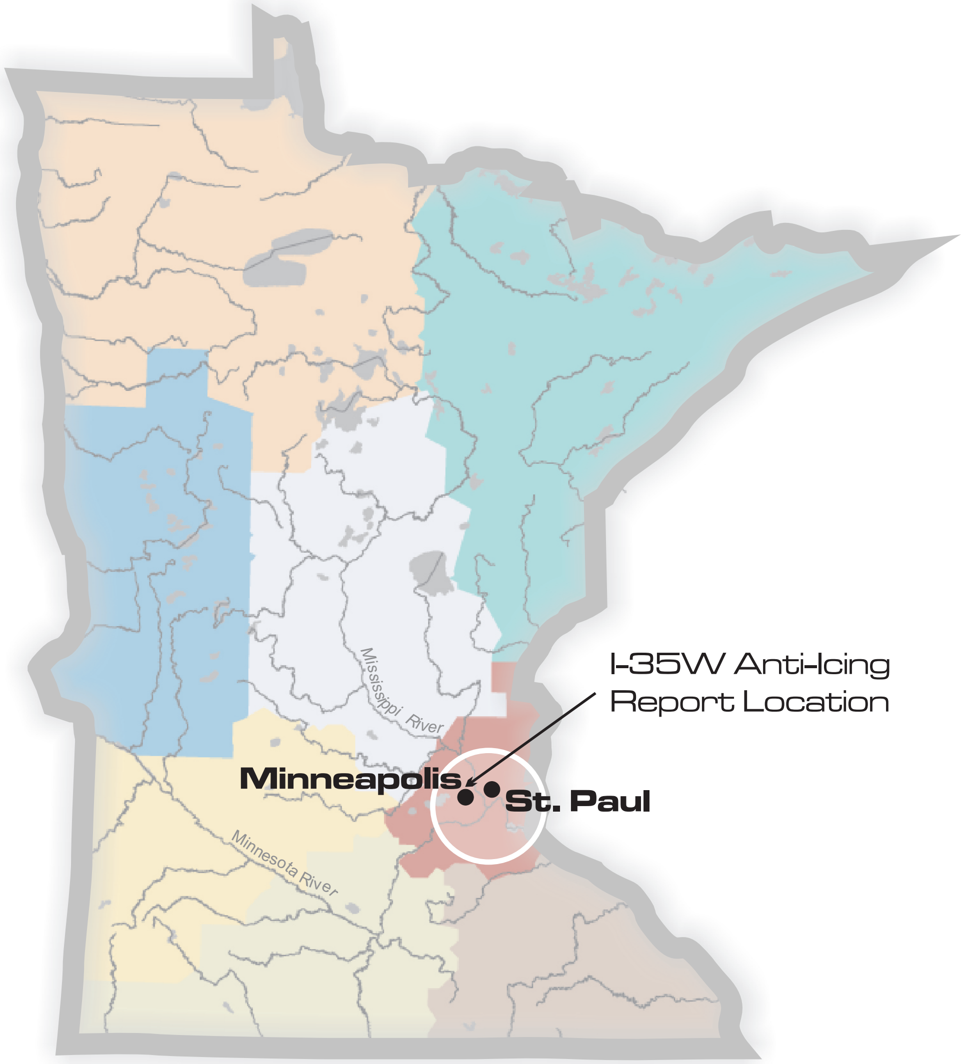
MINNESOTA DEPARTMENT OF TRANSPORTATION

I-35W & Mississippi River Bridge Anti-Icing Project

Operational Evaluation Report



JULY 2001

Office of Metro Maintenance Operations
Author, Cory Johnson
Contributors: Erik Rohde, Brad Estochen, Marc Briese & Calvin Lucas
Report # 2001-22

Table of Contents

LIST OF TABLES

LIST OF FIGURES

I-35W & Mississippi River Bridge

AN OPERATIONAL EVALUATION OF THE ANTI-ICING SYSTEM

INTRODUCTION AND BACKGROUND

A bridge that spans the Mississippi River on U.S. Interstate 35W in Minneapolis, Minnesota has been fitted with a computerized system that sprays potassium acetate, the anti-icing chemical selected, on the bridge deck when data from sensors and a Road Weather Information System (RWIS) determine that hazardous winter driving conditions are imminent. The eight-lane, 1950-ft-long interstate bridge maintained by the Minnesota Department of Transportation (Mn/DOT) is the first of its size in the United States that has been equipped with an anti-icing system. See Figure 1 for a detail of the project area.

The I-35W Bridge (#9340) was a candidate for this high-tech treatment due to the high incidence of winter traffic crashes on the bridge. The bridge is more susceptible to "black ice" and slippery conditions because of moisture from the Mississippi River's St. Anthony Falls, nearby power plants and industrial facilities, and because of the high volume of traffic on the bridge – year 2000 Average Daily Traffic (ADT) is approximately 139,000 vehicles. The formation of "black ice" is due to the combination of extreme cold and heavy vehicle exhaust from congestion on the bridge. In addition to traffic safety, the anti-icing system also contributes to sustainability, because the chemical used is environmentally less toxic and corrosive than sodium chloride, which traditionally has been used.

Boschung Company Incorporated was hired to design, furnish & install, and support the anti-icing system. Boschung is based in Switzerland and has over 50 years of experience in winter maintenance products and services. Local support was provided out of Brainerd, MN. The system was installed over the course of one year and was completed in December 1999.

SYSTEM DESCRIPTION

SENSORS AND RWIS

The bridge anti-icing system works with a combination of sensors, RWIS weather stations, a computerized control system, and a series of 38 valve units and 76 spray nozzles that apply potassium acetate. A 3,100-gallon tank is located in a small control pump building next to the bridge for potassium acetate storage. See Figure 2 for an illustration of the anti-icing system components located on the bridge structure.

The high-tech bridge anti-icing system includes two types of sensors: active ground and pavement temperature/moisture sensors, and ice formation sensors, both of which are proprietary. A simple definition of an active sensor is one that interacts with the environment and observe how the environment affects the sensor or how the sensor affects the environment (a passive sensor simply receives information). The sensors give advanced warning that approaching weather may produce hazardous driving conditions on the bridge.

The RWIS weather stations' optical precipitation sensors measure the air temperature and detect the presence and intensity of rain, sleet, or snow. Information collected by the proprietary sensors and weather station is transmitted to a Mn/DOT computer.

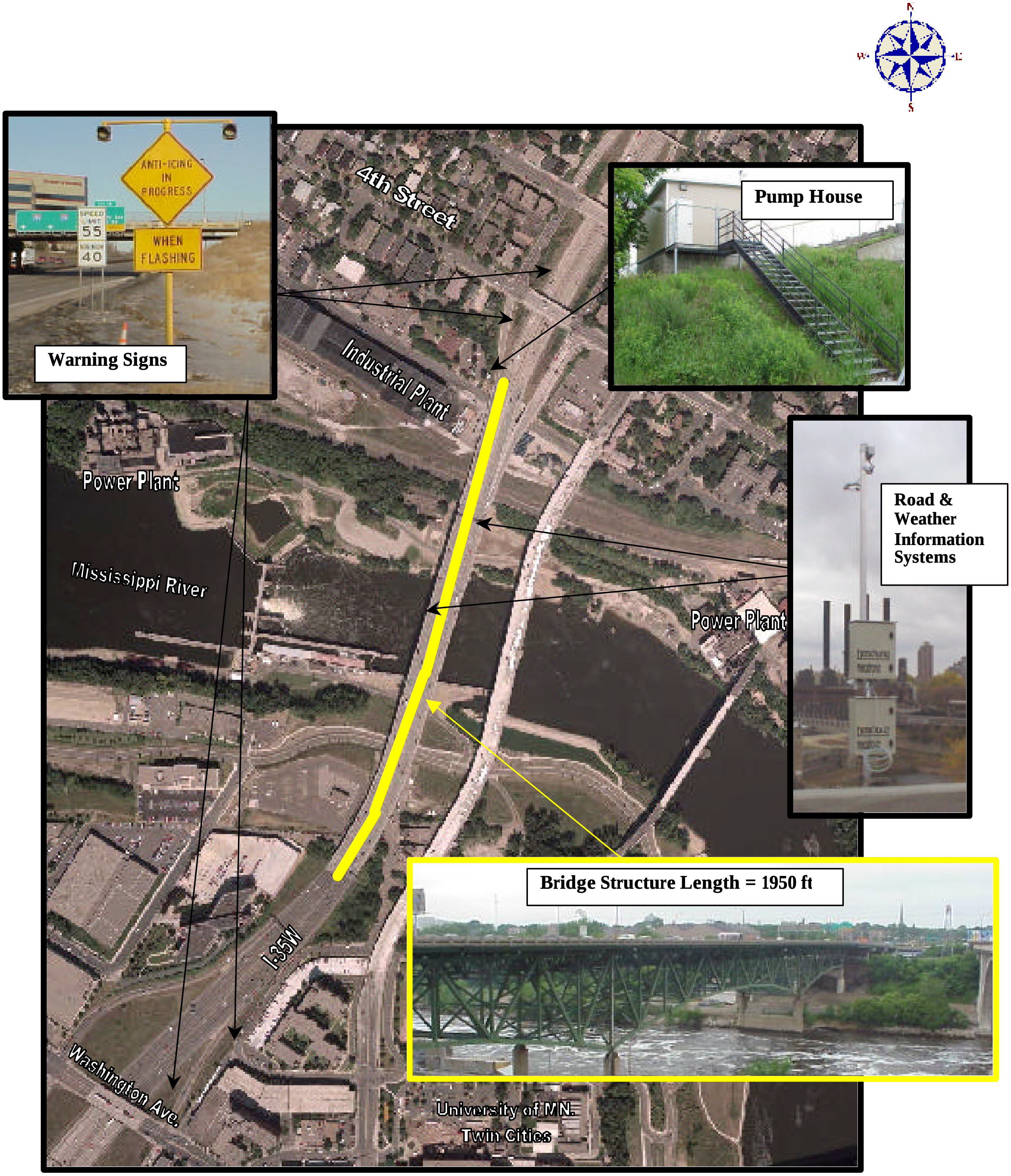


FIGURE 1 PROJECT AREA

Parapet Nozzle:
8 parapet spray nozzles mounted in the right and left J barriers, both travel directions located at the north end of the bridge.

Valve Unit:
38 valve units mounted between the median parapet walls, one valve unit per two nozzles.

Disk Nozzle:
68 flush mounted disk spray nozzles, spaced @ 55' on centerline of each direction of travel.

FIGURE 2 ANTI-ICING SYSTEM COMPONENTS

COMPUTER MONITORING

The computer system on the bridge is programmed to use information from the sensors and weather stations to take action to forestall icing conditions by spraying potassium acetate on the bridge deck when necessary.

A computer, responsible for automatically collecting and recording data that is received from bridge sensors, is located in the Metro Maintenance dispatch center at Water's Edge, a Mn/DOT headquarters building located approximately 5 miles from the bridge. The display on the computer informs dispatch personnel of current conditions detected on the bridge deck and which, if any, spray programs have been activated. During everyday operations, the system is designed to function as a stand-alone unit, with no human intervention needed. However, there are manual override buttons available in cases where additional actuation is warranted.

IN ACTION

When software that controls the anti-icing system has initiated spraying based on the sensor data, advisory yellow flashing lights are activated at the two entrances to the bridge to inform motorists that the system has been activated. As a precautionary measure, the system next checks for leaks in the system. If no leaks are detected, the system begins the bridge spraying process. Each of the thirty-eight valve units on the bridge deck, located inside a double median barrier, contains two liters of potassium acetate. These valve units then distribute the chemical to the 76 spray nozzles for bridge deck spraying. Each spray nozzle dispenses chemical in a semi-circular, fan shaped pattern.

Instead of releasing all of the chemical at one time, the bridge utilizes a double loop system. The computerized control system also allows for spraying action according to varying conditions on the bridge. For example, the computer may direct the system to release chemical from every other nozzle or to spray only the northern or southern portions of the bridge. The entire operation of the system takes from 10 to 12 minutes; however, the actual spraying time is very brief. Each of the nozzles releases chemical for a total of about two seconds.

INVESTMENT

The system utilized on the bridge involved a considerable investment. Initial cost for system was $578,365 (US$), which included installation, hardware, software, the pump house, operation manuals, and two years of support and training. Additional work and modifications to the original contract brought the final price to $618,450.

Mn/DOT recognizes this system as a potential operational improvement. As a result, Mn/DOT - Metro Division Maintenance was charged with preparing this Operational Evaluation.

EVALUATION

A two-year operational test was conducted on the automated anti-icing system. The purpose of the test was to evaluate the operational effectiveness of the system, and to measure the road user benefits provided by the system. In very simple terms, two questions were answered: is this the right thing to do and is it being done correctly? The remainder of this report is dedicated to the presentation of the results from that test.

OPERATIONAL TEST RESULTS

The operational test began in December 1999 and concluded on March 31, 2001. The test was conducted by a small group of Mn/DOT - Metro Division Maintenance engineering personnel. Temporary personnel supplemented this staff during the 2000-2001 winter season and at other critical times. Also, throughout the two-year test period, three project managers have been assigned the responsibility for the conclusion of the study. Each of the first two managers have taken other positions within the Department of Transportation (DOT).

During the 1999-2000 season the system was being modified and brought up to operational readiness in preparation for full time use during the 2000-2001 season. The 1999-2000 season was spent in a "shake-down" mode, but this season would not have provided an adequate set of data for analysis, regardless, because the weather during that season was easily the mildest of all the seasons over the past seven years and only a handful of sprays occurred. For this reason, the 2000-2001 winter season was chosen as the single test year for analysis. At this point, it is necessary to perform a winter season comparison to find a similar winter season (or seasons) to be used as a baseline for analysis.

WINTER SEASON WEATHER CONDITIONS

This analysis examined winter weather conditions for the past seven winters, starting in 1994. Historical weather data recorded by the National Weather Service (NWS) for the Twin Cities of Minneapolis and St. Paul, MN was collected for each of winter season since 1994 to identify previous winter(s) that compare favorably to the 2000-2001 season. However, it was not intuitively obvious which months should be considered winter weather months for this study.

Table 1 shows average weather data for the Twin Cities for the months that typically experience winter weather conditions. The table clearly shows the majority of annual snowfall occurs from November through March. The frequency of daily low temperature at or below freezing is also greatest during this period, occurring 90.4% of the available days. Average water equivalent precipitation is highest in October and April due to increased levels of Gulf moisture reaching the Twin Cities via the prevailing jet streams. However, the smaller percentage of days with average low temperatures at or below freezing during these months (23.9% for October and 37.0% for April) results in less and shorter duration episodes of freezing precipitation. This is also shown by the much lower average monthly snowfall totals for October and April even though they have the highest water equivalent precipitation totals.

For the reasons presented above, a winter season, for the purpose of this study, is defined as November 1 through March 31 of the following year, resulting in a season length of 151 days. The 1995-1996 and 1999-2000 seasons encompassed leap years, thus the season length is 152 days. This period captures those months where the Twin Cities experiences the majority of its winter type weather and for the current season includes those months where the bridge anti-icing system was set in its winter operating mode.

TABLE 1 NORMAL MONTHLY WEATHER DATA FOR MINNEAPOLIS/ST. PAUL, MN

Month	**Average Water Equivalent Precipitation (in.)**	**Average Snowfall (in.)**	**Average Number of Days Low Temperature = 32° F**
October	2.19	0.4	7.4 (23.9%)
November	1.55	7.3	23.4 (78.0%)
December	1.08	11.3	30.1 (97.1%)
January	0.95	12.5	30.9 (99.7%)
February[1]	0.88	9.2	27.0 (96.4%)
March	1.94	11.6	25.1 (81.0%)
April	2.42	3.6	11.1 (37.0%)
Monthly Average (Oct-Apr)	1.6	8.0	22.1 (73.1%)
Monthly Average (Oct-Mar)	1.4	8.7	24.0 (79.1%)
Monthly Average (Nov-Mar)	**1.3**	**10.4**	**27.3 (90.4%)**
Monthly Average (Nov-Apr)	1.5	9.3	24.6 (81.5%)

Source: National Climatic Data Center 1999 Local Climatological Data Annual Summary (Period of Record = 30 Years, 1969-1999)

[1] Non leap year

All National Weather Service (NWS) official weather data except snowfall depth for the Twin Cities has been recorded at the Minneapolis – St. Paul International Airport (MSP) for the entire study period. Starting on October 1, 2000, the official Twin Cities snowfall depth recording location was changed from MSP to Chanhassen, MN. MSP is located approximately 6 miles south of Bridge #9340 while Chanhassen is approximately 15 miles southwest of the bridge. MSP and Chanhassen are approximately 12 miles apart. This study uses MSP recorded data for all weather measurements except 2000-2001 winter season snowfall depth and number of days of recorded snowfall, which was taken from the Chanhassen NWS station. This change could potentially present some concern when comparing previous winter seasons to the 2000-2001 season. Historical weather data for the Chanhassen NWS office is not available prior to the 1999-2000 winter season, thus Chanhassen data, alone, cannot be used for a weather comparison. For the 1999-2000 winter season, a comparison between MSP and Chanhassen data shows Chanhassen recording 4.1 inches more snow, 8 more days of measurable snowfall, and 7 more days of snowfall when days with only trace amounts of snowfall are added. Table 2 shows the recorded snowfall data for the two recording locations. These values show that Chanhassen had 11.7% more snowfall depth, 40.0% more days with measurable snowfall, and 20.0% more days with measurable and trace amounts of snowfall than MSP. These differences for a single winter season do not suffice to establish a valid differential for all seasons studied between the two recording locations. However, it does serve to highlight the highly variable nature of weather phenomena, thus adding a note of caution to the snowfall comparison of the 2000-2001 winter season to the other 6 seasons in this study. Additionally, it is assumed that the weather conditions recorded at the official NWS location, regardless of whether it be MSP or Chanhassen, are indicative of the conditions at the bridge.

TABLE 2 NWS SNOWFALL DATA COMPARISON FOR 1999-2000 WINTER SEASON

NWS Recording Location	**Total Snowfall (in.)**	**Number of Days With Measurable Snowfall**	**Number of Days With Measurable & Trace Amounts of Snowfall**
Minneapolis – St. Paul IAP	34.9	20	35
Chanhassen NWS Office	39.0	28	42

Source: NWS data obtained from National Oceanic and Atmospheric Administration (NOAA), Local Climatological Data and http://ncdc.noaa.gov

To fully characterize and compare the severity of the seven winter seasons in the study additional recorded weather data beyond those given in Table 1 for winter season normals was used. Number of days with measurable amounts of precipitation, number of days with measurable snowfall amounts, and percentage of days with mean temperature >40°F were also used. When combined with water equivalent precipitation, snowfall depth, and percentage of days with a minimum temperature > 32°F, an accurate picture of the severity of a winter season's weather can be presented. Figure 3 shows these recorded weather data categories for all of the winter seasons that were considered in this study. The Appendix contains a monthly breakdown of all the data for each winter season and shows how each winter season compared to average monthly weather data for the Twin Cities.

The data in Figure 3 that best represents the potential for adverse winter weather road conditions are precipitation days, snowfall days, and percentage of days with minimum temperature less than or equal to 32°F. In general terms, these three elements define the relative daily potential of either freezing precipitation occurring or precipitation freezing on road surfaces. Figure 3 shows a close match in these three important data categories for the 1995-1996, 1996-1997, and 2000-2001 winter seasons. Figure 4 consists of the three important data categories for each of the three winter seasons identified above, and further illustrates the strong similarities in weather severity between them.

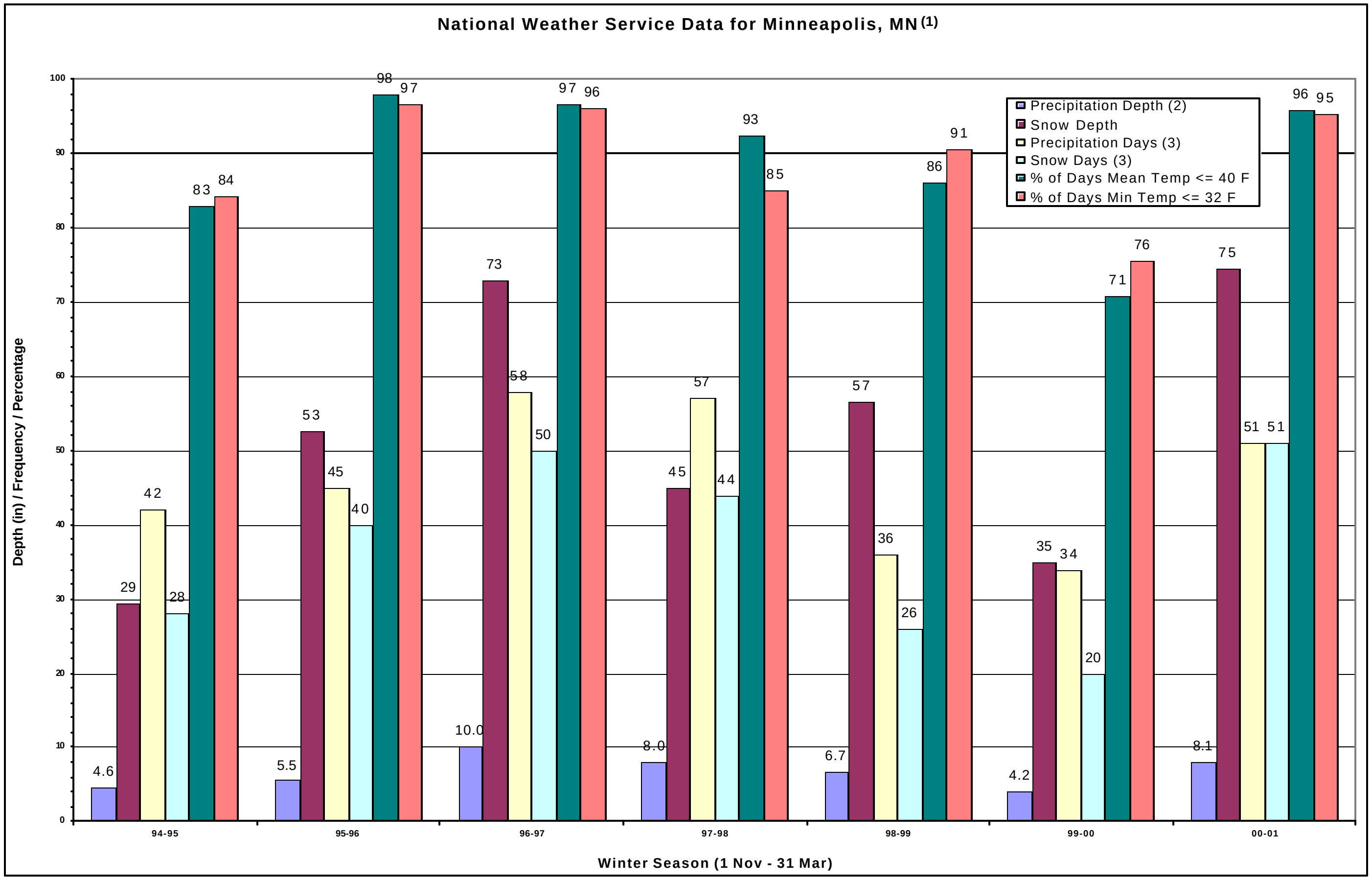
Both Figures 3 and 4 indicate that the 1996-1997 winter season provides the most accurate comparison to the 2000-2001; however, the snowfall depth and number of snow days for the 2000-2001 season was recorded in Chanhassen, not MSP. If it is assumed that the difference in snowfall data shown in Table 2 during the 1999-2000 winter season is constant (differences = 4.1" of snowfall and 8 days of recorded snow), then the snowfall/snowday data for the 2000-2001 winter season falls nicely between the adjusted snowfall/snowday data for the 1995-1996 and 1996-1997 winter seasons – see Table 3.

TABLE 3 ACTUAL AND ADJUSTED SNOWFALL DATA

	Snowfall (inches)		Snowdays	
Winter Season	**Actual**	***Adjusted***	**Actual**	***Adjusted***
1995-1996	53	***57***	40	***48***
1996-1997	73	***77***	50	***58***
2000-2001	75	***75***	51	***51***

Source: Mn/DOT, Metro Division Maintenance

Although no two winter seasons can be identical, the conclusion that can be reached from examining Figures 3 and 4, in combination with Table 3, is that the 1996-1997 winter season is, in fact, the most appropriate winter season for comparison to 2000-2001, with the winter season of 1995-1996 being a close second.

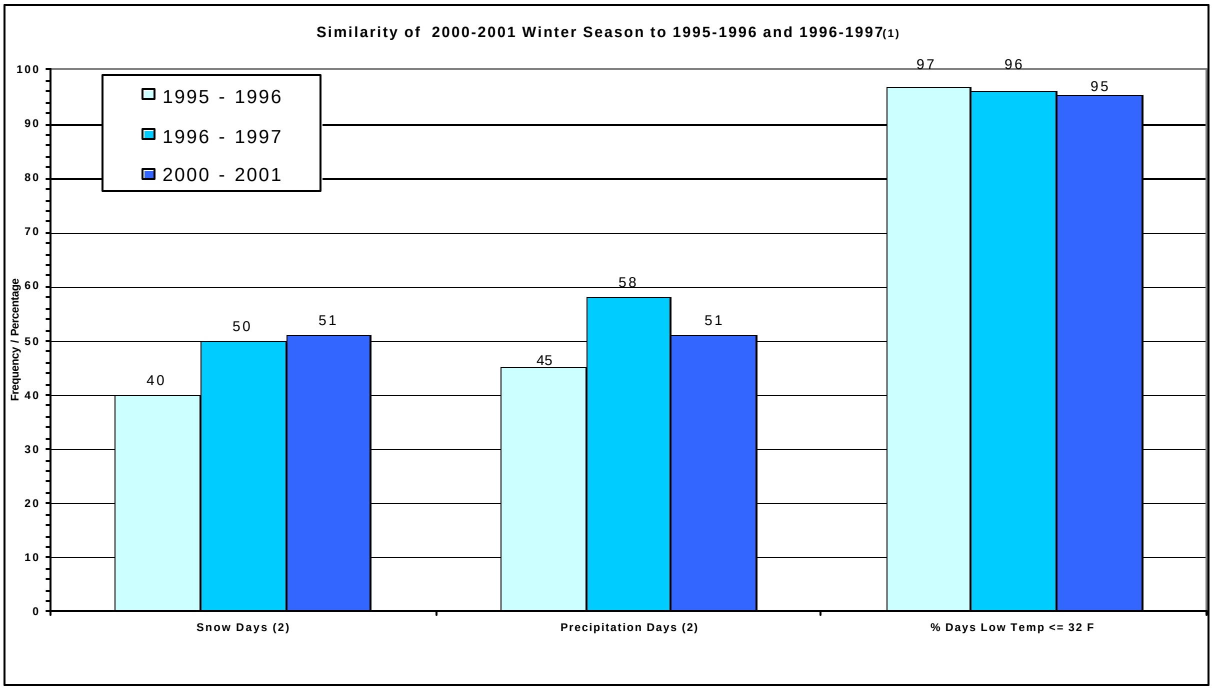


Notes: (1) All National Weather Service (NWS) weather data for Minneapolis is measured at Minneapolis-St. Paul International Airport for all winter seasons except 2000-2001. Data for 2000-2001snow depth and days measured at NWS office in Chanhassen, MN

(2) Precipitation depth is the water equivalent depth of all precipitation types measured

(3) Precipitation and snow days includes only those days where measurable depths were recorded. Days where trace amounts were recorded are not included.

FIGURE 3 COMPARISON OF WINTER SEASONS



Notes: (1) All National Weather Service (NWS) weather data for Minneapolis is measured at Minneapolis-St. Paul International Airport for all winter seasons except 2000-2001. Data for 2000-2001snow days measured at NWS office in Chanhassen, MN.
(2) Precipitation and snow days includes only those days where measurable depths were recorded. Days where trace amounts were recorded are not included.

FIGURE 4 SIMILAR WINTER SEASON COMPARISON

SYSTEM PERFORMANCE – HARDWARE AND SOFTWARE

Because the 1999-2000 winter season was a very mild winter season and the anti-icing system was completing its "shake-down" stage, the system performance can only be measured in the 2000-2001 winter season. It is also important to recognize and reinforce the distinction between a system that is under construction and in the process of its initial "shake-down" and a system that is fully operational. In fact, in this case, most of the construction issues were resolved prior to November 2000 but many of the system operational parameters are still in a state of change even after the operational test. So for the purpose of this evaluation, it is assumed that the anti-icing system was "fully operational" during the entire 2000-2001 winter season.

Before evaluating the performance of the bridge anti-icing system for the 2000-2001 winter season, it is important to understand the fundamental methodology of the anti-icing system. As described earlier, there are several spray nozzles located throughout the bridge deck and parapet walls. These nozzles are responsible for dispensing potassium acetate onto the bridge deck to impede the formation of ice. Several devices located on site, including RWIS stations, Advanced Rural Transportation Information and Coordination (ARTIC) sensors, and BOSO (proprietary Boschung) sensors, obtain weather information specifically occurring on the bridge deck. By using the data from each device, conditions occurring on the bridge deck can be determined and/or predicted.

THE OPERATIONAL STRATEGY

The anti-icing system has been designed to prevent slippery conditions from developing on the driving surfaces of the bridge. The system can detect the presence of “black ice”, frost, frozen snow, or ice buildup and respond by spraying potassium acetate. In addition to sensing conditions on the bridge deck, the system can also predict when precipitation will change phases from a liquid to solid (i.e., ice). By using this predictability function of the system, preventative measures can alter the chemical properties of precipitation prior to phase transformations (i.e. lower the freezing point by adding potassium acetate). Based on the weather conditions at a specific moment, a spray program will automatically be activated. The anti-icing system maintains a log of weather conditions, spray programs, and underlying reasons for spraying the bridge deck. This log of information allows analysis of the overall operations of the bridge anti-icing system.

The operational strategy for bridge deck treatment of the anti-icing system is significantly different than traditional mobile anti-icing programs. The strategy used by this system has two key advantages: 1) fixed sensor networks installed on bridge, 2) availability of a chemical delivery system. These advantages allow the system to apply a smaller amount of chemical at a time closer to the point when the bridge deck requires treatment. For example, the bridge deck sensors continuously sample freezing point data and will activate a spray program when the threshold is met. If the first spray does not drop the freezing point sufficiently, the system will activate additional spray programs as indicated by the sensor data – the system reactively treats the bridge with a small amount of chemical and only applies more chemical if needed.

Some traditional methods of snow and ice removal treatments also occurred on the bridge at other times during the 2000-2001 winter season. This occurred whenever the snowfall intensity was great enough to create snow or slush buildup on the bridge deck. These methods included plowing, sanding, and salting of the bridge deck. No accurate records were kept to indicate specifically when these traditional methods were used. Snow plow truck operators who cover the bridge were instructed to use their experience and judgement to decide if it was necessary to treat the bridge deck as they crossed it on their normal routes. No changes were made to the routes that include the bridge or the number of plow trucks assigned to this area. For the purpose of this study, it is assumed that the automated bridge anti-icing system provided the primary means of daily bridge deck treatment during the 2000-2001 winter season.

The operational test showed the following trends and statistics:

- Per spray, the average amount of chemical applied was 34 gallons (12 gallons per lane mile);
- Single spray events occurred 14 times, usually for frost or ice conditions;
- Multiple spray events occurred 24 times, usually during snow and ice events;
- Pretreatment prior to major snow events occurred as a double spray, or 2 single sprays, only when the first sign of moisture was detected (manual sprays were not utilized in a predictive manner);
- Post snow event clean-up was significantly reduced on the bridge structure.

Operationally, the anti-icing system was also found to be very flexible. This system has many configurable parameters that allow the operator to adjust almost every environmental and operational setting. Each parameter can be adjusted through software programs but are constrained by the hardware design. For example, volume of chemical sprayed on the bridge deck is controlled by adjusting the time that each valve unit is opened. This setting may be any value from 0.01 to 2.75 seconds. The maximum setting of 2.75 seconds is defined by the amount of volume stored in each valve unit's accumulator tank.

SPRAY PROGRAMS

Currently, the bridge anti-icing system has 13 spray programs that are activated based on the temperature and atmospheric conditions occurring on the bridge. Each of the 13 programs varies the valve unit that sprays, sequence, and the number of times the valve unit is sprayed. In general, the valve units spray in a sequence that is against traffic flow. This is done to limit exposure to any one single vehicle – that is, in most cases, the maximum number of times any one vehicle's tires could be sprayed is one.

Threshold values were scientifically determined and tuned by Boschung on other bridge anti-icing projects. These values were not specifically evaluated by Mn/DOT, but seemed to be calibrated correctly in order to trigger the system at the point where conditions that are favorable for the formation of ice or frost on the bridge deck. A complete listing of the thresholds is presented in the Appendix. Further examination of the spray program logs indicates that all of the programs were used during the 2000-2001 winter season and the majority of the time there were double sprays, supplemented with additional sprays of the parapet nozzles.

SYSTEM ACTIVATION

When the anti-icing system sensors detect that a threshold limit has been surpassed, a spray program is selected and the system is activated. Several processes are launched in the software and all functions of the hardware become enabled. Structured performance tests were conducted on 10 randomly selected individual sprays from the 2001-2001 winter season to verify operations of all functions. These tests were conducted to verify operating pressures, temperatures, spray duration, atmospheric and environmental conditions detected, software alarms, and affects on traffic flows.

The results of the structured test observations are as follows:

- The system performed well. Operating pressures, temperatures, and duration, were all within range and all functions operated within specifications;

- The software appropriately detected the environment that was present and accurately displayed the data on the dispatch workstation accurately including all alarms;

- The correct spray program was chosen and all of the correct valve units released on time;

- Traffic flow was not significantly affected by the anti-icing sprays. There existed only a very minimal amount of road spray and no unusual vehicle breaking was observed;

- All sensors were calibrated within range – that is, temperatures reported by the sensors were consistently within 2°F of temperatures determined manually;

- The chemical tracked approximately 500 feet off of the bridge deck during the winter and approximately 4000 feet during the fall and spring deployments;

- All parapet nozzles were consistently blocked by compacted ice and snow that was pushed into the parapet walls during snow plowing operations;

- Some disk type nozzles were partially plugged and prevented 100% lane coverage. These minor and random blockages were usually blown clear during the second spray of that unit.

In addition to the structured test conducted during actual weather event operations, other inspections of the system were completed. These inspections included a scheduled fall and spring shutdown and specific component inspections based on system alarms.

SPRING AND FALL INSPECTIONS

Each Fall and Spring the anti-icing system is changed over from summer to winter operations and visa versa, respectively. The change-over switches from spraying potassium acetate during the winter to water during the summer. Summer operations include a monthly manual spray to ensure the system will be ready for activation in the following winter season. Also at this time, the entire anti-icing system is inspected and some minor preventive maintenance is performed.

As part of the construction contract, Boschung was to conduct the first four seasonal changeovers, while Mn/DOT observed. The first three changeovers primarily identified system “shake-down” issues. The fourth inspection was the first opportunity to observe system durability.

The results of the fourth changeover were excellent in terms of durability. Only one spray disk failed (o-ring seals broke). Other disks had very minor gouging and some loose hold-down tabs. All sealant and epoxies performed well and no spray disks were raised, loose, or gone. Piping, valves, and pumps were also in good working order. Some spray nozzles became plugged by sand particles and, in the future, will require some cleaning prior to each winter operation season. Minor leaking (<200mL) was found at or near the valve units. At the time of this report, Boschung is still performing diagnostics and taking corrective actions to resolve the problem.

SPECIFIC COMPONENT INSPECTIONS

During the 2000-2001 winter season, several specific components were inspected. These components were usually selected due to some sort of system alarm activation. In all cases, Boschung was the first point of contact and response time was excellent for system critical issues.

Software – The system operating software worked well during the 2000-2001 winter. However, the system did experience a virtual memory loading error that was resolved in spring 2001. Also, the software was designed as a stand-alone application with several different editing programs. This design made it difficult to edit system parameters, access real-time and historical data, and have on-site back-ups. Mn/DOT did not procure the application source code or the knowledge to edit that source code and therefore does not have access to the proprietary protocols.

Filters – The originally supplied in–line filter at the pump house failed and a potassium acetate spill occurred (~50 gallons). The spill was temporarily contained in the pump house and a redesigned in-line filter was installed.

RWIS – Two RWIS stations are installed on the bridge. The northbound station is linked to the southbound station where the master controller is housed. The northbound station failed during winter operations and was replaced. During the failure, data from the southbound sensors were used exclusively.

Pump house – The pump house performed poorly. During the chemical spill, the containment area temporarily contained the fluid, but within 24 hours all of the fluid had seeped through the foundation. As a retrofit, a neoprene liner was purchased and installed in the containment area. Also, work space was limited and some safety functions were not present (fire extinguisher, wash area, etc). Graffiti on the exterior of the building is also a recurring problem.

Chemical Storage – The 3,100-gallon storage tank in the pump house was too small. During the 2000-2001 test period, chemical was purchased and transported in quantities of 4,400 gallons. This required an additional storage tank at the nearest maintenance truck station and the additional effort to provide nurse truck operations for refilling the 3,100 gallon tank.

Warning Signs – The flashing warning signs had no visual affect to the traffic flow. These signs flashed prior to every spray and, at most, provided a basic level of expectation to the motorists. In most cases, motorists did not even experience a spray while they passed through the freeway section.

Chemical Product - The most important component for the entire system is the selection of the material sprayed in the anti-icing system. The material, or chemical, used is just as important as all other components in the sense that all components must work well together to achieve the end result. But, the chemical component has the potential to make the system work poorly or has the potential to make the system work very well – so much so, that the evaluation team specifically examined this issue and presented the results in the following material evaluation section.

MATERIAL EVALUATION

The evaluation of the effectiveness of any material sprayed from an anti-icing system is very difficult. It is difficult to specifically measure evaluation criteria in a real-time fashion on a facility that is in operation during inclement weather. Therefore, the evaluation is limited to laboratory results that are usually performed by independent companies and provided to us by chemical sales staff. In these laboratory tests, samples of the chemicals are provided by the manufacturers and many different analyses are conducted to derive comparable results. Other evaluation techniques to scrutinize the performance of the material for various typical winter events are very subjective and were limited to a visual examination of the spray program deployment logs. (See the SYSTEM EFFECTIVENESS section)

Geographic location (Mississippi River crossing, St. Anthony Falls, lock and dam) and other unique characteristics (industrial plants in close proximity) contribute to higher than normal moisture levels on the bridge deck than can result in extremely slippery conditions. Couple that with high levels of traffic (main route into Minneapolis central business district with Year 2000 ADT ~ 139,000), and the result is often a dangerous driving environment with the potential for numerous crashes. For this reason, Mn/DOT desired to use a chemical that would impede the formation of ice in extreme cold temperatures when moisture was present.

Various chemicals are available for use in an anti-icing system including, but not limited to, magnesium, potassium, and calcium chlorides/acetates, glycol, and urea based anti-icing systems. Mn/DOT decided to use potassium acetate in the evaluation of the bridge anti-icing system.

Cryotech's CF7® is a potassium acetate based liquid anti-icing chemical containing no chlorides. It was the product of choice because it is safer for structural steel and reinforcing steel embedded in concrete, readily biodegrades with little environmental impact, and is easily available in bulk quantities. CF7® has a freezing point of -76°F, and is effective at temperatures of -15°F and below. CF7® is an offshoot of Cryotech's runway anti-icing business.

Based on its characteristics and the best information available from Cryotech, CF7® is neither listed as a hazardous waste, nor does it exhibit any of the characteristics that would cause it to be classified or disposed of as a hazardous waste. Tests with CF7® show it readily biodegrades at low temperatures and has a relatively low Biological Oxygen Demand (BOD) when compared to glycol-based anti-icing chemicals. Toxicity tests rate CF7® as "relatively harmless" to aquatic life, the most favorable classification used by the environmental community. Also the fluid contains no nitrogen or chlorides. Therefore, CF7® is considered much safer for the environment than glycol, urea, or chloride based anti-icing chemicals.

During the 2000-2001 winter season, Cryotech's CF7® performed well. Mn/DOT did not observe any environmental problems and observed the chemical performing well in very cold weather. Mn/DOT also observed the need to adjust the volume of chemical sprayed depending on the temperature of the bridge deck. For example, during the early and late winter season when the temperature was generally warmer, the amount of chemical necessary to treat the bridge was much less than during mid-winter conditions, even with seeming identical amounts of moisture. This conclusion was also corroborated by the observation of the increased length of the chemical tracking off of the structure during warmer temperatures.

During the 2000-2001 winter season, two negative aspects of using the potassium acetate product line were discovered:

1) Inside the pump house, a chemical reaction with galvanized metals occurred. During the chemical spill, CF7® came into contact with and began to corrode a galvanized metal grate. Upon cleaning the grate, the chemical reaction ceased;

2) There exists a potential for hydrogen gas buildup in airtight locations. For this reason alone, it is extremely important that the storage facility (the pump house in this case) have adequate ventilation.

Additionally, the price, for the potassium acetate is substantially higher than liquid chloride anti-icing chemicals currently on the market. The price for potassium acetate used in this test, including delivery, was $3.25 per gallon.

MAINTENANCE CREW OBSERVATIONS

Qualitative analysis is equally important as quantitative analysis for this study. For this reason, snow plow operators, responsible for plowing the route containing the bridge, were asked to participate in a small focus group discussion and present their observations of the bridge anti-icing operations at the conclusion of the 2000-2001 winter season. This section summarizes the observations of the maintenance personnel responsible for the winter maintenance of the bridge and adjoining roadway.

Overall, the maintenance workers feel the bridge anti-icing system did an adequate job in treating the bridge during the operational test. However, they did not alter their approach to treating the bridge during the test phase (i.e., sand and sodium chloride continued to be applied to the deck). There was no observable chemical interaction between the potassium acetate and the sand/sodium chloride used to treat the bridge. One major improvement, compared to the traditional approach, is the reduction in the cleanup operations on the bridge after a major snow event occurs, which typically include shoulder cleaning and snow hauling. Additionally, they did not experience any re-freeze problems on the bridge deck and, to the best of their knowledge, there were no instances of snow compaction on the bridge deck. From the operator standpoint, they feel that the amount of chemical being applied to the bridge deck is adequate for normal snow events and does an effective job without wasting chemical. They did not notice any puddles of chemical on the roadway. Also, they could tell when a spray nozzle was partially plugged or not spraying at all.

The workers are very impressed with the chemical because it operates effectively at very low temperatures. In their opinion, they would not change chemicals to test others available on the market – this is the first chemical they have used that addresses their problems and they are happy with the results.

The snow plow operators offered several suggestions for improvement for the anti-icing system. In general, these improvements are geared toward the number of times the anti-icing system sprays, not on chemical performance. The only concern they expressed about the chemical was that it appears shiny and motorists may believe the chemical is ice. The snow plow operators feel the following changes would enhance the anti-icing system: do not spray chemical during rush hour unless absolutely necessary (i.e., chemical hits cars and never makes it to the road), decrease the number of sprays during large snow event, and spray chemical prior to the morning rush hour.

SYSTEM EFFECTIVENESS

During the evaluation period, the bridge anti-icing system sprayed chemical 501 times and applied over 17,000 gallons of potassium acetate. These sprays were used as the basis for the overall evaluation of the anti-icing chemical and system effectiveness. The large number of sprays during the evaluation period presents an opportunity to scrutinize how the system performed in various conditions. SYSTEM EFFECTIVENESS deals with how the system performed in major snow events (>=5"), minor snow events (<5"), and predictability. Additionally, a case study is presented, in detail, that details how the system functioned during a major winter weather event. But, since understanding how events are classified is essential to appreciating the results, the first section will present how events are classified.

EVENT CLASSIFICATION

The time period used for this test evaluation started with the first snowfall of the winter season, November 7, 2000 and ended with the last automatic system activation, which occurred on March 25, 2001. For this evaluation, a snow event is defined as a measurable amount of precipitation in a frozen liquid form (ice or snow) that required maintenance crews to be dispatched for winter operations. However, snow resulting in accumulations less than 0.2" were not considered snow events unless freezing rain or drizzle accompanied it. Events were analyzed by using several different data sources including National Weather Service Data, RWIS information from the bridge, and Mn/DOT - Metro Division Maintenance dispatch logs for winter weather maintenance.

The events were broken down based on two criteria: snowfall amount and ice involvement. A minor event was defined as less than 5 inches of snow, while a major event was defined as 5 inches or more of snow. Additionally, any events that included ice (via freezing rain, sleet, or drizzle) were flagged for analysis. Overall, there were 24 unique events for the evaluation period. The anti-icing system was not operational during events 15 and 16 because system modifications were being completed. Of the

24 events, 7 were considered major events and 17 were minor events; additionally, 6 of the 24 events involved ice. See Table 4 for a summary of the events for the evaluation period.

TABLE 4 WINTER EVENTS FOR I-35W BRIDGE ANTI-ICING SYSTEM (MINNEAPOLIS, MN)

Event #	Classification	Ice Involved	Start date	End Date	Approx. Snow (inches)
1	Minor	Yes	11/7/00	11/8/00	1.0
2	Minor	Yes	11/13/00	11/14/00	0.5
3	Minor	No	11/15/00	11/17/00	3.0
4	Minor	No	11/19/00	11/20/00	3.0
5	Minor	No	11/30/00	12/1/00	0.3
6	Minor	No	12/6/00	12/7/00	1.5
7	Minor	No	12/11/00	12/12/00	0.5
8	Minor	No	12/13/00	12/14/00	2.0
9	Major	No	12/15/00	12/16/00	5.6
10	Major	No	12/18/00	12/19/00	5.9
11	Minor	No	12/23/00	12/23/00	1.0
12	Minor	No	12/25/00	12/26/00	0.3
13	Major	No	12/28/00	12/29/00	13.8
14	Minor	No	1/3/01	1/4/01	0.2
15*	Minor	No	1/8/01	1/8/01	0.3
16*	Minor	No	1/11/01	1/11/01	0.3
17	Minor	Yes	1/14/01	1/15/01	2.4
18	Minor	Yes	1/18/01	1/18/01	0.3
19	Minor	No	1/26/01	1/26/01	1.0
20	Major	Yes	1/29/01	1/30/01	5.0
21	Minor	No	2/2/01	2/3/01	1.0
22	Major	No	2/7/01	2/9/01	10.0
23	Major	Yes	2/23/01	2/25/01	10.0
24	Major	No	3/12/01	3/13/01	8.0

Source: Mn/DOT, Metro Division Maintenance

During the 2000-2001 winter season, 84 snow & ice call-outs were logged throughout the Metro Division, all of which did not necessarily involve crews on the I-35W Mississippi River Bridge. It was found that call-out events nearly perfectly corresponded to the Winter Events identified in Table 4 above. The instances that did not coincide directly could be attributed to varying weather conditions throughout the division (it may have been snowing heavily in Forest Lake, but not at all in Minneapolis). The Appendix contains a list of the 2000-2001 snow & ice call-outs.

MAJOR EVENT ANALYSIS

Seven major events (>=5.0" snow) occurred during the testing period of the bridge anti-icing system. The primary functionality of the anti-icing system is not snow removal. Therefore, it is unrealistic to expect this system to outpace maintenance staff in removing snow from the deck during major snow events – the system is designed to stop the formation of ice, not remove snow during major events. Table 5 is a presentation of the spray summary for major events during the evaluation period.

TABLE 5 SUMMARY OF SPRAY TREATMENTS FOR MAJOR WINTER EVENTS (2000-2001)

Date	Approximate Snowfall	Ice Involved	Total Sprays	Black Ice	Frost	Frozen Snow	Ice	Manual	Predictive
12/15 – 12/16	5.6	no	16	2	1	8	4		1
12/18 – 12/19	5.9	no	15	2	1	5	2	2	3
12/28 – 12/29	13.8	no	21	5		6	5	1	4
1/29 – 1/30	5.0	yes	30	8		11	6	2	3
2/7 -- 2/9	10.0	no	48	3	1	4	5		35
2/23 -- 2/25	10.0	yes	57	9	2	11	7	5	23
3/12 – 3/13	8.0	no	31	5	1	10	3		12

Source: Mn/DOT, Metro Division Maintenance
Shading indicates large and "wet" winter weather event

Inspection of the spray summary for major events identifies no clear relationship between amount of snowfall and number of sprays – the minimum number of sprays to address a major event was 15, with a maximum of 57. These findings were expected due to the variability of the snow composition and time period encompassing the event. However, while the purpose of this report is not microscopic analysis of each individual storm event some general characteristics can be ascertained.

Large snow event – low moisture

In general, the bridge anti-icing system can address large snowfall events if the snow is low in moisture content. If the two 10-inch snowfall events (which were large, wet, slushy, icy events) are eliminated, the total number of sprays for each event are more comparable (15-31 total sprays).

In terms of a large winter storm, the first concern for the bridge is moisture adhering to the deck; therefore, predictive sprays should occur relatively early in the event. When the precipitation rate increases (or the deck temperature decreases), frozen snow and/or ice may form on the deck more quickly than the predictive models can respond. At this instance, the anti-icing system should spray chemical to prevent this quantity from accumulating (i.e., frozen snow or ice sprays). Finally, when the precipitation has stopped, moisture may re-freeze on the deck surface and "black ice" may form. The anti-icing system should spray chemical to address this.

The spray conditions do tend to follow the pattern described above. Generally, there were a few preventative sprays at the beginning of the cycle until the rate of precipitation exceeded the preventative functionality of the system. At that point, the spray programs attempted to address the frozen snow/ice on the bridge deck. For large, "dry" snow events, this condition receives the majority of the sprays. After the precipitation diminished, conditions were favorable for "black ice", primarily due to moisture re-freezing on the deck, and the system did respond with preventative chemical sprays.

Large snow event – high moisture

During the operational testing period, the bridge anti-icing system was active for two large and wet snowfall events, which resulted in heavy snow accumulations (identified with gray shading in Table 5), which will be the basis for evaluation. The anti-icing system did not perform the same for large high moisture snow events as it did for low moisture events.

These two large, "wet" storms have similar characteristics as those identified in the previous section, however due to the large moisture content a predominately longer period of spraying is done at the beginning of the storm – that is, the freezing point cannot be lowered as quickly because the high moisture content dilutes the chemical, thus making it less effective. Based on the information presented in Table 5 above, this is precisely what occurred with the system. There was a substantial increase in the number of predictive sprays attempting to lower the freezing point on the deck – the effectiveness of the chemical was reduced significantly.

MINOR EVENT ANALYSIS

Seventeen minor events (<5.0") occurred during the operational test period for the bridge anti-icing system. Ideally, these events are where the bridge anti-icing system should produce the largest benefits by reducing the need for traditional snow and ice removal operations. Table 6 is a summary of the minor winter weather events occurring during the operational test period.

TABLE 6 SUMMARY OF SPRAY TREATMENTS FOR MINOR WINTER EVENTS (2000-2001)

Date	Approximate Snowfall	Ice Involved	Total Sprays	Black Ice	Frost	Frozen Snow	Ice	Manual	Predictive
11/7 – 11/8	1.0	Yes	4	1	1	1	1		
11/13 – 11/14	0.5	Yes	13	3	1	8			1
11/15 – 11/17	3.0	No	14			7	5		2
11/19 – 11/20	3.0	No	18	4	1	6	2		5
11/30 – 12/1	0.3	No	6		1				5
12/6 – 12/7	1.5	No	12	1		5	4		2
12/11 – 12/12	0.5	No	6	1	1				4
12/13 – 12/14	2.0	No	5	3		1		1	
12/23	1.0	No	5		1	1	1		2
12/25 – 12/26	0.3	No	4		1		2		1
1/3 – 1/4	0.2	No	12					9	3
1/8	0.3	No	System was not operational						
1/11	0.3	No	System was not operational						
1/14 – 1/15	2.4	Yes	15	1	1	6		1	6
1/18	0.3	Yes	5			1		1	3
1/26	1.0	No	11	2	1	2	2	1	3
2/2 – 2/3	1.0	No	7	2	1		1		3

Source: Mn/DOT, Metro Division Maintenance

Shading indicates no operation or no automated operation of system

As expected, the number of sprays required to treat a minor event is substantially less than a major event. Because snow is not a uniform event, it is expected that there will be some degree of randomness to the manner in which the anti-icing system responds to various snow events. This is the case, and it can be seen that there is no dominant pattern driving the spray program pattern; an indication that the bridge anti-icing system is functioning adequately to handle smaller snow events.

For a smaller winter storms, the first concern for the bridge is moisture adhering to the deck. Therefore, predictive sprays should occur relatively early in the event. When the precipitation rate increases (or the deck temperature decreases), frozen snow and/or ice may form on the deck faster. However, unlike the major snow events, the predictive models of the anti-icing system should be able to respond at a rate equal to or greater than the storm intensity. Therefore, the number of chemical sprays should be greatly reduced for frozen snow or ice. Likewise, once the precipitation has stopped, moisture may re-freeze on the deck surface and "black ice" may form. The anti-icing system should spray to address this.

PREVENTATIVE SPRAYS

An additional benefit of having an anti-icing system installed on the bridge deck is that conditions are continuously monitored, thereby allowing proactive measures to be implemented prior to the occurrence of a winter weather event. Due to the unique characteristics of the bridge surroundings, there have historically been several instances of moisture, not directly related to a winter storm, freezing on the deck. Results from the operational test show that the system sprayed on 38 days that were not considered winter weather events. Additional findings include:

- 23 of the 38 (61%) days, the system sprayed three times or less to treat isolated instances;
- Fifty three percent (53%) of the sprays, when the temperature was below 15°F, were not related to an individual event. The majority of these sprays were for the formation of ice, "black ice", or favorable conditions for their formation.

Traditionally, maintenance crews are reactive to conditions not directly related winter weather events such as "black ice" or re-freeze. However, the anti-icing system takes a proactive approach in treating these events prior to incidents occurring. Table 7 presents a summary of the preventative spray during the operational test period.

TABLE 7 SUMMARY OF SPRAY TREATMENTS FOR PREVENTATIVE MEASURES

Days Sprayed	**Black Ice**	**Frost**	**Ice**	**Predictive**	**Frozen Snow**	**Manual**	**Total Sprays**
38	4	4	61	47	5	18	139

Source: Mn/DOT, Metro Division Maintenance

Different sensors react and interact with the anti-icing system differently. Analyses of the aggregate results of the sprays listed in Table 7 indicate the following:

- A majority of the sprays were proactive to treating weather events. Some of the sprays occurred several hours prior to the start of a winter event;
- Sprays in the categories of Black Ice, Frost, and Ice generally occurred because that particular condition was beginning to form;
- Predictive sprays occurred because, although the roadway had not yet become slippery, the situation was favorable for the formation of ice or other slippery conditions (the slippery conditions may or may not have actually formed if there were no sprays);
- The majority of frozen snow sprays occurred during clean up operations after major snow events when snow was being pulled from the shoulder over the sensors on the bridge;
- Manual sprays typically occurred during snow events, however some of the manual sprays could be categorized as routine maintenance and/or testing of the system.

CASE STUDY

During the winter of 2000-2001, December was particularly hard for the Midwest due to a series of Alberta Clipper-type storms that moved across the northern plains. An Alberta Clipper is a fast moving system diving southeast from the Canadian province of Alberta, usually producing a band of snow several hundred miles wide, and usually lasting 6 hours or less, with accumulations of 1-3" of snow. Many times these storms move so fast that conditions at the surface do not have time to form features to match the upper level portion of the storm (i.e., no surface low pressure). Following the storm is usually a brief period of strong winds followed by a reinforcement of cold air. During December of 2000, many of the clippers developed in the textbook fashion, however as these storms reached the upper Mississippi Valley, slowed, and strengthened. This caused much more snow, stronger winds, and in turn drove more cold air south than the typical variety of Alberta Clipper.

The case study storm for the bridge anti-icing system evaluation formed on December 15, 2000, in the mountains over western Montana. As was typical of the storms during December of 2000, it appeared to be a textbook Alberta Clipper system. By 6:00 p.m. on the 15th, the low pressure center was situated across north central Nebraska. The storm produced a band of snow across Iowa and Missouri, then moved north throughout the evening. The band of snow finally reached Minneapolis by midnight. By early morning it had moved east into central Minnesota where it stopped. During the morning of the 16th, the snow band of the storm remained over eastern Minnesota until it finally began to exit the state to the east. Extremely strong winds followed the storm. The storm dropped more than 5" of snow. Temperatures before the storm were around 20°F, while in the subsequent two days, most of the area struggled to get above zero.

During this winter storm (Event 9 in Table 4), the anti-icing system sprayed 16 times. When the storm ended, the system sprayed twice more when temperatures were below 0°F and ice was forming on the bridge deck. Table 8 displays how the system functioned during this winter event. The first spray occurred at 11:55 p.m. as the storm was just entering the Minneapolis area. The air temperature and deck temperature were fairly close and frozen snow was detected on the bridge. For the next five hours the system monitored the conditions on the bridge and sprayed the potassium acetate, in an attempt to eliminate the snow from the deck. After the spray at 5:03 a.m. on December 16, frozen snow was no longer detected on the bridge deck (and snow was no longer falling). The anti-icing system prevented the accumulation of snow on the deck. The chemical continued to melt snow on the deck, but an additional spray was required at 7:07 a.m. to eliminate "black ice" that was forming due to traffic congestion and re-freezing on the deck. An additional spray was needed 32 minutes later as a predictive measure to prevent the moisture from re-freezing. At 10:15 a.m., the deck temperature was lower than the freezing point. Therefore, the system called for a spray due to the formation of ice on the deck. Additional sprays were required for ice and frost formation on the bridge deck until the afternoon commute started. At 5:07 p.m., the anti-icing system sensed moisture on the deck (probably due to vehicle exhaust) and conditions were favorable for the formation of "black ice". As a result, the anti-icing system sprayed chemical onto the bridge to prevent it from forming. The next morning the anti-icing system called for two sprays to address the favorable conditions for ice formation on the bridge deck. The anti-icing system continued to monitor the conditions on the bridge and did not call for any additional sprays until the next storm entered the area in the early morning of December 18.

TABLE 8 CASE STUDY STORM FOR BRIDGE ANTI-ICING EVALUATION

Date	Time	Deck temp	Air temp	Freeze point	Precip	Surface	Conditions	Spray Program
12/15/00	23:55	19.5	19.3		snow	wet	frozen snow	2
12/16/00	1:11	19.9	19.3	32	snow	wet	frozen snow	4
12/16/00	1:31	20.0	19.4	32	snow	wet	frozen snow	4
12/16/00	1:55	20.0	19.5	32	snow	wet	frozen snow	4
12/16/00	3:07	20.0	19.9	32	snow	wet	frozen snow	4
12/16/00	3:31	19.9	19.9	32	snow	wet	frozen snow	4
12/16/00	3:59	19.7	19.5	32	snow	wet	frozen snow	4
12/16/00	5:03	19.6	18.7		snow	wet	frozen snow	3
12/16/00	7:07	19.3	18.8		snow	wet	"black ice"	2
12/16/00	7:39	19.8	19.8		snow	wet	preventative	2
12/16/00	10:15	22.6	20.2	25.4	-	wet	Ice	5
12/16/00	13:15	24.1	14.4	24.1	-	wet	Ice	5
12/16/00	13:43	21.8	13.5	24.3	-	wet	Ice	5
12/16/00	14:11	20.4	12.5	24.3	-	wet	frost	2
12/16/00	17:07	12.5	8.4		level 1	wet	"black ice"	2
12/16/00	19:35	8.1	5.3	9.4	-	wet	Ice	5
12/17/00	8:59	-2.2	-6.1	8.8	-	wet	Ice	5
12/17/00	9:31	0.1	-5.9	4.3	-	wet	Ice	5

Source: Mn/DOT, Metro Division Maintenance (temps in degrees Fahrenheit)

TRAFFIC CRASH ANALYSIS

Traffic crash statistics recorded in the State of Minnesota Traffic Information System (TIS) database have been collected and analyzed for each of the seven winter seasons in this study. The purpose of this portion of the study is to assess whether there was a reduction in crashes during the most recent winter season when the automated bridge anti-icing system was used to provide preventive and corrective snow and ice treatment for the bridge deck. The system was fully operational during the entire winter season except for a 14-day period extending from December 31, 2000 to January 13, 2001, when more traditional snow and ice prevention and removal methods were used to treat the bridge deck. Only one crash occurred during this non-operational period and does not significantly affect the results of this study.

Statistical data is entered into the TIS database from crash reports filed by the responding enforcement officer and the motorists and/or pedestrians involved. The enforcement officer's report is the primary document for data entry into the TIS system, with the drivers'/pedestrians' reports being used for the rare occurrences when an enforcement officer did not respond to the crash. A crash is entered into TIS using crash identification number, date, time, number of vehicles involved, and roadway mile marker reference points. Alpha and numeric coding is used on the crash reports and entered into TIS describes many other parameters and prevailing conditions at the time of the crash. All coding parameters are displayed in the Appendix.

The crash/injury severity code is taken from the enforcement officer's report and in many cases can be very subjective. It reflects only the worst rating given to any person involved in the crash. The enforcement officer uses his/her experience and judgment to assess the severity of the crash based on his/her observations at the scene. In some cases they may accomplish follow up investigation into the severity of injuries sustained by crash victims who are hospitalized immediately from the scene of the crash. This is not reflected in TIS and the safe assumption is most severity codes are assigned solely based on the observations at the crash scene. The severity code is also used to assign a total dollar cost to the crash that only reflects a single application of the worst rating given. Thus a multi vehicle crash with several fatalities and other serious injuries would have the same severity code and dollar cost assigned as a single vehicle crash with one fatality. Baseline dollar values assigned to crashes are specified by the US Department of Transportation's Federal Highway Administration in Technical Advisory T 7570.2, October 31, 1994. These baseline values are adjusted annually using the Gross Domestic Product (GDP) implicit price deflator issued by the Office of the Secretary of Transportation (OST). Current values are as follows: fatal = $3,400,000, "A" injury = $260,000, "B" injury = $56,000, "C" injury = $27,000, property damage only = $4,000.

TIS summary reports, containing all reported crashes on the bridge, were produced for each winter season in this study. Copies of all corresponding crash reports were obtained to check TIS summary data and provide access to comments written on the reports by the people involved in the crashes and the responding enforcement officers. The written comments provided very little if any useful information for this study other than some limited cases where they clarified some coded entries. Table 9 contains a summary of the TIS reports for the study period.

TABLE 9 TIS CRASH SUMMARY

Bridge 9340 Winter Season Crashes			
Winter Season (11/1 – 3/31)	**Average Daily Traffic (ADT)**	**Total Number of Crashes**	**Total Crash Cost ($)**
1994-1995	120,751	13	104,000
1995-1996	123,177	48	491,000
1996-1997	127,018	36	507,000
1997-1998	131,974	13	150,000
1998-1999	135,972	20	253,000
1999-2000	137,484	17	166,000
2000-2001	138,874	18	210,000
Crash Totals		165	1,881,000
Winter Season Averages	130,750	23.57	268,714

Source: Mn/DOT, Metro Division Maintenance

Table 9 shows that the 1995-1996 and 1996-1997 winter seasons easily had the worst total crash history during the study period. The 2000-2001 season had a 50% reduction in total number of crashes over the comparison season (1996-1997), even with an increase in ADT of 9.3%. There was even a greater reduction (62.5%) from the next best comparison winter season of 1995-1996.

Figure 5 highlights the significant decrease in total crashes for the 2000-2001 winter season when compared to the 1995-1996 and 1996-1997 winter seasons. Included in this figure is a separate entry for the total number of crashes in each season where the road surface condition was coded in TIS as anything other than dry. The road surface was coded as dry for 49 of the 165 total crashes. The remaining 116 non-dry road surface crashes includes 28 coded as wet, 11 coded as snow/slush, 76 coded as ice/packed snow, and 1 coded as debris. The single use of the misc. code was for a crash where the enforcement officer's and one driver's report described the debris involved as ice on the road surface. NWS weather data for MSP shows that 93.0% of the time freezing temperatures were recorded at or near the time of all non-dry road surface crashes. For just those non-dry crashes with the road surface coded as wet, freezing temperatures were recorded 77.8% of the time at MSP. No attempt was made during the study to correlate bridge deck (surface) temperatures to those recorded at MSP. For this study it is assumed that the temperature difference between the bridge and MSP is negligible.

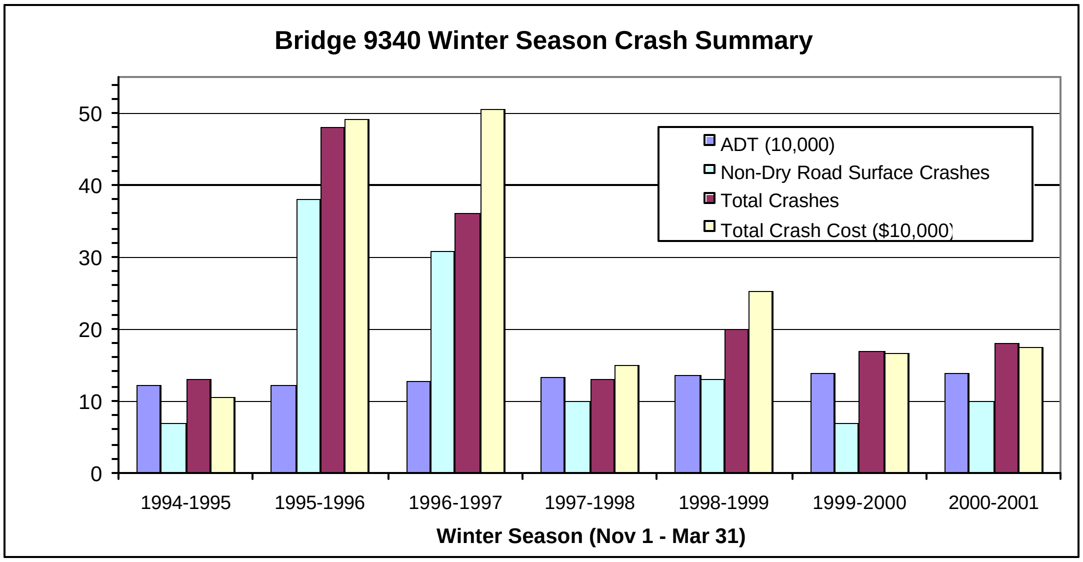


FIGURE 5 TIS CRASH SUMMARY

Tables 10 contains a summary of all non-dry road surface crashes, while Table 11 summarizes all dry road surface crashes, for each of the study's seven winter seasons. Each table contains a more detailed breakdown of all reported crashes to include numbers of vehicles involved and TIS crash severity classification. There are no apparent cost trends evident for either road surface classification crash type from a yearly perspective. The average cost per non-dry road surface crash is higher but the subjective nature of this rating and wide disparity in assigned cost per crash type makes any trend here irrelevant. The important aspect of crash severity cost is that any crash has the potential to involve fatalities or severe non-life threatening injuries thus, the ultimate goal is to reduce crash rates in general.

TABLE 10 TIS NON-DRY SURFACE CRASH SUMMARY

I-35W Mississippi River Bridge No. 9340 Winter Season Non-Dry Road Surface Crash Summary

Winter Season (Nov 1– Mar 31)	Crashes	Vehicles Involved	Average Vehicles Involved	Fatal Crash	Incapacitating Injury (“A”)	Non-Incapacitating Injury (“B”)	Possible Injury (“C”)	Property Damage Only (“N”)	Total Cost* ($)	Average Cost* per Crash ($)
1994-1995	7	16	2.3	0	0	1	0	6	80k	11.4k
1995-1996	38	94	2.5	0	0	0	12	26	428k	11.3k
1996-1997	***31***	***73***	***2.4***	***0***	***0***	***2***	***8***	***21***	***412k***	***13.3k***
1997-1998	10	20	2.0	0	0	1	2	7	138k	13.8k
1998-1999	13	29	2.2	0	0	2	2	9	202k	15.5k
1999-2000	7	13	1.9	0	0	0	1	6	51k	7.3k
2000-2001	***10***	***19***	***1.9***	***0***	***0***	***0***	***5***	***4***	***151k***	***15.1k***
Crash Totals	116	264		0	0	6	30	79	1,462k	
Season Averages	16.6	37.7	2.2	0.0	0.0	0.9	4.3	11.3	209k	12.5k

Source: Mn/DOT, Metro Division Maintenance
* k = 1000’s of dollars
Bold italics represent comparison years

TABLE 11 TIS DRY SURFACE CRASH SUMMARY

I-35W Mississippi River Bridge No. 9340 Winter Season Dry Road Surface Crash Summary

Winter Season (Nov 1– Mar 31)	Crashes	Vehicles Involved	Average Vehicles Involved	Fatal Crash	Incapacitating Injury (“A”)	Non-Incapacitating Injury (“B”)	Possible Injury (“C”)	Property Damage Only (“N”)	Total Cost* ($)	Average Cost* per Crash ($)
1994-1995	6	15	2.5	0	0	0	0	6	24k	4.0k
1995-1996	10	19	1.9	0	0	0	1	9	63k	6.3k
1996-1997	5	18	3.6	0	0	1	1	3	95k	19.0k
1997-1998	3	8	2.7	0	0	0	0	3	12k	4.0k
1998-1999	7	14	2.0	0	0	0	1	6	51k	7.3k
1999-2000	10	22	2.2	0	0	1	1	8	115k	11.5k
2000-2001	8	21	2.6	0	0	0	1	8	59k	7.4k
Crash Totals	49	117		0	0	2	5	43	419k	
Season Averages	7.0	16.7	2.5	0.0	0	0.3	0.7	6.1	59.9k	8.5k

Source: Mn/DOT, Metro Division Maintenance
* k = 1000’s of dollars

The most profound observation from Table 10 is the 68% reduction in non-dry crashes from 1996-1997 (31 non-dry crashes) to the 2000-2001 winter season (10 non-dry crashes). An even greater reduction, 74% (reduction of 28 crashes), is seen when compared to the worst crash season, which is also the next best weather comparison season, 1995-1996. Crashes that occur when the road surface is non-dry and temperatures are at or below freezing are the ones the automated bridge anti-icing system is designed to reduce.

It is expected that the anti-icing system will have no effect on the relative number of dry-road surface crashes. This is apparent in Table 11 where the mildest winter season (1999 -2000) had as many dry road surface crashes as the most severe winter weather seasons.

The TIS crash data for the bridge shows that a significant reduction in crashes occurred with the automated anti-icing system installed and functional on the bridge during the recent winter season as compared to previous winter seasons with similar weather conditions. **This reduction is approximately 68%** (31 non-dry crashes in 1996-1997, 10 in 2000-2001). Since the automated system provided the vast majority of preventive and corrective treatment of the bridge deck, it can be said that this tangible reduction in non-dry road surface crashes is primarily the result of the performance of the automated system. As evidence, dry road surface crashes did not change in any significant manner because they are not linked to the weather conditions and thus the method used to provide road surface snow and ice maintenance.

TRAFFIC CONGESTION IMPACTS

Mn/DOT Traffic Management Center (TMC) loop detector data was used in an attempt to characterize traffic congestion resulting from specific winter season crashes occurring on bridge #9340. The closest loop detectors are located approximately 0.012 miles north of the north abutment for the 3 southbound thru lanes and approximately 0.240 miles south of the south abutment for the 3 northbound thru lanes. Several other loop detectors are located within a few miles both north and south of the bridge.

Bridge #9340 carries I-35W across the Mississippi river near downtown Minneapolis, MN and experiences both heavy local and thru traffic. Morning and evening rush hours significantly increase traffic volume with the largest increase being southbound into Minneapolis during the morning and the opposite direction during the evening. Current bridge ADT is approximately 139,000 vehicles.

The bridge has three main travel lanes with an additional acceleration/deceleration lane in both the north and southbound directions, for a total of eight lanes. The acceleration/deceleration lanes service entrance and exit ramps located on both ends of the bridge for Washington and University Avenues. The close proximity of these two city streets adds to congestion on the bridge by creating a significant merging movement. Positive benefits of nearby exit ramps include providing convenient points for diverting traffic flow after crashes have occurred on the bridge, easily accessible bridge egress points to clear vehicles involved in crashes, and useful ingress points to the bridge for emergency response vehicles.

A congestion analysis considered a test area larger than the bridge structure itself. The Mn/DOT – Metro Division Freeway Operations group recommended a 6.5 mile control section centered on the bridge structure. Examination of this control section reveals that secondary crashes and other incidents occur routinely and coincide with crashes on the bridge structure. ***In fact, there were only three crashes on the bridge over the past seven years that did not also have any sort of secondary traffic impacts.*** Those crashes and congestion costs are summarized in the following list (using a value of $10/veh-hr of delay):

- Crash #1: 1/7/99 – 2 car crash in AM in SB direction, delay = 472 veh-hrs = $4,720.00

- Crash #2: 2/1/96 – 2 car crash in AM in NB direction, delay = 173 veh-hrs = $1,730.00

- Crash #3: 12/18/95 – 2 car crash in PM in NB direction, delay = 0 veh-hrs = $0.00

It should be noted that crash #3 had no measurable delay. This crash occurred at the end of a peak period and was cleared immediately. It should also be noted that the delay and costs identified above are conservative numbers. Another primary source of delay, opposite direction "gawker" slow-down, was not considered. It is beyond the scope of this study to attempt to quantify the delay associated with, and monetary impacts of, opposite direction "gawker" slow-downs.

A standard vehicle delay was calculated for each of the three crashes, but unfortunately it is difficult to represent the average delay encountered by each vehicle due to a crash on the bridge structure. A larger and more in-depth study would be required if those questions need to be answered more accurately. However, these crashes do represent fairly well what the effects on delay are for a single event on the structure. And, by making some assumptions, the delay saved by the anti-icing system can be crudely estimated. A detailed congestion analysis is presented in the Appendix.

TOTAL TRAFFIC DELAY SAVINGS EXTRAPOLATION

For the traffic delay savings extrapolation, it is assumed that crash #1 is a representative crash on the bridge and weather has no impact on the traffic demand. So by using a crash reduction of 68% (taken from reduction of 21 non-dry crashes), delay savings are estimated as:

Value of Delay Savings = (21 events saved/year) * ($4,720 savings/event) = $99,120/year

It was noted above that $4,720 savings/event is a conservative number. Also, secondary crashes that may have been averted (because of the elimination of the primary crash) were not considered in the above value of delay savings. For these two reasons, ***delay savings of $99,120/year should be considered an extremely conservative estimate.***

MANAGEMENT CONSIDERATIONS

The following section will help the Mn/DOT decision makers in quantifying future policy decisions. The following sub-sections define areas that may be need to be given more attention during future anti-icing installation projects. Consideration is also given to the value of anti-icing, both from an operational and financial perspective.

SYSTEM CONSTRUCTION

It was decided very early that Mn/DOT - Metro Division Maintenance forces would coordinate the design and construction of this system. There were only two Maintenance staff positions that could deliver that request and, at that time, they both had little experience with even typical roadway construction projects. In addition, Mn/DOT - Metro Division Maintenance had no funding resources for these kinds of projects. As a direct result, many construction issues arose.

SYSTEM OPERATIONS AND MAINTENANCE

The bridge anti-icing system must be operated and maintained. It requires people to fill the tanks, repair worn out parts, analyze and improve system performance through changing software variables. Inspections and preventative maintenance need to occur every year, to insure that the system is operating properly and efficiently, until it reaches a point where maintenance costs out weigh the replacement cost. Training efforts must be pursued and spare parts must be purchased and maintained to insure speedy repair.

During start-up and the operational test, a Maintenance support staff member was dedicated specifically to this project. Once the test is complete, his responsibilities will be transitioned to routine bridge maintenance staff. Bridge maintenance will develop the expertise to run and maintain the anti-icing system by learning from the previously dedicated Maintenance support staff member as well as through "on-the-job" training. The risk of this transition is one of reducing the knowledge base and priority, and ultimately not providing the attention to the system that it requires, which sometimes can happen when more responsibilities are assigned to existing staff without increasing staffing or budget levels.

ANTI-ICING ENOUGH?

The anti-icing system that is installed on I-35W and the Mississippi River bridge is designed to prevent the bridge deck from becoming icy. The system is not designed to melt heavy snow off of the bridge deck nor designed as a replacement of the snow plow. This was demonstrated during each major winter weather event that occurred during the operational test. The anti-icing system *does* provide benefits during these major events but the system is not, in and of itself, enough. The system is an additional maintenance tool that can be deployed to fight large winter storms and improve level of service.

COST EFFECTIVENESS

Cost effectiveness is very difficult to assess with a first of its kind project. There are no mass production benefits in the chemical or system purchase, and installation and "shake-down" times are long and costly. Subjectively, the following question can be asked: "What does it cost **not** to have an anti-icing system?":

1) Can a DOT supervisor afford to continue to brake-off a crew of six snow plow trucks during rush hour to specially treat an 8-lane bridge deck that is reported to be icy and under stop-and-go traffic conditions?

2) The current anti-icing system resolved the ice condition problem that exists on the bridge at very cold temperatures. The system sprayed 129 times when the temperature was below 15°F, the temperature at which traditional chemicals (i.e., sodium chloride) lose effectiveness. While traditional chemicals would have been useless, CF7® was able to effectively prevent the formation of ice (CF7® is effective to -15°F and below).

The Benefit/Cost ratio is estimated at over 3:1, using the following values:

1) Cost of system:

   - Construction/Installation = $618,450
   - Replacement[1] = $7,420/year (general parts and computers)
   - Maintenance[1] = $2,305/year (pump house, pumps, valves, snooper rental, general)
   - Utilities[1] = $1,050/year (phone and electric)
   - Chemical = $55,250/year (17,000 gal/yr)

   [1] Taken from Preliminary Benefit/Cost Analysis

2) Benefit of the system:

   - Crash reduction = (21 crashes/year)* ($12,529/crash – from Table 10) = $263,109/year
   - Delay reduction = (21 crashes/year) * (472 veh-hrs/crash) * ($10/veh-hr) = $99,120/year

3) Design Life of system = 15 years

$$\text{Benefit/Cost Ratio} = \frac{15*(263{,}109 + 99{,}120)}{618{,}450 + 15*(7{,}420+2{,}305+1{,}050+55{,}250)} = \mathbf{3.4}$$

AUTOMATED VERSUS MANUAL ACTIVATION

During three minor weather events the system was not fully automated (shaded entries in Table 6). This deficiency presented an opportunity to quantify the impact of having a sensing/predicting system versus manually determining the appropriate time to spray the bridge. This comparison reveals that manual spraying results in over a 70% increase in the number of sprays performed. In fact, all minor events were treated with an average of approximately 7 sprays per event and the three non-automated events used an average of 12 sprays per event.

Mn/DOT - Metro Division Maintenance dispatchers have also used the sensor information for other purposes. It was discovered that once the dispatchers were able to trust the sensor information as being accurate, they were able to dispatch trucks to other routine trouble spots in the metro area when ice formation was detected on the I-35W Mississippi River bridge (because trouble spots tend to become icy at approximately the same time). Because the sensor data on this bridge indicated that the formation of ice was imminent approximately 15 minutes before the other trouble locations became icy, and trucks were dispatched to the other trouble spots at that time, the net result was automatic pre-treating of the other trouble spots.

CONCLUSIONS AND RECOMMENDATIONS

The operational testing of the anti-icing system installed on I-35W Bridge over the Mississippi River was very successful. The 2000-2001 winter offered many diverse weather events and from the results, several conclusions can be drawn:

- The system performed very well in all of the winter events encountered. It detected the environmental conditions, selected the correct spray programs, and prevented slippery driving conditions from occurring on the bridge deck even during stop-and-go traffic conditions.

- With the system, a better level of service was provided to the motoring public than was without the system. The number of winter season crashes on the bridge was reduced by 68%, which also economically benefits the general motoring public not involved in the primary crash by reducing congestion and secondary crashes.

- The system eliminates the need for dedicated maintenance responses to slippery conditions on the bridge deck. It continuously monitors environmental conditions thereby allowing proactive measures to be implemented prior to a weather event occurring. This happened 38 different times during the test period.

- Internal DOT knowledge base was increased. The system forces Snow and Ice managers and supervisors to more closely examine what treatments are effective for the different weather events and how newer technologies and chemicals may be integrated with the more traditional methods.

This system sets an anti-icing precedent nationwide, being the first of its kind successfully installed and operated on a 1950-foot bridge structure in a metropolitan area. It is recommended that Mn/DOT management addresses the following recommendations, which were derived from observable data and experiences, and selected based on results obtained during the operational test of this anti-icing system.

1) Continue operations of the existing anti-icing system until maintenance costs out weigh replacement costs, at which time a replacement system should be considered;

2) Continue using CF7® because of its environmental advantages;

3) The use of parapet sprayers should be minimized because of plugging problems;

4) Additional spray disks should be installed upstream of the bridge structure for both approaches. Doing this would allow maintenance crews to approximate deck conditions by judging upstream conditions, which would limit the amount of sodium chloride applied on the deck;

5) For subsequent anti-icing system projects, additional consideration should be given to the pump house design, including tank location and size, containment structure, ventilation, addition of utility closet, and water availability;

6) Bring this anti-icing system to the attention of Mn/DOT upper management to increase awareness and comfort level;

7) Develop an internal Mn/DOT program delivery team to coordinate the deployment of future anti-icing systems. Include the development of a 5 and 10 year plan to identify funding and resources, and integrate with other new bridge construction and rehabilitation projects;

8) Develop warrants for anti-icing system installations (many bridge structures do not need anti-icing systems);

9) Develop an internal Mn/DOT Metro Division team for on-going operations of all anti-icing systems. These systems are not "humanless" and require people to coordinate summer changeovers, fine-tune operational variables, integrate software improvements and new versions, and coordinate with other anti-icing initiatives;

10) Discontinue new research in all areas of bridge anti-icing delivery techniques. Research efforts should concentrate on the following areas:

    - System effectiveness during heavy snow events – this will increase system efficiency by minimizing the amount of chemical necessary.

    - On-grade pavement anti-icing systems on mainline segments.

    - Pavement sensor networking and integrating – this will increase system efficiency by doing a better job of determining the time at which sprays should begin.

11) During the non-winter months (April – October), when CF7® has been replaced with water, the system should be energized on a monthly or bi-monthly basis to check piping and connections, and to help prevent small sand particles from plugging the spray nozzles.

12) In future applications, do not use Advanced Warning Flashers to alert motorists of anti-icing activity on the bridge. Roadway signing usually is used to information motorists of actions they should or should not take. However, in this case it is not clear to the motorist what should do differently when the flashers are active (and in fact, no action should be taken at all).