Bridge Prioritization for Installation of Automatic Anti-icing Systems in Nebraska

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ABSTRACT

During severe winter conditions bridges freeze before the surrounding roadways, often catching unsuspecting drivers off guard. Depending on weather and pavement conditions, automatic bridge deck anti-icing systems spray chemicals that prevent or minimize ice bonding to the pavement. The Nebraska Department of Roads (NDOR) is interested in installing such systems on various bridges statewide. However, the presence of 2,193 bridges in Nebraska and availability of limited funding required candidate bridge prioritization for installation of automatic anti-icing systems based on relevant criteria. This research was undertaken with the objective of developing a decision-aid tool that could aid NDOR with the prioritization of bridges for installation of automatic anti-icing systems.

The authors reviewed literature on automatic bridge anti-icing systems and the experiences of various transportation agencies. Factors considered important in the installation of automatic anti-icing systems included: accident history, bridge alignment, weather, traffic, and bridge distance from maintenance yard, among others. A methodology to build a database of relevant factors and a decision-aid tool that helped with narrowing the list of candidate bridges was developed. Database construction involved merging information from a variety of disparate sources in a geographic information system on factors deemed important in prioritization of bridge deck anti-icing system installations. Some of the sources included NDOR bridge inventory, NDOR accident database, archived weather data from the High Plains Regional Climate Center and the National Weather Service, Nebraska streets database, Nebraska rivers and streams database, and NDOR maintenance yard data. Four different decision-aid methods were initially incorporated in the decision-aid tool: benefit-cost ratio, cost-effectiveness, utility index, and composite programming. However, subsequent research indicated that for various reasons, the prioritization results from the four methods were not suitable for Nebraska. As such a fifth method, called the NDOR Preferred Method, was developed in close consultation with the project's technical advisory committee. The prioritization results from this method were accepted after extensive scrutiny. The data integration methodology and the processes developed in this research should be useful to other transportation agencies contemplating a methodical approach to installation of automatic bridge deck anti-icing systems for highway safety enhancement.

Key words: anti-icing—bridge—geographic information system—Nebraska—prioritization

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BACKGROUND

A major safety issue during severe winter weather is the freezing of moisture on bridge decks before moisture-freeze on the rest of the roadway surface. Many traffic accidents occur when unsuspecting drivers lose control of their vehicles while traveling over frozen bridges. To mitigate this issue, some state transportation agencies have successfully used automatic bridge deck anti-icing systems. These systems apply deicing liquid chemicals to bridge decks when icing conditions are detected, thereby preventing moisture from freezing on the bridge deck (see Figure 1). The Nebraska Department of Roads (NDOR) is interested in installing automatic bridge deck anti-icing systems in Nebraska for safety enhancement. However, the presence of 2,193 bridges and the availability of limited funds necessitate candidate bridge be prioritization for installation of such systems. Therefore, a research project to prioritize bridges for the installation of anti-icing systems was initiated by the NDOR along with the University of Nebraska-Lincoln.

The objective of this research was to develop a decision-aid tool for prioritizing bridges for most effective installation of automatic bridge deck anti-icing systems in Nebraska. To achieve this objective, the authors extensively reviewed literature on automatic bridge deck anti-icing systems as well as experiences of various transportation agencies with such systems. Based on this review, a two-step methodology was developed to guide the construction of an appropriate database and the development of the decision-aid tool for bridge prioritization. Data from a variety of disparate sources were integrated in a geographic information system (GIS) to construct the needed database and a number of prioritization methods were incorporated in the decision-aid tool. Using the decision-aid tool, two candidate lists of bridges were developed for installation of automatic bridge deck anti-icing systems for Omaha and non-Omaha areas. This paper describes the findings from the literature review, the research methodology, construction of the database, development of the decision-aid tool, and prioritization of the candidate bridges for installation of automatic bridge deck anti-icing systems. For complete details on this project, the readers are referred to the report by Khattak et al., (*1*).

LITERATURE REVIEW

An automatic bridge deck anti-icing system sprays deicing chemicals on a bridge deck from nozzles installed in the pavement or bridge parapet/railing. Such a system is intended to prevent freezing of the bridge deck prior to the rest of the roadway, thus making it safer for users. Several studies have documented the benefits of automatic bridge deck anti-icing systems. Friar and Decker (*2*) reported a 64 percent reduction in the number of reported accidents due to installation of such a system in Utah. A study by Stowe (*3*) indicated a benefit-cost ratio of 2.36 and a net benefit of $1,179,274 for an automatic anti-icing system. The Minnesota Department of Transportation (MnDOT) reported on three automatic anti-icing system installations in Minnesota: Interstate 35 Bridge near Duluth, Truck Hwy 61 Bridge near Winona, and an intersection in Dresbach (*4*). MnDOT reported accident reductions of 56, 100, and 100 percent at the Duluth, Winona, and Dresbach locations, respectively. Benefit-cost ratios of 2.0, 3.1, and 2.7 were reported for these three locations. Another Minnesota-based study by Johnson (*5*) evaluated the I-35W and Mississippi River Bridge anti-icing system. The evaluation indicated a reduction of 68 percent in the number of winter season accidents on the bridge and a benefit/cost ratio of 3.4.

Barrett and Pigman (*6*) evaluated a bridge deck anti-icing system installed on southbound I-75 at the North interchange to Corbin, Kentucky. After four winter seasons, the system had minimal problems and worked efficiently. However, the system's effectiveness was limited by its location. Being on an interstate, the bridge was subject to significant winter maintenance activities anyway, and it was located in a part of the state that does not receive abundant precipitation. Barrett and Pigman recommended that the system be used in the following places: 1) accident-prone areas, 2) isolated bridges that require deicing trucks to travel an unreasonable distance to treat, 3) remote areas that are difficult to reach in bad weather, and 4) bridges over water, which may be more susceptible to freezing moisture.

Finally, NDOR conducted a survey (unpublished) to assess automatic anti-icing system usage among state transportation agencies and to determine the existence of any criteria and guidelines for deploying such systems. Of the 19 agencies that responded to the survey, eight (42 percent) indicated they either use or plan to use bridge deck anti-icing systems. Only two (10.5 percent) state agencies (Maryland and Wisconsin) indicated that they have prioritized plans for the installation of such systems. Major criteria used by Wisconsin include: accident history, bridge grade, locations susceptible to black ice or frost, super-elevated decks, average daily traffic (ADT), distance from the nearest salt stockpile, potential for moisture generation, high winds, and bridge span. The NDOR survey asked respondents what criteria they would use for prioritization of bridge locations. Some of the frequently cited criteria were accidents, bridge distance from maintenance yard, and adverse weather.

In summary, the literature review indicated the economic viability of automatic anti-icing systems. The benefit-cost ratios of such systems are in the range of 1.8 to 3.4 and accident frequency reduction varies from 25 to 100 percent. However, benefits from these systems are location-dependent. Very few state transportation agencies have bridge prioritization plans for installation of automatic bridge deck anti-icing systems. Some of the important factors in bridge prioritization include accident history, bridge alignment, weather, and distance from maintenance yard. The next section presents a brief narrative of the methodology adopted by the authors for this research.

METHODOLOGY

Figure 2 presents the methodology used for database construction from various sources and development of the decision-aid tool. Database construction was accomplished in a GIS while the decision-aid tool was developed in a spreadsheet. Data from several sources were integrated in a GIS using a variety of processes. The data utilized included bridge inventory, state accident data, weather information, traffic information, maintenance yard information, and Nebraska streets, rivers, and streams data. Additional elements were added to the integrated data to enhance its effectiveness for usage by the decision-aid tool. The decision-support tool utilized the integrated database to provide prioritized lists of candidate bridges for the installation of automatic bridge deck anti-icing systems. A description of the database construction is given next.

DATABASE CONSTRUCTION

Data from several sources were integrated in a GIS to construct the needed database. The data sources included: state accident and traffic information from the NDOR traffic division, bridge inventory from the NDOR bridge division, and weather-related data from the High Plains Regional Climate Center and the National Weather Service. Information on maintenance yards was obtained from the NDOR maintenance division while data on Nebraska street, rivers, and streams were obtained from commercial sources. A brief description of each source, its contribution, and the integration process are given below.

The NDOR Bridge Division provided data on 2,193 bridges in the state. These data contained information on the following elements:

- structure number
- route number
- location (latitude and longitude)
- functional classification
- length of bridge
- approach roadway width
- alignment
- age
- wearing surface

NDOR maintains separate records for pairs of bridges on the same route if they are physically separate. Since the automatic bridge deck anti-icing system will be installed in both directions therefore, for this study the records of such bridge pairs were aggregated. For example, the number of lanes on both bridges were added, the number of crashes on both bridges were added, and so on. Some elements that were common among bridge pairs were not added; e.g., functional classification, bridge length, type of railing, etc.

Thirteen-year (1988-2000) state accident data were obtained from the NDOR traffic division, which maintains all police-reported accidents in Nebraska. Accident attributes included elements such as date and time of accident, road surface conditions, route number, and injury severity of those involved in the accident. Surface condition was categorized into dry, wet, snow/icy and the injuries were measured on the KABCO scale – Killed, A-type injury (incapacitating), B-type injury (evident), C-Type injury (complaint of pain), and Property-Damage-Only. Using GIS, the accident data were first imported into the GIS and then spatially merged with the bridge data. Accidents reported on or within 300 feet of either end of each bridge in the state were extracted. This effectively excluded non bridge-related accidents from the analysis. The accident data were further culled by limiting to those accidents that were reported during snowy, icy, or frosty surface conditions (information available on the accident report) or when the minimum average temperature for the day was less than 320 F and precipitation was present. The use of the average daily minimum temperature in the selection of crashes for subsequent analysis ensured that all possible crashes that might have occurred under conditions that could be ameliorated by the automatic bridge deck anti-icing system were taken into consideration. Calculation of the average minimum daily temperature is described along with the weather information.

The NDOR traffic division provided Year 2000 statewide traffic data (ADT and truck percentage), which were integrated into the database. However, the use of only Year 2000 traffic data results in bias in some of the calculations. For example, its use in calculation of bridge crash rates prior to Year 2000 results in under-estimation of crash rates, assuming ADT increases over time. The use of yearly ADT (1988, 1989, …, 2000) would overcome such a problem. However, more specific historical traffic data were not readily available. Since bridge prioritization is based on consideration of bridges relative to each other, the bias effect may be limited if the ADT growth is somewhat similar across the bridges.

Two sources were used to obtain relevant weather information: the High Plains Regional Climate Center and the National Weather Service Automated Weather Data Network (AWDN). Access to archived electronic Nebraska temperature data for the 13-year study period (1988-2000) was obtained from the High Plains Regional Climate Center. These data included the daily maximum and minimum air temperatures from 316 weather stations located throughout Nebraska. The extracted temperature data along with the weather station locations were input to the GIS. These extracted temperature data were used in the accident selection process (accidents that occurred on days when the minimum temperature was below freezing). To find temperature at the accident site on the day of its occurrence, a boundary of 25-mile radius was drawn around each bridge. Weather stations located within this boundary provided data for estimation of average minimum and average maximum temperature for the day of the accident. The 25-mile radius was selected to ensure that all accidents had at least one weather station for temperature estimation. The National Weather Service AWDN provided information on minimum and maximum wind speed and daily precipitation (this information was not available in the High Plains Regional Climate Center data). However, the National Weather Service data were limited to only forty weather stations distributed through out Nebraska. These weather stations along with their respective data were input to the GIS. Since the number of stations was less, it was assumed that the weather conditions at any bridge were similar to those reported at the nearest weather station, i.e., data from multiple stations were not averaged. The National Weather Service data also contained temperature information, which was used to estimate the number of days that each bridge experienced below freezing temperatures. Note that the weather information at each bridge was found by assuming that conditions were similar to those recorded at the National Weather Service station. Other options such as inverse distance weighted interpolation, spline interpolation, etc., could be utilized for bridge weather evaluation from the National Weather Service weather stations instead of making the assumption mentioned above. These options were not used for parsimony in this study. Also, the process described above results in the estimation of air temperature and not bridge-deck temperature. The temperature of a bridge-deck may be different than the surrounding air temperature. However, bridge-deck temperature data are rarely available and were not available for this research.

No electronic file containing location information on NDOR maintenance yards in Nebraska was available that could be promptly used in this study. GIS capability to match postal addresses to a street database was used along with postal addresses of the maintenance yards to obtain the appropriate locations of maintenance yards in the database. Information on the service areas of each maintenance yard was obtained from NDOR and manually input to the GIS. Travel times and distances from each maintenance yard to each bridge in its respective service area were calculated using the maintenance yard locations, their respective service areas, the Nebraska street database, and bridge locations. GIS capability to find the shortest path based on travel time or travel distance was utilized.

Commercially available Nebraska street data were obtained from the Environmental Systems Research Institute (ESRI) and utilized for street network and postal address matching. Travel time on each link was calculated by first finding the link length and then the posted link speed limit. The assumption in calculation of travel time is that maintenance vehicles will travel at the speed limit. However, it is possible that travel time during adverse weather may be different than the time calculated based on speed limit. Commercially available Nebraska rivers and streams geographic data were obtained from ESRI and utilized to determine the locations of rivers and streams in Nebraska with respect to the bridges. Using the “select by theme” capability of GIS, bridges located on rivers and streams were selected and identified as bridges with water flowing underneath.

Additional Elements

Additional elements were added to the database including unit accident costs for computing the cost of the accidents reported at each bridge and automatic bridge deck anti-icing system cost for each bridge. Using these costs, the loss ($) during the study period at each bridge was calculated. The addition of the above information to the database completed the database integration process in the GIS. The completed database contained information on various elements that included:

- Accident frequency under during snowy, icy, or frosty surface conditions on or within300 feet either side of bridges
- Bridge accident rate
- Accident loss ($)
- Distance of bridge from its respective maintenance yard
- Travel time to bridge from its respective maintenance yard
- Bridge age (since original construction as well as since last reconstruction)
- Number of lanes
- Bridge functional classification
- Bridge Year 2000 ADT and truck percentage
- Bridge span
- Bridge approach width
- Presence of water under bridge
- Number of days with wind speed greater than 15 mph at the bridge location
- Number of days with precipitation at the bridge
- Number of days with average minimum air temperature below freezing at the bridge
- Number of days with average maximum air temperature below freezing at the bridge

These elements were subsequently utilized in the development of the bridge prioritization decision-aid tool. However, before its usage, a number of tests were conducted to verify the efficacy of the database. These tests and the corresponding remedial measures undertaken are briefly described next.

DATABASE INTEGRITY

Tests were conducted on the database to validate its integrity and effectiveness. Minimum and maximum values for each factor were looked at to ensure that they were with in reasonable range. This test indicated unacceptably high accidents at some bridges on relatively minor routes. Investigation showed that these were overpass bridges that were mistakenly assigned the main route accidents. All overhead bridges were checked and corrected in the database. ADT values at certain locations looked suspiciously low or high. These were verified from NDOR and corrected. A test on speed limit values of various functional class highways indicated that some of the routes in the database did not have correct speed limit values. Again, these were corrected based on information obtained from NDOR. Travel times and travel distances between maintenance yards and various bridges were validated by contacting NDOR personnel who were familiar with bridge and maintenance yard locations. Weather data were validated by looking at general weather patterns in Nebraska and by comparing the values obtained from the analysis to those general weather patterns. These tests ensured, to a certain degree, that the database was ready for use in the decision-aid tool. Development of the decision-aid tool is described next.

BRIDGE PRIORITIZATION DECISION-AID TOOL

The bridge prioritization decision-aid tool was developed in a spreadsheet and it incorporated five different prioritization methods. The five methods were: 1) benefit-cost, 2) cost-effectiveness, 3) utility index, 4) composite programming, and 5) NDOR preferred method. A brief description of each method follows; for complete details of these methods the reader is referred to (*1*).

Benefit-Cost Method

Bridges were prioritized based on the ratio of benefits generated from the installation of anti-icing systems and the associated costs. Bridges with higher benefit-cost ratios were given higher priority for the installation of an automatic anti-icing system. Benefits and costs were quantified in monetary terms; estimation of benefits involved looking at avoided accidents due to installation of automatic anti-icing systems while estimation of costs was based on the purchase cost of such systems. Based on information gleaned from the literature, it was assumed that installation of anti-icing systems would result in a 60 percent reduction in accidents. Benefits were then calculated by using accident costs for different injury levels. Avoided traffic delays due to fewer accidents would also contribute to benefits; however, data required to estimate traffic delay due to accidents were not readily available and therefore, benefits from avoided traffic delays were not included in this method.

Cost-Effectiveness Method

The cost-effectiveness method evaluated each bridge based on the expected safety improvement per unit cost due to installation of an anti-icing system. The expected safety improvement of an anti-icing system was expressed in terms of a safety improvement index (SII), which was a function of the expected reduction in accident frequency and severity. Using different injury levels, SII was calculated by assuming a 60 percent reduction in accidents due to installation of the automatic anti-icing systems. The weights expressing the relative importance of accidents with different injury severity levels were proportional to the accident costs involving different injuries. The system cost was determined for each bridge based on the costs estimates used in the benefit-cost analysis. The SII was divided by the system cost to determine the safety improvement index per unit cost. Bridges were prioritized on the basis of this ratio with higher priority given to those with higher values.

Utility Index

The utility index method involved assigning weights to various criteria that were important in the comparative evaluation of bridges. A panel of experts from the NDOR was asked to provide weights to different criteria used in the Utility Index method. The weighted score for each bridge was then normalized on the 0-1 interval and used in prioritizing bridges.

Composite Programming

The Composite Programming method is somewhat similar to successive application of the Utility Index method. Individual criteria were weighted and then grouped. The groups were then assigned weights to reflect their importance relative to each other. Successive weightings and groupings produced a final score that was normalized on the 0-1 interval. The individual criteria and group weights were assigned by the panel of experts from the NDOR.

NDOR Preferred Method

The NDOR Preferred Method was developed because prioritization results from the earlier four methods were not sufficiently discriminating amongst the various criteria considered important in the installation of automatic anti-icing systems. This was due to the fact that most of the criteria were given relatively high scores by the panel of experts. Also, the project technical advisory committee placed high importance on a method that was simple and straightforward. To this end, various scenarios were created where bridges were prioritized based on different criteria. These included prioritization based on all reported accidents within +/- 300 ft of the bridges, bridge accident rate, bridge environmental considerations, geographic considerations, etc. Depending on the scenario, the high traffic experienced by the Omaha bridges resulted in skewed prioritized bridge candidate list. To avoid skewed results, Omaha bridges were separated from other bridges and two candidate priority lists developed. It was also decided to limit candidate bridges to those experiencing 13 or more accidents during the study period.

Results from the various scenarios were closely inspected; the prioritization by simple accident frequency provided the most realistic and useful results for Nebraska. As such, the decision-aid tool was modified to first limit candidate bridges to those that experienced 13 or more accidents during the study period and then prioritize those bridges on simple accident frequency. This method was simple and straight forward and provided results deemed appropriate for this research by the project's Technical Advisory Committee and the research team. Two priority lists, one each for Omaha and non-Omaha bridges, were generated based on this method. NDOR will consider bridges at the top of these two lists for the installation of automatic bridge deck anti-icing systems.

CONCLUSIONS

This research indicated that data from a variety of sources can be combined for decision-aid in installation of automatic bridge deck anti-icing systems. Several methods were incorporated in the decision-aid tool that developed in this research. This decision-aid tool provided two priority lists of candidate bridges based on criteria that were deemed most pertinent for Nebraska. Even though a relatively straight forward ranking by accident frequency was eventually used in the production of the two lists via the NDOR Preferred Method, the other methods incorporated in the decision-aid tool provide options for conducting analyses based on different considerations. Regarding the two prioritization lists, the authors recommend that they are not the final word in terms of which bridges should be installed with the automatic anti-icing systems in Nebraska. Institutional decision making is a complex process that must consider a variety of issues that are impossible to capture by a computerized process. As such, the use of these priority lists should be restricted to narrowing the list of candidate bridges to a manageable few. The authors recommended that the final decision on the bridges that would receive an automatic anti-icing system from amongst the prioritized bridges should be made by the NDOR by taking into consideration additional issues that could not be captured by the decision-aid tool.

The methodology and database integration processes presented in this paper should be useful to transportation agencies contemplating installation of automatic bridge deck anti-icing systems for highway safety enhancement. Some aspects of this research can be further refined in future studies. Better estimates of weather conditions can be obtained by using more sophisticated analyses techniques. The analyses can be improved by using pavement temperature rather than air temperature or by establishing a relationship between air and pavement temperature on a local basis (the relationship might vary from place to place). Finally, other states may have additional data sources that might be relevant in the bridge prioritization process. It is recommended that those additional data sources should be utilized to the full to help make better decisions.

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FIGURE 1. A Bridge-Deck Anti-Icing System in Operation
(Source: Odin Systems International, Inc.)

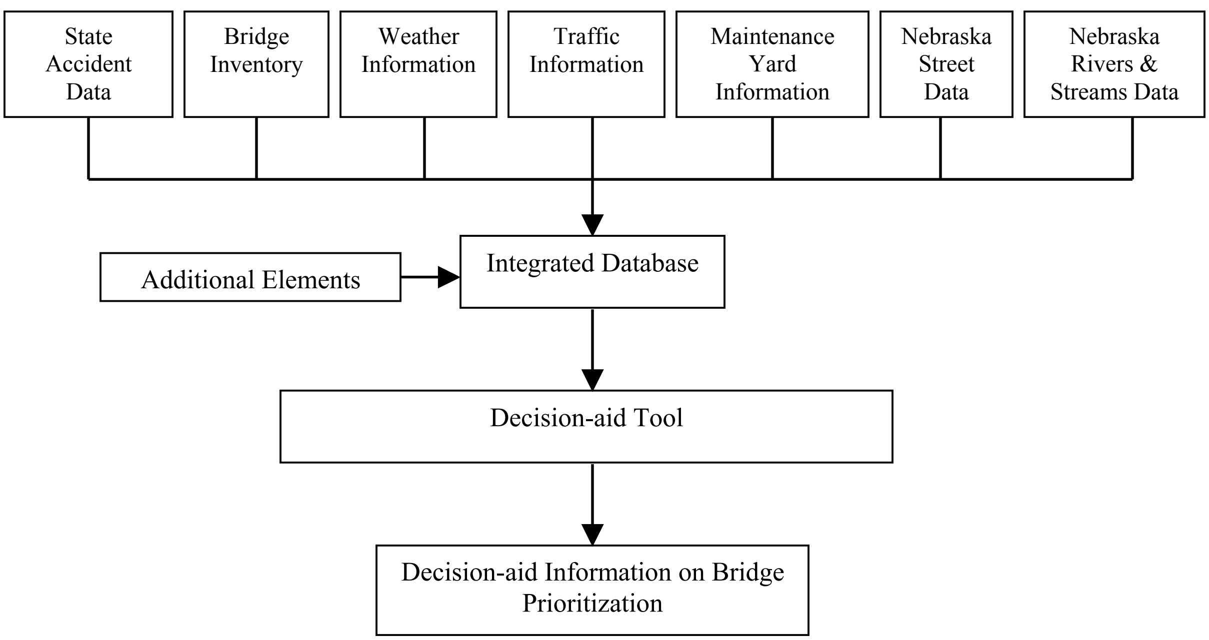

FIGURE 2. Adopted Research Methodology