Determining the Cost/Benefit of Routine Maintenance Cleaning on Steel Bridges

Course No: S03-024
Credit: 3 PDH

Gilbert Gedeon, P.E.

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.com

This course was adapted from the WSDOT Research Report "Determining the Cost/Benefit of Routine Maintenance Cleaning on Steel Bridges to Prevent Structural Deterioration", reference WA-RD 811.1, which is in the public domain.

CONTENTS

Figures

EXECUTIVE SUMMARY

Objectives

The objective of this study is to identify the key variables necessary in estimating the impact of regular washing of steel bridges on the paint and service life, recommend methods for recording data in order to most effectively estimate the benefits of bridge washing, and to develop a framework for assessing the impact of bridge washing on paint life.

Background

Thirty years ago when the environmental rules changed the WSDOT stopped annual cleaning of steel truss bridges. Some cleaning was done after this time only to assist inspection crews or to determine what the cost would be to hand clean a steel truss bridge. WSDOT is investigating the feasibility of an annual steel truss bridge washing program. A pilot study was implemented in 2011 that will help to determine the benefits and environmental impacts of such a program. This work builds on the pilot study to identify current bridge washing practices around the country and to select the measurements necessary to determine whether more regular washing has positive cost benefits.

Research Activities

A literature review was conducted to gather information from previous studies on bridge washing, the effects of washing on corrosion, and gain general knowledge on corrosion of steel, how paint condition is recorded, and environmental considerations.

To get background information on the state of practice of bridge washing across the United States a general survey was sent out to transportation agencies in North America. This was used to determine which states institute a bridge washing program and for how long they have been in place. A smaller number of states were contacted again with a more intensive survey to gain more insight into the benefits of washing programs. These states were chosen because they have had a bridge washing program in place for multiple years. The responses received were analyzed in order to draw conclusions about this issue.

A framework for assessing the benefits of bridge washing is still under development. It is suggested that WSDOT continue a pilot bridge washing program with at least 6 bridges in each of at least two different climate zones in the state. In each zone, three bridges should be washed annually and three bridges should not. Recommended statistics can then be calculated to determine the likelihood that the difference in paint life between washed and unwashed bridges will be enough to justify the costs of annual washing.

Conclusions

There appears to be little information on the ability of regular bridge washing programs to impact the paint life or corrosion performance of steel bridges. The information available has used anecdotal assumptions to demonstrate that benefits are likely but the data to support those assumptions is absent.

From the initial survey and information from the follow-up surveys it seems that very few studies relating to bridge washing and paint life have been performed. It also shows that any correlation drawn from the data received would be hypothetical at best. However, there are agencies that have demonstrated long bridge lives with a maintained washing program in addition to other routine maintenance and painting.

It is suggested that WSDOT set up an experiment that specifically monitors sets of bridges in the different areas of the state. This will enable the generation of data for the different climates as these sections of the state experience unique environments. A framework for the statistical analysis of a specified number of these bridges is under development to determine with confidence whether or not bridge washing can be considered effective. With routine inspections and well documented information WSDOT will be able to use this framework to determine whether to move forward with an annual bridge washing program.

INTRODUCTION AND MOTIVATION

The University of Washington (UW) is working with the Washington State Department of Transportation (WSDOT) to determine the costs and benefits of a routine steel bridge washing program. For almost thirty years since the change in environmental regulations, WSDOT has not cleaned bridges. During this time period the only cleaning that steel bridges received was the cleaning that was part of the contract to paint the bridge. There was some spot cleaning that occurred to facilitate inspection or repairs. The long time interval between painting contracts resulted in significant accumulation of debris and accelerated the deterioration of the paint under the debris. These materials cannot be washed into waterways and instead must be collected by hand prior to washing, resulting in an expensive and labor intensive bridge washing effort.

WSDOT is investigating the feasibility of a more frequent steel bridge washing program. A pilot study was implemented in 2011 that will help to determine the benefits and environmental impacts of such a program. The program would wash bridges annually with no manual removal of debris since the volume of debris is likely to be considerably less than what currently accumulates over the longer interval between washings, resulting in less material washed into waterways. Further, washing steel bridges more regularly may be beneficial for increasing paint life and slowing corrosion. Such benefits would help to offset the cost of more regular washing and potentially provide overall economic benefit. However, the impacts of bridge washing frequency on paint life and corrosion are currently unknown and circumstantial at best.

The research summarized in this report is a first step towards understanding and quantifying the benefits of a more regular bridge washing program on paint life and corrosion. A literature review was conducted on bridge washing programs and the effects of washing on paint life and corrosion. Notably, the literature available on these topics is sparse.

Applicable summaries of the literature obtained are given in this report. A survey of other Departments of Transportation (DOTs) was conducted to collect pertinent data regarding steel bridge washing practices and frequencies. The responses were compiled and summarized for the purposes of this report. More detailed follow-up surveys were sent to DOTs with bridge washing programs. These responses are also summarized here and provide a more detailed insight into steel bridge washing practices that may be of help to WSDOT. Finally, a preliminary framework for estimating effectiveness of steel bridge washing in extending paint life is provided. Necessary data to be collected is identified and a statistical method to determine whether bridge washing is benefitting paint life is presented.

LITERATURE REVIEW

WSDOT

WSDOT provided some cases of bridges previously inspected. One case was the 005/036E bridge located in the Southwest region of Washington on the Interstate 5 crossing the Lewis River. Some bolts attaching stringers to the floor beams of this bridge were installed in 2006. Recently these had to be replaced. Following are pictures from a bridge inspection performed shortly during this bolt replacement.

Figure 1. Bottom chord ends

Figure 1 shows the significant amount of debris buildup that can occur when a bridge is left untended for a large number of years. These debris buildups were documented at 6-10 inches in height.

Figure 2. Bottom chord interiors

Figure 2 shows the interior of the bridge bottom chords. The left picture shows a 10” debris buildup before cleaning. The right picture is an interior chord after it has been cleaned out. The heavy surface rust is clear and would have been left unseen had the bridge not been cleaned.

The next bridge is the Sol Duc bridge 101/320 located on the Olympic Peninsula crossing the Sol Duc River. This bridge is part of the Pilot Bridge Washing study and was repainted in 1997. The following photos were taken after repainting but before the Pilot Bridge Washing program started.

Figure 3. Chord interiors

The pictures in Figure 3 show the interior chords of the Sol Duc bridge. There is clearly significant corrosion present that will continue to spread.

The main point of these figures is to show the importance of cleaning. The Sol Duc bridge has some severely corroded areas but it is considered sufficiently clean so these areas are easily seen and coded during an inspection. This allows WSDOT to plan accordingly. The Lewis bridge, being unwashed, has the potential to have many severely corroded areas but these go unnoticed due to the large amounts of debris that have built up.

Hara et al. (2005)

The Shikoku Regional Bureau of Japan Highway Public Co. (JH) completed a study in 2005 that documents their results from an experimental bridge washing program from 2001-2004. The program was initiated due to the well-known fact that salts from the majority of deicers often cause corrosion problems in weathering steel. Their solution was to implement the pilot study to wash off these corrosive materials and determine if there were measurable effects (Hara et al., 2005).

JH chose two bridges for inspection located in a mountainous region. The relative humidities in these areas are generally high setting up an ideal environment for corrosion to start. On each bridge there were fixed points for rust observation inspected once a year before deicers were used. These points were focused almost exclusively on the bottom flanges of the steel girders as this is where rusts mainly form. The bridges were also washed once a year in the same specified locations at the beginning of April. Corrosion was not only visually observed, but JH also performed mass loss testing and characterization of the rust.

At the conclusion of the study JH was able to come to certain general conclusions regarding bridge washing. It was determined that the sprinkling of deicing salts in the winter, leaves a remaining chloride ion concentration in the summer which greatly accelerates rust formation. The residual chloride ions further accelerate rust particle size in subsequent years. Lastly, the bridge washing program had a suppressing effect on the increasing rust particle size and is a useful bridge maintenance tool (Hara et al., 2005).

RIDOT (2002)

The Rhode Island Department of Transportation (RIDOT) completed a study in 2002 to document the benefits of their bridge washing program (placed into effect in 1999) over a span of 4 years. A large number of bridges were washed in the years 1999, 2001, and 2002 with the inspection results documented in this study. Over the course of these washings and inspections multiple structural deficiencies were located and addressed which would not have been otherwise apparent. This study found 3 significant benefits to a bridge washing program (RIDOT, 2002).

1. Bridge inspection quality increases due to a lack of debris covering the structure.
2. Bridge inspector safety increases due to the elimination of bird droppings which can be extremely harmful if inhaled.
3. Structural benefits, including extended bridge and paint life, due to the cleansing of corrosive salts and debris from the paint surface.

The appendix of the Rhode Island study includes a cost benefit analysis of a bridge washing program using probability based paint lifetime cost estimates using estimated bridge washing related reductions in repairs to the painting system. The study analyzed the effects and cost of washing 45 bridges bi-annually as opposed to doing nothing over the course of 8 years. The Federal Highway Administration's (FHWA) PONTIS program is highlighted as an effective action-generating tool stating that it will be used to develop the state's Bridge Management System (RIDOT, 2002). Using the condition states from the PONTIS program for Element 107, "Painted Open Steel Girder," allowed RIDOT to extrapolate future condition states from a prescribed starting point. It also provides recommended actions for specified condition states.

The PONTIS condition states are described as follows:

1 - There is no evidence of active corrosion and the paint system is sound and functioning as intended to protect the metal surface.

2 - There is little or no active corrosion. The paint system may be chalking, pooling, curling or showing other early evidence of paint system distress but there is no exposure of metal.

3 - Surface or freckled rust has formed or is forming. The paint system is no longer effective. There may be exposed metal but there is no active corrosion that is causing loss of section.

4 - The paint system has failed. Surface pitting may be present but any section loss due to

active corrosion does not yet warrant structural analysis of either the element or the bridge.

5 - Corrosion has caused section loss and is sufficient to warrant structural analysis to ascertain the impact on the ultimate strength and/or serviceability of either the element or the bridge (RIDOT, 2002).

The test set of 45 bridges that carry interstate traffic were chosen and their initial paint conditions assessed based on PONTIS condition states 1, 2, 3, 4, and 5. Only bridges with condition ratings 1 and 2 have a recommended action of 'Surface clean' designated by PONTIS. Using these initial paint condition states, future conditions were determined based on the estimated probabilities that a given condition state will transition to the next condition state during a specific time period. This process was implemented with the two separate scenarios of washing every bridge bi-annually for 8 years, or doing nothing to the bridges over the course of 8 years. Data sets of the hypothetical final paint condition were created using this formula.

Under the scenario of bi-annual washing, every bridge that was assessed as condition 1 or 2 at the beginning of the time period was still at conditions 1 or 2 at the end. Under the scenario of doing nothing for 8 years, 53% were at rating 3 or above at the end of the time period. Using the final paint condition, a cost estimate was assessed for each of the two scenarios. For bi-annual washing, the cost of the washing operations every other year was evaluated. For doing nothing, the cost of performing the PONTIS recommended maintenance for each paint condition state was evaluated. The final outcome of the scenario given was a cost savings of roughly $850,000, or $20,000 per bridge every 8 years (RIDOT, 2002). This was subject to the assumptions of the benefits in paint deterioration with bridge washing.

Tam and Stiemer (1996)

Various other research papers have been written on different types of paint, painting methods, and effects that corrosion has on not only the life of the bridge, but the aesthetics. Tam and Stiemer (1996) performed a study to develop a bridge corrosion cost model for coating maintenance that concluded that spot repairing is the most cost effective method for corrosion resistance. The researchers used historical data from other research projects in order to set up a simulation of the deterioration of a coating system. Equivalent annual cost analysis was used to develop life cycle costs of the spot painting, over-coating, and recoating of a bridge. To accomplish this, an equation was used that accounted for the cost of existing paint removal (if applicable), surface preparation, the amount of area to be treated, cost factors for height/size of the bridge, and inflation.

Tam and Stiemer (1996) concluded that the most cost effective maintenance was spot painting so long as the structure is not severely corroded. This is because spot painting requires only the affected area to be prepared and painted, thereby minimizing costs and more environmentally hazardous preparation methods. The preparation most often includes the removal of existing coatings and surface rust by hand tools and then cleaning of the exposed area. The second most cost effective method was determined to be over-coating. This is mainly because the entire painted surface requires washing and in some cases special preparation before an over-coating can be applied. These conclusions however, are based on the assumption that all the correct procedures are followed and that the surface is properly prepared for the type of coating it is going to receive. Also, it was acknowledged that certain coatings cannot be spot painted or over-coated and require the repainting of the entire bridge.

FHWA (2012)

The geographical location of a bridge has also been shown to have a significant effect on the severity or frequency of corrosion. A study performed by the FHWA in 2012 details the proper methods to corrosion protection design. It describes the different factors normally affecting the seriousness of corrosion and different methods to combat these variables. One factor, which has a significant bearing in this study, is the surrounding environment of the structure. The FHWA classifies the environments of highway bridges as Mild, Industrial, Moderate, and Severe. These are useful in determining the type of corrosion protection to use on a bridge system. The environments are described as follows:

- Mild (Rural): Little to no exposure to natural airborne and applied deicing salts. Low pollution in the form of sulfur dioxide, low relative humidity, absence of chemical fumes, usually an interior (inland) location.

- Industrial: High sulfur dioxide or other potentially corrosive airborne pollutants, moderate or high humidity. This classification has become less important in recent years as long-term corrosion data shows the corrosive effects of airborne pollutants has diminished with the implementation of clean stack gas regulations. This atmospheric classification is still a consideration directly downwind of known corrosive process stream contaminants.
- Moderate: Some (occasional) exposure to airborne salts or deicing salt runoff.
- Severe (Marine): High salt content from proximity to seacoast or from deicing salt, high humidity and moisture (FHWA, Steel Bridge Design Handbook, 2012).

The most important of these 4 designations are Moderate and Severe. Distinguishing between these two environments is the difference between under or over designing the corrosive resistance of the bridge.

The FHWA report also references the effect of consistent moisture on a steel surface whether it comes from the atmosphere or from splash zones. Steel surfaces that are consistently wet have a higher rate of corrosion than steels that have a routine wet/dry cycle. This wet/dry cycle is essential in the formation of a protective corrosion film on weathering steel (FHWA, Steel Bridge Design Handbook, 2012). Steel that is not allowed a proper cycle will continue to corrode through its lifetime. For this reason, designs that create pockets or dips for water to collect should be avoided.

The distance of a bridge from a coast is a significant issue in corrosion assessment. These regions can be exposed to a large frequency of airborne salts depending on their proximity to the coastline. This becomes one of the dividing lines between a Moderate and Severe environment (FHWA, Steel Bridge Design Handbook, 2012). Moving inland, the chance of exposure to airborne salts diminishes significantly however is still quite possible due to the spray from passing trucks. For this reason, the main dividing line between Moderate and Severe away from a coastline depends on how frequently de-icing salts are used and the ability to keep them off of steel surfaces. If salts are routinely adhering to the steel surface the corrosivity increases dramatically (FHWA, Steel Bridge Design Handbook, 2012). This can be seen on steel above the deck located in splash zones.

Performance Measures for Bridge Preservation (2012)

A joint paper written by employees of the University of Colorado, Michigan Department of Transportation, US Federal Highway Administration, and Oregon Department of Transportation was published in 2012 titled, Performance Measures for Bridge Preservation. The paper used information collected from Departments of Transportation across the United States to compile a list of four performance measures to aid in the preservation of the bridge infrastructure in the country. This information was compiled through the use of internet databases and a national questionnaire. The performance measures were then mathematically tested on the state-owned bridge inventory of Colorado.

It is stated that effective bridge preservation strategies and actions keep bridges in good condition and extend bridge service life (Ahmad et al, 2012). These strategies are aimed at bridges that are already in good condition and are fit for continued service. The performance measures outlined in this report are as follows:

P1 – Preservation Candidates: The population of bridges to preserve expressed as count, deck area, or percentage of the full inventory of bridges.

P2 – Preservation need: The work needed to preserve the P1 candidates, usually expressed as annual need.

P3 – Preservation plan: The resources required to deliver the P2 annual need, usually expressed as cost.

P4 – Preservation impact: The effects of preservation programs on bridge conditions, work need, and work plan (Ahmad et al, 2012).

Explained in more detail, P1 can be reported as count of bridges, deck area of bridges, or quantities of bridge elements (Ahmad et al, 2012). It is stated that these and all following criteria are subjective and determined by the particular state wishing to perform the analysis. P2 is the maintenance required to avert the transition of a bridge to poor condition. This is converted to an annual maintenance need by dividing the preservation candidates (P1), by the service interval (number of years bridges remain in good condition). P3 are costs computed by multiplying the annual work need (P2) by the average cost of this work. This calculated value is very beneficial to a states budgeting process and allows for comparison with a replacement program. P4 compares the conditions and costs for a preservation program with those obtained from a replacement program and is split up into three separate values to be computed. P4r is the calculated average condition of bridges in a preservation program minus the average condition ratings from that of a replacement program. P4w is the measured impact of a preservation program on work by subtracting the annual number of replacement projects (Wr) from the annual work need of a preservation program P2. P4c is a comparison of the cost of a preservation program versus a replacement program and is computed by subtracting the annual cost of replacement projects from the annual preservation cost (P3) (Ahmad et al, 2012).

These performance measures were applied to the state-owned bridge inventory of Colorado to test their effectiveness. The calculations were performed using condition information and service intervals from Colorado's files. The measures were applied at both the network level and the element level. In this case the element level was comprised of compression joints and bare concrete decks). The final calculations yielded a significant ($2.4 million) cost savings, a greater number of bridges with condition ratings greater than or equal to 6, and only 12 more projects per year.

Summary

Every study agrees on the fact that deicers, if left unattended on the steel surface, will expedite corrosion. It is also common knowledge that corrosion is detrimental to the life and performance of a bridge and is therefore undesirable. There is very little information on the impact of other debris such as bird guano or moss on paint life or corrosion. Further, the information on the impact of salts is primarily focused on corrosion of the steel rather than deterioration of the steel coating.

There appears to be little information on the ability of regular bridge washing programs to impact the paint life or corrosion performance of steel bridges. The information available has used anecdotal assumptions to demonstrate that benefits are likely but the data to support those assumptions is absent. Based on this literature review, a long-term study of the effectiveness of bridge washing on paint life is necessary.

PILOT WASHING PROGRAM

In 2011, WSDOT proposed a pilot bridge washing study to amend its current washing program. The purpose of this is to study the effects of a yearly washing consisting of a simple flushing of the bridge as opposed to its current washing strategy. WSDOT currently must dry-clean the structure before cleaning with a low pressure high volume wash. The dry cleaning part of the process is labor intensive and is dependent upon the availability of an Under Bridge Inspection Truck (WSDOT, 2011). The pilot study's objective was to determine the environmental impact of switching the washing program to an annual program of bridge flushing without dry cleaning. The impact is determined by monitoring the effluent from the flushing of the bridge structure.

The logistics of the pilot study include 4 bridges in the state of Washington. Two bridges, the US 12 Black River Bridge and the US 101 Sol Duc River Bridge #4, selected because they had been cleaned within one year, were washed without the dry cleaning process. The other two bridges, US 101 Sol Duc River Bridge #5 and the US 12 Naches River Bridge, selected because they had not been cleaned within 5 years, were washed using the dry cleaning process. This included brushing, sweeping, and collecting the majority of solid detriment prior to bridge flushing.

A year later, these bridges were revisited and washed again. This time there was no dry-cleaning process and the effluent from the bridge was measured in the flow of the river below. The completion of the pilot study will help to determine the environmental impact of washing a bridge every year. In this way, WSDOT can conform to environmental regulations required to maintain the ecosystem of the rivers below.

A follow-up investigation for the purpose of this current research took place in December 2011. Five bridges crossing the Sol Duc River and 2 bridges crossing the Hoquiam River were inspected by Prof. Charles Roeder. The five bridges, Sol Duc #'s 1, 2, 3, 4, and 5 were last repainted in 1990, 1997, 1997, 1997, and 1997 respectively. Of the five crossing the Sol Duc River, two of the bridges (Sol Duc #4 and #5) are included in the WSDOT pilot washing program. For this reason all 5 were observed in order to determine if there was already any difference between the washed and unwashed bridges.

The results of the observations were that there was a slight difference, but nothing structurally glaring or hazardous. Bridges #4 and #5 were significantly cleaner on the surface than Bridges 1, 2, and 3. For Bridges 1, 2, and 3, scaly dirt covering the surface, and in some cases moss, is present that cannot be seen on #4 or #5. All five were observed to have rough paint surfaces which showed that the paint coating below the surface was not completely removed in all areas as shown in Figures 4 and 5. Both #4 and #5 appeared to be in general good condition with minimal rusting and paint peeling. For point of reference, Bridge #1 was last fully re-painted in 1990 while Bridges #2-4 were all fully re-painted in 1997. The trusses on the decks of both bridges appear to continually take damage from motorists as there are dents and paint abrasions from vehicles.

Figure 4. Sol Duc #4 Bridge with rough paint surface and motorist damage

Figure 5. Sol Duc #5 Bridge with rough paint surface and problem area where girder meets the deck

The Hoquiam River bridges were observed on this same trip because of their potential to act as control bridges in the Pilot Study as they have not been washed in recent years. The first bridge observed was the Riverside 1417 Bridge. This bridge is older than all of the Sol Duc River bridges with its outermost paint surface aged 20 years (re-painted in 1992) while being in generally good condition. A noticeable amount of moss was observed on areas of the bridge which can be seen in Figure 6. These accumulations are less than that observed on Sol Duc River bridges #1, 2, and 3. A scaly coating of dirt was also observed adhering to the paint in multiple areas as can also be seen in Figure 6. This coating appeared to support the growth of fungus.

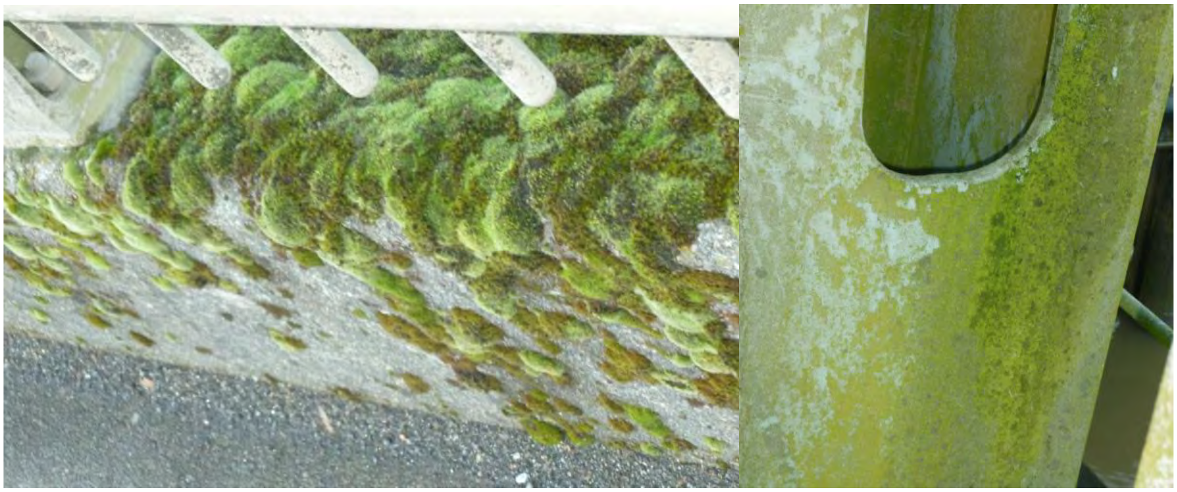

Figure 6. Hoquiam River Riverside 1417 Bridge

The second bridge spanning the Hoquiam River was the Southeast Bound US 101 Bridge. This bridge appeared to be of the same age as the Sol Duc River bridges yet the paint was in clearly worse condition. There was greater paint loss and corrosion than any of the other bridges observed. These qualities can be observed in Figure 7.

Figure 7. Southeast-bound US 101 Bridge

NATIONWIDE SURVEY

The initial step in the research study was to obtain information from Transportation agencies and Departments of Transportation (DOT's) about bridge washing programs they might employ. The preliminary survey sought information to determine if they had a consistent program, how long the program had been in place, whether or not there was a visible/measured difference in paint life for washed bridges, and if washing the bridge led to a longer service life. An encompassing survey was sent out to state DOT's and various other agencies in charge of transportation or bridge maintenance. The questions were as follows:

1. Does your DOT have a steel bridge washing program?
2. Approximately how frequently are steel bridges washed?
3. Are there environmental regulations that your bridge washing program must satisfy?
4. Has effluent in rivers under bridges that are being washed ever been monitored?
5. What types of bridges are washed?
6. Does your DOT have records on paint life for steel bridges?
7. Does your DOT collect data on the condition of paint on steel bridges?
8. Does your DOT collect data on the corrosion of steel bridges?

The total responses came out to 35 states, 1 Canadian province, 1 bridge agency, and 16 responses of unknown origin because they contained no contact information. This led to a total of 53 unique responses with 19 confirming that their agency had a bridge washing program in place. Figure 8 represents these responses mapped on the United States. A frequency of "0" means that that agency does not employ a washing program. As can be geographically seen in Figure 8, these states are mainly located along one of the North coasts. All of the states that employ a washing program routinely experience a winter freeze and summer thaw cycle somewhere in their state. The majority of these states also routinely employ some type of deicer on their roadways which would most likely aggravate corrosion issues. This is a logical corollary as the washing of a bridge would have the most effect in this type of environment. Of these states Alaska, Kentucky, Maine, New Hampshire, New York, Oregon, Virginia, and Washington reported that there were environmental regulations in their state that must be adhered to. It can be seen that the majority of these states are located on a coast and might therefore have water ecological issues that wouldn't normally correlate with other landlocked states. The graph also shows multiple states as unknown. This is not necessarily the case as 16 responses were received without any contact information so it was not possible to distinguish what states these were referencing.

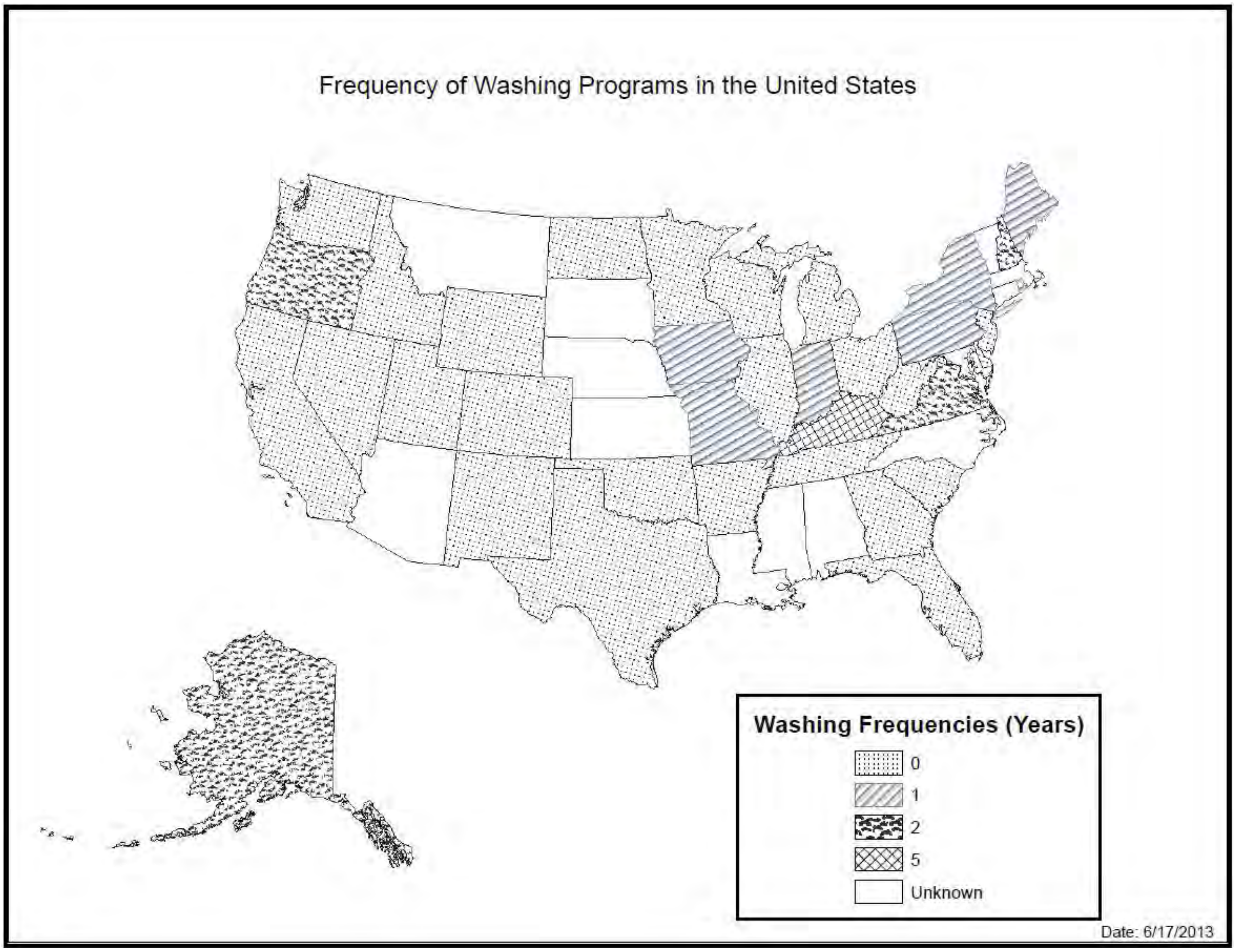

Figure 8. U.S. map of washing programs

Every state keeps track of corrosion and paint life with the exception of one DOT that doesn't monitor paint life. These responses to questions 1, 6, 7, and 8 are summarized in Figure 9. Summaries of questions 2, 3, and 4 are shown in Figures 10 and 11. No state has made a study on the correlation between bridge washing and paint life. In fact, few DOT's appear to collect and retain the types of information needed to make this kind of correlation.

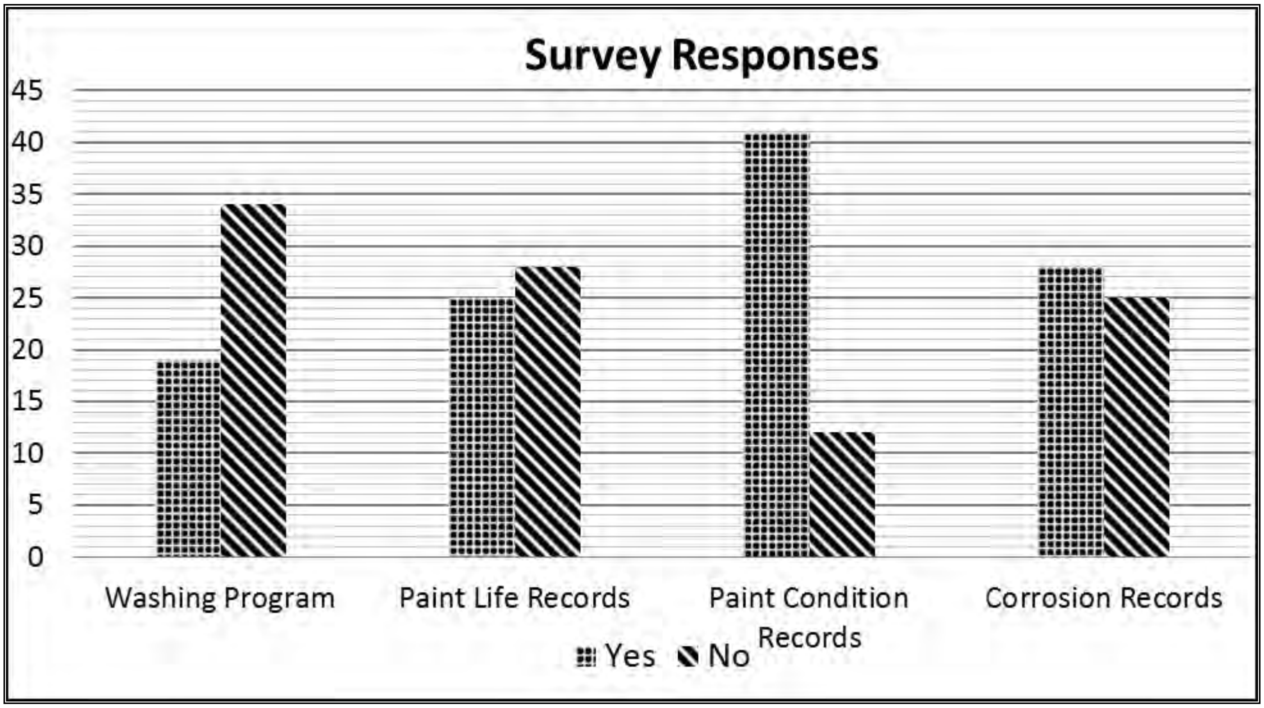

Figure 9. Programs and inspections utilized by DOTs

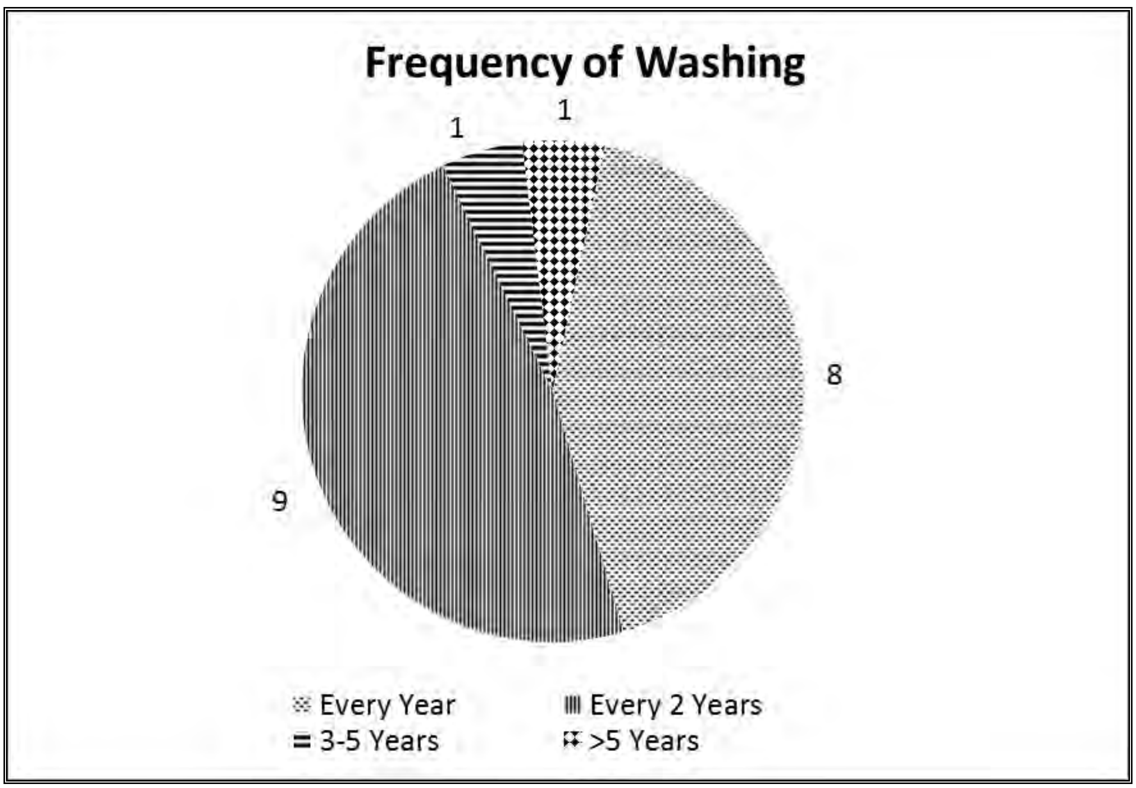

Figure 10. Frequency of washing for states with a washing program

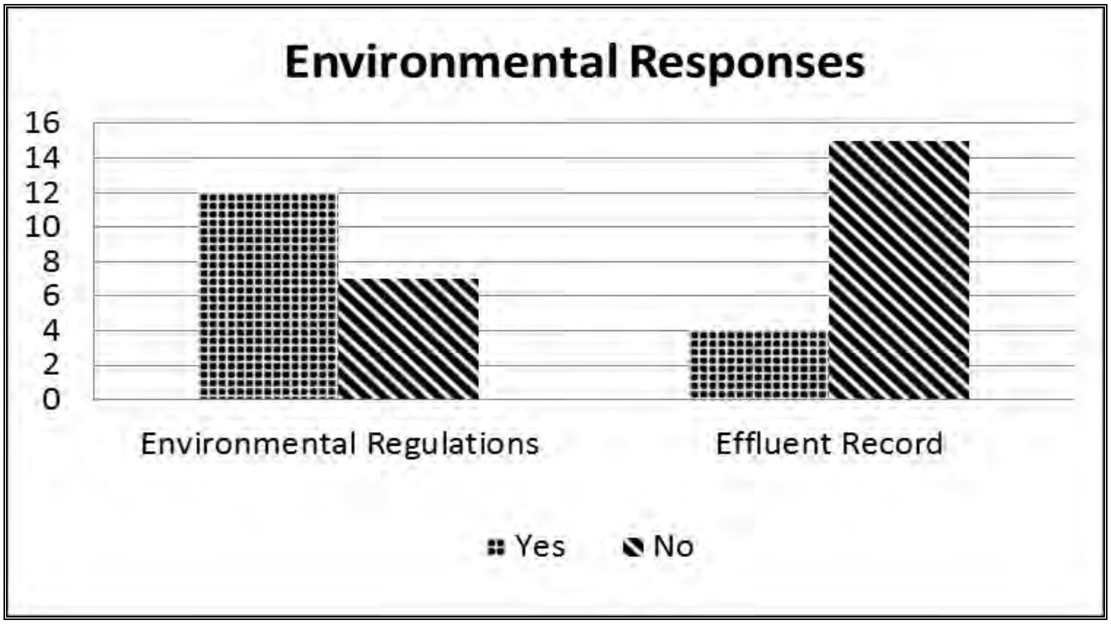

Figure 11. Environmental information collected from states with a washing program

FOLLOW-UP SURVEY

Once the initial nationwide responses were analyzed, a follow-up survey was sent to the states that had confirmed their use of a bridge washing program. Focus was put on agencies with washing programs because they would be the most likely to have information relevant to this study. These agencies were contacted either by phone or e-mail and their responses to the follow-up survey were collected. The follow-up survey contained more in-depth questions pertaining to the details of the respective programs as well as monitoring and recording techniques for paint and corrosion. Replies to the follow-up questionnaire were gathered from 8 agencies. These responses are summarized below.

Iowa Department of Transportation

The Iowa Department of Transportation (IowaDOT) has had a bridge washing program in place for 20 years. There is no specific selection process for bridges because every weathering steel bridge and every bridge located along the East and West borders are slated to be washed every year. These "border" bridges are specified because they span the Missouri or Mississippi Rivers and are considerably larger than most bridges in the states inventory. This is preferably done shortly after the winter season to dispose of corrosive salts or other de-icers used on the bridge decks. The process involves collecting, bagging, and disposing of dry debris before washing. The employees of the IowaDOT do not believe this program to be in violation of any environmental regulations.

Paint condition data is provided in inspection reports and is not a determining factor of the bridge getting washed. The condition of the paint is assessed visually based on the amount of corrosion apparent on the steel surface. Likewise, this visually assesses corrosion the same way.

As of yet, the state of Iowa has not studied any correlation between bridge washing and paint life or corrosion.

Alaska Department of Transportation

The Alaska Department of Transportation (AlaskaDOT) officially started a bridge inspection program in 2004 labeled the Fracture Critical Inspection Program (FCIP) which requires this classification of bridge to be cleaned before it is inspected by the department. Before this, the cleaning of bridges in Alaska was spotty. Every bridge under FCIP is cleaned and inspected every 2 years.

There are two predominant methods in use in Alaska depending on where the bridge is located. Bridges at the interior of the state have debris cleared off with compressed air. These bridges often have the paint abraded off of deck joists up to a few feet from the deck from repeated snow plowing of the road. There is very little need for re-painting in these locations. The climate is extremely cold and dry creating conditions that make it difficult for steel to corrode.

Bridges located in the coastal regions of the state are cleaned differently. The bridge is washed with low pressure hoses without any dry debris collected beforehand. Debris washed off bridges located over water is not collected and allowed to run off into the water below without environmental regulations being broken. These regions require a spray washing due to the fact that they are exposed to a greater number of corrosive substances. Air and moisture near the coast is much more salt-laden than at the interior of the state and the coastal regions have a greater tendency to use salt or other deicers. The majority of painting and re-painting also happens on these coastal bridges.

According to maintenance engineers, there is rarely an issue with regulations as salt is rarely used, especially at the interior of the state. Cleaning of the bridge only introduces a few yards of debris into the river below in a day long period. There have been instances in the past where the debris run-off was collected in order to protect the biological ecosystem of the river underneath. The dates a bridge is washed are not recorded. They are simply washed after plowing season and before inspection.

Paint condition and corrosion are assessed visually across the state. Both of these are checked during the bridge inspection but paint condition is also checked at least every two years. In the case of corrosion that appears debilitative, thickness measurements are taken. This information is stored in the AlaskaDOT's PONTIS program and can be obtained by a DOT employee.

Neither attribute determines whether a bridge is washed except in rare cases where there is significant debris build-up. The AlaskaDOT is currently attempting to set up an over-coating program that could potentially alleviate repainting expenditures. Over-coating involves adding a new layer of paint over an existing paint layer. This also requires some surface preparation but unlike spot painting or a full re-painting of the bridge, it doesn't require removal of the existing paint system. The absence of this step promises cost savings. On average, one full bridge repainting is performed per year.

The AlaskaDOT has not studied any correlation between bridge washing and paint life or corrosion.

Kentucky Transportation Cabinet

The Kentucky Transportation Cabinet (KYTC), like WSDOT, recently started a bridge washing program beginning in 2010. The initial phase involved 6 bridges and focused on washing the lower chords, abutments, joints, and any other problem/splash areas. Only bridges that were already in moderately good condition were chosen to be cleaned so that this type of preventative maintenance would be the most cost effective. The KYTC collects the majority of solid waste with brooms and shovels before spray washing. This keeps them in compliance with the environmental regulations set forth by the state. However, regulations do require that if active nests of certain types of birds are found, the KYTC Division of Environmental Analysis must be notified (Kentucky Transportation Cabinet, 2012). Specific dates of washing for bridges are not recorded but there are records of when groups of bridges were contracted to be washed.

Paint condition and corrosion are visually assessed by the state bridge painting coordinator who also notes the type of paint. Currently, this information is stored in a spreadsheet which will potentially be incorporated into the KYTC PONTIS program once it has been modified. Paint and corrosion do not specifically determine when a bridge is scheduled to be washed, but bridges marked with a low to poor condition rating are not considered for washing. Instead these structures are slotted for repainting so that paint flakes are not introduced into the surrounding ecosystem. If there are areas of stratified rust or pack rust, these are to be removed using wire brushes, hand scrapers, or impact devices (Kentucky Transportation Cabinet, 2012).

It is a future goal of the KYTC that condition determines when a structure is to be washed but the program is still too new for those parameters. They have also drawn no correlation between paint life/corrosion and bridge washing due to the youth of the program but this is another future goal.

New York State Bridge Authority

The New York State Bridge Authority (NYSBA) is separate from the New York Department of Transportation and has had authority over the majority of bridges crossing over the Hudson River since the mid 1930's. The NYSBA initiated their bridge washing program in the 1960's. Even though salt is not used on bridge decks as a deicer, all sections of all bridges are washed annually. They instead use sand; more recently a sand treated with Magnesium Chloride. There is a dry-cleaning process in which the sand and other debris is swept and shoveled up and disposed of before spraying. The bridge is then sprayed at garden hose pressure with water from the river below or potable water in order to comply with the policies of the New York State Department of Environmental Conservation.

Paint condition and corrosion are assessed visually on an annual basis. In more severe cases, corrosion may also be assessed by section loss and estimated area affected. The bridges are roughly inspected during the washing process but the NYSBA also performs an annual inspection on every bridge. This annual inspection allows for spot painting all year round. Paint has become a variable situation with the NYSBA due to the age of a majority of the bridges. Most of them were painted during a time when lead paints were not known to be hazardous so the NYSBA has been attempting to de-lead and repaint the bridges from bare steel. With this process, an over-coating is proving to last roughly 10-12 years, and the new paint lasting 20+ years.

The NYSBA has no documented correlation between bridge washing and paint life but remarked that they have only needed about 25,000 pounds of steel replacement in the past 80 years. On the surface this may seem like too small of an amount. However, the contact in charge of bridge maintenance attributes this and the NYSBA's paint life to routine proper cleaning and maintenance.

New Hampshire Department of Transportation

The New Hampshire Department of Transportation (NHDOT) has had a bridge washing program since the 1970's. According to the program, every bridge is ideally washed every other year. There is a dry-cleaning process that involves sweeping, shoveling, and collecting debris on the surface before spraying. Dry cleaning and spray washing focus mainly on splash areas (areas normally directly splashed by spray from tires) and only occasionally move to the underside of the bridge deck. There are a few large structures in which the truss areas are routinely washed as well. Until recently, the bridges were coated with linseed oil after cleaning but the NHDOT has now switched to using a siloxane coating instead. This has required the state to coat bridges less often due to the superiority of siloxane over linseed oil.

Paint condition and corrosion are assessed visually during inspection and the information is stored in the NHDOT's PONTIS program. These properties have no impact on whether or not a bridge is washed and oiled.

The NHDOT has completed no studies on the correlation between bridge washing and paint life and are skeptical that a connection can be made due to the large variety of factors that can affect the paint.

Missouri Department of Transportation

The Missouri Department of Transportation (MoDOT) has had a bridge washing program in effect since 2002. A bridge washing program was being employed before this time but there wasn't an official guideline for standard practices until 2002. There is a dry-cleaning process that involves sweeping, shoveling, and removal of debris before spraying but this is not performed during every washing. Every bridge is washed twice per year; once in the spring to remove any de-icers and debris that have accumulated over the winter, and once in the fall to remove debris that has accumulated over the summer.

Paint condition and corrosion are assessed visually during inspection and given a rating according to the MoDOT's rating code. These two attributes do not determine if a bridge is slated to be washed. The condition rating is determined by a trained bridge inspector and then input into the MoDOT's Bridge Management System. This system allows the paint condition to be gauged over time starting from its initial painting date.

The MoDOT has no documented correlation between bridge washing and paint life. Since the start of the program MoDOT has been slightly reorganized. This has caused the washing program to change as well making the benefits difficult to measure.

Indiana Department of Transportation

The Indiana Department of Transportation (INDOT) currently employs a washing program that includes all bridges in the state. The program dictates that every bridge be washed every year. The process used includes a dry cleaning procedure before spray washing is performed. During spray washing, there is an effort to contain solids that are washed off the bridge. This is done even though there aren't any known environmental regulations that would require it. Any deficiencies noted by the washing crew are passed on to the state's bridge inspectors.

Paint condition and corrosion are assessed visually during inspection and are stored in an INDOT database. Paint condition is evaluated on a scale of 0 to 9 with 0 equating to complete failure of the paint, and 9 equating to brand new paint. Paint life is also recorded and is estimated as the "Remaining Life" which is documented in years. If severe corrosion is observed, thickness measurements are taken.

The INDOT washes all bridges in their inventory every year and therefore has not compared deterioration for washed and unwashed bridges to study the correlation between bridge washing and paint life.

RECOMMENDED BRIDGE WASHING STUDY

It is clear from the literature review and DOT surveys that bridge washing is beneficial. However, to justify the costs of an annual bridge washing program it must be demonstrated that the paint life will be extended long enough to offset those costs. To assess whether this is the case it is recommended WSDOT carry out a carefully planned study of selected bridges. In this study, some selected bridges would be washed annually and some would not be washed (or washed at the currently used longer interval). Their condition would be annually inspected and both paint condition and extent of corrosion would be recorded. The following issues were considered when developing the proposed study: (i) impact of regional factors, (ii) impact of bridge type and age, (iii) minimum sample sizes necessary to produce statistics to demonstrate significance, and (iv) information already collected in WSDOT's annual inspection of bridges. A flow chart for the overall study is shown in Figure 12. A spreadsheet has been developed and provided to WSDOT that will help them in carrying out the recommended study. That spreadsheet and its assumptions are described in the next section.

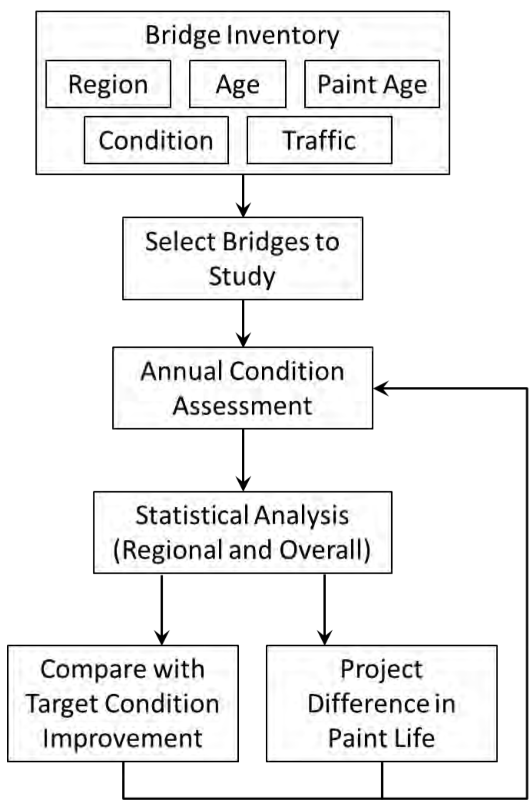

Figure 12. Flow chart for proposed bridge washing study

Selection of Bridges and Sample Size

To account for the impacts of climate, use of de-icing chemicals and other regional factors it is suggested that bridges be studied in at least two, preferably three, regions of the state. Further, it is desirable that bridges are selected such that there are at least 6 bridges of reasonably similar age, characteristics and traffic density within each region. Of those, three bridges can be washed and three not washed allowing for the study to somewhat compensate for any impacts of bridge age, configuration, etc. These minimum bridge numbers ensure a usable sample size as discussed below.

In order to be able to determine basic statistical quantities such as means and standard deviations that could be used to determine if bridge washing has a significant impact on extending paint life, it is necessary to have sample sizes of at least three washed and three unwashed bridges in each region of the state. The three bridges in the washed or unwashed categories in each region could be of different age and configuration but they should have a similar bridge in the other category. In the framework provided there are spaces provided for a total of 4 washed and 4 unwashed bridges in each region such that WSDOT may include more than the minimum number of bridges.

Condition Assessment

WSDOT already has inspectors trained in assessing paint condition and corrosion and a standard of practice for doing so. It is suggested that those condition assessments are used as the key data for the study of the impact of bridge washing. Currently, the square footage of a bridge in Condition States 1 through 4 is estimated with each inspection. It must be recognized that this is a general assessment and will vary depending on the inspector. However, by recording this data annually for the washed and unwashed bridges in each region and performing some relatively simple statistical tests it should be possible to determine how beneficial bridge washing is to paint life.

Establishing Target Differences in Condition

It is possible to establish target annual differences in condition necessary to achieve a specific difference in the number of years between required repainting of washed and unwashed bridges. To do this WSDOT must first determine, for each bridge pair in the study, the necessary number of years that repainting of a bridge must be delayed in order to offset the costs of bridge washing. This requires estimating the cost of annual bridge washing and a per year cost benefit of delaying painting. WSDOT also must determine a percent area of bridge in Conditions 3 and 4 necessary to trigger repainting. It can then be assumed that the percent deterioration between Conditions 1 through 4 is linear, i.e., that each year X% of the bridge square footage in Condition 1 deteriorates to Condition 2 and so on. This assumption can be modified to reflect other considerations or WSDOTs in house expertise. Using the above assumption and the minimum number of years of repainting delay necessary for annual washing to be effective, the spreadsheets under development can be used to determine a target difference in annual deterioration between washed and unwashed bridges. Note that in the spreadsheet developed for WSDOT and described below, the default target difference in condition is set to zero. The spreadsheet determines only whether there is a statistically significant difference in the deterioration of washed versus unwashed bridges and not whether that difference exceeds a target value. WSDOT must first establish what that target value is using the above procedure and then insert the value into the appropriate place in the spreadsheet.

Hypothesis Testing

A hypothesis test is proposed to determine whether the target difference in deterioration levels between washed and unwashed bridges is achieved. For all of the bridges in the study as well as in each region separately, the difference between the annual deterioration rate (% of bridge area moving between conditions) is computed for conditions 1, 3, and 4 as explained below.

$$\mu = \mathbf{av}_{unw} - \mathbf{av}_{w}$$

This data will be provided from the condition reports observed by WSDOT throughout the course of the experiment. Then the mean and standard deviation of the difference between the annual deterioration rates are computed for all bridges in a region and/or all bridges in all regions. The z statistic, which assumes a normal distribution of the difference between the deterioration rates for washed and unwashed bridges, can then be used to test the hypothesis that annual bridge washing can achieve the necessary difference in annual deterioration rate to provide long-term cost savings. The z-statistic is computed as:

$$Z = \frac{\mu - \ddot{x}}{\sigma / \sqrt{n}}$$

Where μ is the mean of the difference in the annual deterioration percentage of the bridges, $\ddot{x}$ = target difference in annual deterioration percentage, σ is the standard deviation of the difference in annual deterioration percentage from the bridges and *n* is the number of bridges. A target z value can be found for different levels of confidence using probability tables or Excel.

Summary

The above framework should provide a mechanism to determine, year-by-year, whether washing seems to be having the necessary effect to result in a positive economic benefit for WSDOT. Some information must provided by WSDOT to initiate the process, including the years the paint life must be extended to make an annual washing program beneficial. In the section below, a spreadsheet that has been developed to help WSDOT implement this recommended study is described.

FRAMEWORK USER MANUAL

1. Go to the correct bridge tab
2. If not already done enter initial conditions of the bridge based on the initial bridge report you want to start with
3. IMPORTANT: Mark the sheet as "Yes" (Active) or "No" (Not Active) in cell B5
    a. this determines whether or not the sheet is used in further calculations
4. Enter information for subsequent years
5. Cells highlighted in Yellow are cells where you input information
6. Cells highlighted in Blue are calculation cells: DO NOT CHANGE THESE
7. Enter the date, inspector, whether or not the bridge was washed since previous inspection, bridge condition, whether or not the bridge was painted since its last inspection, and any notes for that particular year
8. If the bridge has not had any painting done since the previous inspection then mark the cell "No" or leave it blank. If the bridge has been painted since the last inspection it is very important to mark the cell "Yes", this accounts for future calculations
9. Perform these steps for every bridge that is going to be monitored
10. On the statistics pages enter the target deterioration rate in the "Target Deterioration Rate" cell. Currently it is set at 0 for each page.

Assumptions

All cells base calculations on the Element 904 – Paint System recordings in WSDOT's Bridge Inspection Reports. The spreadsheet operates under the assumption that paint deteriorates linearly. Meaning that paint is assumed to move from Condition 1 to Condition 2, Condition 2 to Condition 3, and Condition 3 to Condition 4. This is the only way calculations can be performed with the given data. If a bridge has been painted since the previous inspection it is important to mark the corresponding "Painted Since Last Inspection?" cell for that year as "Yes". Performing this action skips the calculation of "Cumulative Area Changed" for that year so that the overall calculations are not affected. The next year simply add data as normal and the spreadsheet will calculate normally again.

The calculation cells are as follows:

From Condition 1 to Condition 2

These calculate the percent changed per year, the percent of total bridge area changed from condition 1 to condition 2, and the cumulative percent of total bridge area changed from condition 1 to condition 2. These cells are operating under the assumption that all of the square footage that decreases from condition 1, moves to condition 2. The calculations here are then based on the deterioration of cells under condition 1 rather than the change in cells under condition 2. This is because condition 2 has increasing square footage coming from condition 1 but simultaneously has square footage moving to condition 3. Because the calculations are based on this one way shift, this is the most accurate calculation cell.

The statistics sheet uses the cumulative percent changed column to perform analysis. This column, because condition 1 should always theoretically be staying the same or decreasing, is calculated by:

$$\left(\frac{SF\ of\ Cond.1\ of\ Previous\ Year - SF\ of\ Cond.1\ of\ Current\ Year}{Total\ Bridge\ Area} * 100\right) + Previous\ Year\ \%\ Change$$

This gives the cumulative percent change throughout the experiment. If the top part of the fraction is negative, meaning that condition 1 has gained square footage, then the fraction automatically equals 0. This keeps the cumulative percent change the same as the previous year. If painting is performed since the last inspection then the fraction automatically equals 0. This keeps the current year from changing negatively and restarts the cumulative count the next year.

Change in Condition 3

These cells perform calculations based on the change in square footage of condition 3. Direct calculations on condition 2 have been neglected because, as stated before, condition 2 is getting larger with square footage from condition 1 and is getting smaller with square footage moving to condition 3. In addition to this, the positive change in the amount of square footage in condition 2 is already being calculated by the decrease in condition 1. Therefore the calculations move directly to the change in condition 3.

Like condition 2 however, condition 3 is both gaining square footage from condition 2 and losing square footage moving to condition 4. Therefore a similar calculation as before is performed:

$$\left(\frac{(SF\ of\ Cond.3\ of\ Current\ Year - SF\ of\ Cond.3\ of\ Previous\ Year) - SF\ of\ Cond.4\ of\ Current\ Year}{Total\ Bridge\ Area} * 100\right) + Previous\ Year\ \%\ Change$$

The top of this fraction is the current year minus the previous year which is the opposite of the condition 1 calculation. This is because the square footage of condition 3 will hypothetically be getting larger from year to year.

Like the previous equations, if the top of the fraction is negative or if the bridge has been painted since the previous inspection then the equation automatically equals the previous year's cumulative percent change.

Change in Condition 4

These calculations are the same as the Change in Condition 3 calculations. However, like the condition 1 calculations, these are more accurate. This is because there is no square footage of condition 4 moving to a condition 5. There is only square footage moving from condition 3 to condition 4. The problem is that there is often very little square footage of condition 4 and therefore the values in this column are normally equal to 0.

Statistical Analysis

These pages perform calculations using the cumulative percent area changed calculated in each individual bridge page. The statistics pages split the bridges into two groups, washed and unwashed. The average cumulative percent change and standard deviation for each condition and each year is calculated for both washed and unwashed bridges separately. This information is used to calculate an average and standard deviation for the difference of these two categories as follows:

$$\mu = \mathrm{av}_{unw} - \mathrm{av}_{w}$$

$$\sigma = \sqrt{\mathrm{s}_{w}^{2} + \mathrm{s}_{unw}^{2}}$$

A Z statistic is then computed to determine the level of confidence that this computed difference is greater than 0:

$$Z = \frac{\mu - \ddot{x}}{\sigma / \sqrt{n}}$$

$$n = number\ of\ bridges\ in\ experiment$$

With a Z value greater than 0, the annual deterioration rate of unwashed bridges is higher than washed bridges which is ideally what should happen.

As stated above, if the Z value is greater than 0 then the rate of deterioration of unwashed bridges is higher than 0. Z values for each condition are shown for each year on the statistics pages. If these values are greater than a certain number then they represent a certain level of confidence. The cells are color coded to have a certain background color based on the level of confidence represented for that particular year.

CONCLUSIONS

The literature review demonstrated a lack of data on the effectiveness of bridge washing programs to slow corrosion or improve paint life. Studies have demonstrated that washing is effective in removing chloride ions from bridge surfaces which should slow corrosion. The WSDOT pilot washing program could provide the data necessary to demonstrate bridge washing effectiveness by monitoring the condition of washed and unwashed bridges over a somewhat long term (5-20 years). This data would be beneficial in helping DOTs across the country decide on the appropriate course of action for bridge washing programs.

A survey of DOTs with bridge washing programs found the common practice, for states that employ a washing program, first involves an initial dry cleaning process of the deck. Different methods are used such as brushing or shoveling and collecting the dry debris before a spray washer is used to complete the washing process. No state reported extensively collecting dry debris from underneath the deck before washing. Eliminating this process in Washington would alleviate cost and scheduling conflicts with an Under Bridge Inspection Truck. Spray washing is typically completed using normal water hose pressures the majority of the time as high pressure washers can actually damage the paint integrity more. Very few states collect the effluent from the spray washing process and normally only under special conditions.

States with routine bridge washing programs are very often operating within environmental regulations, if applicable, without collecting debris from underneath the deck. Once the debris from the roadway is collected and disposed of, the bridge can be washed without an issue. This appears to be because the amount of effluent reaching the water below isn't adding a detrimental amount of deleterious substances if they are performing washing up to every other year.

From the initial survey and information from the follow-up surveys it seems that very few studies relating bridge washing and paint life have been performed. It also shows that any correlation drawn from the data received would be hypothetical at best. However, there are some important facts to speculate on. The NYSBA's washing program, in effect since the 1960's, is quite extensive and kept well under account. Under the guidelines of washing every bridge every year and dry collecting potentially hazardous chloride de-icers the NYSBA's infrastructure is in fair shape. These bridges are located in a climate that is both near a coast with salt laden air and experiences a routine freeze thaw cycle. These parameters are ideal for rust to form yet the NYSBA has only needed to replace 13 tons of steel in the past 80 years.

A framework for assessing whether annual bridge washing is economically beneficial has been proposed and is still under additional development and testing. The framework relies on WSDOT being able to estimate the necessary number of years paint life must be extended in order to make annual washing economically beneficial. It then uses the condition data that WSDOT already collects to determine whether paint life is extended the necessary amount on a year –by-year basis. The framework also relies on WSDOT identifying a percentage of total bridge area in Conditions 3 or 4 to trigger repainting. A spreadsheet has been provided to WSDOT begin a long-term study of bridge washing effectiveness and determine whether it has a statistically significant impact on the change in paint condition.

REFERENCES

Hara S, Miura M, Uchiumi Y, Fujiwara T, Yamamoto M, (2005) "Suppression of deicing salt corrosion of weathering steel bridges by washing", Corrosion Science, Volume 47, Issue 10, October, Pages 2419-2430. (http://www.sciencedirect.com/science/article/pii/S0010938X05001058)

Rhode Island Department of Transportation, (2002) "Bridge Inspection/Washing Program", Operations Division, February.

Stiemer SF, Tam CK, (1996) "Development of Bridge Corrosion Cost Model for Coating Maintenance", ASCE Journal of Performance of Constructed Facilities. 10(2): 47-56.

Washington State Department of Transportation, (2011) "Bridge Maintenance Washing Pilot Study", Maintenance and Operations Environmental Service Branch, August.

Federal Highway Administration, (2012). *Corrosion Protection of Steel Bridges*, Steel Bridge Design Handbook. Publication No. FHWA-IF-12-052, Vol. 19.

Kentucky Transportation Cabinet, (2012). District No. 2, Contract #117GR12M102. *Special Notes on Bridge Cleaning and Preventive Maintenance.* Kentucky Transportation Cabinet.

Ahmad A, Hearn G, Johnson BV, Juntunen D., (2013) "Performance Measures for Bridge Preservation", Transportation Research Board Annual Meeting.