FIXED AUTOMATED SPRAY TECHNOLOGY: CURRENT PRACTICES AND A CASE STUDY

Anburaj Muthumani, M. Sc.
Research Associate
Winter Maintenance & Effects Program
Western Transportation Institute
Montana State University
PO Box 174250, Bozeman, MT 59717
Phone: (406) 994-6782; Fax: (406) 994-1697
Email: anburaj.muthumani@coe.montana.edu

Jiang Huang, M.Sc.
Research Associate
Western Transportation Institute
Montana State University
P O Box 174250, Bozeman, MT 59717
Email: jiang.huang@coe.montana.edu

Xianming Shi, Ph.D., P.E.*
Associate Professor, Department of Civil & Environmental Engineering
P.O. Box 642910, Washington State University
Pullman, WA 99164-2910
Phone: (509) 335-7088; Fax: (509) 335-7632
Email: Xianming.shi@wsu.edu

*Corresponding Author

Prepared for the TRB 2014 Annual Meeting and Transportation Research Record
Sponsoring committee: Committee on Surface Transportation Weather (AHD010)

Total words: 5,500
Figures & Tables = 6*250
Submitted on July 30, 2014
ABSTRACT

Anti-icing is an application of chemicals before a storm event in order to prevent the formation of black ice and to prevent or weaken the bond between ice and the road surface. Compared with traditional methods for snow and ice control (e.g., deicing and sanding), anti-icing can lead to decreased applications of chemicals and abrasives, decreased maintenance costs, improved level of service, and lower accident rates. Fixed Automated Spray Technology (FAST) systems are designed as a fixed asset technology for anti-icing operations at specific target areas such as bridges, tunnels, ramps and other elevated roadways. This work synthesizes information obtained from agency surveys and a field investigation on the state of the practice of FAST systems. The key findings from the study are as follows. First, every installed FAST system (reported in this survey) needed significant maintenance activities for its successful operation. Second, inconsistency in proper functioning of FAST systems is mostly due to the poor design, poor quality of installation and lack of maintenance practices for some cases. Last, non-invasive technology may help improve the reliability of FAST technology.
INTRODUCTION

Anti-icing is the application of chemical freezing-point depressants on the roadways in advance of deteriorating weather conditions, aimed to prevent black ice formation and to prevent or weaken the bond between ice and the road surface. Recent study has revealed that anti-icing works by not only depressing the freezing point of the solution on pavement but also physically weakening the ice on pavement [1]. Compared with traditional methods for snow and ice control (e.g., deicing and sanding), anti-icing (if applied appropriately) can lead to decreased applications of chemicals and abrasives, decreased maintenance costs, improved level of service, and lower accident rates [2, 3].

Anti-icing can be performed through either fixed asset or mobile asset technologies. Mobile asset anti-icing technology is widely accepted and practiced by many agencies to pro-actively combat severe winter roadway conditions and maintain a high level of service. Fixed Automated Spray Technology (FAST) systems are designed as a fixed asset technology for anti-icing operations at specific target areas such as bridges, tunnels, ramps and other elevated roadways [4]. This technology entails a permanent installation of a pump, tank, spray nozzles, and a controller, with the application of anti-icing chemicals on a predetermined area (Figure 1). The system can be initiated by manual command, or by automation based on detected highway conditions. FAST systems, if coupled with road weather information systems (RWIS), reliable weather forecasts and performance metrics, make the anti-icing program complete and promote the paradigm shift from being reactive to proactive in fighting winter storms at key locations.

FAST technologies remotely sense the potential of frost or ice formation on pavement in light of atmospheric and pavement data from RWIS or an Environmental Sensor System (ESS), and apply chemical freezing-point depressant in a timely manner. There are sensitive structures and critical segments of the roadway network that need to be free of snow and ice in a timely manner, before the winter maintenance vehicles can travel to the site and treat them. During the winter season, accidents often occur on bridge decks or shaded areas where the surface temperature tends to be lower than the adjacent areas and to create potentially hazardous driving conditions, such as frequent frost and black ice [5, 6]. With conventional mobile operations, it is difficult and costly to maintain levels of service and traffic safety for locations far from the winter maintenance sheds [7], or for areas that experience a high traffic volume. In contrast, FAST is a technological solution designed to provide quick, effective service delivery to such high-risk locations prone to icy conditions and/or with high traffic volumes. FAST also intend to reduce the amount of labor and materials needed through timely prevention of ice formation/bonding or snow packing. FAST systems are ideal where stretches of highway: (1) are very remote and application of material by truck would take several hours, (2) have very high traffic volumes and traffic congestion creates a significant barrier to winter maintenance, or (3) are prone to icing or accidents, such as bridges, off ramps, and intersections [8]
Figure 1: Schematic Diagram and Components of FAST System
The benefits of FAST may include: quick response time, enhanced roadway safety, reduced chemical use, reduced corrosion and negative environmental impacts, and reduced traveler delay and stress. A custom-built FAST system installed on an interchange/overpass on I-215 in Salt Lake City, Utah was analyzed for the 1997-98 winter season. The system applied approximately 60 gallons/lane-mile/spray event of liquid magnesium chloride to the northbound lanes of the freeway bridge deck. Comparing the 1997-98 winter season data with the five previous winters, a 64 percent reduction in snow and ice-related accidents was reported on the northbound lanes, at least part of which was attributable to the FAST system. No operational issues were reported with this FAST system.

Studies have found reductions in mobile operation costs and significant reductions in crash frequency, resulting in favorable benefit–cost ratios of FAST technology [9]. A conceptual study for the Minnesota Department of Transportation (MnDOT) indicated that eliminating even one accident per year would provide a benefit-cost ratio greater than 1 for two automated systems installed at bridge locations [10]. Another study indicated a benefit/cost ratio of 2.36 for a proposed FAST installation on a section of I-90 in Washington State, assuming a 60 percent reduction in snow and ice-related accidents [11].

North American transportation agencies still consider FAST as an evolving technology [9], as many systems had encountered challenges related to activation frequency, system maintenance and training. For example, a study conducted by the Virginia DOT [12] on a pilot FAST installation found issues with the automated triggering system. The environmental sensor station was unable to determine the chemical concentration on the structure; therefore, the system failed to accurately determine the freezing-point temperature of the bridge surface. As such, the automated triggering mechanism could not work appropriately. Numerous studies also reported issues on the reliability of the automated triggering mechanism [9]. Ye et al. [9] suggested the need for more research in enhancing the reliability of FAST technology, which may necessitate more distributed deployment of low-cost sensors to cover more pavement area of interest.

It is important to document the practitioner’s knowledge about the challenges during the installation, maintenance and operating a FAST system. This renewed information could be very helpful for designing a new FAST system and for successfully operating an existing FAST system. In this context, this work conducted a national survey to examine the user experience of FAST systems and a field survey to examine the FAST systems operated by the Colorado Department of Transportation (CDOT).
The online survey consisted of 23 questions and was designed to seek information regarding general experience during planning, installation, maintenance and operations of FAST systems, user acceptance, perceived or documented costs and benefits. Respondents from a total of 25 FAST agencies/vendors participated in the survey, with two from Canada and one from the United Kingdom, and the rest from the U.S. representing agencies from 12 different states and one vendor from California. Figure 2 shows the distribution of the survey respondents in North America.

Figure 2: Survey respondents in North America

Reasons for Use and Deployment of FAST system

Respondents listed numerous reasons for using FAST systems, most of which can be grouped into four major categories as follows.

- Safety concerns
- Material savings
- Crash reduction
- Environmental concerns

For example, the Illinois (IL) DOT uses FAST to reduce chloride use on the bridge and protect bridge components from chloride corrosion and the North Dakota (ND) DOT uses FAST to reduce maintenance activities in rural areas. FAST systems were also installed on the economically important routes to prevent ice formation and avoid road closure (Canada and U.K.). In addition,
FAST were installed on locations based on the past accident history, high traffic count, roads that pose unique hazard due to weather and/or geometry and remote locations. Further, FAST systems were installed on bridges with only few placed on interstate ramps.

**Chemicals used for FAST system**

Liquid chemicals that can be used by FAST systems include, but are not limited to:

- Calcium Chloride (CaCl₂)
- Magnesium Chloride (MgCl₂)
- Potassium Acetate (KAc)
- Sodium Chloride (NaCl)
- Calcium Magnesium Acetate (CMA)
- Blend of CMA/KAc (CMAK).

KAc is the most commonly used chemical in the FAST systems due to its non-corrosiveness, extremely low freezing temperature, environmental friendliness and reasonable cost. A vendor from California also stated that KAc was by far the best chemical for a FAST system; the other chemicals were either corrosive or had limited temperature range use. A researcher from Alberta, Canada also mentioned the problems of using KAc, as it is still corrosive to non-stainless steel components inside junction boxes. This is consistent with the laboratory results by Fay and Shi (2011), which found “acetate-based deicers …to be noncorrosive to mild steel, but comparably corrosive to galvanized steel as the chloride-based deicers” [13]. KAc may also have a negative effect on concrete [14], but this issue still requires further assessment. With regard to other chemicals, the Ontario Ministry of Transportation (Canada) suggested that even if other products were available they should be researched and considered with the design of the FAST system. Shi et al. [15] also noted the potential safety risk of acetate-based deicers reacting with chloride-based deicers from adjacent roadway segments.

**Conditions that Increase Effectiveness and System Limitations**

In general, survey respondents agreed that the FAST system was most effective when the targeted area had frost, ice formation and light snow (< 1 inch). FAST system worked most effectively when the temperature was between mid-20s to 32°F (Alaska DOT). The FAST was also used effectively during night hours when freezing conditions could occur (New Hampshire (NH) DOT). FAST system was also effective when used for repeated chemical application over a short period, which would not be possible with a vehicle based treatment (U’K).

The survey agencies cited several system limitations, including:

- High wind (ND DOT: >15mph, KS DOT, and Ontario Canada);
- Extreme low temperatures (KS DOT and ND DOT: <12°F);
- Extreme snow falls (Ontario Canada);
• Rapidly falling temperatures (KS DOT);
• Lack of precipitation (Kentucky Transportation Cabinet);
• Low traffic volumes (NYS DOT: rely on tire tracking to spread potassium acetate).

Further, one agency stated that competing winter maintenance activities (salting/sanding) tend to interfere with FAST operations, which has made the use of FAST more complex and less effective. Other limitations to FAST systems were attributed to their mechanical and technological complexity, which requires a lot of maintenance to remain operational.

**Activation Features and Challenges**

Majority of agencies reported that they use Road Weather Information System (RWIS) in the activation of FAST (ND DOT, NYS DOT, MT DOT, NH DOT, KS DOT, Penn DOT, IL DOT, Alberta Canada, Ontario Canada and United Kingdom). In most cases, the RWIS was used without any major problems and functioned well. Some of the reported issues with the RWIS include false alert in activating the FAST system (IL DOT) and its reliability. Respondents favored the idea of using active sensors instead of passive ones for the mix of chloride deicers, but poor algorithms or poor sensors made appropriate treatments an unattainable goal. The PA DOT system was generally set to spray automatically at 34°F and newer FAST systems can be controlled manually by traffic centers; to optimize the system effectiveness, staff also recommended setting the trigger temperature to fit the temperature profile of the bridge. In the southern part of England, the two FAST systems were triggered from a combination of grip readings and snow level readings. A vendor from California has pointed out that the most important measure for activating FAST is a grip reading, which uses less chemical and always treats slick problems. There were two agencies that reported no problems with RWIS (NYS DOT and Ontario, Canada).

Survey respondent’s reported various problems related to surface sensors such as damage due to traffic and snow plows and less reliability. The KS DOT has used passive and active sensors but has never achieved reliable activation. However, agencies some agencies had no with their surface sensors. Other activation features include manual activation by cell phone (KS DOT) and manual operation and web activation from the controller software.

**Problems with Operations, Maintenance and Reliability**

Maintenance is a critical component of using FAST systems effectively, and according to one respondent, regular maintenance resolves most problems (Alaska). Typical maintenance requirements included regular service on system hardware to ensure the system is operating correctly, such as checking for leaks, pressure loss, and plugged nozzles. Respondents suggested regular checks on the FAST system, once a month and more frequently (weekly, or as determined by the regional representatives) during the winter maintenance period. Some responding agencies reported high reliability of over 75% (ND DOT 95%, Alaska Central Region 85%, Penn DOT 75%). However, problems with operation and maintenance did occur regularly. The major
problems reported were air leakage, sensor failure, plugged nozzles and communication problems.
The following operation and maintenance problems were identified by the surveyed agencies.

- It needs to be flushed and changed over to fire water during the summer. (NYS DOT Region 6, MT DOT, ND DOT, NH DOT, and Alberta Canada)
- Lack of initial training and staff turnover, issue on cleaning (ND DOT and MT DOT)
- Periodic sensor problems (Alaska)
- Leakage air in the system, remote activation has communication problems: high level of data usage on the 3g network. (UK)
- Leakage problem once in a year. (NH DOT District 2)
- The reliability is declining due to the age of most of our systems and the need to upgrade system.
- Some reliability issues have occurred; a good maintenance agreement with 24 hour response time is paramount for success. (Penn DOT District 11-0)
- North Saskatchewan River Bridge (NSRB) - there was one road sensor failure that required replacement. Otherwise is reliable. Athabasca River Bridge (ARB) - there are some communication problems, the system over sprayed but no conclusions as to why. (Alberta, Canada).
- It is a fully automatic FAST system. It is important to follow the suppliers’ recommended maintenance protocol that can typically be found in their respective manuals. (Ontario MTO, Canada)

Problems with maintenance of each major system component

RWIS:
- Pavement sensors issue (IL)
- Active sensors did not make the system fire at the right times (KS)
- During operational months, maintenance is an issue: access to the equipment requires a full closure on bridge. (UK, Vendor)

Pumping/Storage:
- Issue with air getting into the system (UK, vendor)
- Major failure (KY DOT); various leaks (Penn DOT)
- Component failure (NH DOT)
- Mice and other outdoor life (IL DOT)
- Filter change on hydraulic manifold (Alberta, Canada).

Controller – False alerts and software issues, but improved (IL DOT), No problems for other agencies.

Chemical Distribution/Spray System:
• Small leaks where the hoses connect due to differential pressure caused by the location on steep slope (UK, Vendor)
• Spray heads are clogged (NYS DOT)
• Nozzle clogging is big issue (ND DOT)
• Nozzle clogging (Penn DOT); periodic leaks (NH DOT)
• Initial leaks (IL DOT)
• Pressurized manifold makes leak, prevention and early identification are critical (KS DOT); maintenance on nozzle to prevent dirt accumulation (Alberta, Canada).

**Features that are critical/important or most problematic and innovations for future use**

**Critical/important:**
- Non-invasive sensors that measure grip for best results (CA vendor)
- Regular and good quality maintenance (UK vendor)
- Training, ongoing support for repair parts and software upgrades (MT)
- Controls/configurations that determine the amount and frequency of treatments (NH)
- Proactive responses (Alberta, Canada).

**Most problematic:**
- Valves (CA vendor)
- Sensors and nozzles (Alaska);
- Maintaining same pressure throughout the system (UK vendor);
- Corrosion, leaking valve boxes, maintenance (Ontario, Canada);
- Nozzle plugging (MT, ND, NH, Alaska, Alberta, Canada);
- Leaks in supply tubing (NH);
- Conduits for hydraulic lines (fit ups) on the bridge caused significant pavement cracking, nozzles failed frequently, causes may be inadequate sealant epoxy, bridge heavy traffic, vibration, conduits and nozzle installation method (Alberta, Canada)

**Innovations for future use:**
- Buy maintenance program from vendor along with the system (CA vendor)
- More durable nozzle (Alaska)
- PC based triggering system rather than simple relays (UK vendor)
- Micro FAST (Ontario, Canada)
- Non-intrusive sensors and nozzles (Alberta, Canada).

**Costs and Evaluations**

FAST system is relatively an expensive technology and its implementation needs to be weighed against the costs of winter maintenance activities related to the structure or target area.
Mobilization of maintenance equipment to treat frosted bridge decks carries an associated cost. The use of a FAST system is intended to reduce the need for such mobilizations. Rather than replacing winter maintenance activities, it is intended to enhance activities. More experience and data with the use of FAST systems will help to review the cost-benefit ratios associated with FAST (Ontario, Canada). FAST system initial costs include: design, construction, project management and commissioning of the RWIS system, the spray system and the chemical storage facilities. Annual operating and maintenance costs include: chemical costs, monthly monitoring/reporting, site inspections, maintenance and utility costs. The variable costs (chemicals and utilities) will depend on the severity and nature of winter. No formal evaluation was conducted for most of the surveyed agencies, except for the ND DOT and the KY DOT. The Alberta Ministry of Transportation indicated a planned benefit-cost study next year, in which safety records would be used to assess the benefits of using FAST. Table 1 has summarized the initial costs and annual operating costs associated with FAST systems for surveyed agencies.
### Table 1: Initial costs and annual operating costs for the respondents’ FAST systems

<table>
<thead>
<tr>
<th>FAST Agency Surveyed</th>
<th>FAST Description</th>
<th>Initial Costs</th>
<th>Annual Operating Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska DOT Central Region</td>
<td>Has been in service for 7 years, 4 lanes, the only FAST in this region</td>
<td>$1.3 million for/ installation of plumbing and pumping systems</td>
<td>$30,000- $40,000/chemical and component replacements</td>
</tr>
<tr>
<td>New York State DOT Region 6</td>
<td>Full scale demonstration at two locations 2007-2009</td>
<td>$1 million+</td>
<td>$25000-$50000/ material and sensor replacements</td>
</tr>
<tr>
<td>Montana DOT</td>
<td>Pilot study 8-9 years of operation, &lt;500 feet length</td>
<td>$600,000 for initial construction including material and maintenance costs</td>
<td>N/A</td>
</tr>
<tr>
<td>North Dakota DOT</td>
<td>Red River Bridge-7 years (1300 feet and 3 lanes)</td>
<td>$650,000 Red River Bridge not including the ESS costs</td>
<td>$1000/maintenance $1162/utilities $9471/chemicals</td>
</tr>
<tr>
<td></td>
<td>Buxton Bridge-11 years (370 feet and 4 lanes)</td>
<td>168,000 Buxton Bridge not including the ESS costs</td>
<td>$2000/maintenance $2955/utilities $66,703/chemicals</td>
</tr>
<tr>
<td>New Hampshire DOT</td>
<td>30 feet curb to curb wide and 2 lane bridge</td>
<td>$200,000-$250,000 without labor and equipment</td>
<td>$25,000 - $50,000/liquid anti-icer cost, repair costs of $500 annually</td>
</tr>
<tr>
<td>Kansas DOT</td>
<td>12 years of operation, 200 feet and 2 lanes</td>
<td>$200,000</td>
<td>High maintenance cost and high cost of inappropriate spray</td>
</tr>
<tr>
<td>Ontario, Canada</td>
<td>Demonstration, installed in 2000 (Coverage is 1974.5m² AADT=3000)</td>
<td>$300,000 or $153/m² /design, construction and commissioning</td>
<td>$30,000</td>
</tr>
<tr>
<td>Alberta, Canada</td>
<td>NSRB (2 lanes, one direction, AADT=43,000) Boschung system (Switzerland)</td>
<td>$2.1 million/NSRB (2 lanes, 400 m long)</td>
<td>$100,000 - $300,000/ $90 - $140 per lane per meter per season</td>
</tr>
</tbody>
</table>
### Benefits, Lessons Learned, and Improvement on New FAST Systems

The benefits of using FAST listed by the agencies include: winter road related accident reduction, labor and material savings, and immediate roadway treatment (enhanced response time). Ontario Ministry of Transportation (MTO) has indicated that although the FAST systems are far more expensive to implement than traditional mobile anti-icing and deicing technology, the benefits are indirect and can be listed as: collision avoidance, reduced liability, environmental benefits, and reduced corrosion and travel delays. The surveyed practitioners listed the following lessons learned.

- Each point should be considered and addressed in the installation stage (Ontario, Canada).
- Maintenance (NYS DOT, region 6)
- Operator buy-in, staff cross-training (MT DOT)
- More appropriate location (Kentucky Transportation Cabinet)
- Older pavements will crack and rut, with more failure and early replacement if overlay required, not as good as new surface (NH DOT)
- For bridge deicing, systems were expensive and frost events are challenging to detect (IL DOT).
- Hydraulic tubing should be installed in the final surface after paving (surface cut method), metal conduits are damaging to the pavement, and embedded nozzles also cause pavement deterioration (Alberta Ministry of Transportation, Canada)

Some agencies showed interest in using a new FAST system or improving its features. The ND DOT and Ontario MTO were interested in the Micro FAST technology. The U.K. vendor would add a camera for improved effectiveness and wind sensor to allow wind speed to be taken into account in the decision making process. The MT DOT had a new FAST system in the planning stage.

### CDOT FIELD SURVEY

In order to further document the practitioner’s knowledge about the FAST system, a field survey was conducted in the CDOT FAST systems. The main aim of the field survey was to identify the differences between the fully functional system and a problematic system. The field surveys
consisted of site visits to the selected existing FAST systems and interview the maintenance crews. The field survey mainly focused on answering the following questions:

- Where the FAST system should be installed?
- What should be considered during FAST installation?
- What are the advantages and disadvantages of various components of the FAST system?
- How can various components of the FAST system be improved for future FAST installations?

The following section provides a summary of the field survey, based on the interviews with maintenance crew members and the in-depth field investigation by researchers.

**Location Selection**

At times, FAST systems can be very expensive to install and maintain. Therefore, it is important to select a suitable location to install the system to achieve the most benefits. During the site visit, CDOT staff provided several reasons for their decision on where to install FAST systems. Overall, CDOT staff considered or suggested the following key locations for installing FAST systems.

- Long-span bridges with slope and curves
- Short-span (less than 50 feet) bridges ending with an intersection and/or traffic signal
- Tunnel exits with curvy and slippery road conditions
- Remote bridges that require unreasonable time to treat with deicer.
- High-priority roads and bridges

CDOT staff members also noted that a FAST system may not be of significant use for straight and short-span bridges that are less than 40 feet.

From the site interview, most participants selected ‘bridges’ as their first choice to install FAST systems, based on the fact that ice can form on bridges at a faster pace relative to pavements. However, in-depth analysis and on-site interviews suggest that short-span bridges (span length less than 50 feet) located in a straight lane with high traffic volume do not necessarily need a FAST system (Figure 3a). This is due to the fact that incoming traffic can bring brine/abrasive with their tires, which “treats” most of the bridge surface. However, a FAST system can be beneficial to short-span bridges, if there is an intersection and/or traffic signal at the end of the bridge (Figure 3b).
Among types of bridges, respondents prefer to install FAST systems on long-span bridges that have significant slopes and curves. In addition, respondents suggest accident prone areas as another location to install FAST system. A tunnel exit could be an example of an accident prone zone. During slippery road conditions, drivers tend to drive slowly while they approach a tunnel. Once they hit the tunnel, drivers tend to increase their speed due to better road conditions inside the tunnel. However, when they exit from the tunnel, drivers tend to maintain the same speed without realizing the slippery road conditions outside the tunnel. Vehicles exiting tunnels at relatively high speed (during slippery conditions outside tunnels) are more prone to accidents, especially if the exit from the tunnel is a curvy bridge.

Further, interview respondents also suggest installing FAST systems on remote structures/bridges that are difficult to reach in bad weather conditions or where trucks would need to travel an unreasonable distance to treat a single bridge. Respondents believe that a functioning FAST system on remote structures/bridges will allow the maintenance crews to concentrate on other roadways instead of taking care of a single bridge. In addition, respondents suggest high-priority roads, bridges and flyovers that connect the airport and major intersections as other locations to install FAST systems. Respondents prefer these high-priority structures/bridges to be treated in a timely manner to prevent any formation of ice.

System Installation

FAST systems don’t have a manual to follow for installation. It is therefore necessary for the maintenance crew and the vendor to work together to analyze the location requirements and select an appropriate installation technique. In general, installation technique varies based on the selected location and requirements of the customers. FAST systems in Colorado used various installation
techniques within and between regions of the state. During site interviews, maintenance staff emphasized that the success or failure of FAST system is highly dependent on the installation technique.

Respondents highlight the importance of involving maintenance crews for a successful FAST system installation. This is due to the fact that maintenance crews tend to have a better knowledge of the locations that are selected for FAST system. For example, the information from a maintenance crew about the ease in accessibility to various structures within the bridge could be helpful in selecting a location to install valve systems. Installing a valve system in an appropriate location may well help the maintenance crew to perform a maintenance operation without access difficulty. One of the major issues encountered by maintenance crews is their difficulty to access and perform maintenance activities on the broken components (spray nozzles, valves, storage tanks, controllers etc.). For instance, a deicer storage tank was difficult to access during a heavy snow storm. The FAST system in this location was not operated for a few weeks, because a truck could not reach the storage tank and fill the deicer. These examples illustrate the need for involving both the vendor and maintenance staff during the installation phase of the FAST system. The inputs from the maintenance crew will provide guidance in selecting the locations to install various components of the FAST system.

Considerations in FAST Design

**Spray nozzles:** The spray nozzle is a very important part of a FAST system. Maintenance crews expressed their concern about the clogged nozzles, which prevent the system from functioning. Selecting proper locations to mount spray nozzles may help to reduce the clogging problem. Typically, spray nozzles are mounted on three locations of the bridge structure such as

- Bridge shoulder (Figure 4a)
- Side rail or side wall (Figure 4b)
- Between two lanes (Figure 4c)

From the interview responses, mounting on the side rail or side wall was the most preferable choice because of 1) easy access to nozzles 2) no clogging from abrasives and 3) less damage to nozzles. However, in some scenarios mounting on the shoulder or between lanes is unavoidable. In particular, a bridge that has four or more lanes needs spray nozzles mounted on the shoulder or between lanes so that deicers can reach all lanes. Also, if the side rail or side walls are far away from the lanes, then nozzles may have to be mounted on the shoulder or between lanes.
Figure 4: Various locations to mount spray nozzles

A) Bridge shoulder  B) side rail or side wall  C) between two lanes

Respondents prefer plastic nozzles (if mounted on the side rail/wall) to nullify the corrosion factor. Conversely, the mounting height of the nozzles from the lane surface should be decided such that the deicer doesn’t shoot very high at the running vehicle, and also so that the plowing trucks don’t block and damage the nozzles. In the case of nozzles mounted inside the pavement (Shoulder and...
between lanes), respondents suggest various considerations in nozzle design and mounting. Respondents do not recommend mounting nozzles in asphalt pavement and they prefer it in concrete pavement. Spray nozzles mounted in the asphalt pavement could get buried due to the melting of asphalt pavement during warm weather. Respondents also suggest installing side rail near the shoulder of asphalt pavement if side rails are not already in place. Respondents also suggest having strong and thick outer walls for nozzles to withstand stress induced by the vehicle. Furthermore, the pattern of nozzles should be designed in such a way that it is sufficient to provide chemical coverage to the whole structure. Finally, the nozzle design should be improved for easy removal from its location (in pavement or side walls/rails) to perform any maintenance activities.

**Valves and pipe lines:** Valves are another important part of the FAST system; they open automatically to shoot deicers at the prescribed settings. In the CDOT regions visited, the agencies use two types of valves: motorized ball valves and solenoid valves. The selection of solenoid valves versus motorized ball valves should consider the advantages and disadvantages of each type, as shown as in Table 2.

<table>
<thead>
<tr>
<th>Valve selection</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solenoid valve</td>
<td>• Small in size</td>
<td>• Corrosive to chloride products</td>
</tr>
<tr>
<td></td>
<td>• No need for big valve boxes</td>
<td>• For chloride products, expected</td>
</tr>
<tr>
<td></td>
<td>• Water can enter in valve box</td>
<td>service life 3-5 years</td>
</tr>
<tr>
<td>Motorized ball valve</td>
<td>• Less corrosive to chloride products</td>
<td>• Bigger in size</td>
</tr>
<tr>
<td></td>
<td>• Longer service life</td>
<td>• Need big valve boxes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Water cannot enter the valve box</td>
</tr>
</tbody>
</table>

However, most respondents recommend changing from solenoid valves to motorized ball valves. Respondents said that solenoid valves do not hold up to the MgCl2, and the best life expectancy of the solenoid valves is between 3 and 5 years. Further, location of valves should be carefully selected to ensure easy access, which will make it easy to perform maintenance activities without traffic control. If needed, small structures can be constructed to mount valves boxes or enclosures.

The respondents also suggest not using brass components in the pipe lines due to corrosion issues. They prefer using stainless steel, polypropylene, nylon 12, rubber hose and schedule 80 PVC for the pipe lines.
Fluid tank, fluid pump and storage facility: The maintenance crews strongly recommend having a fluid tank that can store enough chemicals so that it does not need to be refilled too often. In particular, they prefer a fluid tank with a minimum capacity of 1000 gallons. Respondents also suggest having aboveground storage facilities for a fluid reservoir, a fluid pump and associated components (Figure 4a), instead of an underground vault (Figure 4b). This preference is mainly due to difficulty in accessibility and high moisture (which damages the system components and reduces life time) in underground storage units. Finally, storage units must be secured from vandalism or any other related issues.

![Figure 5: Storage facility for fluid tank, fluid pump and its associated components](image)

A) Under the ground B) Above the ground

For a fluid pump, there is no real concern about the pump’s capacity (typically 220 psi) to pressurize the pipe lines and shoot the chemicals from the nozzles. However, respondents expressed concern about the malfunctioning of the fluid pump due to electrical issues. Respondents suggest periodic maintenance to mitigate this problem.

Activation systems: The activation system is another important component for the successful operation of a FAST system. All the respondents prefer a fully automated system that can be triggered by a computer from web-based PC software. The input for the trigger mechanism is provided by the pavement sensors. Respondents prefer using non-invasive sensor technology instead of in-pavement sensors (sensors mounted in the pavement). This is due to the fact that in-pavement sensors were damaged by the traffic and snow plows. Further, in-pavement sensors can be potentially damaged while performing maintenance operations on the bridge structure. In addition, FAST systems that use non-invasive sensors mounted on a pole should be installed at an appropriate location. Respondents emphasize locating the non-invasive sensors on the center of a bridge instead of on the entry or exit of a bridge. The center of a bridge provides a better representation of the actual prevailing conditions on the bridge.
Water leakage into the electrical systems is another area of concern expressed by respondents. In some cases, rats were seen inside the control boxes. Respondents suggest that the electrical components should be sealed by a watertight enclosure. Further, maintenance crews expressed their concern about the inability to perform a repair of an electrical system due to the unavailability of parts in local stores. This emphasizes the need to use standard parts that can be purchased from the local area.

DISCUSSION

In general, the field survey respondents like the concept of FAST system. However, inconsistency in performance of FAST systems among different regions in CDOT is mostly due to the lack of maintenance activities. The regions which have more FAST systems perform a routine maintenance activity, whereas regions which have fewer FAST systems do not have a routine maintenance activity. It can be also noted that some regions have a better knowledge about the FAST system than others. This is related to the change in maintenance personnel responsible of FAST system over the years.

A proper functioning FAST system provides benefits such as reduction on winter related accidents and savings on material use and labor. In addition, FAST system also directly contributes to reductions in environmental impact by reducing chemical usage and fuel consumption for winter maintenance vehicles.

Issues related to specific chemicals used in FAST systems can be a major impediment to their success. These may include corrosion to equipment and other accessories, detrimental effects on the concrete or asphalt pavement, insufficient performance at cold temperature, clogging of spray nozzle, etc. To ensure a successful FAST program, the right type of anti-icing chemical needs to be selected, properly stored, and applied at the right application frequency and rates as a function of the specific road weather scenario.

CONCLUSION

The FAST system uses complex technologies, and implementation challenges are often site-specific. Difficulties can be expected during operations, particularly in areas related to software, activation processes, and pumping systems.

The key findings from the national survey are as follows.

- Almost every installed FAST system (reported in this survey) needed significant maintenance activities for its successful operation. In some cases, a FAST system failed to operate even after repeated maintenance activities.
- Initial cost of a FAST system is significantly higher than the operating and maintenance costs. However, respondents believe that payback period could be as short as one year for a properly functioning FAST system.
• The benefits of using FAST perceived by the agencies include: reduction on winter related accidents, savings on material use and labor, and reduction of negative environmental impacts.

The key findings from the CDOT field survey are as follows.

• Inconsistency in proper functioning of FAST systems is mostly due to the poor design, poor quality of installation and lack of maintenance practices for some cases.

• FAST systems faced frequent mechanical, electrical and software issues.

• Involving maintenance crew in every aspect of design and installation of FAST systems could help reduce the maintenance issues.

• Non-invasive technology may help improve the reliability of the FAST systems.

• Location selection is an important factor for the success of a FAST system. Further, FAST systems may not be of benefit for some types of bridges (e.g., straight and short-span bridges that are less than 40 feet).
ACKNOWLEDGMENTS

The authors wish to thank the CDOT Applied Research and Innovation Branch for funding this research and David Reeves for overseeing the project. Authors also acknowledge the guidance and valuable support provided by the panel members Phillip Anderle, David Wielder, Masoud Ghaeli, Stephen Henry, Aziz Khan, Mark Mueller, Skip Outcalt, Steve Pineiro, Andrew Pott, David Swenka, Matt Rickard, Matt Greer and Richard Griffin. Further, they would like to thank Todd Anselman, Thomas Aguilar, Mark Carrillo, Kenneth Quintana, Ronald Morin, Wayne Lupton and Allen E. Roys for their support during the field site visits. The professionals who responded to the surveys are sincerely acknowledged.
REFERENCES


