilings shall be epoxy-coated in accordance with section 602 of the Standard Specifications. The walls and ceilings shall be designed and constructed in a manner that will prevent any moisture or rodents from entering the building along the roof or walls. Piping supports shall be installed to support the interior piping and valves as approved by the Engineer. Galvanized materials shall not be allowed unless approved by the project engineer. The vault shall have adequate ventilation to prevent any buildup of toxic or flammable gases and adequate heating to prevent freezing of piping or clear water storage.

If required in the construction plans a sump with a permanent sump pump and piping shall be provided from the sump to an exterior discharge as shown on the plans. All exterior piping shall be schedule 80 PVE. Interior piping shall be PVC. The discharge pipe shall have a 2 inch brass cam and groove male end adapter, dust cap and retainer chain. The sump pump shall be manually controlled with a switch at the exterior box and shall be operable when vault is completely submerged. The minimum requirements for pump shall be a flow of 18 gpm with 20 feet of head. A check valve shall be located in the discharge line above the pump. The sump diameter shall be sized for the pump used.

Working drawings shall show equipment locations on a floor plan and views using revolved wall elevations. A lockable Exterior NEMA weatherproof box shall be provided with switches for lights, sump pump, system override and shutoff of all electrical power. An exterior light with an amber globe shall be supplied for indication of pump operation and high water level. The exterior light shall have a safety cover. A high water indicator shall be supplied for the vault. When a liquid within the vault reaches an elevation one (1) foot above the base of the vault, the high water indicator shall turn on the exterior light.

The exterior of the vault shall be rodent proof and sprayed with waterproofing before backfilling operations. The vault shall be equipped with a four-inch diameter galvanized steel vent with a rodent screen. Vault access shall be by a Fiber Reinforced Plastic (FRP) ladder or manhole steps. Manhole steps shall be steel-reinforced copolymer polypropylene plastic conforming to OSHA 29 CFR 1910.27 and AASHTO M 199. The color of the steps shall be safety yellow.

The Roof Access Hatch shall be a raised hatch of galvanized steel construction with minimum clear opening dimensions of 3 feet x 3 feet. The hatch shall be insulated and shall have an exterior padlock hasp, a hold open arm and a lifting mechanism to help in opening the hatch.

The hatch shall be equipped with a safety bar, grab rail or similar ladder extension approved by the Engineer to aid in egress/ingress. The hatch shall be similar to:

Bilco Model S-20 ROOF SCUTTLE

Nystrom Model RHG –STEEL ROOF HATCH

Babcock-Davis Model BRHG STEEL ROOF HATCH

Milcor Model M-7.

The top of the frame for the manhole cover shall extend above the top of the vault as shown in the plans to prevent surface water from entering the vault. The lid shall be capable of being fastened to the vault by means of stainless steel bolts.

The Contractor shall provide to the Engineer for review, design plans for the vault that are sealed by a Colorado Registered Professional Engineer. The plan shall be provided to the Engineer four weeks prior to commencement of construction of the vault. The Engineer will review and provide comments within two weeks after receipt of the plans.

The cost for all structure excavation, trenching excavation, backfill and materials as shown in the drawings for installation of the vault, underground piping and underground utilities shall not be paid for separately, but be included in the cost of the work.

The Contractor shall be responsible for a foundation investigation and foundation design for the vault. A Colorado Registered Professional Engineer shall approve the foundation investigation and design. (insert any Building Code, BOCA National Building Code or Structural Codes required by CDOT or State Code).

Ventilation

A ventilator fan shall be provided as required or where shown on the Plans. The ventilator fan shall consist of an electric motor driven propeller fan. The fan motor shall be suitable for variable speed operation. The propeller fan shall be provided with a wire guard located on the motor side. The propeller fan shall have a minimum capacity under 12-inch standard pressure or as required to meet the structure design code and shall be fabricated from durable non-corrosive materials

.

Power

A 240 VAC, 100 Amp, 60 Hz, single phase electrical service shall be installed by the contractor to a breaker box inside the pump house/vault for powering the FAST system, up to 150% of actual load. The contractor must supply and install a circuit breaker panel and enclosure for one 240 VAC, 30 Amp service to the pump motor, and two 120 VAC, 20 Amp services for the controller and a dual outlet wall socket. . Installation of electrical components within the pump house/vault shall be in accordance with the requirements of the National Electrical Code, dated (latest edition), including clearances. The Contractor shall provide electrical power from the nearest available source as approved by the Engineer. The Contractor shall be responsible for coordinating with the local electrical utility in order to make all electrical connections between the pumping vault system and the electrical source. Any additional power source i.e., battery backup, standby generator, etc., shall be determined based on each site location and needs assessment. The cost for utility runs and tie-ins shall not be paid for separately but included in the cost of the work.

Telephone

Telephone lines shall be provided by underground line to support pager communications and connection to a remote monitoring site. The Contractor shall provide the telephone lines from the nearest available source as approved by the Engineer. The Contractor shall be responsible for coordinating with the local telephone utility in order to make all connections between the pumping vault system and the telephone source. The cost for utility runs and tie-ins shall not be paid for separately but included in the cost of the work.

Instrumentation

Instrumentation in the pump house/vault shall include but not be limited to:

- Pressure Gauges: Analog type, industrial grade, all Type 316 stainless steel, minimum pressure range = 0 to 290.08 psi.
- Flowmeter Transmitter: senses flow rate in system and sends signal to RPU spray system controller. Flowmeter shall be fabricated from durable non-corrosive materials. All metallic parts shall be Type 316 stainless steel. Minimum flow rate range = 0.98 to 19.7 feet per second.

- Pressure Switch Transducer: senses pressure in system and sends signal to RPU spray system controller. All metallic parts shall be Type 316 stainless steel. Pressure range = 0 to 290.08 psi.
- Ultrasonic Level Sensor: ultrasonic device to detect the level of chemical in the storage tanks. The ultrasonic level sensor shall be connected to an alarm horn mounted on the exterior of the pump house to alert personnel filling the tanks when the tanks are full. The ultrasonic level sensor shall also send signals to a digital level display located in the housing for the chemical fill tube on the exterior of the pump house.

Additional instrumentation shall be added, as required, for additional specialized equipment as shown on the plan sheets and approved by the Engineer.

Anti-Icing Chemical Storage- (if aboveground pump house is used)

Storage tanks for the anti-icing chemical shall be cylindrical tanks in a vertical configuration as shown on the plans and of sufficient size and quantity to accommodate a minimum of 50 system activations at a rate of 40 gallons per lane mile. Storage tanks shall be sized to fit through available door entries. Each tank shall have an entry port through the top with a minimum dimension of 1.3 feet and with a removable cover. The tank shall be vented at the top. Vent openings shall be covered with type 304 stainless steel wire cloth with mesh opening size 0.5 inch by 0.6 inch, using 0.009 inch diameter wire. The tank shall be rated for a maximum fluid specific gravity of 1.5 or greater and shall be made from an approved polymer or glass fiber-reinforced epoxy material. Any metal components of the tank shall be type 316 stainless steel. Galvanized steel shall not be permitted.

Anti-Icing Chemical Storage- (if underground vault is used)

The anti-icing chemicals shall be stored within the buried mechanical and electrical vault. Storage tanks shall be sized to fit through the access hatch in the roof slab and shall be of sufficient size and quantity to accommodate a minimum of 50 system activations at a rate of 40 gallons per lane mile. A fill pipe through the roof slab over the tanks shall be supplied with a 2 inch brass cam and groove male end with dust cap and retainer. Either a locking dust cap or a locking cover mechanism shall be provided to secure the fill pipe from vandalism. All fill piping above grade and through the slab shall be extra strong red brass. The Piping system

shall function as shown in the plans. A strainer/filter shall be included in the fill piping as well as approved venting mechanisms. The strainer screen shall be non-corrosive and compatible with the anti-icing chemical with a mesh size of 1/8 inch and shall be easily accessible for cleaning and/or replacement. One spare screen and gasket shall be supplied. All valves shall be PVC True Union type valves. Tanks shall be prevented from flotation or movement due to vault flooding.

Note: CDOT has two buried tank installations at the present time. The tanks are buried separate from the underground vault and the liquid is piped to pumps in the underground control vault. While this method can be used it poses the same problems as any buried tank, i.e., undetected leakage from tank or buried supply lines, difficulty of inspection, confined space entry requirements, etc.. General CDOT opinion is that buried tanks will not be used due to the potential problems listed. This option should only be considered when other options are not viable.

Flush Water Storage Tank (Optional)

The flush water storage tank shall be installed inside the pump house/vault in a vertical position as shown on the plan sheets. Tank capacity shall be sized to accommodate the final system design as shown on the plan sheets or approved by the Engineer. The tank shall have an entry port through the top with a removable cover as well as a vent opening covered with stainless steel wire mesh size of 1/8 inch. The tank shall be rated for a maximum fluid specific gravity of 1.5 or greater and shall be made from an approved polymer or glass fiber-reinforced epoxy material. Any metal components of the tank shall be type 316 stainless steel. Galvanized steel shall not be permitted.

System Supply Pump

The Contractor shall provide a pump of appropriate size to assure proper operation of the designed system. Pump and housing shall be type 316 stainless steel with seals and bearings appropriate for exposure to chloride-based chemicals, potassium acetate, calcium magnesium acetate or CMA, CMA with potassium or CMAK, and other anti-icing chemicals. Electric motor to be 220 volt, 60 Hz, appropriate for the system design and use in corrosive environments. Pump shall be capable of refilling any individual accumulator, if applicable,

within the finished system within 10 seconds. All pump designs and specifications used on this project shall be submitted to and approved by the Engineer.

Valve Units

Valve units shall control the flow of anti-icing chemical from the main supply line to each spray disk. Valve units shall consist of electro magnetically controlled solenoid valves and electronic solenoid control cards. Solenoid valves and control cards shall operate on a 24-volt system. Each control card shall have the capability to independently control the operation of multiple solenoid valves and through a signal cable. The control cards shall allow each solenoid valve to be remotely activated using different spray programs from the controller. Each control card shall be addressable allowing individual control. The control cards shall have remote fault testing.

Solenoid Valve Boxes

All solenoid valves shall be installed in NEMA 3R compliant electrical enclosures that are galvanized and firmly attached to the deck and/or curb as approved by the Engineer. Four extra valves and eight extra diaphragms shall be supplied for each bridge installation. For each line, the valve box located furthest from the pump shall contain a valve for purging said line with clean water at the end of the season, or when switching chemicals. Purge valves shall also be located at low points in the system as necessary for purging of the system.

Note: Ball valves are not used for this application due to the speed required for rapid opening and closing of each nozzle. Ball valves do not respond as rapidly as solenoid valves.

Valve/Sensor Control Cable

Shielded cable shall be used for all valve and pavement sensor systems.

Nozzles

All nozzles shall be removable for cleaning or replacement without the need for removing the entire nozzle assembly and shall be capable of withstanding high-volume interstate traffic and snow plowing procedures conducted with maintenance trucks. Nozzles shall be inset ¼ inch from face of curb/wall or as recommended by the manufacturer. Nozzles shall be adjusted for

cross slope of the roadway as required. Puck type nozzles shall be located in the approximate center of the anticipated driving lanes, in the shoulder areas or as recommended by the manufacturer. Puck type nozzles shall be recessed 1/8 inch to 1/4 inch from the top of pavement or as recommended by the manufacturer. The overall thickness of puck type nozzles shall not exceed 2 3/4 inches in order to be installed in a 3 inch thick asphalt mat. The spray disks shall be made of a durable non-metallic synthetic material that remains stable under exposure to sunlight, weather, and traffic. The spray heads shall be non-metallic, flush mounted, and non-mechanical. The synthetic material shall be comparable in stiffness and rigidity to stainless steel. All metallic components of the spray disk shall be type 316 stainless steel. The spray disks mounted in the bridge deck shall have piping connections located on the underside of the disk. The spray disks mounted in the roadway pavement off the bridge shall have side-mounted pipe connections. The spray disks shall be fabricated in such a manner that the nozzle directions can be adjusted while the disk is embedded in the bridge deck or roadway surface without removal of the disk assembly. Puck type nozzles shall be affixed to the surrounding asphalt mat with a black colored epoxy, or equivalent material as approved by the Engineer, and care shall be taken during the installation to avoid damaging the underlying waterproofing membrane. Any damage to the waterproofing membrane shall be repaired at the Contractor's expense. A working drawing for the location and pattern of nozzles shall be submitted to the Engineer for approval. The number and pattern of nozzles shall be designed for required coverage as shown on the bridge layout drawings. The number and pattern of nozzles shall be such that they provide the required coverage. This coverage shall include the all traffic lanes and the shoulders. In determining the extent of coverage, the phenomenon of vehicle tracking of chemicals may be considered, subject to approval of the Engineer. The nozzles shall be capable of being raised for overlay application or lowered for surface removal, without complete unit replacement, to accommodate for roadway or deck surface upgrades.

Pressure Piping

The system shall be designed for anti-icing chemicals currently in use by CDOT but shall have the flexibility to be adjusted for anti-icing chemicals of different specific gravities such as calcium chloride (CaCl_2), magnesium chloride (MgCl_2), sodium chloride (NaCl), calcium

magnesium acetate (CMA), potassium acetate (KAc), CMA/KAc blend (CMAK). All piping outside of the pump house shall be Polyamide 11, 18/14 pipes or approved equal. All pipe connections, joints, elbows, fixed points, and pipe clamps shall be type 316 stainless steel. Chemical pressure pipe within the pump house shall be beta polypropylene rigid pipe with socket-fused joints, rated for 120% of system pressure.

Chemical pressure piping shall be routed within a protective conduit system consisting of non-metallic conduit where embedded in concrete or buried in the ground and schedule 80 PVC where exposed except as shown on the plans. Conduit pipes shall be secured to bridge members as approved by the Engineer. Contractor shall coordinate locations of cast-in-place carrier conduits prior to construction. A buried conduit pipe shall be used to pass a carrier pipe underneath the approach roadway to service those installations with nozzles on both sides of the deck. Conduit and all fittings, connections, elbows, and mounting hardware shall be in accordance with the CDOT Specifications, and shall be sized as shown on the plans. The system shall be designed to mitigate any problems due to water hammer. All valves and valve enclosures shall be labeled to match the piping schematic and operation table.

System Controller

A microprocessor-based RPU controller shall control the anti-icing system with capacity for multiple spray disks and the ability to monitor pump functions, system pressure and flow characteristics, and tank fluid levels. The RPU spray system controller shall be able to interpret between various signals from surface and atmospheric sensors to initiate different spray programs to apply measured amounts of liquid anti-icing chemical to the roadway surface. The control of the application of anti-icing chemical shall be fully automated, with provisions for operator intervention and notification. The automated control system shall include atmospheric sensor capabilities and active and passive pavement sensor technology. The RPU spray system controller shall be capable of storing and running multiple software programs for automatic spray activation sequences. The RPU spray system controller shall vary the length of time each solenoid valve is opened, thus varying the quantity of liquid anti-icing agent that is applied to the roadway surface, and shall change the length of time for pauses between sprays, according to different conditions on the roadway surface. Fully

automatic operation shall have manual override capability, with the options for manual pushbutton operation from the pump house, operation via telephone call with touch tone and/or voice recognition, and computer activation from Window-based PC software. The system shall provide surge protection for the incoming telephone line. The RPU shall detect failures of system components and initiate automatic system shutdown in the event of a failure.

The RPU spray system controller shall be contained within a waterproof stainless steel or aluminum housing with lockable lid. The contractor shall be able to demonstrate a minimum of five years of proven field operation of the RPU spray system controller software in automated liquid anti-icing spray systems.

Logic Controller

The logic controller shall have a data logger and be NTCIP 9001 compatible for connection to future equipment. The controller shall have the capability to record time, pavement sensor data and times of system operation. The controller shall be able to automatically activate the system when the surface and atmospheric sensors indicate that the temperatures and moisture conditions are appropriate for activation. The system and its operation shall be completely independent of the Department's existing or planned road weather information system network. The system shall be connected via modem to the Department's wide area network through a central computer located at the Area Headquarters, from which the system shall be capable of remote control of operation and monitoring. The information from the system sensors shall be available on a web-based system and shall be Microsoft Office compatible.

Pushbutton Remote Control Device

The Pushbutton Remote Control device shall be a programmable device similar to a garage door opener. The device shall be able to be set to a desired frequency chosen by CDOT. The device signal shall be strong enough to start the anti-icing system from 1,000 feet away from the pump house.

Conduit for Sensor and Power Cable

Sensor control cable and power cable shall be routed within a protective conduit system consisting of non-metallic conduit where embedded in concrete except as shown on the plans, and galvanized steel conduit where buried or exposed except as shown on the plans. Conduit and all fittings, connections, elbows, and mounting hardware shall be in accordance with CDOT Specifications, and shall be sized as shown on the plans.

Anti-Icing Chemical

The system shall be able to safely store and apply the commonly encountered liquid deicing chemicals. Those liquid chemical include but are not limited to: Calcium Chloride (CaCl_2), Magnesium Chloride (MgCl_2), Potassium Acetate (KAc), Sodium Chloride (NaCl), Calcium Magnesium Acetate (CMA), CMA/KAc blend (CMAK).

Road Weather Information System – RWIS

The contractor installed RWIS equipment at the site shall include a tower mounted Environmental Sensing Station (ESS) with sensors specifically designed for monitoring and displaying pavement surface conditions, pavement temperature, freeze point temperature, chemical percentage, subsurface temperature, and atmospheric temperatures and conditions from the locations as shown in the contract plans. The RWIS system and associated Remote Processing Units shall allow for total flexibility in the selection of meteorological sensors and the system adaptability. The system shall include the integration of active and passive pavement sensors. The System shall include but not be limited to:

- Air Temperature/Relative Humidity Sensor. An air temperature-sensing element that operates over the temperature range of -40°C to 80°C (-40°F to 176°F), temperature sensing accuracy throughout range = $\pm 0.2^{\circ}\text{C}$ ($\pm 0.37^{\circ}\text{F}$), relative humidity (RH) measurement range = 0 percent to 100 percent, with an accuracy of less than 3 percent in the range from 0 percent to 95 percent RH, and less than 5 percent in the range from 95 percent to 100 percent RH. Sensors shall have a wind and solar radiation shielded housing and shall be mounted approximately six feet above ground level.

- Optical Precipitation Sensor. Shall be able to detect the rate and type of precipitation by sensing falling particles, and shall be capable of distinguishing between rain, freezing rain, hail, and snow. The sensor shall be capable of detecting minimum precipitation particle sizes of .02 inch diameter. Operating temperature range shall be -50°C to +70°C (-58°F to +158°F). False alarm error rate for precipitation shall be less than 0.2 percent. Precipitation intensity error rate shall be less than 5 percent for the range 0.39 inches/hour to 3.94 inches/hour, and less than 10 percent for the range 0.12 inches/hour to 19.7 inches/hour. The sensor shall be mounted approximately six feet above ground level.
- Wind Speed/Direction Sensor. Shall have an operating range of 0 to 100 mph. The sensor survival operation limit shall be 180 mph with an operating azimuth of 360° mechanical and 355° electrical. The temperature operating range shall be -40°C to 60°C (-40°F to 140°F). The sensor shall be installed at the standard meteorological height of approximately 30 feet above ground level at the top of the ESS tower.
- PTZ Color Video Camera. Shall be mounted on the ESS tower approximately 30 feet above ground level, and grab up to 8 preset color video still frame images approximately every 5 to 10 minutes for display at the Colorado Department of Transportation Facilities. It shall be fixed mounted, and positioned to take up to eight views of the roadway, bridge and pump house locations to view traffic and weather conditions. It shall be enclosed in an environmental video dome housing to operate in 100 percent humidity, -40°C to 60°C (-40° F to 140° F) operating temperature, and withstand common air contaminants found along roadway locations. The small video dome shall provide dual mode, day (color) and night (monochrome) video camera with optical zoom lens and a high speed positioning system enclosed within a sealed and pressurized seven inch optical dome. The lens shall have a focal length of 0.14 inch to 3.26 inches (23:1). It shall include auto/manual focus with focus control and variable speed zoom. A digital zoom range of up to 10X providing an effective zoom ratio of 230:1, and an effective focal length of 0.14 inch to 32.6 inches on a ¼ inch format Progressive Scan CCD camera, resulting in an effective horizontal angle of view of 54° wide angle to 2.5° maximum telephoto. The camera shall provide Wide Dynamic Range (WDR) by use of dual shutter exposure technique. The pan function

shall provide 360° of continuous rotation, with a variable speed from 0.5° per second to 225° per second. The tilt function shall provide 180° of movement (0° to 90° down to 0°, with video rotation), with a variable speed from 0.5° per second to 60° per second. The camera shall be capable of tour sequencing using up to 64 preset positions. All camera and pan & tilt functions are operable via RS-422/RS-232 serial communications by maintenance terminal on-site or connection to the ESS.

- Environmental Sensing Station (ESS). A remote processing unit (RPU) shall gather data from all connected atmospheric sensors and remote pavement sensors, process, store and transmit this data to the computer monitor at the Colorado Department of Transportation Facilities or to a location as determined by the Engineer. The RPU supplied shall be part of a standard product line and not custom or specially produced for this project. The RWIS RPU shall transmit data to the RPU spray system controller in the required formats when polled. The RWIS RPU shall consist of a microprocessor of current manufacture that is capable of performing all of the required functions. A card cage or other modular layout shall provide the data bus for the microprocessor, and individual components shall be replaceable to perform maintenance and repairs. The RPU shall include serial ports, analog and digital drivers, and inputs to fully support and correctly interpret the pavement and meteorological sensors. The RPU shall be supplied with a host serial port for interfacing to a laptop computer to perform diagnostic and calibration functions. The RPU shall have the capability for future expansion of the number of sensor inputs, serial ports, and shall be capable of adding digital outputs. Any units required for extending the normal operating range of pavement or meteorological sensors shall be compatible with and meet the same requirements as the main RPU. All RPU units shall be contained in appropriate water tight and durable enclosures capable of continuous operation in the roadside environment and harsh weather conditions.
- RWIS Tower/Pole. The RPU enclosure and atmospheric sensors shall be mounted on a tower/pole approximately 30 feet high. The tower/pole with mounted equipment shall be capable of withstanding a wind load of 100 mph. It shall be grounded with four ground rods, each 10 feet in length and connected with 00 ground cable. RWIS

mounting tower/pole and foundation drawings shall be submitted for approval in accordance with the local specifications.

Pavement Sensors

Pavement sensors are solid-state electronic devices intended to be installed in the bridge deck or roadway pavement. Sensors shall be constructed of materials that have thermal characteristics similar to the bridge deck or pavement materials into which they are installed. They shall be flush-mounted in the bridge deck with an epoxy sealer, and be capable of withstanding high-volume traffic and snow plowing procedures conducted with maintenance trucks.

Pavement sensors shall be of both the active and passive type. Active pavement sensors are defined as surface sensors that measure the freeze point by artificially cooling the surface of the sensor. Active sensors detect the formation of ice at the sensor head with any mixture of anti-icing chemical or liquid used during snow removal operations. Passive pavement sensors are defined as surface sensors that measure the physical properties of the pavement surface, or the moisture on the pavement surface without artificially cooling the sensor head and detect specific programmed types of anti-icing chemical used during snow removal operations.

The overall thickness of pavement sensors shall not exceed 2 ¾ inches in order to be installed in a 3-inch thick asphalt mat. Sensors shall be affixed to the surrounding asphalt mat with a CDOT approved epoxy and care shall be taken during the installation to avoid damaging the underlying waterproofing membrane. Any damage to the waterproofing membrane shall be repaired at the Contractor's expense. Sensors shall be recessed 1/8 inch to ¼ inch from the top of pavement or as recommended by the manufacturer. Pavement sensors shall be located in the approximate center of the anticipated driving lanes or as recommended by the manufacturer. A working drawing for the location and pattern of sensors shall be submitted to the Engineer for approval. The pattern, type and number of sensors shall be designed to provide adequate sensing of freezing conditions on the bridge or roadway. Passive sensors shall be calibrated for anti-icing chemical currently in use by CDOT

The Active/Passive surface sensors shall provide the following minimum pavement information:

- Surface Temperature Range -40°C to 80°C (-40F to 176°)
- Surface Temperature Accuracy $\pm 0.25^{\circ}\text{C}$
- Wet Surface Condition
- Presence of Moisture on Surface
- Presence of Frost or Ice on Surface
- Presence of Chemical on Surface
- Freezing point of the water/ice-control-chemical solution present on the surface
- State of Surface Condition with temperature below 0°C (32°F)
- Surface Sensor performance shall not be degraded by weather conditions, traffic, or road contaminants.

System Central Computer

The system shall be supplied with a central computer from a major manufacturer capable of effectively running the supplied client software for remote operation of the anti-icing system, which shall be approved by the Engineer at the time of installation. The central computer operating system shall be the latest version of Microsoft Business OS and minimum true 32-bit operating system or approved equivalent and shall be approved by the Engineer at the time of installation.

Modem

The system shall be supplied with the necessary modems to provide communications between the RPU spray system controller, RWIS RPU, and central computer over standard telephone lines. The modems shall be industrial grade, intended for exterior installation, capable of operating in a temperature range from 5° F to 176° F, and a humidity range from 0 percent RH to 100 percent RH. The system shall be compatible with existing Department servers. The RPU shall be able to support communications with the central computer utilizing telephone line autodial/answer modem. Communications between the RPU and central computer shall be verified via user name and password method. The Contractor shall supply all modems.

System Requirements

General:

- Ambient Environment. The System shall be able to withstand temperatures in the range of -40° F to 149° F with no permanent loss of function or component failure. The pavement sensors and nozzles shall withstand temperatures up to 185° F.
- Operating Environment. The System shall accurately apply liquid anti-icing chemicals to a pavement surface in the temperature range of -22° F to 41° F.
- Chemical Environment. The System shall be able to safely store and apply the commonly encountered liquid anti-icing chemicals. Those liquid chemicals include but are not limited to: Calcium Chloride, Magnesium Chloride, Potassium Acetate, Sodium Chloride, Calcium Magnesium Acetate, and Calcium Magnesium Acetate/Potassium Acetate blend. The entire permanent anti-icing spray system components shall consist of materials that are resistant to corrosion from whatever chemical is selected by the Department for use in the system.
- Communications and Software. The System communication software delivered shall meet standard communication protocol specifications. The System shall communicate functions such as automatic system operation and display, the system software programs in the controller, tank level, pressure and fluid flow control along with manual operation of the system. The system data collection software shall run as a background service on the central computer. The central computer need not be logged on to the Department's network to continue to log data from the anti-icing system.
- Operating System. Latest Microsoft Business OS and minimum true 32-bit operating system or approved equivalent. The Engineer shall approve operating system at the time of installation.
- Software/Firmware. Client software shall not require OS administrative privilege to operate. Software/Firmware manufacturer shall support bug fixes and maintenance upgrades for a minimum of one year after system acceptance.
- Software Licensing. Contractor shall provide a minimum of (XX) remote access licenses and one license for the software on the central computer or a web based system.

- Users. The system shall permit a minimum of (XX) simultaneous users with user-configurable and changeable web access.
- Security. All communication to and from the RPU shall be verified by user name and password. The system shall provide two levels of password security, one with administrative configuration abilities, and the other user as read-only access. All passwords shall be stored in an encrypted format with no clear text. User accounts names and passwords shall be user definable and changeable. The system shall support a minimum of two user accounts within the RPU.
- Regulatory Requirements. The System shall comply with all applicable national, state, and local construction and safety codes.
- The System provided shall be capable of two-way communication using any or all of the following methods:
 - o Computer Network. The System provided shall be capable of networking with wide area networks. The System provided shall utilize a current state of the art Windows Server approved by the Engineer. The server provided shall network with standard computers via modem, network router, and frame relay, etc.
 - o Telephone Modem. The System provided shall be capable of supporting conventional telephone modem operation. This capability shall include the ability to originate, or receive, calls to remote control sites.
 - o Onsite Hook-up. The System provided shall provide the capability for local on-site connection of a portable computer to the RPU spray controller and RWIS RPU using RS-232C serial interface protocol.

Control Options

The System provided shall provide for the control of the liquid chemical application with full automation. The system provided shall be capable of the following control modes:

- Fully Automated. The System operation shall be automatic utilizing user defined parameters and the pavement and weather conditions sensed by the RWIS.
- Manual Override. The System provided shall allow for manual override of the automated mode locally, at the site, or remotely.

- Fully Manual. The System provided shall respond only to a user generated command. Manual control options shall include the override ability by networked computers, modem, manual on-site locking pushbutton, or telephone.

Detection and Remediation

The System provided shall detect problems and compensate for these problems and notify the user of the problems by the following methods:

- Self-Check. The System provided shall detect chemical leakage and restrictions within the entire spray system. Additionally, the System provided shall detect hardware failures in all other connecting systems and alert the system user of the problem.
- Remediation. The System delivered shall provide for a single push button reset of normal functions upon completed system repairs or inspections. The system shall automatically detect system defects and take action without operator intervention to prevent system damage or environmental damage.
- User Notification. The System shall automatically notify system user through the central computer of detected problems including location of abnormalities and actions taken. The notification system shall include user definable and configurable alarms and notifications.

Inventory Tracking and Control

The System shall automatically provide tracking of material used by the anti-icing system. The system shall provide inventory control. The system shall detect and report liquid levels in the tank throughout the range from full tank to empty tank. The status of the tank level shall be reported to the user using the communications system. The system also shall have alarms for full tank, low level refilling required, and low level-not sufficient chemical to operate the system. The system shall provide an alarm to the operator and an automatic shut-off to prevent system damage. All alarm levels shall be settable by system user.

Operating Capabilities

The system shall have the following basic operating capabilities as a minimum:

- Automatic system tests on a preprogrammed and/or timed basis. The system shall measure system pressure and quantity of liquid flow and prevent system operation if parameters exist outside of acceptable operating conditions.
- The system shall monitor and alarm for tank levels of low and or empty.
- Ability to activate a warning device before the spraying operation commences.
- The system shall be capable of going through a system evaluation before activating the spraying operation. This system evaluation shall check for system leaks, low chemical reservoir levels, and other system defects and shall not activate the system if any of these conditions exist. During system activation, the system shall evaluate if individual spray valves do not activate and shall document in the system log and alert the operator of these conditions.
- Autonomous operations based on various weather parameters in the RWIS.

The RWIS and pavement sensor technology shall include the following:

- The sensor technology must insure that the sensor shall work with any anti-icing chemical, multiple chemicals, varying water depths, oils, dirt, and other remaining residuals on the road surface that can change the freezing point temperature. This includes any potential chemical applied on the surface by maintenance trucks.

Sensor technology must allow the system to have total user flexibility in system operation.

Pavement and atmospheric sensors shall allow the following detection of the system:

- Comparison of active and passive pavement sensors utilizing the advantages of each;
- Detection of accurate Freeze Point Pavement Temperature on the pavement which does not require re-calibration with each chemical used;
- Able to operate with multiple chemicals, for example when exposed to various combinations of truck-applied chemicals;
- Allows for system activation at different thresholds before freezing, for example, 1, 2, or 3 degrees before freezing, and provides accurate detection of freeze point temperature to –4 degrees F.

- The System provided shall allow for software logic programs that utilize all of the capabilities of the RWIS remote processor to properly interface with the anti-icing spray system controller. The System provided shall have user settable thresholds for adjusting automatic operation of the system:
- System activation when road moisture is at or near freezing via user settable thresholds;
- System activation when freeze point temperature sensors detect when pavement surface moisture is near freezing via user settable thresholds;
- System activation when chemical dilution is occurring via user settable thresholds;
- System activation and accurate freeze point temperature measurements even when multiple chemicals are used via user settable thresholds;
- Accurate system activation without calibration of pavement sensors with changing chemicals;
- Immediate system activation when falling snow or freezing precipitation is detected and surface temperatures is below user settable threshold;
- The ability to include other weather parameters in the system logic such as low pavement temperature lockout according to different anti-icing chemicals for minimum temperature, relative humidity, etc. or high wind lockout, via user settable thresholds.

The system shall have a minimum of 16 different spray programs available for activation of the various nozzles, separate timed sequences, or separate circuits. A circuit is defined as a pump, supply lines, valve units and controlling device. These programs shall be capable of operating a minimum of 240 valves. Programs shall be capable of spraying each nozzle through its electromagnetic valve for a specific length of time, selectable from 1 to 10,000 milli-seconds. Programs shall be capable of changing the length of pauses between nozzle spraying, selectable from 1 to 10,000 seconds.

Manual override of system operations shall be available from any of the manual options. The system shall include the following manual operating capabilities:

- Manual pushbutton at the site;
- Remote (line of site from the roadway) pushbutton from hand held device, similar to a garage door opener;
- Activation from telephone voice or data transmission;
- Computer activation from a state of the art Web or Windows based PC software approved by the Engineer.

Commissioning, Testing, and Training

A qualified representative shall provide for the installation of the automatic anti-icing system including the start up, alignment, and testing of the entire system. The chemical storage tanks and the entire system shall be filled to capacity with anti-icing chemical at commissioning of the system. The flush water storage tank shall be filled to capacity with clean, potable water at commissioning of the system.

Testing Requirements

An installation test of the system shall be conducted at the conclusion of installation in the presence of the Engineer. The installation test shall simulate the full range of functions the anti-icing system is intended to provide. A successful installation test is required before acceptance by the Engineer.

Training

A qualified representative shall provide a minimum of one eight hour day of on-site training. This training shall cover operation, seasonal commissioning and decommissioning, and preventive maintenance of the fixed automatic anti-icing system.

Warranty

The system shall be warranted to meet the manufactures specifications and for defects in material and workmanship for a period of one year starting on the date of system acceptance. Both material and labor shall be covered by this warranty.

Submittals

The Contractor shall submit the following for review and approval in accordance with subsection 105.02 of the Standard Specifications:

- Detailed design and installation working drawings for the complete anti-icing spray system with sufficient detail to allow review of all power and communications for compliance with the Specifications. Working drawings shall clearly indicate any and all deviations from the contract documents. The working drawings shall include specific details and exact locations of all system components including proprietary equipment.
- Compliance Traceability Matrix for all components including computer and electronic device hardware and software that give evidence of the compliance of each component or function with the requirements in these specifications and the vendors specifications.
- Communications Infrastructure Plan showing routing of electronic communications between devices in the field, between devices and computers, between systems, and between the field computers/systems and remote users.
- Installation schedule that shall outline the steps the Contractor intends to make to complete the contract. The installation schedule shall be revised and resubmitted if there is a significant change to the schedule.
- Contractor qualifications and resumes in accordance with Section II – Contractor Qualifications.
- Documentation of five years of proven field operation of the active pavement sensors in automated liquid anti-icing spray systems.
- Documentation of five years of proven field operation of the programmable system controller software in automated liquid anti-icing spray systems.
- Structural engineering design calculations and shop drawings for the pump house precast concrete building prepared and sealed by a Professional Engineer registered in Colorado.
- Electrical engineering design calculations and shop drawings for the system prepared and sealed by a Professional Engineer registered in Colorado.

- Mechanical engineering design calculations and shop drawings for the system prepared and sealed by a Professional Engineer registered in Colorado.
- Working drawings and product data for doors, louvers, frames and all accessories and hardware for the pump house.
- Design calculations and working drawings for the pump house stair framing that have been prepared and sealed by a Professional Engineer registered in Colorado.
- Working drawings for RWIS mounting pole and foundation.
- Product data sheets and certificates of conformance with the Specifications, and Quality Assurance reports for the following system components:
 1. Spray disks;
 2. Pavement sensors;
 3. Chemical pressure piping;
 4. Conduit for chemical pressure piping;
 5. Valve and valve controller;
 6. Pressurized accumulator tanks;
 7. System control cable;
 8. Sensor control cable;
 9. Conduit for sensor control cable and RPU slave unit power cable;
 10. Anti-icing chemical;
 11. Anti-icing chemical storage tanks;
 12. Flush water storage tank;
 13. Pump and motor;
 14. RPU spray system controller;
 15. RWIS RPU and all meteorological sensors;
 16. Modems;
 17. Uninterruptible power supply;
 18. Standby electric generator set;
 19. Automatic transfer switch for standby electric generator set;
 20. CDOT concrete, in accordance with section 601 of the Standard Specifications, for cast-in-place building foundation;

21. CDOT concrete, in accordance with section 601 of the Standard Specifications, for precast building;
22. Epoxy resin waterproofing for concrete surfaces;
23. Deformed steel reinforcing bars, epoxy-coated;
24. 7-wire steel post-tensioning strand for precast building;
25. Silicone sealant and bond breaking tape for building joints;
26. Floor grating for building;
27. Removable handrail for building.

Operations and Maintenance Manual

The Contractor shall furnish an Operations and Maintenance Manual, or O&M Manual, for the anti-icing system. The O&M Manual shall include detailed operation and maintenance instructions for all systems and items of equipment provided under the contract. The O&M Manual shall be in the form of neatly formatted bound ring binders and electronic format in the form of CD-ROM disks. Prior to completion of the work, and at least 90 days prior to final payment, the Contractor shall furnish for the Engineer's review ten O&M Manual draft copies. At least 30 day prior to final payment, the Contractor shall furnish for the Engineer's use ten copies of the final O&M Manual. The Engineer before a final acceptance of the work shall approve the final O&M Manual.

The O&M Manual shall consist of product data sheets, brochures, bulletins, charts, schedules, approved working drawings corrected to as-built conditions, assembly drawings, wiring diagrams, operation and maintenance information for equipment, and other information necessary for the Department to establish an effective operating maintenance program. Oversized sheets and working drawings larger than 8.5 inches by 11 inches shall be neatly folded to that size with title block exposed along one edge, and bound or placed in pockets within the Manual. The O&M Manual shall include:

- Title page giving the name and location of the facility, bridge plan numbers, and Project Numbers;
- Performance curves for all pumps and equipment;
- Approved working drawings of each component;

- Approved product data sheets and dimensioned drawings of each piece of equipment, and details of all replacement parts;
- Manufacturer's installation, operation, and maintenance instructions for each piece of equipment and complete listing of nameplate data;
- Complete wiring diagrams of all individual pieces of equipment and systems including one line diagrams, schematic or elementary diagrams, and interconnection diagrams;
- Complete piping and interconnection drawings;
- Complete parts list with parts assembly drawing preferably by exploded view, names and addresses of spare parts suppliers, recommended list of spare parts to be kept on hand by the Department, and sample order forms for ordering spare parts. Lead time required for ordering spare parts shall be estimated;
- Instructions with easily understood schematics or diagrams for disassembling and assembling the equipment for overhaul or repair.

Delivery of O&M Manual satisfactory to the Engineer is an essential part of project delivery. Incomplete or inadequate manuals will be returned to the Contractor for correction and resubmission.

The Contractor shall not start construction or installation of any part of the anti-icing system until the complete design and installation working drawings and installation schedule have been received and reviewed, and written approval to begin construction has been issued by the Engineer. Such approval shall not relieve the Contractor of responsibility for results obtained by the use of these designs and drawings or any of the Contractor's other responsibilities under the contract.

Known manufacturers of anti-icing systems include:

Boschung America LLC

930 Cass St.

New Castle, PA 16101-8427

(724) 658-3300

Quixote Transportation Safety, Inc.

35 E. Wacker Drive

Chicago, Ill. 60601

(312) 705-8444

APPENDIX B

Survey Instruments

Interview questions for CDOT staff.

CDOT Interview Questions

1. What are the major disappointments with your existing systems and what are your suggestions for improvement?
2. What type(s) of data do you feel is necessary for the effective operation of a FAST site?
3. What type(s) of equipment are necessary for optimal operation of your FAST site?
4. What type(s) of communications do you feel are necessary for reliable, current and accessible information, for all users, from your FAST sites?
5. Do you prefer a specific type of chemical for your FAST sites and have you had problems with any of the chemicals used?

Survey questions mailed to transportation agencies.

Fixed Anti-icing System Technology (FAST) Interview Questions

Name:_____ **Date:**_____

Organization:_____

Contact information: Phone _____ Fax _____ Email _____

SYSTEM DESIGN

1. How many Fixed Anti-icing Spray Systems does your organization have?_____
2. Which vendor supplied each system?

FAST Vendor Ratings

Vendor	No. of Systems	Date in Operation	High	Quality		Comments
				Medium	Low	
Odin International						
Boschung						
All Weather Inc.						
Quixote						
NuMetrics						
Other						

Table 1

3. How would you rate each system for quality? i.e., dependability, quality of materials/ workmanship, vendor availability, etc. (mark in table above, add additional sheet if necessary)
4. Which vendor would you prefer for your next system?_____
5. What criteria does your organization use to select a vendor? Performance
History Quality Low Bid Other_____

6. Which criteria is most important for selecting a vendor?_____

7. In your contracts, is the FAST vendor the prime contractor or a sub-contractor ?

8. Who installs the system, FAST vendor or another contractor ?

9. Does your system operate as your originally intended? Yes ☐ No ☐

10. Does it exceed your expectations ☐ or has it failed to meet your expectations ☐?

11. Do you have any reports that describe your system(s) successes or failures?

Yes ☐ No ☐

12. May we have copies of the reports? Yes ☐ No ☐

13. What recommendations would you make for contracting a FAST installation?

14. Does your organization have criteria for selecting locations for FAST installations? Yes

No What are the criteria?_____

15. What types of locations are selected? Bridges Intersections Remote locations
Non-structure roadways High accident locations High traffic locations Other

16. Did your organization ☐ or the vendor ☐ draft the specifications for your system(s).

17. Have you updated your specifications with each system installation? Yes ☐ No ☐

18. Would you share your specifications with the CDOT? Yes ☐ No ☐

19. What FAST system features are critical, important, or not useful to your operations? e.g.,
automation, weather monitoring, safety, video, etc.

Importance of FAST Features

Critical	Important	Not useful or not required

Table 2

20. Are your pump houses above ground ☐ or below ground ☐?

21. In your opinion, what are the advantages or disadvantages of each?

22. Has corrosion in the pump house been a problem for you? Yes ☐ No ☐

23. What steps were taken to prevent or mitigate corrosion in the pump house?

24. What other problems have you experienced with maintaining pump houses?

25. What recommendations would you make for pump house design and location?

SYSTEM MATERIALS/OPERATIONS

26. Which method of mounting nozzles do you use? Flush mount (in pavement) ☐

Side mount (in barrier) ☐ Both ☐

27. Which method works best? Flush mount ☐ Side mount ☐ No difference ☐

28. What criteria do you use to select nozzle type? e.g., in-house decision, vendor recommendation

29. What are the benefits of your preferred nozzle type?

30. If in-pavement nozzles are used, where is the position of choice?

Shoulder Between lanes

31. Do you have preferred nozzle details? Yes ☐ No ☐

32. Do you install nozzles beyond the limits of a bridge? Yes ☐ No ☐

33. If yes, how far from bridge approaches? _____

34. What are the benefits of nozzles before the bridge?

35. How effective are the nozzles for distributing chemical uniformly over the traveled surface? _____

36. What nozzle spacing do you recommend? _____

37. Have you had any problems with the nozzle firing sequence? Yes ☐ No ☐

38. Have you had any problems with nozzle pressure? Yes ☐ No ☐

39. Have you had any problems with corrosion of nozzles or valves? Yes ☐ No ☐

40. Have you experienced any electronic/software compatibility problems? Yes ☐ No ☐

CHEMICALS/STORAGE

41. Which anti-icing chemicals have you used in your systems?

Chemicals in FAST Systems

Chemical	Prior Use?	Using Now?	Comments
CaCl ₂ Calcium Chloride			
CMA Calcium Magnesium Acetate			
MgCl ₂ Magnesium Chloride			
NaCl Sodium Chloride			
KAc Potassium Acetate			
Other_____			

Table 3

42. Have you experienced any problems with the types of chemical you have used?

Yes ☐ No ☐

43. Which features are available and used in the activation process for your systems?

System Activation and Monitoring Features

System Feature	Yes	Used	Not Used	Comments
Automatic detection (RWIS) Wx instrumentation-type e.g., WS, WD, Dew pt., Etc				
Surface Sensors 1. Active 2. Passive 3. Thermal 4. Infrared 5. Other	____ ____ ____ ____ ____	____ ____ ____ ____ ____	____ ____ ____ ____ ____	1. 2. 3. 4. 5.
Alarm message 1. email 2. pager 3. fax 4. other _____	____ ____ ____ ____	____ ____ ____ ____	____ ____ ____ ____	1. 2. 3. 4.
Activation 1. on site 2. remote (how) _____	____ ____	____ ____	____ ____	1. 2.
Fully automatic detection and activation				
Data recording 1. atmospheric 2. road condition 3. system functions	____ ____ ____	____ ____ ____	____ ____ ____	1. 2. 3.

Table 4

44. Are you using the vendor's activation parameters for your operations? Yes ☐ No ☐

45. Have you experienced problems with system activation? Yes ☐ No ☐

46. Do your surface/weather sensors provide adequate information for the operation of your FAST installation(s)?

47. What criteria do you use to size the storage capacity of the tanks?

48. Have you encountered any environmental issues with any FAST sites? Yes ☐ No ☐

49. Do you have accident history records showing a decrease in crashes due to freezing road events? Yes ☐ No ☐

50. Would you share the findings with CDOT? Yes ☐ No ☐

51. What other benefits have your organization documented?

52. What regular or preventive maintenance is performed on your systems?

53. Does your organization have defined and documented system maintenance procedures?
Yes ☐ No ☐

54. What are the operation and maintenance costs for each of your systems?

55. What other comments do you have about FAST systems?

Survey questions mailed to FAST manufacturers.

FAST Manufacturer/Vendor Survey

Name:_____ **Date:**_____

Organization:_____

Contact information: *Phone* _____ *Fax* _____ *Email* _____

1. What features differentiates your company's FAST system from other manufacturers? _____

2. What information on new system features or improvements would you like to share with CDOT? _____

3. Which elements of your system meets standards established by NTCIP 9001? ____

4. Do you have recommended proposal or bidding specifications that you would share with CDOT? _____
5. Which anti-icing chemicals do you recommend for use in your system? _____

6. Which chemicals should not be used in your system? _____

7. What problems do agricultural based corrosion inhibiting products, when mixed with chemicals, cause with the functioning of your system? _____

8. What corrosion problems have occurred with your system? _____

9. What causes for corrosion problems were identified? _____

10. Have these problems been resolved and, if so, how were they resolved? _____

11. What options are available in your system for operating the system, from manual to fully automatic? _____

12. What is the minimum level of sensing data from a weather station (RWIS) necessary to properly operate your system in a manual mode? _____

_____ In
automatic mode? _____

13. What problems have occurred with the operating system? _____

14. Have these problems been resolved and, if so, how were they resolved? _____

15. What brand RWIS is supplied with your system? _____

16. Is your FAST system interoperable with RWIS from the following manufacturers (indicate yes or no): Boschung _____, NuMetrics _____, SSI _____, Vaisala _____, others (please list) _____
17. What type of sensors are supplied with you system to monitor roadway surface and subsurface conditions? passive _____? active _____? other (please list) _____
18. Do you have nozzle details and specifications that identify nozzle type and location options that you would share with CDOT? _____
19. Do you have pumping system details and specifications that describe pump type, operating pressures, pump materials, pipe materials, etc. that you would share with CDOT? _____
20. Do you offer in-ground or above-ground pump houses and chemical storage tanks? _____
21. What aesthetic options are available for above-ground pump houses? _____
22. Do you locate chemical storage tanks inside pump houses? _____
23. What criteria are used to size chemical storage tanks? _____
24. Is your system capable of hosting cameras which are viewed and controlled from a personal computer? _____
25. What types of cameras are available? streaming video _____?, still _____?
26. Is your system supplied with proprietary software? _____
27. Which computer operating systems are compatible with your software? _____
28. Is your software compatible with common database software? Please list the specific software. _____
29. Does your software create user-defined reports? _____

30. Is roadway weather information available through your company? _____

31. Which weather information features are available to the customer? _____

32. What options are available for the delivery of weather information? _____

33. If a part or equipment malfunctioned such that a system was not fully operable, what is the maximum estimated response time to replace or repair a system in Colorado to full operation? _____

34. Do you have parts list with replacement costs that you would share with CDOT?

35. Do you offer full system maintenance services? _____

What is the cost for these services? _____

36. Do you have technical support personnel resident in Colorado? _____

37. Do you offer training to customers who wish to perform their own system maintenance? _____

What is the cost for training? _____

38. What is the approximate cost for the following major system components (assume an installation on a 300 foot long, two lane bridge): RWIS _____, Pumping/storage system _____, Controller _____, Chemical distribution/spray system _____?

Note: Cost information from responding vendors/manufacturers will remain confidential to the project research team. The average costs will be reported to CDOT without any link to a vendor/manufacturer.

On behalf of CDOT, Bell Enterprises, and Asset Insight Technologies, thank you for your responses to this survey.

APPENDIX C

Survey Responses

CDOT Staff Interview Notes

Interviews with CDOT employees included the following comments and desires for all new FAST System installations:

- Storage and Delivery Systems - There is a strong adversity to underground storage and delivery systems. Maintenance and Operational issues have plagued the existing sites and the issue of confined space entry can be a major problem. Most of the sites in the State have not proven satisfactory. Their recommendation is to have all new sites provide aboveground facilities for ease of maintenance and operation. The facilities should be sized for installation and removal of all hardware without the use of specialized equipment. Tank sizes should be determined on a site per site basis.
- Site Data Collection - It is suggested that all sites have RWIS stations for accurate delivery of current weather conditions and control of the FAST operations. The site should use the latest types surface sensors, i.e., active, passive, overhead near light, infrared, etc., for accurate control of automated surface anti-icing operations. The sensor array should be tailored meet the needs of each site as determined by a detailed site survey. The RWIS must be able to communicate with ALL equipment at the site and transmit all current and historical data to a central site for dissemination to any user.
- System Equipment – The desire is to have pressure controlled/operated valves for consistent and reliable nozzle operation. The flush nozzle is preferred with the use of parapet or guardrail nozzles used where the flush nozzle is not practical. The system should be able to determine and utilize multiple fire and time cycles for various surfaces and weather conditions determined by the RWIS. The system should contain a flow control monitor protection against possible line, valve or tank leakage.

- Communications – The communications must be reliable and capable of handling PTZ from the site cameras and multiple equipment arrays. The communication should meet the current NTCIP standards and must be compatible with all equipment at the site. The specification should be established across the network to allow for common links. Communication is the key to system operations.
- Materials – The material of choice, at least for Grand Junction was CF7 from Cryotech. They have had fewer equipment problems and good surface results with this product. Ice Slicer 3000 was also used but did not perform as well.

The statements above represent the collective notes from interviews with CDOT staff.

Survey Response from Boschung America, LLC

FAST Manufacturer/Vendor Survey

Name: David Kennedy Date: August 23, 2005

Organization: Boschung America, LLC

Contact information: Phone 724-658-3300 Fax 724-658-2300

Email- dbk@boschungamerica.com

1. What features differentiates your company's FAST system from other manufacturers?

We use a low pressure system (150 psi) and incorporate accumulators throughout the system. Typically the system is designed to have 1 accumulator for every two disks. The accumulators have a nitrogen bladder inside. The liquid flows into the accumulator and is pressurized locally. It is then released via a solenoid valve and distributed to the disk. This design allows us to ensure equal pressure throughout the system, regardless of the number of disks.

Closed Loop System- This enables the user to recover anti-icing chemical present in piping system when flushing with water. Also, in case of malfunction, the system can still be operated by isolating the problem area and feeding the system from both sides of the loop.

Active Sensor Performance- Our ARCTIS sensor has proven reliable under the

most extreme conditions and temperatures, where other sensors have ceased to operate. In fact, Ministry of Ontario (MTO), due to their unhappiness with the Performance of other manufacturer's sensors will only permit the Boschung Sensors to be used without further testing. All other sensors must now undergo extensive independent testing to document their ability to work under the extreme Ontario conditions.

Low Voltage System- All of our valve control cards are operated on 24 VDC power. The valve cards are individually frequency addressable. These features allows us to run only low voltage out on the structure or road surface where high voltage could pose a potential danger to the public. By using frequency addressable cards, we limit the amount of wiring required to control the cards. Each card does not require it's own separate run of wiring.

2. What information on new system features or improvements would you like to share with CDOT?

Our new Micro-Fast system. The Spray system come fully assembled in 100 meter strips (328'). Spray nozzles are located every 5 meters (15'). The Micro strip is installed in a saw cut on the road surface. Each strip can treat up to 2 lanes. The Micro-Fast system allows us the ability to treat up to 650' of surface simultaneously (2 strips) instead of firing 1 disk at a time. Also, only 1 valve unit and solenoid are required per strip (vs. 6 for the standard spray over the same length).

3. Which elements of your system meet standards established by NTCIP 9001?
Our systems and components are fully NTCIP compliant.

4. Do you have recommended proposal or bidding specifications that you would share with CDOT?

See attached files.

5. Which anti-icing chemicals do you recommend for use in your system?

Using active sensor technology, our systems are not reliant on any particular chemical. No calibration is needed if chemicals are switched. We have found that Potassium acetate works very well in our systems due to the high performance of its anti-icing capabilities in extreme temperatures.

6. Which chemicals should not be used in your system?

As long as the liquid is free from potentially clogging impurities and does not thicken in cold temperatures, our system does not have any limitations with regard to anti-icing liquids.

7. What problems do agricultural based corrosion-inhibiting products, when mixed with chemicals, cause with the functioning of your system?

See answer above.

8. What corrosion problems have occurred with your system?

Because we incorporate supply lines made from special plastic for use in extreme climatic conditions and non-reactive to chemicals. All fittings are 316 stainless steel, and every pipe support is corrosion resistant we do not experience corrosion problems.

9. What causes for corrosion problems were identified?

N/A

10. Have these problems been resolved and, if so, how were they resolved?

N/A

11. What options are available in your system for operating the system, from manual to fully automatic?

Our system can be activated manually by push button at site, manually via software, or manually via remote control device (ex- from maintenance vehicle at site). The system also works in fully automatic mode.

12. What is the minimum level of sensing data from a weather station (RWIS) necessary to properly operate your system in a manual mode?

None. If manually activated it will spray unless it senses tank is empty.

In automatic mode?

Air temperature, pavement temperature, humidity.

13. What problems have occurred with the operating system?

None outside of regular maintenance issues.

14. Have these problems been resolved and, if so, how were they resolved? _____

15. What brand RWIS is supplied with your system?

Boschung Mecatronics

16. Is your FAST system interoperable with RWIS from the following manufacturers (indicate yes or no): Boschung *YES*____, NuMetrics *Yes, if NTCIP*_, SSI *Yes, if NTCIP*_, Vaisala_ *Yes, if NTCIP*_, others (please list) *All, if NTCIP* ____

17. What types of sensors are supplied with you system to monitor roadway surface and subsurface conditions? passive *X*____? active *X*____? other (please list)_____

18. Do you have nozzle details and specifications that identify nozzle type and location options that you would share with CDOT? _____*Yes*_____

19. Do you have pumping system details and specifications that describe pump type, operating pressures, pump materials, pipe materials, etc. that you would share with CDOT? _____*Yes*_____

20. Do you offer in-ground or above-ground pump houses and chemical storage tanks? _____ *Either* _____

21. What aesthetic options are available for above-ground pump houses?

Pump houses can include any aesthetic options the owner desires as long as it is sized to properly match the needs of the system.

22. Do you locate chemical storage tanks inside pump houses?

Typically, yes. We have installed systems with exterior tanks as per owner's requirements.

23. What criteria are used to size chemical storage tanks?

We use a formula that takes into account number of disks, length of system, and average expected firings of system per season. We also factor in quantity discounts available when ordering chemicals to make capacity more economical for the owner.

24. Is your system capable of hosting cameras that are viewed and controlled from a personal computer? ____ *Yes* _____

25. What types of cameras are available? streaming video ____ *Yes* ____, still ____ *Yes* ____?

26. Is your system supplied with proprietary software? ____ *Yes* _____

27. Which computer operating systems are compatible with your software?

All current Microsoft operating systems.

28. Is your software compatible with common database software? Please list the specific software.

We use a DBXport module that allows data to be integrated to any standard database program.

29. Does your software create user-defined reports?

Yes

30. Is roadway weather information available through your company?

All of the data collected by the system is the property of the owner of the system. Boschung America does not require the customer to buy or subscribe to data.

31. Which weather information features are available to the customer?

Typically- Wind speed, wind direction, air temperature, amount and type of precipitation, humidity.

Others include- Visibility, fog detection, ozone information, sun radiation level, barometric pressure, and others.

32. What options are available for the delivery of weather information?

Data can be obtain via any communication method required including- dial up, DSL, fiber, cable modem, SMS, radio, or dedicated IP.

33. If a part or equipment malfunctioned such that a system was not fully operable, what is the maximum estimated response time to replace or repair a system in Colorado to full operation?

Response would be immediate, during normal business hours. Our techs would initially try to diagnose and correct the problem by contacting the site remotely via software. If a site visit is required, our lead Tech is located in Minnesota and would address the problem. Additional resources could be allocated depending on contractual requirements.

34. Do you have parts list with replacement costs that you would share with CDOT?

Yes

35. Do you offer full system maintenance services? Yes_____

What is the cost for these services? Completely dependent on the size of the system and the length of contract.

36. Do you have technical support personnel resident in Colorado?

Not currently, but we plan to have in place in the near future.

37. Do you offer training to customers who wish to perform their own system maintenance? Yes_____

What is the cost for training? Dependent on the scope of required training.____

38. What is the approximate cost for the following major system components (assume an installation on a 300 foot long, two lane bridge): RWIS_____,
Pumping/storage system_____, Controller_____,
Chemical distribution/spray system_____?

The above parameters are too general, with too many variables and options to accurately provide cost estimate.

APPENDIX D

Benefit Cost Worksheet

FAST BenefitCost.xls

	A	B	C	D	E	F	G	H	I	J
1	Benefit Cost Worksheet									
2										
3	Proposed FAST Location:		SR		MP			MP		
4										
5	Annual Benefit from Crash Reduction									
	Crash Type	1. Number of Snow or Ice Crashes	2. Number of Years of Crash Data	3. Calculated Annual Crash Rate	4. Estimated Percent of Crashes Reduced by FAST (decimal)	5. Estimated Annual Crash Reduction	6. Agency Established Cost of Crashes	7. Annual Benefit of Crash Reduction		
6										
7	Fatality			$B7/C7$		$E7/D7$		$G7/F7$		
8	Injury			$B8/C8$		$E8/D8$		$G8/F8$		
9	Property Damage Only			$B9/C9$		$E9/D9$		$G9/F9$		
10	Total Annual Benefit of Crash Reduction							$SUM(H7:H9)$		
11										
12										
13	Total Project Cost, I:									
14										
15	Annual Operations and Maintenance Cost, OM:									
16										
17	Salvage Value, S:									
18										
19	Service Life, n:									
20										
21	Annual Interest Rate, i (expressed as decimal)									
22										
23	Present Value of Benefits, PV_B :									
24								$equation: H10 * (1 - (1 + F21)^{-F19}) / F21$		
25										
26	Present Value of Operations and Maintenance Cost, PV_{OM} :									
27								$equation: F15 * (1 - (1 + F21)^{-F19}) / F21$		
28										
29	Present Value of Salvage, PV_S :									
30								$equation: F17 * (1 - (1 + F21)^{-F19})$		
31										
32	Present Value of Costs, PV_C :									
33								$equation: F13 + G26 - G29$		
34										
35	Benefit Cost Ratio, B/C:									
36								$equation: G23/G32$		
37										

Sheet1 / Sheet2 / Sheet3 /

Start | Inbox - Microsoft Outlook | Microsoft Excel | Microsoft Word | 4:50 PM

APPENDIX E

Study Proposal

SCOPE OF WORK

Identification section:

- a. Study Title: A Synthesis to Improve the Design and Construction of Colorado's Bridge Anti-Icing Systems.
- b. Abbreviated Title: Bridge Anti-Icing System
- c. Total Cost: TBD based upon budget
- d. Study Number: 80.22
- e. Study Type / Funding Source (SP&R)
- f. Project Number (N/A)
- g. Panel Leader: Andrew Pott
- h. Study Manager name and address: Dr. Naser Abu-Hejleh, CDOT Research
- i. Principle Investigators name and address: TBD
- j. Study Panel Members / Area of Employment

A SYNTHESIS TO IMPROVE THE DESIGN AND CONSTRUCTION OF COLORADO'S BRIDGE ANTI-ICING SYSTEMS

I. BACKGROUND

Anti-Icing is the winter maintenance practice of making timely application of a freeze point depressant chemical to prevent and minimize the snow and ice bond to the pavement surface. As a result, anti-icing has the potential to provide increased traffic safety at the lowest possible costs. The timing is especially critical for bridge structures, where icing can occur in advance of icing on normal pavements. Additional information may be found in Appendix A.

One tool for anti-icing treatment of bridges are fixed systems to dispense anti-icing chemicals on a predetermined area. Through a combination of direct treatment and tracking, the bridge is kept ice free. These systems generally consist of sensors, logic system, pumping system and delivery system. Anti-Icing systems are now in use in more than 20 U.S. states, including Utah, California, Minnesota, Kansas, Maryland, Michigan, Nebraska, New York, Virginia, Pennsylvania and Wisconsin, and in several locations in Canada.

CDOT Region 4 has the most installed Anti-Icing systems and several more are being planned in other regions. From the experiences with these first installations, many changes have been made to the previous special provision and drawings. Some of these experiences include software compatibility problems, corrosion problems, and dissimilar systems in the same

region. CDOT would like to benefit from the experiences of other cities, states and entities to improve their Anti-Icing systems further.

II. OBJECTIVES OF THE STUDY

- 1) Create a report containing the practices, experiences, problems, performance, layout, benefits, and costs of existing fixed anti-icing bridge systems. This should include details on pumping systems, materials, installation details, maintenance details and problems, spray systems, storage systems, weather information availability, software and electronic compatibility, compatibility between different vendors and corrosion problems.
- 2) Based on the reported best management and performance practices and assessment of the information collected, provide recommendations for the improvement of the CDOT's existing Anti-Icing Special Provision (Section 614) and worksheets.
- 3) Briefly discuss the current state of the art for alternate bridge anti-icing systems including geothermally heated decks, electrically heated decks, etc., as well as their feasibility considering Colorado's geology, elevation and weather.

III. RESEARCH TASKS

The following tasks may be reduced on a priority basis due to budgetary constraints. Tasks will be removed from the bottom of the list as required based on the itemized costs submitted in the bid for each research task. The Panel Committee shall approve changes to the list of tasks. Proposed tasks are:

1. In a combination of literature search, surveys, field visits (as allowed within budgetary limits) and interviews with local, state, tollway entities, provincial entities, and vendors/manufacturers, compile a listing of existing anti-icing systems. Emphasis should be on existing systems excluding CDOT Region 4. Some suggestions include the City of Fort Collins and the E470 tollway as well as the aforementioned states.
 - a. Type of system (manufacturer)
 - b. Pavement sensor types (active, passive, thermal, etc.)
 - c. Electronic/software compatibility details
 - d. Minimum weather station system requirements
 - e. Weather information availability (web based, server based, etc.)
 - f. Camera/video capability
 - g. Spray nozzle details (type, location, height above roadway, location in roadway)
 - h. Pump information (pump type, pump materials, piping materials, operating pressures, etc)
 - i. Storage information (enclosure types, vault types, in-ground tanks, aboveground)
 - j. Replacement part availability and cost
 - k. Operation capabilities (fully automatic, semi-automatic)
 - l. Anti-icing chemicals and Corrosion inhibitors used

- m. Corrosion problems experienced
 - n. Operations problems/successes.
 - o. Criteria for Bridge Selection (Why were sites/bridges selected for Anti-Icing Systems?).
- 2. List approximate cost of system components (weather station, pump house, spray system, etc.).
- 3. Assess the information collected in surveys, literature search and interviews for Best Management Practices.
- 4. Identify the current and promising fixed systems and suppliers (Quixote, Odin, Boschung, etc.) that are available in the market.
- 5. Provide proprietary specifications in Appendix.
- 6. Provide a list of previous Colorado or other mountain states successes in Appendix.
- 7. Briefly list CDOT's current practice and locations of Anti-Icing equipment.
- 8. Tabularize previous CDOT problems (Region 4) in Appendix (list to be provided by CDOT).
- 9. List current research and activity for FHWA, AASHTO and HITEC and other research entities.
- 10. Briefly discuss the current state of the art for alternate bridge anti-icing systems including geothermally heated decks, electrically heated decks, etc. as well as their feasibility considering Colorado's geology, elevation and weather.

IV. DELIVERABLES

- 1. Quarterly progress report showing the progress on each task, the expected time to complete each task, and significant events.
- 2. Preliminary Final research report, prepared in accordance with CDOT Research Report Format (see Appendix B), summarizing findings of each task.
- 3. A one-half (½) day meeting including the Principal Investigator, Research Manager and Panel Leader to discuss revisions and final report.
- 4. Final research report, prepared in accordance with CDOT Research Report Format (see Appendix B), summarizing findings of each task. In the final chapter, provide recommendations for the improvement of CDOT's existing Anti-Icing Special Provision (Section 614) and worksheets and the basis for the recommendations (e.g., Best Practices).
- 5. A one-half (½) day meeting with CDOT panel members to discuss the study findings and promote the implementation of the study findings in CDOT operations.

6. Copies of meeting minutes, trip reports, and original responses to mailed questionnaires or surveys, etc. in Appendix of Final Report.

V. MINIMUM QUALIFICATIONS (Must be documented with your response)

Responses must document bidder's familiarity and expertise with the following:

- a. CDOT's maintenance organization and winter operations.
- b. Fixed Anti-Icing Spray Technology (FAST) specifications and vendors.
- c. Weather information integration and application to FAST systems in winter maintenance operations.
- d. Road Weather Information Systems (RWIS) and how to integrate them with FAST systems and winter maintenance operations.
- e. Research data analysis and evaluation to develop documentation and reports

VI. SCHEDULE

Maximum time for study shall be 14 months from the date of award. This includes the two months for review and revision of the preliminary final report after meeting with the study panel.

APPENDIX A

BACKGROUND INFORMATION

Anti-icing is the winter maintenance practice of making timely application of a freeze point depressant chemical to prevent and minimize the snow and ice bond to the pavement surface. It provides the winter maintenance manager with two major benefits:

- Maintain the best possible and safest pavement condition during a winter storm event without the deployment of typical winter maintenance equipment and personnel.
- Reduce (optimize) the amount of chemical required to maintain safer driving conditions.

As results, anti-icing has the potential to provide increased traffic safety at the lowest possible costs. Applying anti-icing chemical at the optimum time is critical for an effective anti-icing program. The timing is especially critical for bridge structures, where icing can occur in advance of icing on normal pavements. Additionally, other highway characteristics such as ramps and steep grades can require different treatment strategies as compared to anti-icing treatments for normal pavements.

One tool for such an anti-icing program is the fixed automated spray technology (from Transportation Research Circular, E-C063). This technology is permanent installation of a pump, tank nozzles, and a controller that dispense anti-icing chemicals on a predetermined area. These systems can initiate chemical applications either on manual command or be integrated with road weather information system (RWIS) to operate automatically based on detected highway conditions. An automated fixed spray system generally consists of four components:

- . Pump house: weatherproof structure that houses the pumps, tank, flushing system, valves, programmable systems, and optional communication equipment.
- . Outdoor equipments including: conduit raceways for housing the pipes, wires, and valves, expansion joints for raceways and pipes, nonmetallic, no corrosive high-pressure piping, electrical wiring, boxes to house valves, nozzles.
- . A system Controller that includes programmable system controller with multiple input for initiating system activation and system monitoring output, pushbutton for on-site activation, or automatic activation by on-site RWIS, pager control input for system activation, and optional communication for remote manual activation and monitoring.
- . RWIS that includes pavement and atmospheric sensors, and remote equipment to monitor the sensors.

Much research has been done outlining the economic impact of utilizing Anti-Icing systems. Automated fixed spray systems are now in use on more than 20 U.S. states (Utah, California, Minnesota, Kansas, Maryland, Michigan, Nebraska, New York, Virginia, Pennsylvania, Kansas District 6 and Wisconsin) and in several locations in CANADA (Ontario described most of its work and specifications via a web site). A report published by Minnesota DOT in July 2001 reported a success of an automated system installed on eight-lane bridge with 70% reduction of accidents with yearly savings of \$100,000 and return on investment of \$3.4 for every \$1 invested in the project. Ontario Ministry of Transportation and Operations published a report in May 2001 outlined the success of a fixed spray system where 14 ice-related accidents reported on the bridge before the installation of systems and no accidents reported after that in the following 3 years. An article published by Pennsylvania DOT in December 2001 outlined the success of six systems over two years. A detailed research report on this subject was published by Kentucky Transportation center in December 2001. A recent conference in Pennsylvania (June 2004) discussed the use and effectiveness of these systems. Descriptions and specifications for many fixed automated spray systems are available via the Internet.

In Colorado, Region 4 has the most experience with bridge anti-icing systems. Problems encountered in their systems have been summarized (to be documented in this study) and resolved with revisions to the project special provision for Section 614 of CDOT Standard specifications. Currently, each system utilizes proprietary software and electronics. This introduces compatibility problems for existing and future systems from other vendors in the same region.

A relatively new idea involves heating a bridge deck (and pavements) with geothermal energy via a heat exchanger (radiator) that consists of several deep holes that are drilled into the surrounding earth to collect heat and a temperature controlled pump to circulate the radiator fluid.

APPENDIX F

Problems Documented by CDOT

CDOT has documented problems with in-place FAST systems. Long Nguyen, Pete Graham, and Dick Osmun inspected three FAST installations and prepared a report titled, “US 34 Deicing Problems Big Thompson Canyon East/West of Drake” dated October 21, 2003. Their observations were supplemented with information provided by Don Miller. A summary of the problems identified by the group and their recommendations is listed below.

Problems:

1. Wall penetrations were drilled instead of cored and grouted without using approved watertight grommets.
2. All three vaults flooded after installation. It appears that most of the water came in through the floor to wall connection; one wall joint had been fixed with Water Plug or equal. All three vaults were retrofitted with sump pumps to make them usable.
3. Heaters did not have controls to maintain a uniform temperature inside the vault.
4. The deicing chemical is highly corrosive and ALL painted or plain steel components that came in contact with deicing chemicals show signs of significant corrosion.
5. Most all PVC fittings appear to be leaking with no pump pressure; because they are plastic, it may not be possible to tighten them sufficiently to prevent leakage.
6. The tank lids are very heavy (as planned) and require mooring eyes (as planned) for future removal; no mooring eyes were provided.
7. The air quality inside these vaults is TERRIBLE and could be a health hazard.
8. The presence of water due to flooding and electrical power poses a serious health threat (electrocution is a possibility).
9. Each vault was retrofitted with an above grade grab bar to allow easier access.
10. Each vault was retrofitted with a three-way valve to aid in the removal of deicing liquid for decommissioning the system during the summer months.

11. The specified manhole ring and covers leak.
12. The spray nozzles project about an inch beyond the curb faces; several were damaged by snow plows.
13. The asphalt around the pavement sensors needs to be sealed; some sensors may be ponding water causing the system to activate when it shouldn't.
14. None of the systems appears to be functional. "Dirty" power may be causing some of the line activation problems.
15. One pump was destroyed when its vault flooded. Accordingly, painted steel pump stands were installed to raise the pumps out of the water and prevent further damage. Because all of the pumps leak, all of the pump stands are corroding away.
16. Computer equipment is exposed to dirt and potential moisture leaking from the roof.
17. Computer equipment is supported on a makeshift plywood shelf.
18. There is no place to sit in order to operate the computer.

Recommendations:

1. Specify an acceptable brand of grommet to seal pipe penetrations.
2. Call for CIP concrete vaults with a waterstop at the floor to wall connection. Call for the vault walls to be sealed with Volclay (bentonite sheets) or equal.
3. Provide a sump pump inside the vault (to remove lost deicing chemicals even if the vault doesn't leak) and a perimeter drainage system to lower the groundwater level by gravity flow around the outside of the vault.
4. Provide heaters with temperature controls to maintain the air temperature inside the vault at a constant (60 degrees Fahrenheit?) during the winter months.
5. Use only stainless steel metals inside the vaults. Call for stainless steel plumbing inside the vaults with enough unions to allow any leaking connection to be isolated and tightened in 10 minutes or less.
6. Provide adequate ventilation inside the vault; have this atmosphere tested periodically to make sure it is safe for humans to breath. Install a ventilation fan to exchange the air inside the vault every (10 minutes?).
7. Provide standard grab bars for easy access.

8. Provide standard three-way valves for easy decommissioning in the spring of each year.
9. Specify watertight manhole rings and covers.
10. Call for all spray nozzles to be depressed 0.5” behind the curb faces.
11. Don’t use the electrical power source to “signal” the valves. Call for an activation system that can be operated from inside a moving vehicle, ie, a CDOT snow plow traveling at 55 mph.
12. Support pumps and computer equipment on stainless steel benches: 15” x 60” for the pump and 24” x 60” for the computer equipment.
13. Provide plastic covers to protect computer hardware when it is unattended.
14. Provide a stool for the computer operator’s use.
15. Provide at least 6” from the bottom of the roof to the finished grade.
16. Site the vault as close to the bridge as possible and don’t site vaults in a leach field (as was done on C-15-O).
17. Deicing systems in the North Program call for direct burial tanks and deicing systems in the South Program call for the deicing chemical tank to be placed inside the vault; there should only be one alternative for both Programs. Determine the advantages and disadvantages for each alternative in order to make a final decision.
18. Hire a consultant with architectural, HVAC and electrical capabilities to assist CDOT engineers in the design process. Ask Maintenance forces to collectively establish the design criteria and review the proposed plans and specifications; Maintenance forces are the end users and must be completely satisfied with the end product.

APPENDIX G

Locations of CDOT Fixed Anti-Icing Equipment

Structure	Route	Milepoint	Region	Operation	Pump House
D-17-DM	I-25	231.09	4	Fully automatic Remote manual Onsite manual	Underground vault
D-17-CR	I-25	233.11	4	Fully automatic Remote manual Onsite manual	Underground vault
D-17-AP	SH 52	235.15	4	Fully automatic Remote manual Onsite manual	Underground vault
D-17-EA	I-25	238.12	4	Fully automatic Remote manual Onsite manual	
D-17-EQ	I-25	241.12	4	Fully automatic Remote manual Onsite manual	
D-17-ES	I-25	242.15	4	Fully automatic Remote manual Onsite manual	
D-17-EP	SH 66	42.73	4	Fully automatic Remote manual Onsite manual	
C-15-0	US 34	68.75	4	Fully automatic Onsite manual	Underground vault
C-15-U	US 34	70.58	4	Fully automatic Onsite manual	Underground vault
C-15-Y	US34	75.69	4	Fully automatic Onsite manual	Underground vault
D-16-DT	SH 52	0.1	4	Fully automatic Remote manual Onsite manual	
F-08-AM	I-70	125.01	3	Fully automatic Remote manual Onsite manual	Hanging Lake Tunnel CP-1
F-11-D	I-70	171.1	3	Fully automatic Remote manual Onsite manual	Above grade structure

Structure	Route	Milepoint	Region	Operation	Pump House
G-09-J	SH 82	82	3		
TUNNEL	SH 160		5	Fully automatic Remote manual Onsite manual	
H-17-CH	I-25	171.82	1	Fully automatic Remote manual Onsite manual	Above grade structure
F-13-P	I-70	216.139	1	Fully automatic Remote manual Onsite manual	Proposed
I-17-FJ	I-25	139.84	2	Fully automatic Remote manual Onsite manual	Abutment
I-17-DU	I-25	147.389	2	Onsite manual	
J-16-C	SH 67	47	2	Fully automatic Remote manual Onsite manual	