Evaluation of North Dakota's Fixed Automated Spray Technology Systems

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October 2009

Acknowledgements

The Upper Great Plains Transportation Institute thanks those individuals who contributed to this project. Special thanks to the NDDOT – Fargo District staff, specifically Troy Gilbertson and Bob Walton, for providing their insight, experiences, cost and sprayer data, and reviewing material. In addition, special thanks to Mn/DOT's Office of Traffic, Safety, and Technology, specifically Bradley Estochen and his staff, for providing the detailed crash data. The NDDOT's Office of Traffic Safety (Karin Mongeon) and Planning & Programming Division (Christopher Holzer) also provided valuable crash data.

EXECUTIVE SUMMARY

The North Dakota Department of Transportation (NDDOT) has installed two fixed automated spray technology (FAST) systems. One system is installed at the Interstate 29 (I-29) Buxton Bridge (near Buxton, ND), while the second installation is at the Interstate 94 (I-94) Red River Bridge between Fargo, ND, and Moorhead, MN.

This study evaluates the two existing FAST systems to assist in determining if additional systems are feasible. This study has three main objectives: 1) describe how the FAST systems work; 2) document how the current NDDOT FAST systems perform related to treating the bridge decks, and 3) analyze the benefits and costs of the systems.

Both FAST systems in North Dakota are operated and maintained by the NDDOT – Fargo District. Because a steep learning curve exists with these systems, vendor support was very important during the first winter season. Since the Buxton Bridge installation in 2002, the district staff has been gaining valuable experience with these systems. Fargo District staff believes the two FAST systems are very effective in treating the bridge structures, especially for frost conditions, which occur over several weeks during the fall and spring seasons. In addition, frost typically develops late at night or early in the morning, which is outside the normal hours of operation for maintenance personnel. District staff is also satisfied with the system's ability to treat freezing conditions.

Both systems operate as expected in terms of spraying at the appropriate time, applying the proper amount of chemical agent, and achieving the proper system pressure. In addition, the district estimates that both systems are at least 95% reliable. Although the two NDDOT FAST systems work very well overall, these systems have some limitations, such as not spraying when the wind is greater than 15 mph and when the pavement temperature drops below 12^{o}F.

Significant crash reductions were observed at both locations after the FAST systems were installed. The Buxton Bridge FAST system provided a total crash reduction of 66%. Crashes related to property damage were reduced by 62% and injury related crashes were reduced by 75% (6.5 winter seasons before and 5.5 winter seasons after implementation). These crash reductions contribute to the location's removal from the high crash location list, where it had consistently ranked among the top five. The Red River Bridge also experienced crash reductions after the FAST system was installed. The combined crash reductions for the Minnesota and North Dakota systems observed a total crash reduction of 50% (9.5 winter seasons before and 2.5 winter seasons after implementation).

Benefit-cost analyses produced favorable results for both FAST system installations. The major benefits of the FAST systems relate to reductions in societal (resulting from vehicle crashes) and transportation agency costs (maintenance activities). The costs of FAST systems include initial implementation, anti-icing chemicals, and annual maintenance. The benefit-cost analysis of the Buxton Bridge FAST system provided a benefit-cost ratio of 4.3 with a net benefit of $1,257,869. The benefit-cost analysis of the Red River Bridge FAST system provided a benefit-cost ratio of 1.3 with a net benefit of $675,184.

The two ND FAST system installations appear to be working as intended based on feedback from NDDOT – Fargo District staff and the results from the benefit-cost analyses. Several factors contribute to these successful systems, such as selecting appropriate locations for FAST systems (primarily based on winter crash data); and having knowledgeable and dedicated staff for assisting in the design and implementation of the system, monitoring its operation, and performing the required maintenance procedures.

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1. INTRODUCTION & BACKGROUND

Frost, ice, and snow on roadways create dangerous driving conditions. Bridge decks can be especially dangerous because the cold air flowing underneath the structure can freeze moisture on the deck, which may not freeze on adjacent roadways. Therefore, road crews must treat roads and bridges with sand, salt, or other chemicals to improve traction and melt the accumulated ice/snow. Because manual treatments of bridge decks can be expensive and unfeasible at times, transportation departments can deploy automated anti-icing systems.

Roadway anti-icing systems, which are also known as fixed automated spray technology (FAST) systems, eliminate or reduce the formation of frost, ice, and snow on the road surface through the use of chemical agents. These systems are used to improve roadway safety and reduce maintenance costs compared to traditional manual surface treatments (sand, salt, etc.). Hundreds of FAST systems have been installed in Europe since the mid-1980s and gained popularity in the United States in the late 1990s (*1*).

The North Dakota Department of Transportation (NDDOT) has installed two FAST systems. One system is installed at the Interstate 29 (I-29) Buxton Bridge (near Buxton, ND), while the second installation is at the Interstate 94 (I-94) Red River Bridge between Fargo, ND, and Moorhead, MN. Both systems appear to be effective in treating the bridges and reducing crashes; however, no formal evaluation or documentation has been performed to support this position.

2. OBJECTIVES

The objectives of this study are threefold. First, the study will describe how the FAST systems work. This information relates to the components and processes involved to chemically treat the bridge decks. Second, the study will document how the current NDDOT FAST systems perform related to treating the bridge decks. This information will be primarily based on interviews with NDDOT staff and analyzing crash data at the bridge locations. Third, the study will analyze the benefits and costs of the systems. Information related to these three objectives will assist the NDDOT in evaluating deployments of future FAST systems within North Dakota.

3. WINTER WEATHER CONDITIONS

The weather conditions in the upper Midwest can create dangerous driving conditions due to the formation/accumulation of frost, snow, and ice on roadways. Three weather related factors play a role in degrading roadway surface conditions: temperature, precipitation, and dew point. The addition of high winds to a slippery road surface compounds the adverse driving conditions. North Dakota has several months of temperatures at or below the freezing point.

National Weather Service (NWS) historical data were gathered from the weather station at Fargo's Hector International Airport. When observing monthly weather data over the past 30 years, almost 95% of the days in November through March have a low temperature at or below 32 degrees Fahrenheit (^{o}F) (Table 3.1). In addition, these five months account for the highest monthly snowfalls, averaging 8.6 inches per month.

Table 3.1 Monthly Weather Data for Fargo, ND

Month	Total Precipitation (in.)	Total Snow Fall (in.)	Average Number of Days Low Temperature ≤ 32º F	
September	2.3	0.0	1	(4.3%)
October	1.9	0.7	13	(42.5%)
November	0.9	7.5	27	(88.8%)
December	0.7	8.6	31	(99.6%)
January	0.7	11.2	31	(99.9%)
February	0.6	7.1	28	(98.7%)
March	1.2	8.5	27	(86.7%)
April	1.3	2.6	16	(53.7%)
May	2.8	0.0	3	(9.2%)
Monthly Average (Oct-Apr)	1.0	6.6	25	(81.2%)
Monthly Average (Oct-Mar)	1.0	7.2	26	(85.9%)
Monthly Average (Nov-Mar)	**0.8**	**8.6**	**29**	**(94.4%)**
Monthly Average (Nov-Apr)	0.9	7.6	27	(87.5%)

Source: NOAA's National Weather Service, Monthly data for Fargo, ND, 1978-2007 (*2*)
Note: Snowfall data was not available for 1996 (Sep, Oct, Nov, Dec) and 1997 (Jan, Apr)

Bridge decks are more susceptible to frost and freeze conditions because they are elevated off the ground. During the day, especially when the sun is shining, the ground and roadways absorb heat. When the sun goes down, the roadway surface cools at a slower pace than the air temperature. However, because bridges allow air to flow underneath the deck, these structures can cool down faster than other roadways, which make them more vulnerable to frost and ice formations.

Ice forms on roadways when precipitation from rain or snow freezes as a result of the temperature falling below 32^{o}F. Frost forms on roadways without the obvious presence of precipitation. When the air temperature cools, the water vapor present in the air will condense into water, which is referred to as the dew point. As the dew-point temperature drops to or below 32^{o}F, the water vapor freezes to create frost. Because the dew point is dependent on relative humidity and air temperature, frost can develop when temperatures are well below the freeze point.

4. SYSTEM DESCRIPTION

Fixed automated spray technology systems chemically treat roadways to prevent the formation/bonding of frost, ice and snow. Key components of a FAST system include pavement sensors; weather sensors/station; a pump house containing pumps, storage tanks, power/communication equipment, and a computer controller; spray nozzles; and plumbing (electrical/anti-icing chemical) connecting the pump house to the spray nozzles. The NDDOT pump houses also have a warning light on the outside of the structure in case a problem occurs with the system, such as having a low quantity of anti-icing solution in the storage tank.

Both of the FAST system installations in North Dakota are Energy Absorption Systems, Inc. FreezeFree Systems. These systems incorporate a Road Weather Information System (RWIS) Environmental Sensor Station (ESS) to measure pavement and atmospheric conditions to determine the optimal time to activate the FAST system. When the FAST systems are activated, a self-priming pump sequentially activates the spray nozzles. Once the spray cycle is completed, the remote processing unit (RPU) pressurizes the system to approximately 200 pounds per square inch (psi). The systems can be activated automatically using spray algorithms and manually using various methods of communication.

4.1 Pavement Sensors

Pavement sensors provide information related to the roadway's surface condition. Two main types of pavement sensors exist: passive and active. Passive sensors typically provide pavement temperature and determine whether the pavement is dry or wet. In addition, if liquid is present on the roadway, passive sensors measure the conductivity of the liquid to estimate its freezing point. The freezing point of an anti-icing chemical is determined in a laboratory by freezing various samples of the diluted chemical (using water), which will have different conductivity measurements. In the field, the sensor will determine the conductivity of the liquid on the sensor and estimate its freeze point based on the laboratory tests. A problem with this methodology is that the liquid on the pavement will include anti-icing chemicals, water, and other impurities (salt, oil, etc.) that can influence the conductivity of the chemical solution.

Active sensors provide pavement temperature, determine whether the pavement is dry or wet, and determine the freeze point of the liquid on the pavement. Using a Peltier element, these sensors cool a small sample of liquid to determine its freezing point. A benefit of these sensors is they can determine the freeze point of the actual liquid on the bridge deck.

Agencies may be inclined to use both passive and active sensors for FAST systems. Passive sensors provide accurate temperature readings and can operate under extreme temperature conditions, while active sensors provide more accurate liquid freeze point information. Both NDDOT installations include a combination of up to three sensors: FP 2000 (a passive sensor from Quixote Transportation Technologies, Inc.), Sensit (an active sensor from Quixote Transportation Technologies, Inc.), and a Frensor (an active sensor from SAAB AB).

5. SYSTEM OVERVIEW

A FAST system automatically sprays chemicals on roadways using various mechanical and electrical components based on atmospheric and road surface conditions. Vendors may have varying equipment and algorithms; however, the following information provides an overview of NDDOT's FAST installations.

Pavement sensors provide surface condition information (temperature, dry or wet, freeze point if liquid exists, etc.) to the ESS remote processing unit (RPU). The ESS gathers atmospheric information, including dew point, snow precipitation rate, and wind speed. Spray algorithms are established for frost, freeze, and snow conditions, which include the following pavement/atmospheric data:
Frost condition: pavement temperature, dew point
Freeze condition: pavement temperature, liquid freeze point
Precipitation condition: pavement temperature, rate of precipitation

If any of the three conditions are met and the wind speed is less than the established threshold, the ESS RPU will send a spray command to the FAST system's RPU, which is located in the pumping house. The FAST system will then cycle through the spray nozzles for a specified amount of time to provide the desired amount of anti-icing chemical. After the spray cycle has finished, pumps will pressurize the system for the next spray command. To provide adequate chemical treatment while not wasting anti-icing chemical, each spray condition is set up to have a minimum time lapse between spray applications.

5.1 Buxton Bridge FAST System

The Buxton Bridge near Buxton, ND, is located on a rural section of I-29. The bridge consists of two structures (one for each direction of travel) having lengths of 330 feet (Figure 5.1). Two lanes of travel are provided for each direction and the location had an average annual daily traffic (AADT) of 10,951 in 2007 (*3*).

Figure 5.1 I-29 Buxton Bridge showing ESS and pump house in median (source: Google Maps)

The I-29 Buxton Bridge had been an area of concern for the NDDOT for many years due to its high crash rate (this location consistently ranked in the top five on the high crash location list for North Dakota interstate highways). Prior to the FAST system installation, the structures were treated by NDDOT staff out of the Hillsboro, ND, facility, which is approximately 10 miles from the site. The NDDOT was awarded a grant of $165,000 from Energy Absorption Systems, Inc. (which is a Quixote Company) to install a FreezeFree Anti-icing System. The total cost of the system was $168,531 (not including the ESS which was previously installed). The system was installed in 2002 and became operational in December of that year.

The Buxton Bridge FAST system treats 370 ft., which consists of 330 ft. of bridge deck and 40 ft. of roadway, per bridge. The plumbing of the FAST system consists of a single line for dispersing the anti-icing agent (potassium acetate, CF7). The system consists of 20 spray nozzles (10 for each direction). Each bridge includes 8 spray nozzles imbedded in the pavement (commonly referred to as surface mounted) and 2 spray nozzles mounted on the guardrail (Figure 5.2). The pump house contains a storage tank having a capacity of 500 gallons of anti-icing agent.

An ESS already existed at this location prior to installing the FAST system; however, a camera was added to the ESS when the FAST system was installed. The pump house was installed next to the ESS, which is located in the median of the roadway.

Two types of pavement sensors are used at the Buxton Bridge location: a FP 2000 (passive sensor) and a Frensor (active sensor). The spray algorithms for frost and freeze conditions are based on information from the Frensor sensor, which is only installed in the northbound direction.

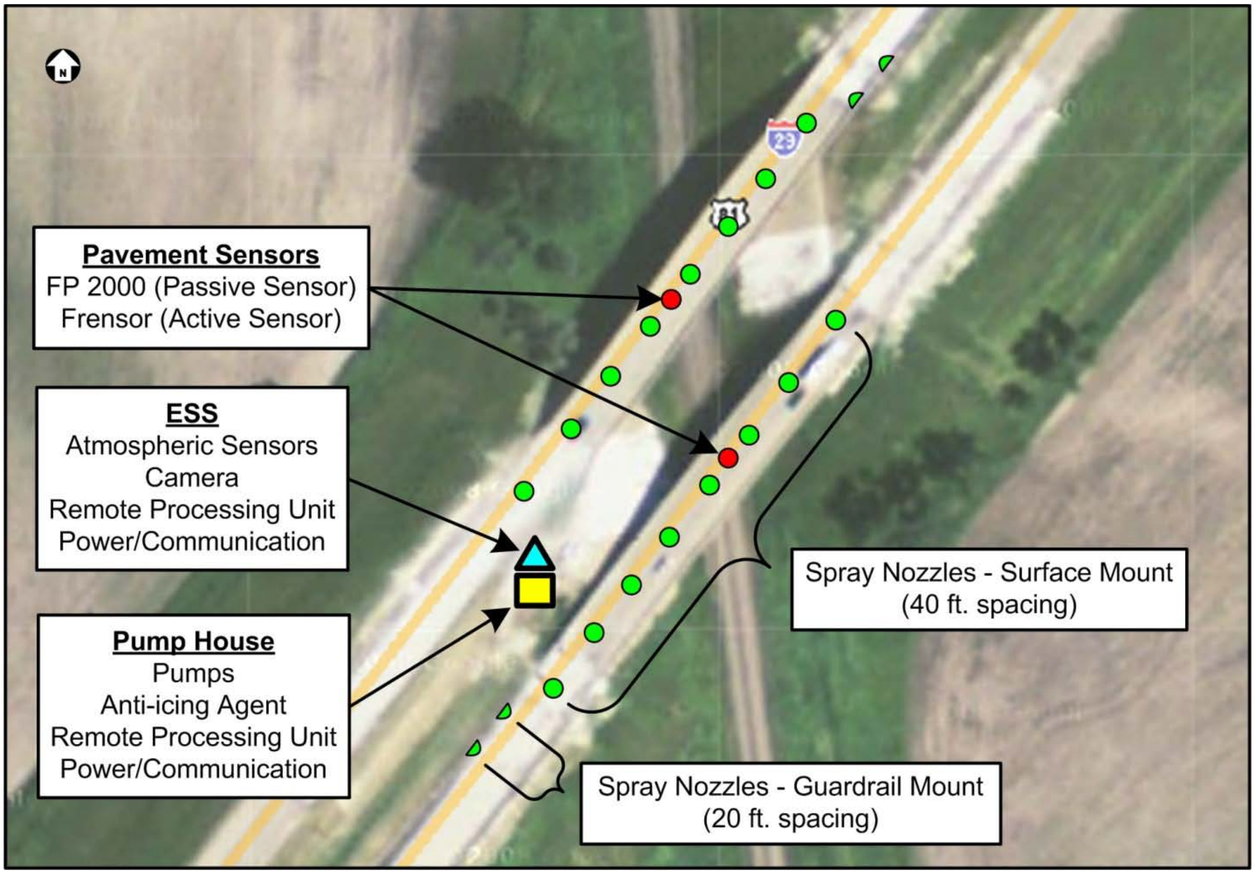

Figure 5.2 I-29 Buxton Bridge FAST system components (source: Google Maps)

5.2 Red River Bridge FAST System

The I-94 Red River Bridge spans the Red River of the North and connects North Dakota and Minnesota. This section of I-94 is classified as an urban interstate. The bridge is a single structure having a length of 1,300 ft. (Figure 5.3). The structure has three lanes of travel for each direction and the location had an average annual daily traffic (AADT) of 63,051 in 2007, which is the highest volume bridge crossing in the Fargo-Moorhead metropolitan area (*3*).

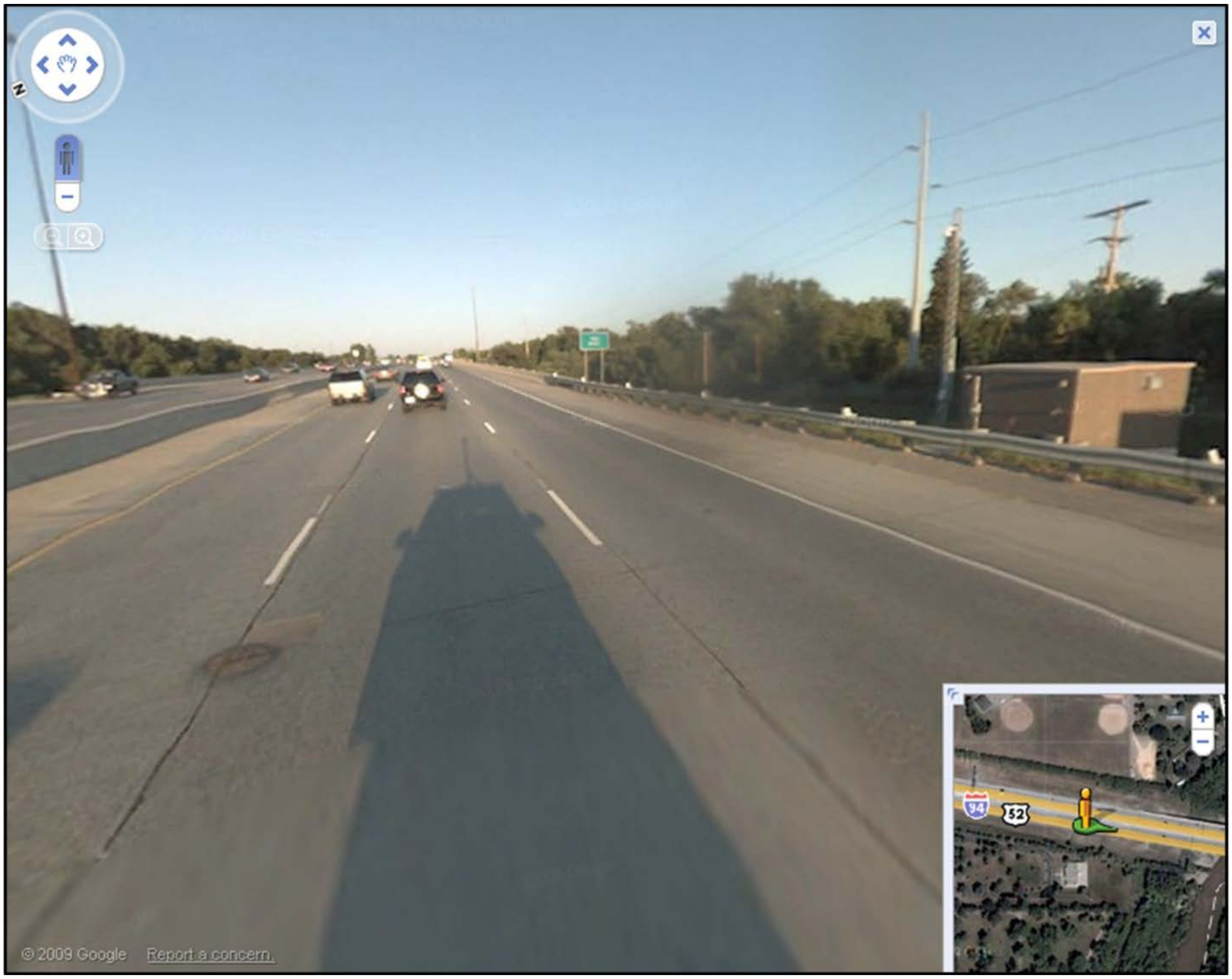

Figure 5.3 I-94 Red River Bridge with pump house off of right shoulder (source: Google Maps)

The Red River Bridge FAST system was a joint venture between NDDOT and Mn/DOT. The cost of NDDOT's portion of the project was $650,575. Although the two states split the total cost of the system, Mn/DOT's portion was slightly higher since an ESS needed to be installed on the Minnesota side of the river, while an ESS already existed on the North Dakota side. The system was installed in 2005 and became operational in January of 2006.

The Red River Bridge FAST system treats 1,300 ft of bridge deck. In addition, NDDOT treats 200 ft. of roadway leading up to the bridge, while Mn/DOT treats 800 ft. of roadway (Figure 5.4). The additional distance for Mn/DOT was due to treating moisture that develops from vehicles coming from the I-94 and 8th St. Interchange. The plumbing for each side of the bridge consists of dual closed-loop systems for dispersing the anti-icing agent (potassium acetate, CF7). If a spray nozzle/section encounters problems, these nozzles can be isolated and the remaining nozzles can spray by pressurizing the line from the opposite direction. The NDDOT system (eastbound) consists of 30 spray nozzles, while the Mn/DOT system (westbound) consists of 41 spray nozzles. Each pump house contains a storage tank having a capacity of 2,000 gallons of anti-icing agent.

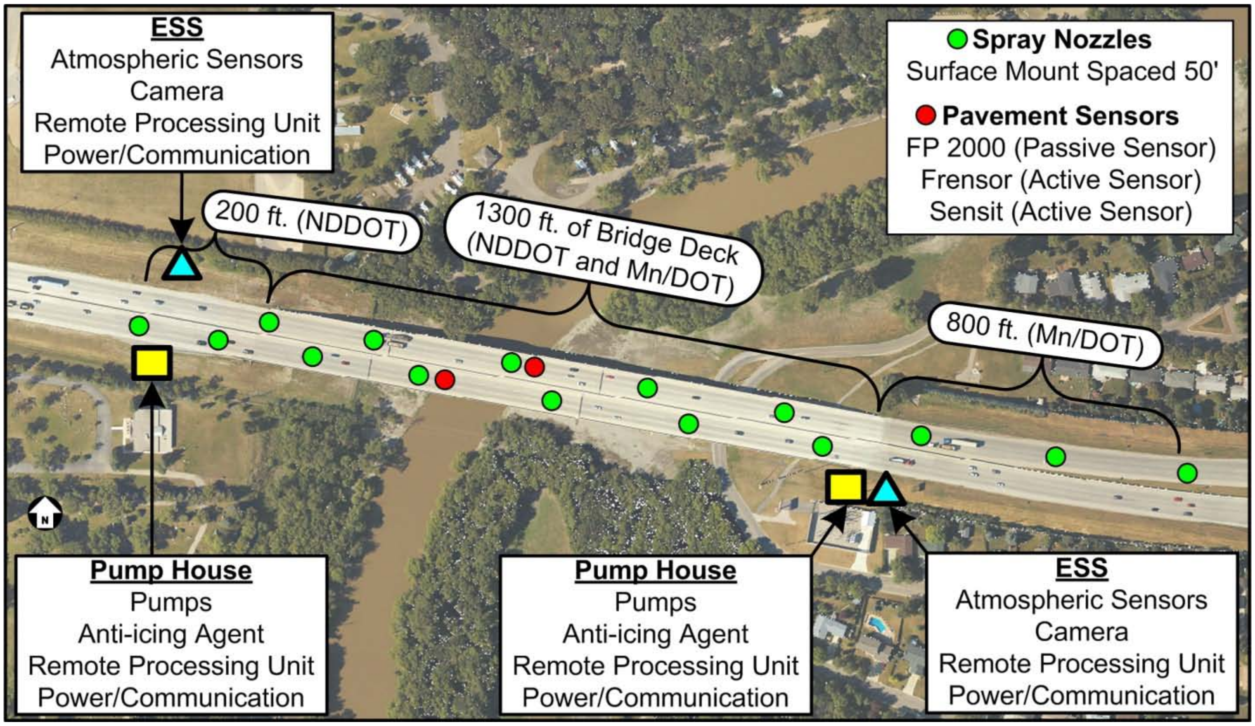

Figure 5.4 I-94 Red River Bridge FAST system components (source: Metro COG MrSid)

Each FAST system uses the same equipment; however, they are independent from each other. The NDDOT operates and maintains the eastbound system, while Mn/DOT operates and maintains the westbound system. An ESS already existed on the ND side of the Red River (north of the pump house). However, Mn/DOT needed to install an ESS for their system.

Three pavement sensors are used for both Red River Bridge FAST systems: a FP 2000 (passive sensor), a Frensor (active sensor), and a Sensit (active sensor). Typically, the spray algorithms for frost and freeze conditions at this location are based on information from the Sensit sensor but can be changed to other sensors as desired.

5.3 Spray Programs

Both the Buxton Bridge and Red River Bridge anti-icing systems can be sprayed automatically or manually. The automatic method, which is the primary method of application, uses spray algorithms that account for frost conditions, freeze conditions, and precipitation based on the pavement and atmospheric sensors.

5.3.1 Automatic Sprays

The automatic spray mode requires various parameters to be configured for the spray algorithm. Most of these parameters relate to temperature, wind speed, and activation time thresholds; and the values are based on experience, vendor recommendations, and guidance from the Federal Highway Administration (FHWA).

The spray algorithms are configured using the RWIS web interface called SCAN Web, which was developed by Surface Systems, Inc. The automatic spray configuration for the Red River Bridge (NDDOT system), which is the same for the Mn/DOT system, is shown in Figure 5.5. The Buxton Bridge system uses similar parameters; however, it does not use the precipitation condition.

SCAN Web ssi®

North Dakota
Fargo - I-94 @ Red River Bridge - Red River Sprayer (597012.0)
Bridge Sprayer Configuration History

Bridge Sprayer History

Sprayer Configuration at 02/08/2009 21:55

- Allow the RPU to **automatically** activate the sprayer while also allowing **on demand** activation.

Automatic Mode Operating Ranges

- Only allow automatic activation when the surface temperature is between:
  High Temperature: **33F**
  Low Temperature: **12F**
- Do not allow automatic activation to occur when the average wind speed is above **15mph**.

Automatic Freeze Point Condition Settings

- Activate sprayer when the surface temperature is within **1.8F** or is less than the freeze point temperature. A negative value can be specified to delay the automatic activation of the sprayer.
- Require a minimum of **60** minutes to elapse before reactivating the sprayer due to a freeze point condition.

Automatic Frost Condition Settings

- Activate sprayer when the surface temperature is within **1.8F** or is less than the dew point. A negative value can be specified to delay the automatic activation of the sprayer.
- Require a minimum of **240** minutes to elapse before reactivating the sprayer due to a frost condition.

Automatic Precipitation Condition Settings

- Automatic Precipitation Activation: **Enabled**
- Activate sprayer when the surface temperature is within **1.8F** or is less than freezing and rain (also requires moisture present on the pavement) or freezing rain is occurring. A negative value can be specified to delay the automatic activation of the sprayer.
- Activate sprayer when the surface temperature is within **3.6F** or is less than freezing and snow is occurring at a rate greater than .2"/hr (5mm/hr). A negative value can be specified to delay the automatic activation of the sprayer.
- Require a minimum of **60** minutes to elapse before reactivating the sprayer due to a precipitation condition.

Figure 5.5 Spray Configuration for NDDOT I-94 Red River Bridge

5.3.2 Manual Sprays

Manual sprays are primarily used to supplement the automatic sprays but can also be used during maintenance activities. Operators may perform predictive sprays or more frequent sprays before/during major snow/freezing rain events. In addition to viewing the sensor data, the operator can observe the images from the ESS camera and surveillance camera (NDDOT at Red River Bridge) to determine if additional treatments are necessary.

Manual sprays may be performed using a variety of methods, including cellular communication, SCAN Web, and HyperTerminal. SCAN Web is a Web-based interface with the ESS controller allowing operators and the traveling public (to a much lesser extent) to view camera, sensor, and sprayer information. Operators are provided with a user name and password to access the ESS RPU to check the system status, view log files of historical data, and manually spray the system. It should be noted that the spray history only includes those events that were performed using the ESS (all automatic sprays and manual sprays performed through SCAN Web).

The final method of manual activation is performed using HyperTerminal. HyperTerminal communication is between a computer(s) at the DOT district and the FAST system (FreezeFree Remote Processing Unit) using a phone modem or serial port. This method of communication requires a password, which allows operators to check the history (spool codes) and manually spray the system. Compared to SCAN Web, the HyperTerminal communication method allows the operator to access more detailed information related to the sensor and system, such as amount of chemical agent applied for each application, tank level, etc.

5.4 Anti-icing Chemical

Several chemicals are available for FAST systems, which include magnesium chloride ($MgCl_2$), sodium chloride (NaCl), calcium chloride ($CaCl_2$), calcium magnesium acetate (CMA), and potassium acetate (KAc). These chemicals have various corrosive properties, treatment effectiveness, environmental impacts, and costs. Both of NDDOT's FAST systems use Cryotech CF7, which is manufactured by Cryotech Deicing Technology. CF7 is a potassium acetate based deicing/anti-icing liquid that contains no nitrates, sodium, or chlorides. The product has a freezing point of -76 ^{o}F and is effective to temperatures of -20 ^{o}F and below (*4*).

CF7 is generally safe for the environment since it readily biodegrades and has a low biological oxygen demand (*4*). In addition, CF7 is generally non-corrosive, which is highly desirable for structures, such as bridges, consisting of reinforced concrete. However, it should be pointed out the product can be corrosive to galvanized, zinc, and brass components.

The cost of potassium acetate, specifically CF7, is substantially higher than liquid chloride anti-icing chemicals. The price for CF7 in previous years was about $2.80/gallon for bulk delivery (4,400 gallon minimum). However, due to limited availability of the CF7, the cost of the product was $8.20/gallon when the NDDOT – Fargo District purchased it in 2008.

5.5 System Maintenance

Preventative maintenance programs are important for ensuring a FAST system operates properly in both the short and long term. Once the winter season is over, NDDOT personnel pumps out the CF7 (which is transferred to a storage tank at the Fargo District) and cleans the tank of any mold that may have developed within the tank. Once this is performed, water and bleach are added to the tank and maintenance sprays are conducted weekly (which occur at 2:00 am). The bleach prevents mold or bacteria from forming within the tank or piping. In mid/late September, the water is removed from the tank and replaced with the CF7 anti-icing agent.

6. SYSTEM PERFORMANCE – FARGO DISTRICT PERSPECTIVES

Both FAST systems in ND are operated and maintained by the NDDOT – Fargo District. Since the Buxton Bridge installation in 2002, district staff has gained valuable experience with these systems. As with most new advanced technologies, a steep learning curve existed; therefore, vendor assistance was very important during the first winter season. The Fargo District was very satisfied with the technical support and training provided by Energy Absorption Systems, Inc. Experience gained after three years of using the Buxton Bridge FAST system greatly assisted in developing the specifications for the Red River Bridge FAST system.

Fargo District staff believes the two FAST systems are very effective in treating the bridge structures, especially for frost conditions. Frost conditions can be prevalent for several weeks during the fall and spring seasons. In addition, frost typically develops late at night or early in the morning, which is outside the normal hours of operation for maintenance personnel. District staff is also satisfied with the system's ability to treat freezing conditions; however, they stated that the systems are not as effective in treating heavy snow precipitation since the amount of chemical additive used may not be enough to melt the snow. During heavy snow events, applying anti-icing chemicals assists in snow plow operations since it prevents the snow from bonding to the pavement.

District staff values the remote access capability of the FAST systems. Staff can monitor the road conditions at the bridges while out of the office, such as at home. In addition, staff can perform manual (predictive) sprays as a preventative measure when a condition is close to being met, especially prior to peak traffic conditions.

6.1 System Reliability

Both systems operate as expected in terms of spraying at the appropriate time, applying the proper amount of chemical agent, and achieving the proper system pressure. In addition, the district estimates that both systems are at least 95% reliable. On occasion, the systems may not spray when a spray condition is met, which is primarily due to communication problems between the ESS RPU and the FreezeFree RPU. It should be pointed out that most of the communication issues were a result of performing maintenance on one of the RPUs and not properly reconfiguring the system afterwards.

6.2 System Limitations

Although the two NDDOT FAST systems work very well overall, they have some limitations which must be taken into account. First, the systems are not used when the wind is greater than 15 mph. Experience has shown that crosswinds greater than 15 mph can cause snow to drift across the roadway, which may stick to the pavement if it is wet from the anti-icing chemical (*5*). Higher wind speed also may impact the spray effectiveness by blowing the material off the roadway.

In addition to wind, the NDDOT FAST systems are not used when the pavement temperature drops below 12°F. Although the anti-icing chemical (CF7) can be effective to -20°F and below according to the manufacturer, the amount of chemical required to maintain anti-icing effectiveness would be significant. Moreover, safety issues could arise if the chemical concentration was not adequate during the low temperatures. The low temperature threshold is similar to guidance provided by FHWA, which is 15°F (*5*).

6.3 Anti-icing Chemical

Based on vendor information and research performed by Fargo District staff, Cryotech CF7 was selected for both FAST systems. The product was selected due to its deicing/anti-icing properties, minimal environmental impacts, and non-corrosive properties. It was very important to the NDDOT to use an anti-icing chemical that is non-corrosive to the bridge structure (primarily structural steel).
District staff is very satisfied with CF7's performance because it is effective at low temperature and has good longevity (it doesn't seem to evaporate or wear off). Because of their success with the product, they are not interested in using/testing other available products. However, the recent price increase of CF7 is a concern.

7. FAST SYSTEM CASE STUDIES

Two case studies will be provided to illustrate how the FAST systems perform during different conditions. The first case study will discuss a frost event that occurred in April 2009, while the second case study will discuss a rain/snow event that occurred in February 2009.

7.1 Frost Event (Buxton Bridge)

A frost event occurred at the Buxton Bridge from April 5, 2009 (8:00 a.m.) to April 6, 2009 (8:00 a.m.). The SCAN Web data will be presented and discussed during this event. A feature of SCAN Web illustrates the environmental data using a history graph. Figure 7.1 shows the system information along with comments related to the FAST spray status during the 24-hour period. The top horizontal bar shows the precipitation on the roadway. The bar is gray, which means no precipitation has occurred during the analysis interval. The bottom horizontal bar shows the surface status of the bridge deck. During the 24-hour period, the surface encountered three conditions: dry (green), trace moisture (cyan), and combinations of ice and frost watches and warnings (red). Plots of various data, include air temperature (green line), surface temperature (purple line), and dew point temperature (blue line) are available.

Throughout the day of April 5, 2009, the deck surface was above both the freezing and the dew point temperatures. During the evening, the deck surface dropped below 32 °F and frost conditions were met at about midnight. The system did not spray for frost due to high wind speeds. When the wind subsided later in the morning of April 6, 2009, the system sprayed for frost on two occasions.

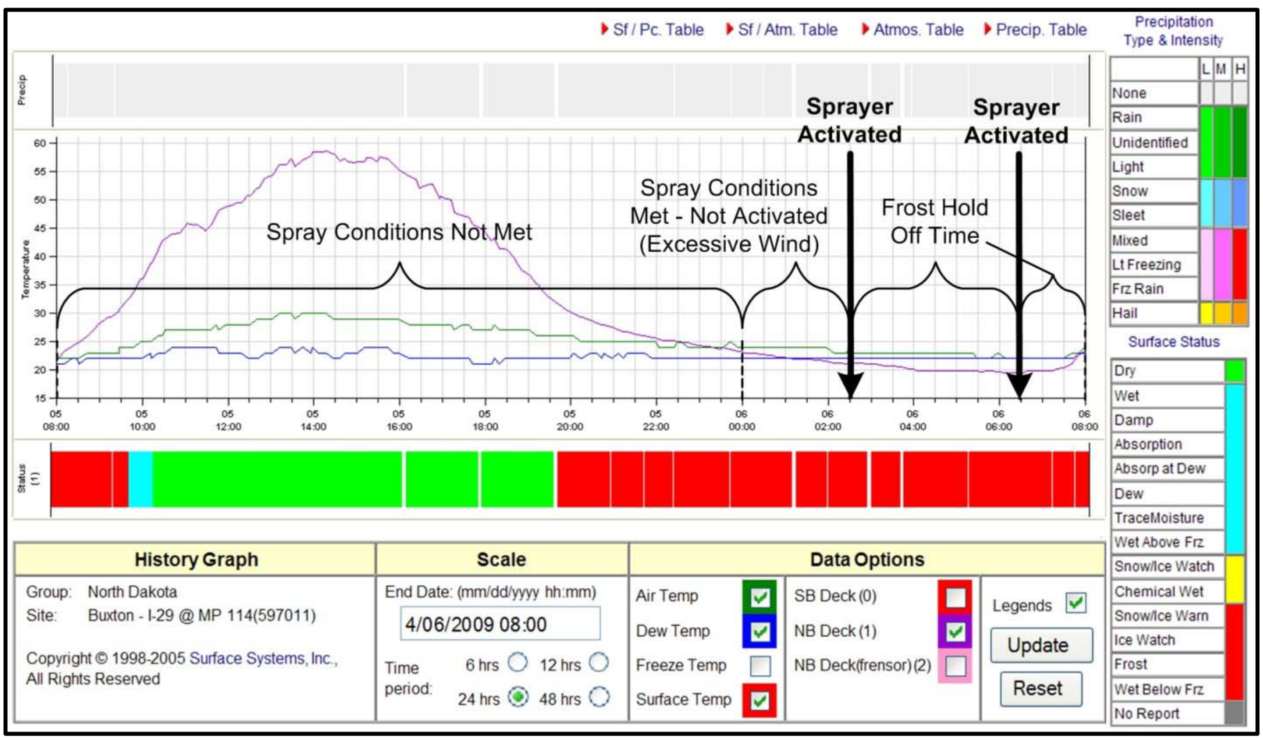

Figure 7.1 History Graph of Frost Event (Buxton Bridge: 4/5/2009 to 4/6/2009)

In addition to the history graphs, SCAN Web provides detailed information related to the environmental conditions and the system status. The timeline of events for the 24-hour period from April 5, 2009 (8:00 a.m.) to April 6, 2009 (8:00 a.m.) are shown in Table 7.1.

Table 7.1 Buxton Bridge Frost Event (8:00 a.m., 4/5/2009 to 8:00 a.m., 4/6/2009)

Date Time (CST)	Status	Atmospheric Control Conditions		
		Surface Temp	Dew Point	Wind Speed
04/05/2009 23:43	Inactive - critical conditions not detected	23.7F	21.9F	19 mph
04/05/2009 23:58	Sprayer not activated since the wind speed of 17 mph exceeds the maximum wind speed threshold of 15 mph.	23.2F	21.8F	17 mph
04/06/2009 02:28	Sprayer activated due to a frost condition. The surface temperature of 21.0F is within 1.8 or lower of the dew point of 22.3F.	21.0F	22.3F	14 mph
04/06/2009 06:28	Inactive due to frost hold off time	19.4F	21.7F	15 mph
04/06/2009 06:34	Sprayer activated due to a frost condition. The surface temperature of 19.4F is within 1.8 or lower of the dew point of 21.6F.	19.4F	21.6F	14 mph

Information was extracted from the SCAN Web data.

As noted in Table 7.1, two spray activations occurred during the analysis period. At 11:58 p.m. on April 5, 2009, the spray algorithm for frost was met (surface temperature was within 1.8 ^{o}F or less than dew point); however, the wind speed of 17 mph exceeded the threshold of 15 mph. The frost conditions were met numerous times between 11:58 p.m. and 2:28 a.m. (April 6, 2009) but the system did not spray due to the high wind speed. Finally, at 2:28 a.m. (April 6, 2009) the wind speed dropped below 15 mph, allowing the system to spray. Over the next four hours, the system was inactive due to the frost hold-off time. At 6:34 a.m. on April 6, 2009, the system sprayed again due to a frost condition.

7.2 Rain/Snow Event (Red River Bridge)

A rain/snow event occurred at the Red River Bridge from February 7, 2009 (noon), to February 13, 2009 (noon). Similar to the frost event, this event will incorporate SCAN Web data. Figure 7.2 shows the system information along with comments related to the FAST status during the 6-day period. The top horizontal bar shows the precipitation on the roadway, such as none (grey), rain (green), and snow/sleet (cyan). The bottom horizontal bar shows the surface status of the bridge deck. During this period, the surface encountered three conditions: dry (green), trace moisture/wet (cyan), and ice/frost watches and warnings (red). Plots of various data, include air temperature (green line), surface temperature (purple line), and dew point temperature (blue line) are available.

Prior to rain occurring, three frost conditions were met on February 8, 2009. The rain started at approximately midnight, which met several freeze conditions since precipitation was falling on the deck, which had a temperature near the freeze point. Precipitation (mostly rain) fell throughout February 9-10, 2009, and the FAST system did not need to spray because the surface temperature was above freezing. During the early morning of February 11, 2009, a frost and a freeze condition were met before the surface temperature rose above freezing. The surface temperature dropped below freezing during the afternoon of February 11, 2009, and several freeze sprays occurred because precipitation in the form of rain/sleet/snow created a wet/icy surface. By noon on February 12, 2009, the surface was dry and no additional sprays occurred through noon on February 13, 2009.

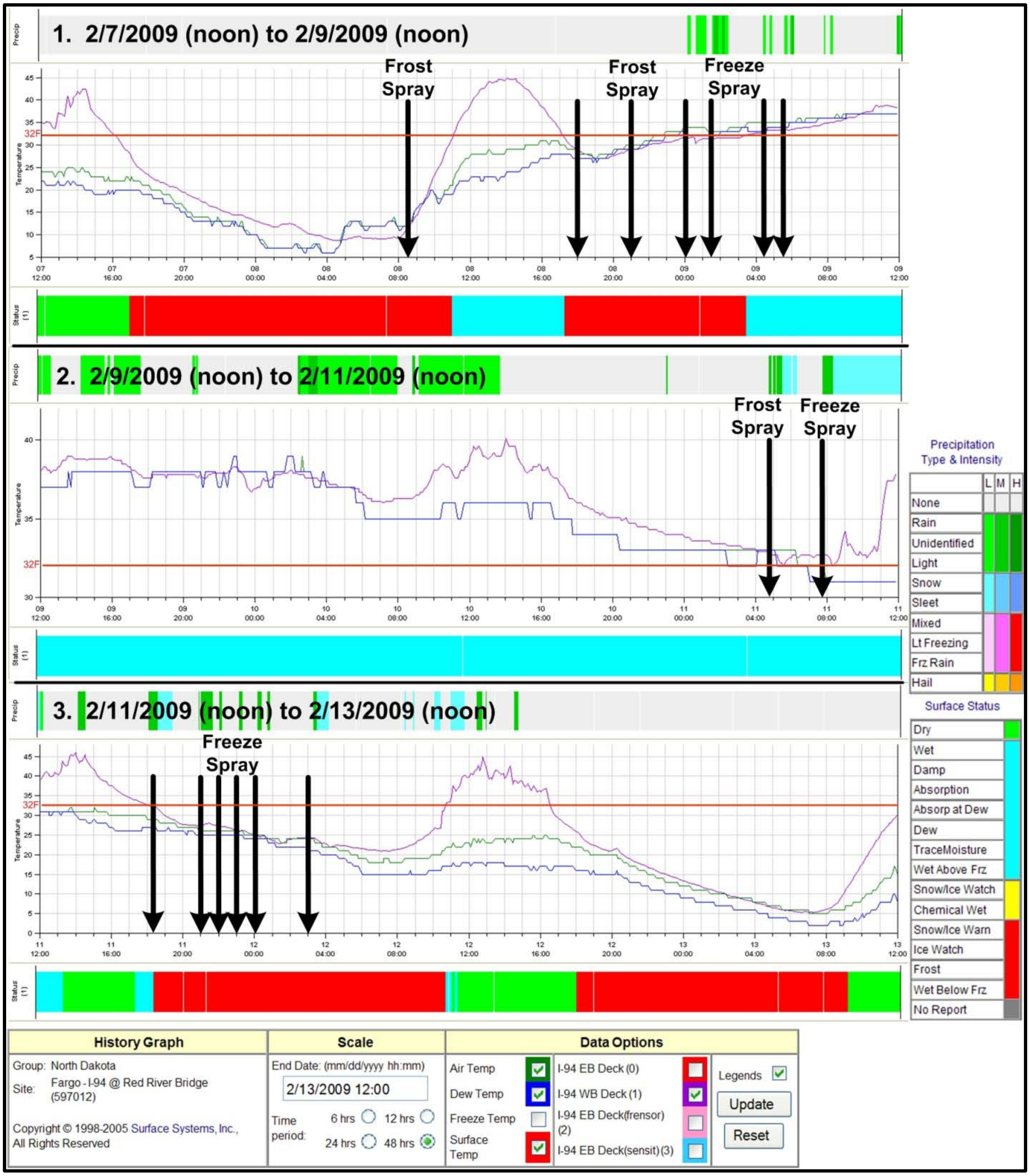

Figure 7.2 History Graph of Rain/Snow Event (Red River Bridge: 2/7/2009 to 2/13/2009)

Similar to the frost event, data related to the environmental conditions and the system status will be discussed for the rain/snow event. The timeline and significant status changes for the 6-day period from February 7, 2009 (noon), to February 13, 2009 (noon), are shown in Table 7.2.

Table 7.2 Red River Bridge Rain/Snow Event (noon, 2/7/2009 to noon, 2/13/2009)

Date Time (CST)	Status	Atmospheric Control Conditions			
		Surface Temp	Dew Point	Precip	Wind Speed
02/08/2009 08:32	Sprayer activated due to a frost condition. The surface temperature of 12.2F is within 1.8 or lower of the dew point of 12.6F.	12.2F	12.6F	None	4 mph
02/08/2009 17:53	Sprayer activated due to a frost condition. The surface temperature of 28.8F is within 1.8 or lower of the dew point of 27.1F.	28.8F	27.1F	None	6 mph
02/08/2009 21:55	Sprayer activated due to a frost condition. The surface temperature of 29.3F is within 1.8 or lower of the dew point of 30.4F.	29.3F	30.4F	None	4 mph
02/09/2009 00:07	Active due to rain and wet surface conditions	31.5F	32.4F	Rain	4 mph
02/09/2009 01:30	Active due to rain and wet surface conditions	31.3F	32.2F	Rain	Calm
02/09/2009 04:18	Active due to rain and wet surface conditions	32.5F	33.4F	Rain	5 mph
02/09/2009 05:30	Active due to rain and wet surface conditions	32.7F	34.0F	Rain	4 mph
02/11/2009 04:43	Sprayer activated due to a frost condition. The surface temperature of 32.9F is within 1.8 or lower of the dew point of 32.5F.	32.9F	32.5F	Unidentified	6 mph
02/11/2009 07:39	Active due to rain and wet surface conditions	32.7F	31.5F	Unidentified	Calm
02/11/2009 18:13	Active due to rain and wet surface conditions	32.5F	26.8F	Unidentified	6 mph
02/11/2009 21:08	Active due to rain and wet surface conditions	27.3F	25.2F	Unidentified	6 mph
02/11/2009 22:11	Active due to rain and wet surface conditions	27.1F	25.0F	Unidentified	4 mph
02/11/2009 23:16	Active due to rain and wet surface conditions	26.1F	24.6F	Unidentified	4 mph
02/12/2009 00:19	Active due to rain and wet surface conditions	24.8F	23.7F	Unidentified	5 mph
02/12/2009 03:24	Active due to rain and wet surface conditions	24.4F	20.8F	Unidentified	4 mph

Information was extracted from the SCAN Web data.

As noted from Table 7.2, 15 spray activations occurred during the rain/snow event from February 7, 2009 (noon), through February 12, 2009. On February 8, 2009, which was prior to receiving any precipitation, three frost conditions were met (8:32 a.m., 5:53 p.m., and 9:55 p.m.). The rain started to fall shortly after midnight on February 9, 2009, and 4 freeze conditions were met because the surface temperature hovered around 32 ^{o}F (12:07 a.m., 1:30 a.m., 4:18 a.m., and 5:30 a.m.). For almost two days, the FAST system did not spray since the surface temperature remained above the freeze point, which is unusual for this time of year. Prior to the morning precipitation on February 12, 2009, a frost condition was met at 4:43 a.m. From the evening of February 11, 2009 (6:13 p.m., 9:08 p.m., 10:22 p.m., and 11:16 p.m.) to the early morning of February 12, 2009 (12:19 a.m. and 3:24 a.m.), 6 freeze conditions were met due to freezing temperatures and precipitation in the form of rain/snow. By noon on February 12, 2009, the bridge deck was dry.

8. VEHICLE CRASH ANALYSIS

Since one of the main goals of a FAST system is to reduce crashes at the installation location, several years of crash data were gathered and analyzed for both NDDOT FAST installations. As previously discussed, winter weather may greatly vary from year to year. Therefore, having several years of crash data before and after the FAST system installation will provide a more accurate comparison. Crash data from the NDDOT and Mn/DOT were obtained from January 1, 1996, to May 31, 2008, which covers 12 winter seasons. It should be noted that the NDDOT is only required to keep seven years of crash data accessible. Once the data are older than seven years, they are archived into a different format which loses some of the data's attributes, such as the comments/notes section. The comments are very beneficial in identifying the cause(s) of the crash. Crash data from Mn/DOT were provided in the complete form. In addition, copies of almost all the crash reports were provided by Mn/DOT for review.

Many factors can contribute to a motor-vehicle crash, such as weather, road conditions, driving behavior, etc. Therefore, it can be difficult to distinguish and determine the exact cause(s) of the crash. In addition, the level of detail/accuracy can differ between each crash report, which is based on driver interviews, witness interviews, and highway patrol officer site observations.

In 2007, 43% of all crashes in North Dakota were speed related (*6*). Driving too fast for the road conditions is a major contributing factor of winter season crashes. Therefore, most of the crashes could be eliminated if motorists drove a speed that was appropriate for the road conditions. However, some road conditions, such as frost and black ice, may not be noticed by motorists.

The crash analyses will concentrate on determining the change in crashes at the location (segment of roadway) before and after implementing the FAST systems. It should be pointed out that crashes that occurred just prior to the bridge were included for both before and after scenarios. Although a FAST system could not reduce these crash occurrences, it is important to illustrate that bridge structures will continue to incur more crashes than a typical roadway because of their physical attributes. If a motorist lost control of their vehicle on a typical road segment, they may not hit an obstruction. However, if a motorist loses control just prior to or on a bridge, they may hit a median or guardrail.

Each FAST installation location uses slightly different methods for filtering crash data. Those methods will be discussed in the following sections. The purpose of filtering the crash data is to focus on crashes that occur during winter driving conditions and are based on normal contributing factors (unsafe speed, weather, etc.). Crashes that occurred from October 1st to April 1st were considered to be typical winter crashes. In addition, crashes that occurred outside these dates were included when road conditions were ice or snow covered. Contributing factors, such as vehicles that have collisions with deer/debris, catch on fire, and experience tire failure, were removed from the analysis because their occurrence may happen with or without a FAST system.

8.1 Buxton Bridge Crashes

The Buxton Bridge is located at mile post 114.0 of I-29. To insure that all bridge location crashes were obtained, crash data between mile posts 113.5 to 114.5 were initially analyzed. From January 1996 to May 2008, 115 crashes occurred within this mile section of I-29. Approximately 53% of the total crashes were removed from the analysis, resulting in 54 crashes during 12 winter seasons (note Appendix A).

Thirty-nine crashes occurred near the Buxton Bridge between October 1996 through December 2002 (6.5 winter seasons), which represents the before-FAST system scenario. Crashes per winter season ranged from 1 (2001) to 9 (1996 and 1998), as shown in Figure 8.1. It should be pointed out that a winter season will be named for the year in which it started (e.g., winter of 2002 includes the fall of 2002 through the spring of 2003). Of the 6 crashes that occurred in the winter of 2002, 4 occurred prior to the FAST installation. Fourteen crashes occurred near the bridge between January 2003 and May 2008 (5.5 winter seasons).

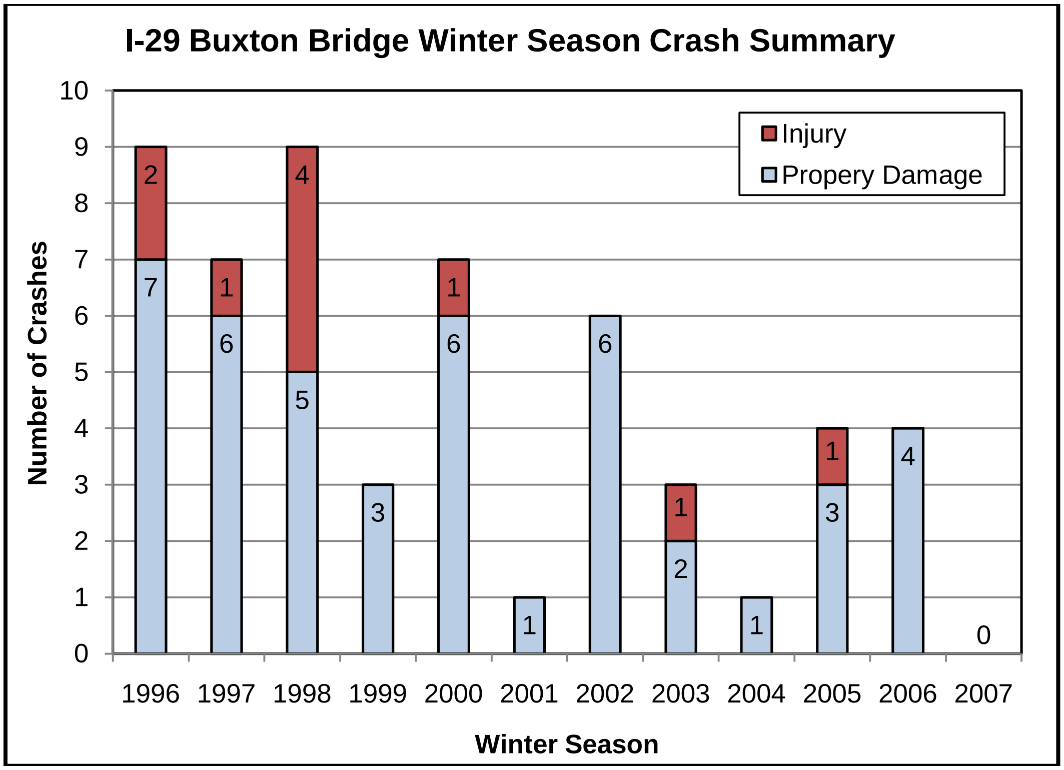

Figure 8.1 Winter Season Crash Summary for I-29 Buxton Bridge

Based on the before and after crash data, the FAST system provided a significant reduction in crashes. Prior to installing the FAST system, 6.2 total crashes per winter season occurred near the Buxton Bridge compared to 2.5 total crashes per winter season after installation, resulting in a total crash reduction of 59% (Table 8.1). Crashes involving only property damage were reduced by 54% while injury related crashes were reduced by 70%.

Table 8.1 I-29 Buxton Bridge Crash Data

Crash Scenario	Winter Seasons	Total Crashes	Avg. Total Crashes	Avg. Property Damage Crashes	Avg. Injury Crashes
Before FAST	6.5	40	6.2	4.8	1.2
After FAST	5.5	14	2.5	2.2	0.4
Change in Crashes with FAST System			**-59%**	**-54%**	**-70%**

Because the crash comparison covers several years, the crash rates were normalized using AADT. The AADT just south of the Buxton Bridge was 8,000 vehicles in 1996, which increased to 11,325 vehicles in 2007. This is an increase of 42%, which averages 3.8% per year. The average AADT for the before and after scenarios were 9,293 and 11,177 vehicles, respectively (Table 8.2). When the crashes were factored for AADT, implementing the FAST system provided a total crash reduction of 66%. Crashes related to property damage were reduced by 62% and injury related crashes were reduced by 75%.

Table 8.2 I-29 Buxton Bridge Crash Data Normalized for AADT

Crash Scenario	Avg. AADT/Crash Scenario	Avg. Annual Traffic Volume	Total Crashes/Annual Volume x 10^6	Property Crashes/Annual Volume x 10^6	Injury Crashes/Annual Volume x 10^6
Before FAST	9,293	3,391,965	1.81	1.41	0.36
After FAST	11,177	4,079,686	0.62	0.53	0.09
Change in Crashes with FAST System			**-66%**	**-62%**	**-75%**

8.2 Red River Bridge Crashes

The crash analysis for the Red River Bridge was more challenging due to the proximity to other transportation facilities (e.g., underpasses, on/off ramps, and weaving sections) and because it involved two states. The center of the Red River Bridge is located at mile post 352.454 on the North Dakota side and 0.000 on the Minnesota side. Because crash data are recorded and stored differently for each state, the crash analyses for the Red River Bridge will be separated by state.

8.2.1 Red River Bridge Crashes – North Dakota

To ensure that all Red River Bridge location crashes were obtained, crash data from mile post 352.000 to 352. 454 were analyzed. From January 1996 to May 2008, 136 crashes occurred within this approximate half-mile section of I-94. Approximately 51% of the total crashes were removed from the analysis, resulting in 66 crashes during 12 winter seasons (note Appendix A).

Fifty-eight crashes occurred near the Red River Bridge between October 1996 through December 2005 (9.5 winter seasons), which represents the before-FAST system scenario. Crashes per winter season ranged from 1 (2004) to 11 (1996 and 1998), as shown in Figure 8.2. Of the 6 crashes that occurred in the winter of 2005, 4 occurred prior to the FAST installation. Eight crashes occurred near the bridge from January 2006 through May 2008 (2.5 winter seasons).

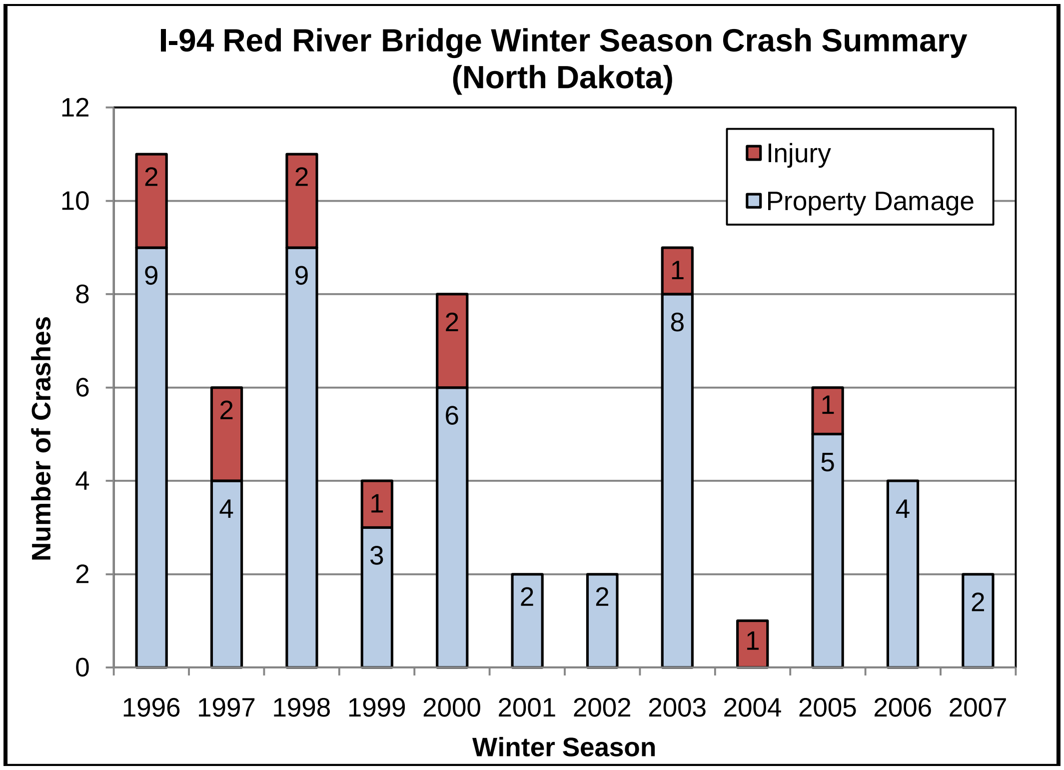

Figure 8.2 Winter Season Crash Summary for I-94 Red River Bridge – North Dakota

The FAST system installation provided reductions in both property damage and injury crashes. Before implementing the FAST system, an average of 6.1 total crashes per winter season occurred near the Red River Bridge compared to 3.2 total cashes per winter season after the FAST installation, resulting in a total crash reduction of 48% (Table 8.3). Crashes involving property damage were reduced by 34% while injury related crashes were eliminated.

Table 8.3 Red River Bridge Crash Data - North Dakota

Crash Scenario	Winter Seasons	Total Crashes	Avg. Total Crashes	Avg. Property Damage Crashes	Avg. Injury Crashes
Before FAST	9.5	58	6.1	4.8	1.3
After FAST	2.5	8	3.2	3.2	0.0
Change in Crashes with FAST System			**-48%**	**-34%**	**-100%**

To account for increased traffic volume at the analysis area, the crash data were normalized for AADT. The AADT at the Red River Bridge was 48,388 vehicles in 1997, which increased to 63,050 vehicles in 2007. This is an increase of 30%, which averages 2.8% per year. The average AADT for the before and after scenarios were 53,520 and 62,317 vehicles, respectively (Table 8.4). When the crashes were factored for AADT, implementing the FAST system reduced total crashes and property damage crashes by 55% and 43%, respectively.

Table 8.4 Red River Bridge Crash Data Normalized for AADT – North Dakota

Crash Scenario	Avg. AADT/Crash Scenario	Avg. Annual Traffic Volume	Total Crashes/Annual Volume x 10^6	Property Crashes/Annual Volume x 10^6	Injury Crashes/Annual Volume x 10^6
Before FAST	53,520	19,534,800	0.31	0.25	0.06
After FAST	62,317	22,745,705	0.14	0.14	0.00
Change in Crashes with FAST System			**-55%**	**-43%**	**-100%**

8.2.2 Red River Bridge Crashes – Minnesota

The crash analysis on the Minnesota side of the Red River focused on a shorter segment of roadway because of the close proximity of the I-94 and 8th St. Interchange. The initial crash data analyzed approximately 1,500 ft. of I-94 (mile post 0.000 to 0.300). Initially, it was determined that 141 crashes occurred along this section of I-94. However, 20 crashes were removed since they occurred on another roadway (e.g., roads near or under I-94) or in a different city. The issue of originally having crashes from different cities relates to the fact that a default mile post of 0.000 is entered for the roadway if no mile post was provided by a patrol officer. Of the remaining 121 crashes, approximately 55% of the total crashes were removed from the analysis by reviewing the crash reports, resulting in 66 crashes over 12 winter seasons (note Appendix A). Four crash reports were not available but the provided data did not give any reason for removing them from the analysis. In addition, 64 crashes were identified to be definitely (37) or probably (27) related to the Red River Bridge location.

Fifty-four crashes occurred near the Red River Bridge between October 1996 through December 2005 (9.5 winter seasons), which represents the before-FAST system scenario. Crashes per winter season ranged from 2 (1997) to 13 (2005), as shown in Figure 8.3. Of the 13 crashes that occurred in the winter of 2005, 12 occurred prior to the FAST installation. Twelve crashes occurred near the bridge between January 2006 through May 2008 (2.5 winter seasons).

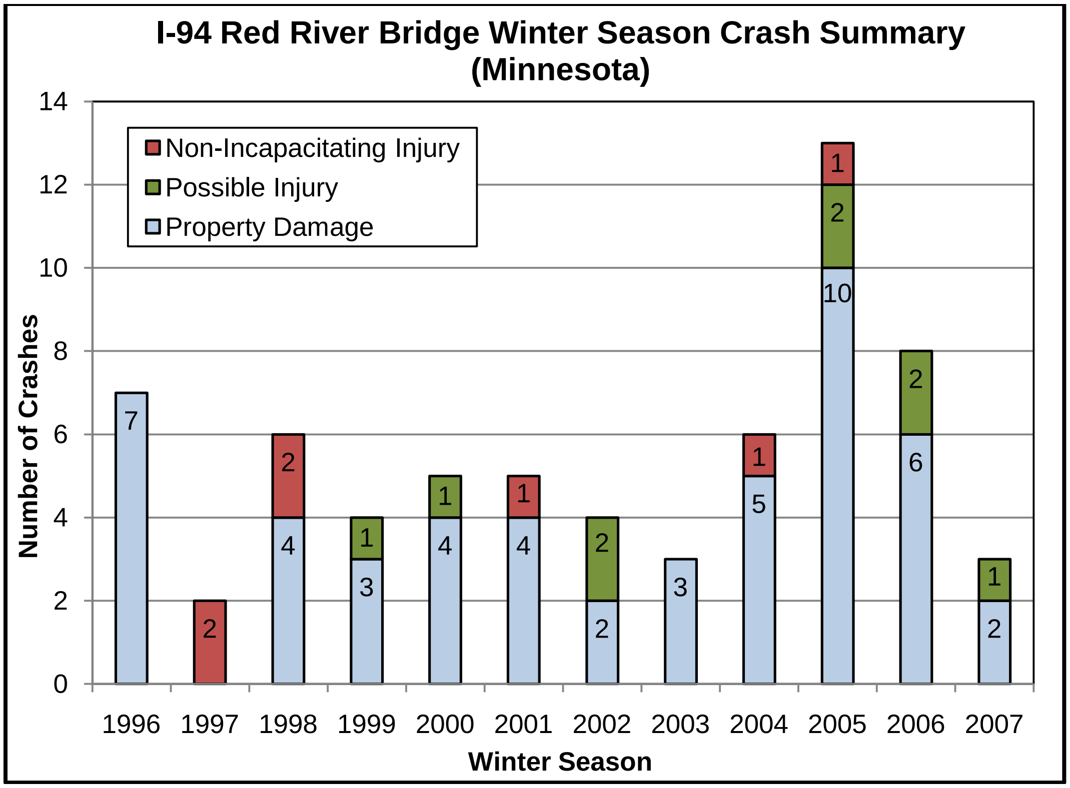

Figure 8.3 Winter Season Crash Summary for I-94 Red River Bridge – Minnesota

On October 11, 2007, the FAST system on the North Dakota side of the river failed to spray due to an issue with a pump. Since this was the first spray request of the winter season, the problem was not evident until that time. The pump issue was resolved and will be discussed in the Lessons Learned section of this report. Unfortunately, three crashes occurred on the eastbound direction of the Red River Bridge, which included 2 property damage crashes (involving 9 vehicles) and 1 possible injury crash (involving 1 vehicle). Since the failure to spray was primarily based on operating procedures that have been addressed, these crashes were not included in the after-FAST system scenario.

The FAST system implementation generally provided reductions in all types of crashes. Prior to implementing the FAST system, an average of 5.7 total crashes per year occurred near the Red River Bridge compared to 3.6 total cashes per year, resulting in a crash reduction of 37% (Table 8.5). Crashes involving property damage and those classified as non-incapacitating injury were reduced by 46% and 37%, respectively. Possible injury crashes increased 27% after the FAST system was installed.

Table 8.5 River Bridge Crash Data - Minnesota Side

Crash Scenario	Winter Seasons	Total Crashes	Avg. Total Crashes	Avg. Property Damage Crashes	Avg. Possible Injury Crashes	Avg. Non-Incapacitating Injury Crashes
Before FAST	9.5	51	5.7	4.4	0.6	0.6
After FAST	2.5	9*	3.6	2.4	0.8	0.4
Change in Crashes with FAST System			**-37%**	**-46%**	**27%**	**-37%**

* Removed 2 property damage and 1 possible injury crashes

When normalizing for traffic volume, the benefits of the FAST system are increased. When the crashes were factored for AADT, implementing the FAST system reduced total, property damage, and non-incapacitating crashes by 46%, 53%, and 46%, respectively (Table 8.6).

Table 8.6 Red River Bridge Crash Data Normalized for AADT – Minnesota

Crash Scenario	Avg. AADT/Crash Scenario	Avg. Annual Traffic Volume	Total Crashes/ Volume x 10^6	Property Damage/ Volume x 10^6	Possible Injury/ Volume x 10^6	Non-Capacitating Injury/ Volume x 10^6
Before FAST	53,520	19,534,800	0.29	0.23	0.032	0.032
After FAST	62,317	22,745,705	0.16	0.11	0.035	0.018
Change in Crashes with FAST System			**-46%**	**-53%**	**9%**	**-46%**

8.2.3 Red River Bridge Crashes – North Dakota and Minnesota

When combining the total crashes on both sides of the Red River, 112 crashes occurred prior to the FAST system (9.5 winter seasons) and 17 occurred after the FAST system (2.5 winter seasons). The total crashes near the Red River Bridge were reduced by 42% (Table 8.7). When the crash rates were normalized using AADT, total crashes were reduced by 50%.

Table 8.7 Red River Bridge Total Crash Data – North Dakota and Minnesota

Crash Scenario	Avg. AADT/Crash Scenario	Avg. Annual Traffic Volume	Avg. Total Crashes/Year	Total Crashes/Annual Volume x 10^6
Before FAST	53,520	19,534,800	11.79	0.60
After FAST	62,317	22,745,705	6.80*	0.30
Change in Crashes with FAST System			**-42%**	**-50%**

* Removed 2 property damage and 1 possible injury crashes

9. BENEFITS/COST OF FAST SYSTEMS

Fixed automated spray technology systems are intended to provide several qualitative and quantitative benefits for both motorists and transportation departments. These systems can provide safer travel conditions by improving road surface conditions, which reduces crash occurrences. In addition, motorists can receive traveler information by observing the ESS camera images and sensor data through SCAN Web.

Transportation agencies can experience reductions in maintenance costs by using less staff, equipment, and material (sand, salt, etc.). Because bridges can develop frost and ice before other road sections, they often receive extra attention from maintenance staff. Since frost typically develops late at night or early in the morning, which is outside of normal working hours, FAST systems reduce staff overtime, truck costs, and material/chemical costs.

The main quantitative benefit of FAST systems relates to reductions in societal costs from crash occurrences. Societal costs include the loss of life and quality of life, loss of productivity, legal costs, and property damage costs. The crash analyses in this section will be based on crash-vehicles (the number of vehicles involved in each crash category) and factored for AADT.

The FHWA has provided technical advisories related to the comprehensive costs for motor-vehicle crashes. The most recent update to the technical advisory occurred in 1994 (*7*). To account for inflation, the document recommends using the Gross Domestic Product (GDP) implicit price deflator, which is issued by the Office of the Secretary of Transportation (OST). The cost values (2008 dollars) for the five crash severities are as follows: $3,522,229 for a fatality, $243,847 for an incapacitating injury, $48,769 for an evident injury, $25,739 for a possible injury, and $2,709 for a property-damage-only crash. Because the NDDOT does not separate incapacitating and evident (non-incapacitating) injuries, the injury crashes were considered to be non-incapacitating.

The main costs of FAST systems include initial implementation, anti-icing chemicals, and annual maintenance. Manual application costs include the cost of the operator, truck, and chemical/material (GEOMELT or sand/salt). If treatment occurs after normal hours of operation, overtime pay is required. The cost analyses for manual and automated treatment methods will be based on the spray applications for the winter of 2007. The actual cost savings of reduced manual treatments is difficult to determine since maintenance staff also would be treating other road surfaces, especially during freeze conditions. However, manual treatments for frost and freeze conditions that occur outside of normal hours of operation will be considered as a quantitative benefit of the FAST system. The labor costs for these treatments would include overtime and have a three-hour minimum. The following sections will discuss the benefit-cost analyses for the two ND FAST installations.

9.1 Buxton Bridge FAST System – Benefit-Cost Analysis

The following sections will provide data related to the benefits and costs of the Buxton Bridge FAST System. This analysis will focus on critical quantitative data and a detailed benefit/cost worksheet is located in Appendix B.

9.1.1 Buxton Bridge – FAST Benefits

The Buxton Bridge has experienced crash-vehicle reductions of 72% since the FAST system has been installed (Table 9.1). The average annual crash-vehicles before and after installing the FAST system were 7.5 and 2.1, respectively. Therefore, total crash-vehicle reductions were 5.4 vehicles annually (4.0

for property damage and 1.4 for injury crashes). Using the crash cost information provided by the FHWA, the crash reductions result in annual safety benefits of $78,735.

Table 9.1 Buxton Bridge Crash-Vehicle Data (Factored for AADT)

Crash Scenario	Winter Seasons	Total Vehicles	Avg. Crash-Vehicles	Avg. Property Damage Crash – Vehicles	Avg. Injury Crash – Vehicles
Before FAST	6.5	49	7.5	5.8	1.7
After FAST	5.5	12	2.1	1.8	0.3
Change in Crash-Vehicles w/ FAST			**-72%**	**-69%**	**-82%**

Note: Unfactored After FAST data: Total Veh. = 14, Avg. Veh. = 2.5, Avg. PD Veh. = 2.2, Avg. Injury Veh. = .4

The Buxton Bridge FAST system has reduced manual maintenance costs for the NDDOT. Although manual treatments at the bridge are not eliminated, the frequency and amount of chemical treatment is reduced by the automated system. The bridge is located approximately 10 miles from the Hillsboro, ND, maintenance shop. During frost and freeze conditions prior to the FAST system, maintenance staff would treat the bridge often because the structure was a high crash location.

To provide the same level of frost and freeze prevention as a FAST system, the NDDOT would have to treat the bridge after normal hours of operation. According to the SCAN Web data for the winter of 2007, the FAST system sprayed 99 times for frost and 110 times for freeze conditions. Seventy-nine percent of frost treatments occurred outside of normal operations, while 74% of the freeze treatments occurred outside of normal operations (Table 9.2). To account for the time needed for traveling to and from the bridge structure, normal manual treatment hours were 30 minutes after normal starting time and 30 minutes before normal ending time, which equates to 7:30 a.m. to 3:00 p.m. The FAST system could provide annual cost savings in manual treatments of $31,860, which would consist of staff overtime, truck, and material/chemical costs

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Table 9.2 Winter 2007 Spray Occurrences by Condition (Buxton Bridge)

Spray Condition	Sprays During Normal Hours	Sprays Outside of Normal Hours
Frost	21%	79%
Freeze	26%	74%

Normal hours of conducting manual applications were 7:30 a.m. to 3:00 p.m.

9.1.2 Buxton Bridge – FAST Costs

The initial cost of the Buxton Bridge FAST system was $168,531 (not including the ESS that was previously installed). Annual utility costs averaged $1,162 per year for the winters of 2006 and 2007 ($789 during winter months and $373 during summer months). The utility costs primarily consist of power consumption. Estimated annual maintenance costs are less than $1,000, which includes filling, removing, and cleaning the storage tank at the pump house. As with any system, components/equipment will need to be replaced at various intervals. To account for replacing pumps and other equipment, the cost analysis will include $5,000 in expenditures every 7 years.

Costs of anti-icing agent vary depending on the winter season. A detailed analysis of spray activations was performed to determine the frequency and purpose of a spray event during the winter of 2007. The system sprayed at least once on 102 days having 210 automatic sprays (Table 9.3). Six spray commands were issued that did not spray due to communication problems between the ESS RPU and the FreezeFree RPU.

Table 9.3 Winter 2007 Buxton Bridge FAST Applications

Spray Application Event	**Frequency**
Days with Spray Applications	102
Days with Frost and Freeze Conditions	24
Total Sprays	210
Manual Sprays	1
Failed Sprays	6

During the winter season, 64 days met frost conditions, 62 days met freeze conditions, and 24 days met both frost and freeze conditions (Table 9.4).To chemically treat for a frost condition, the system sprayed an average of 1.5 times per day. Spray applications of 1, 2, and 3 or more were required to treat for frost 59%, 28%, and 13% of the time, respectively.

Freeze conditions required slightly more spray applications. On average, freeze conditions required 1.8 sprays per day. Spray applications of 1, 2, and 3 or more were required to treat for freezing conditions 56%, 23%, and 21% of the time, respectively (Table 9.4).

Table 9.4 Winter 2007 Buxton Bridge FAST Application by Condition

Spray Condition	**Number of Days**	**Total Sprays**	**Avg. Sprays/Day**	**Number of Sprays/Day**				
				1	**2**	**3**	**4**	**5**
Frost	64	99	1.5	38 (59%)	18 (28%)	7 (11%)	1 (2%)	-
Freeze	62	110	1.8	35 (56%)	14 (23%)	6 (10%)	6 (10%)	1 (2%)

Since the Buxton Bridge FAST system sprays approximately 5.5 gallons of CF7 per spray, approximately 1,155 gallons of chemical agent were used for the winter 2007 season. Using a product cost of $8.20 per gallon (which was the 2008 price), the total cost of CF7 would be $9,471.

9.1.3 Buxton Bridge – Benefit/Costs

A benefit-cost analysis was performed using the initial cost of the system, annual maintenance and operating costs, and annual savings in terms of reductions in crashes and manual treatments. A summary of the system benefits and costs are shown below (note Appendix B for more detailed information):

System Costs

- Installation: $168,531 (2002 Dollars)
- Maintenance: $1,000/year (plus pump replacements of $5,000 at year 7 and 14)
- Utilities: $1,162/year
- Chemical: $9,471/year (1,155 gallons)

System Benefits

- Crash reduction: $78,735/year (1.39 non-incapacitating injuries and 1.81 property damage crashes)
- Manual treatment reduction: $31,860/year (78 frost treatments and 81 freeze treatments)

Benefit-Cost Ratio

- 4.3 (net benefits of $1,257,869)

Using a 20-year design life, the benefit-cost ratio of the system was 4.3. In addition, the net benefits (present worth benefits minus present worth costs) was $1,257,869. The major reasons for the high benefit-cost ratio relates to the low installation costs and significant crash reductions. Due to the lower installation costs of the system, the cost of the chemical agent has a large impact on the benefit-cost analysis. Average CF7 costs over the 20-year analysis period of $4.10 per gallon (50% of the 2008 price) and $12.30 per gallon (50% higher than the 2008 price) would equate to benefit-cost ratios of 5.3 and 3.6, respectively.

9.2 Red River Bridge FAST System – Benefit-Cost Analysis

The following sections will provide data related to the benefits and costs of the Red River Bridge FAST system. This analysis will focus on critical quantitative data and the detailed benefit/cost worksheet is located in Appendix C.

9.2.1 Red River Bridge – FAST Benefits

The Red River Bridge has experienced crash-vehicle reductions of 46% since installing the FAST systems (Table 9.5). The average annual crash-vehicles before and after installing the FAST system were 17.7 and 9.6, respectively. Therefore, total crash-vehicles were reduced by 8.1 vehicles annually (4.4 for property damage, 2.4 for non-incapacitating injury, and 1.3 possible injury crashes). Using the crash cost information provided by the FHWA, the crash reductions result in annual safety benefits of $162,578.

Table 9.5 Red River Bridge Crash-Vehicle Data (Factored for AADT)

Crash Scenario	Winter Seasons	Total Vehicles	Avg. Crash-Vehicles	Avg. Property Damage Crash - Vehicles	Avg. Non-Incapacitating Injury Crash - Vehicles	Avg. Possible Injury Crash - Vehicles
Before FAST	9.5	168	17.7	12.9	2.7	2.0
After FAST	2.5	24	9.6	8.6	0.3	0.7
Change in Crash-Vehicles w/ FAST			**-46%**	**-34%**	**-87%**	**-66%**

Note: Unfactored After FAST data: Total Veh. = 28, Avg. Veh. = 11.2, Avg. PD Veh. = 10.0, Avg. Non-Incap. Injury Veh. = .4, Avg. Poss. Injury = .8

Similar to the Buxton Bridge, the Red River Bridge FAST system reduces manual maintenance costs for the NDDOT (Fargo District) by reducing the frequency and amount of chemical treatment. During frost and freeze conditions prior to the installation of the FAST system, maintenance staff would treat the bridge often since the structure was a high crash location and served a significant amount of traffic.

To provide the same level of frost and freeze prevention, the NDDOT would have to treat the bridge after normal hours of operation. According to the SCAN Web data for the winter of 2007, the FAST system sprayed 127 times for frost and 88 times for freeze conditions. Eighty percent of frost treatments occurred outside of normal operations, while 60% of the freeze treatments occurred outside of normal operations (Table 9.6). Using the same methodology as the Buxton Bridge FAST system, the Red River Bridge FAST system could provide cost savings in manual treatments of $48,983 (because Mn/DOT data were not available, the NDDOT cost data were taken times two).

Table 9.6 Winter 2007 Spray Occurrences by Condition (Red River Bridge)

Spray Condition	Sprays During Normal Hours	Sprays Outside of Normal Hours
Frost	20%	80%
Freeze	40%	60%

Normal hours of conducting manual applications were 7:30 a.m. to 3:00 p.m.

Because the Red River Bridge is one of the highest traffic volume locations in ND, a user cost analysis was performed to quantify delay time due to crash occurrences. Although field data is not available during incident and non-incident conditions (except for hourly volume), a simulation analysis was performed to estimate the crash impacts. A CORSIM network was constructed to simulate an eastbound incident during the afternoon peak hour. The incident blocked 1 of the 3 travel lanes for 30 minutes, which is a conservative incident severity and duration. A rubbernecking factor of 20% was used for the remaining two travel lanes (no reduction in capacity occurred for the westbound traffic). Based on the simulation analysis, the incident creates 52 vehicle-hours of delay time. Using a passenger vehicle cost of $12.50 (95% of traffic) and truck cost of $25.00 (5% of traffic), a crash costs motorists approximately $700 in delay time. With an annual crash reduction of 5.9, annual delay time costs would equal $4,060.

9.2.2 Red River Bridge – FAST Costs

The initial cost of the Red River Bridge FAST system was approximately $1.32 million (not including the NDDOT ESS which was previously installed). Annual utility costs averaged $1,478 per year for the winters of 2006 and 2007 ($1,341 during winter months and $136 during summer months). The utility costs primarily consist of power consumption. Estimated annual maintenance costs are less than $1,000, which includes filling, removing, and cleaning the storage tank at the pump house. To account for replacing pumps and other equipment, the cost analysis will include $5,000 in expenditures every 7 years.

To account for the cost of both FAST systems, the NDDOT maintenance cost data were multiplied by two.

During the winter of 2007, the system sprayed at least once on 67 days having 269 automatic sprays (Table 9.7). Eight spray commands were issued that did not spray due to communication problems between the ESS RPU and the FreezeFree RPU.

Table 9.7 Winter 2007 Red River Bridge FAST Applications

Spray Application Event	Frequency
Days with Spray Applications	67
Days with Frost and Freeze Conditions	23
Days with Frost and Precipitation Conditions	9
Days with Freeze and Precipitation Conditions	11
Days with Frost, Freeze and Precipitation Conditions	7
Total Sprays	269
Manual Sprays	4
Failed Sprays	8

During the winter season, 64 days met frost conditions, 38 days met freeze conditions, and 15 days met precipitation conditions (Table 9.8). To chemically treat for a frost condition, the system sprayed an average of 2.0 times per day. Spray applications of 1, 2, and 3 or more were required to treat for frost 38%, 39%, and 23% of the time, respectively.

Freeze conditions required slightly more spray applications. On average, freeze conditions required 2.3 sprays per day. Spray applications of 1, 2, and 3 or more were required to treat for freezing conditions 50%, 16%, and 34% of the time, respectively (Table 9.8).

Precipitation conditions required an average of 3.3 sprays per day. Spray applications of 1, 2, and 3 or more were required to treat for precipitation 47%, 27%, and 26% of the time, respectively (Table 9.8).

Table 9.8 Winter 2007 Buxton Bridge FAST Application by Condition

Spray Condition	Number of Days	Total Sprays	Avg. Sprays/ Day	Number of Sprays / Day									
				1	2	3	4	5	6	7	8	9	10
Frost	64	127	2.0	24 (38%)	25 (39%)	10 (16%)	2 (3%)	3 (5%)	-	-	-	-	-
Freeze	38	88	2.3	19 (50%)	6 (16%)	4 (11%)	5 (13%)	2 (5%)	-	1 (3%)	1 (3%)	-	-
Precipitation	15	50	3.3	7 (47%)	4 (27%)	-	-	-	-	-	2 (13%)	1 (7%)	1 (7%)

Since the Red River Bridge FAST system sprays approximately 12.6 gallons of CF7 per spray, approximately 8,135 gallons of chemical agent were used for the 2007 winter season (3,390 gallons by NDDOT and 4,745 gallons by Mn/DOT – estimated). Using a product cost of $8.20 per gallon (which was the 2008 price), the total cost of CF7 would be $66,703.

9.2.3 Red River Bridge FAST – Benefit/Costs

A benefit-cost analysis was performed using the initial cost of the system, annual maintenance and operating costs, and annual savings in terms of reductions in crashes and manual treatments. A summary of the system benefits and costs are shown below (note Appendix C for more detailed information):

System Costs

- Installation: $1,320,000 (2005 Dollars)
- Maintenance: $2,000/year (plus pump replacements of $5,000 at year 7 and 14)
- Utilities: $2,955/year
- Chemical: $66,703/year (8,135 gallons)

  Note: Maintenance and utility costs for the Mn/DOT system were estimated using NDDOT costs. Chemical usage for Mn/DOT system was estimated using NDDOT usage and number of spray nozzles.

System Benefits

- Crash reduction: $162,578/year (2.40 non-incapacitating injuries, 1.31 possible injuries, and 4.36 property damage crashes)
- Manual treatment reduction: $48,983/year (102 frost treatments and 53 freeze treatments)
- Traffic congestion savings: $4,060/year

Benefit-Cost Ratio

- 1.3 (net benefits of $675,184)

Using a 20-year design life, the benefit-cost ratio of the system was 1.3. In addition, the net benefits (present worth benefits minus present worth costs) was $675,184. The lower benefit-cost ratio of the Red River Bridge FAST system, when compared to the Buxton Bridge FAST system, is a result of the significantly higher installation cost. The higher installation cost causes the chemical agent costs to have a smaller impact on the benefit-cost analysis. Average CF7 costs over the 20 year analysis period of $4.10 per gallon (50% of the 2008 price) and $12.30 per gallon (50% increase of the 2008 price) would equate to benefit-cost ratios of 1.6 and 1.1, respectively.

10. LESSONS LEARNED

Several factors are required for a successful FAST system, such as performing proper system design and construction, receiving adequate training on the system, and allocating sufficient staff time for operating and maintaining the system. NDDOT staff performed significant research on FAST systems prior to the Buxton Bridge installation to ensure that the system would provide the proper components, functions, and capabilities. In addition, knowledge from this system was beneficial for the Red River Bridge FAST installation.

Training is very important to understand the proper operating and maintenance procedures. Energy Absorption Systems, Inc. performed the FAST training for both systems. NDDOT staff stated that vendor support was very good and that it was used often during the first year of using the systems.

Several lessons were learned during the Buxton Bridge and Red river Bridge FAST designs and implementations. Some of these lessons/suggestions include but are not limited to the following:

- A dual closed-loop system should be implemented (when possible) to isolate and bypass malfunctioning spray nozzles
- A fiberglass walkway should be used in the pump house (metal will corrode)
- Stainless steel piping should be used throughout the system (reduce corrosion)
- A low liquid warning light should be installed outside of the pump house
- Additional filters should be included to better protect equipment
- Active sensors should be used in addition to passive sensors (the first system initially only had a passive sensor)
- Sensors should be installed in different lanes from the spray pucks (weeping from the puck may occur, which will adversely affect system performance by spraying unnecessarily)
- Composite valve control boxes should be used (painted metal will corrode)
- New bridges should have plumbing in deck rather than anchored to the bridge deck (less environmental issues and easier to maintain)
- A valve should be installed after the water tank's supply line and the sprayer pump to avoid losing the pump's prime (discussed below)

As previously mentioned in the Vehicle Crash Analysis section, an issue with the Red River Bridge FAST System occurred in October 2007, which prevented the system from spraying during a frost condition. After the first summer season concluded with the FAST system, NDDOT personnel pumped out the water from the tank in the pump house, which was used for summer maintenance sprays. Next, NDDOT personnel opened the valve to allow CF7 chemical to supply the main pump. Unknown to NDDOT personnel, an air void developed in the line to the main pump when the water was removed from the tank. When the first frost condition occurred on October 11, 2007, the system did not spray. Because this was the NDDOT's first spray failure, it took some time to troubleshoot the event. Unfortunately, before the issue was resolved, which required the air to be removed from the main supply line, three crashes occurred. Future installations can incorporate a valve to prohibit air from entering the system.

11. SUMMARY AND CONCLUSIONS

This study provided a variety of information related to FAST systems, such as a description of systems, the NDDOT – Fargo District's experiences and perspectives, and benefit-cost information for NDDOT's two systems. This information will assist the NDDOT in evaluating future FAST systems within North Dakota.

The NDDOT – Fargo District has had experience with FAST systems since 2002. The Fargo District believes the two FAST systems are very effective in treating the bridge structures, especially for frost conditions. Both systems have operated as expected in terms of spraying at the appropriate time and applying the proper amount of chemical agent. The district estimates that both systems are at least 95% reliable. Although the number of treatment sprays will vary each winter season, the two existing FAST systems had a high level of use during the winter of 2007. The Buxton Bridge FAST system sprayed 210 times over 102 days, while the Red River Bridge FAST system sprayed 269 times over 67 days.

Although the two FAST systems work very well overall, system limitations are evident. The systems are not used when the wind is greater than 15 mph and/or when the pavement temperature drops below 12^{o}F. These limitations are similar to the guidance provided by FHWA. As with most new advanced technologies, a steep learning curve existed; therefore, vendor assistance was very important during the first winter season. The Fargo District has been very satisfied with the technical support and training provided by Energy Absorption Systems, Inc.

Significant crash reductions were observed at both locations after the FAST systems were installed. When crashes were factored for AADT, the Buxton Bridge FAST system provided a total crash reduction of 66%. Crashes related to property damage were reduced by 62% and injury related crashes were reduced by 75% (6.5 winter seasons before and 5.5 winter seasons after implementation). Prior to installing the FAST system at the Buxton Bridge, the location was continually on the high crash location list for interstate highways in North Dakota (consistently ranked in the top five). However, since the FAST system was installed, the location in no longer included in the high crash location report. The Red River Bridge also experienced crash reductions after the FAST system was installed. The combined crash reductions for the MN and ND systems observed a total crash reduction of 50% (9.5 winter seasons before and 2.5 winter seasons after implementation).

Benefit-cost analyses produced favorable results for both FAST system installations. The major benefits of the FAST systems relate to reductions in societal (resulting from vehicle crashes) and transportation agency costs (maintenance activities). The costs of FAST systems include initial implementation, anti-icing chemicals, and annual maintenance. The benefit-cost analysis of the Buxton Bridge FAST system provided a benefit-cost ratio of 4.3 with a net benefit of $1,257,869. The benefit-cost analysis of the Red River Bridge FAST system provided a benefit-cost ratio of 1.3 with a net benefit of $675,184.

The two ND FAST system installations appear to be working as intended based on feedback from NDDOT – Fargo District staff and the results from the benefit-cost analyses. Several factors contribute to these successful systems, such as selecting appropriate locations for FAST systems (primarily based on winter crash data); and having knowledgeable and dedicated staff to assist in the design and implementation of the system, monitor its operation, and perform the required maintenance procedures.

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APPENDIX A: Crash Data Buxton and Red River Bridges

I-29 Crashes, Buxton Bridge (Winter 1996 – 2008)

115	**Total Crashes (1JAN96-31MAY08, M.P 113.5 – 114.5)**
10	Summer crashes (1APR – 30SEP)
28	Distance from bridge (± .2 miles or M.P. 113.8 – 114.2)
17	Deer/debris
3	Driver error and beyond bridge
2	Fire/explosion
1	Driver error and dry surface
54	**Filtered Crashes**

* Crashes with frost, snow, or ice during non-winter months were included

I-94 Crashes, Red River Bridge – North Dakota (Winter 1996 – 2008)

136	**Total Crashes (1JAN96-31MAY08, M.P 0.000 – 0.300)**
42	Summer crashes (1APR – 30SEP)
12	Driver error and dry surface
3	Deer/debris
3	Traffic backup from 8th St. interchange (eastbound)
2	Traffic control (at 8th St. interchange)
2	Improper yield/merge
2	Fire/explosion
1	Stopped vehicle/illegally parked
1	Fell asleep
1	Snow plow fog
1	Under the influence of drugs
66	**Filtered Crashes**

* Crashes with frost, snow, or ice during non-winter months were included

I-94 Crashes, Red River Bridge – Minnesota (Winter 1996 – 2008)

141	**Total Crashes (1JAN96-31MAY08, M.P 0.000 – 0.300)**
18	Different city (default value of crash along I-94 is 0.000)
24	Summer crashes (1APR – 30SEP)
2	Wrong location (not actually on I-94)
19	Probably not at or near bridge
3	Deer/debris
3	Stopped vehicle/illegally parked
2	Failure to yield
2	Traffic control (at 8th St. interchange)
1	Tire failure
1	Under the influence of drugs
66	**Filtered Crashes**

* Crashes with frost, snow, or ice during non-winter months were included
* Crashes were within .130 miles of center of bridge except one (.263 miles)

APPENDIX B: Benefit/Cost Worksheet for Buxton Bridge Fast System

Benefit/Cost Worksheet

Safety Improvement Location: I-29 Buxton Bridge MP: 113.8 MP: 114.2

Safety Improvement Description: FAST System

Evaluator: UGPTI-ATAC Date: 3/17/2009

1. Initial Project Cost, I: $168,531 (2002)

2. Net Annual Operations and Maintenance Costs, K: $11,633 (2008)
   Maintenance:$1,000/yr (plus replace pumps - $5,000 at yr 7 and 14),
   Utilities:$1,162, Chemical Agent:$9,471 (1,155gal at $8.20/gal)

3. Annual Safety Benefits in Number of Crash-Vehicles

Collision Type	Before No.	Yrs.	- After No.	Yrs.	= Annual Benefits
a) Fatality	0.00	6.5	0.00	5.5	0.00
b) Incapacitating Injury	0.00	6.5	0.00	5.5	0.00
c) Non-incapacitating Injury	1.69	6.5	0.30	5.5	1.39
d) Possible Injury	0.00	6.5	0.00	5.5	0.00
e) Property Damage Only	5.85	6.5	1.81	5.5	4.04

4. Cost Per Crash: FHWA (T7570.2) - 1994
   Cost adjusted to 2008 using GDP deflator: 10/1/1994 = 90.952, 10/1/2008 = 123.213

5. Annual Safety Benefits by Costs of Crash

Crash Type	Cost			
a) Fatality	$3,522,229	a) (3a)(4a)	=	$0
b) Incapacitating Injury	$243,847	b) (3b)(4b)	=	$0
c) Non-incapacitating Injury	$48,769	c) (3c)(4c)	=	$67,789
d) Possible Injury	$25,739	d) (3d)(4d)	=	$0
e) Property Damage Only	$2,709	e) (3e)(4e)	=	$10,946
		f) Total Benefits	=	$78,735

6. Service Life, n = 20 7. Salvage Value, T = 0 8. Interest Rate, i = 3.04%
   CPI (1988-2008)

9. Present Worth of Costs, PWOC (2008 Dollars)
   I = $168,531(1.197) = $201,704
   K = $11,633(14.823)+$5,000(.811)+$5,000(.658) = $179,781

   PWOC = I + K - T = $381,485

10. Present Worth of Benefits, PWOB (2008 Dollars)
    Reduced Manual Treatment (Frost & Freeze) = $31,860(14.823) = $472,260
    Crash Reductions = $78,735(14.823) = $1,167,094

    PWOB = Reduced Manual Treatment + Crash Reductions = $1,639,354

11. Benefit Cost Ratio, B/C = PWOB/PWOC = 4.3

12. Net Benefit = PWOB - PWOC = $1,257,869

APPENDIX C: Benefit/Cost Worksheet for Red River Bridge Fast System

Benefit/Cost Worksheet

Safety Improvement Location:	I-94 Red River Bridge	MP:	353.0	MP:	352.454	(ND)
		MP:	0.000	MP:	0.300	(MN)

Safety Improvement Description: FAST System

Evaluator: UGPTI-ATAC Date: 3/17/2009

1. Initial Project Cost, I: $1,320,000 (2005)

2. Net Annual Operations and Maintenance Costs, K: $71,658 (2008)
   Maintenance:$2,000/yr (plus replace pumps, etc. - $5,000 at yr 7 and 14),
   Utilities:$2,955, Chemical Agent:$66,703 (8,135gal at $8.20/gal)

3. Annual Safety Benefits in Number of Crash-Vehicles

Collision Type	Before No.	Yrs.	- After No.	Yrs.	= Annual Benefits
a) Fatality	0.00	9.5	0.00	2.5	0.00
b) Incapacitating Injury	0.00	9.5	0.00	2.5	0.00
c) Non-incapacitating Injury	2.74	9.5	0.34	2.5	2.40
d) Possible Injury	2.00	9.5	0.69	2.5	1.31
e) Property Damage Only	12.95	9.5	8.59	2.5	4.36

4. Cost Per Crash: FHWA (T7570.2) - 1994
   Cost adjusted to 2008 using GDP deflator: 10/1/1994 = 90.952, 10/1/2008 = 123.213

5. Annual Safety Benefits by Costs of Crash

Crash Type	Cost			
a) Fatality	$3,522,229	a) (3a)(4a)	=	$0
b) Incapacitating Injury	$243,847	b) (3b)(4b)	=	$0
c) Non-incapacitating Injury	$48,769	c) (3c)(4c)	=	$117,046
d) Possible Injury	$25,739	d) (3d)(4d)	=	$33,719
e) Property Damage Only	$2,709	e) (3e)(4e)	=	$11,813
		f) Total Benefits	=	$162,578

6. Service Life, n = 20 7. Salvage Value, T = 0 8. Interest Rate, i = 3.04%
   CPI (1988-2008)

9. Present Worth of Costs, PWOC (2008 Dollars)
   I = $1,320,000(1.094) = $1,444,081
   K = $71,658(14.823)+$5000(2)(.811)+$5000(2)(.658) = $1,076,882

   PWOC = I + K - T = $2,520,963

10. Present Worth of Benefits, PWOB (2008 Dollars)
    Reduced Manual Treatment (Frost & Freeze) = $48,983(14.823) = $726,073
    Crash Reductions = $162,578(14.823) = $2,409,893
    Traffic Congestion Savings = $4,060(14.823) = $60,181

    PWOB = Reduced Manual Treatment + Crash Reductions = $3,196,147

11. Benefit Cost Ratio, B/C = PWOB/PWOC = 1.3

12. Net Benefit = PWOB - PWOC = $675,184