Bridge Maintenance Program for the City of Columbia, Missouri

Final Report
September 2017

Sponsored by
City of Columbia, Missouri
Midwest Transportation Center
U.S. Department of Transportation
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16. Abstract

In this project, a bridge maintenance and preservation program was developed for the City of Columbia, Missouri. The program focuses on practical and implementable technologies and procedures that can be applied to extend the service lives of the bridges, reduce maintenance costs, and ensure safety and serviceability. Specific technologies that were considered included bridge deck flushing, fog and seal programs, and crack sealers.

The researchers analyzed the state of the practice for bridge preservation through a literature search, consultations with contacts within the preservation community, and interviews with state-level bridge owners who use these technologies. Existing and historical activities undertaken by the city were also evaluated, and current needs were assessed. An informal risk analysis was used to prioritize activities and link the identified procedures with specific structures within the city. A field survey of bridges in Columbia was completed to help identify bridge preservation needs for particular bridges. These data were summarized and used to develop an implementable procedure for short-term (12 to 24 months after program implementation), mid-term (25 to 72 months after program implementation), and long-term (73 to 120 months after program implementation) actions to extend the life of bridges and reduce maintenance costs.

Key recommendations for the program include the identification and prioritization of low-cost preventive maintenance (PM) activities such as cleaning, periodic washing of bridges, and sealing of bridge decks that are currently in good condition. The identification of condition-based preservation needs through the implementation of a bridge preservation inspection program (BPIP) and the review of maintenance notes in the Missouri Department of Transportation (MoDOT) biennial inspection reports were recommended.

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BRIDGE MAINTENANCE PROGRAM FOR THE CITY OF COLUMBIA, MISSOURI

Final Report
September 2017

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EXECUTIVE SUMMARY

The goal of this project was to extend the service lives of bridges located in Columbia, Missouri. The objective of the project was to develop guidelines for bridge maintenance and preservation. The guidelines developed are focused on practical and implementable technologies and procedures that could be applied to extend the service lives of the bridges, reduce maintenance costs, and ensure safety and serviceability.

Bridge preservation activities have been increasing nationwide in recent years. The purpose of bridge preservation activities is to prolong the useful life of bridges and forestall repairs and replacement. Maintaining a bridge in good condition can extend the service life of the bridge and has proven to be cost-effective compared with allowing the bridge to deteriorate, which can lead to more extensive and costly repairs. Bridge preservation includes activities completed in response to bridge conditions and activities completed periodically to prevent or delay damage.

The research approach to developing the guidelines consisted of assessing the current state of the practice for bridge preservation through a literature search, consulting contacts within the preservation community, and interviewing state-level bridge owners. The focus of the research was to identify practical and implementable technologies and procedures that could be applied. In addition, the current needs of the City of Columbia, Missouri were assessed, and existing and historical activities performed by the city were reviewed. To help identify and prioritize preventive maintenance (PM) activities for specific bridges in the city, an informal risk analysis was performed and a field survey of bridges in Columbia was undertaken. These data were synthesized with the state of the existing practice to develop specific recommendations for the bridges in Columbia.

The literature review focused on most of the common technologies used for bridge preservation activities, interval of application of the products, cost of the products, and ease of application. Bridge washing, sealing of concrete bridge decks, and crack sealing are among the most common preservation activities currently being implemented by bridge owners. A detailed analysis and summary of the existing literature is provided in the report.

The recommendations in the report are focused on practical and implementable technologies such as bridge deck flushing, bridge cleaning, crack sealing, and sealing concrete bridge decks currently in good condition. The guidelines include implementable procedures for the short-term (12 to 24 months after program implementation), mid-term (24 to 72 months after program implementation), and long-term (73 to 120 months after program implementation). The recommendations for bridge preservation for Columbia can be summarized as follows:

- Focus on low-cost activities to prevent bridge deterioration and keep good bridges in good condition.

- Identify and prioritize PM activities such as cleaning and washing bridges to extend their service lives.

- Include a mix of short-term, mid-term, and long-term PM activities

- Identify preservation needs through the implementation of a bridge preservation inspection program (BPIP) to provide data on preservation needs.

- Consult the maintenance notes provided in the Missouri Department of Transportation (MoDOT) biennial inspection reports for additional guidance regarding short-term, condition-based PM activities for each bridge.

- Utilize the MoDOT Engineering Policy Guide (EPG) and other resources for guidance regarding specific details and procedures for bridge PM activities.

Implementation of this bridge preservation program will help the city keep its network of 38 bridges and culverts in good condition using limited resources and thereby meet its future transportation demands created by continued growth.

1 INTRODUCTION

The goal of this project was to extend the service lives of local bridges in Columbia, Missouri. The objective of the project was to develop guidelines for bridge maintenance and preservation. The guidelines developed are focused on practical and implementable technologies and procedures that could be applied to extend the service lives of the bridges, reduce maintenance costs, and ensure safety and serviceability. Specific technologies that were considered included the following:

- Bridge deck flushing
- Bridge washing
- Bridge cleaning
- Deck sealing
- Fog and seal programs
- Crack sealers

To meet the objectives of the research, university researchers analyzed the state of the practice for bridge deck preservation. This analysis was completed through a literature search, consultation of contacts within the preservation community, and interviews with state-level bridge owners using these technologies. Available research results that had been documented through research reports were reviewed and summarized as appropriate. Existing and historical activities undertaken by the sponsor were also evaluated, and current needs were assessed. An informal risk analysis was used to prioritize activities and link the identified procedures with specific structures within the city. A field survey of bridges in Columbia was completed to identify bridge preservation needs for particular bridges and to develop knowledge regarding the characteristics of bridges in Columbia. These data were summarized and then used to develop an implementable procedure for short-term (12 to 24 months after program implementation), mid-term (25 to 72 months after program implementation), and long-term (73 to 120 months after program implementation) actions to extend the life of bridges and reduce maintenance costs.

1.1 Recommendations

This section of the report summarizes the recommendations stemming from the research conducted for this project. The recommendations are as follows:

- Focus on low-cost activities to prevent bridge deterioration and keep good bridges in good condition.

- Identify and prioritize preventive maintenance (PM) activities such as cleaning and washing bridges to extend their service lives.

- Include a mix of short-term, mid-term, and long-term PM activities.

- Identify preservation needs through the implementation of a bridge preservation inspection program (BPIP) to provide data on preservation needs.

- Consult the maintenance notes provided in the Missouri Department of Transportation (MoDOT) biennial inspection reports for additional guidance regarding short-term, condition-based PM activities for each bridge.

- Utilize the MoDOT Engineering Policy Guide (EPG) and other resources for guidance regarding specific details and procedures for bridge PM activities.

2 BRIDGE PRESERVATION

Bridge preservation activities have been increasing nationwide in recent years. The purpose of bridge preservation activities is to prolong the useful life of bridges and forestall repairs and replacement. Maintaining a bridge in good condition can extend the service life of the bridge and has proven to be cost-effective compared with allowing bridges to deteriorate, which leads to more extensive and costly repairs. Bridge preservation is defined by the Federal Highway Administration (FHWA) as "actions or strategies that prevent, delay, or reduce deterioration of bridge elements; restore the function of existing bridges; keep bridges in good condition; and extend their useful life. Preservation actions may be preventive or condition-driven." Bridge preservation includes activities completed in response to bridge conditions, such as sealing cracks in a bridge deck, and activities completed to prevent or delay damage, such as sealing the entire deck to prevent or delay the intrusion of moisture and chlorides.

The most common deterioration mechanism for bridges is corrosion-related damage. For steel bridge elements, corrosion can lead to the loss of steel sections, which reduces the bridge's load carrying capacity. For concrete, corrosion of embedded reinforcing steel leads to cracking, delamination, and spalling of concrete. As corrosion damage progresses, the load bearing capacity of concrete members can be reduced. For concrete bridge decks, spalling of the concrete reduces the serviceability of the deck, i.e., the drivability of the bridge deck. Cracking and spalling of concrete further exposes the reinforcing steel to corrosive elements and affects the integrity of the concrete, thereby accelerating the deterioration of the material.

The detrimental effects of corrosion are well known, and the most common preservation activities are intended to reduce the rate of corrosion damage. The corrosion process for steel is an electrolytic process that requires oxygen and an electrolyte, i.e., moisture. The rate at which corrosion occurs is affected by the acidity of the electrolyte, which is increased by the presence of chlorides and other salts. Therefore, the application of deicing chemicals during the winter months to control icing on bridge decks accelerates corrosion damage in bridges. The majority of preservation activities are focused on reducing exposure to chlorides and moisture. For example, spot painting, deck washing, and applying concrete sealers reduce the exposure of steel to a corrosive environment.

The following sections describe the most valuable bridge preservation activities that could be applied by the city to extend the service lives of its bridges and keep the bridges in good condition. Section 2.1 describes different classifications of bridge preservation activities. Section 2.2 documents the existing bridges in the bridge inventory of Columbia, Missouri. Section 0 discusses the most common types of bridge preservation activities, which are described in more detail in Sections 2.4, 2.6, and 2.7.

2.1 Bridge Preservation Classifications

Preservation is typically achieved through a program of PM that consists of a planned strategy of cost-effective treatments to existing bridges. These actions are differentiated from bridge rehabilitation, which describes major work to restore the structural integrity of a bridge or to correct major safety defects. Figure 1 shows a schematic diagram indicating the relationship between PM activities and bridge rehabilitation.

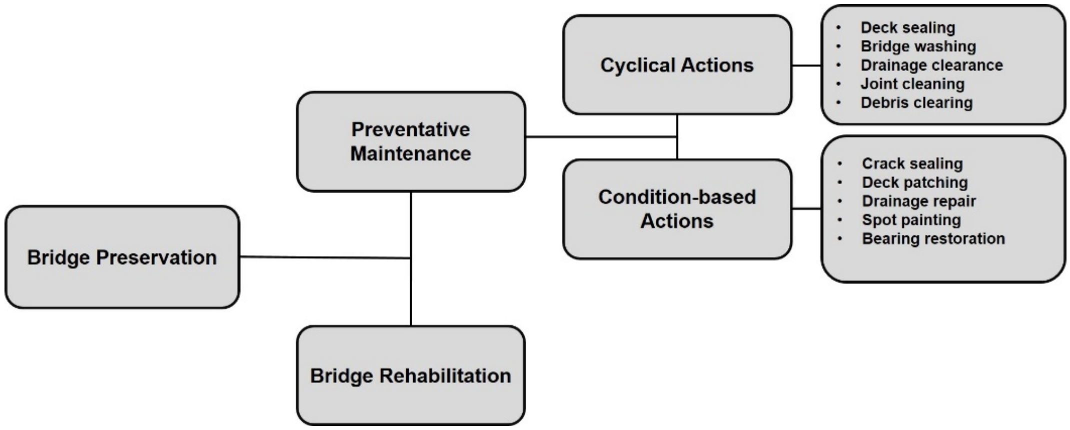


Figure 1. Schematic diagram of bridge preservation activities

PM treatments or actions are intended to prevent the deterioration of bridge elements and maintain or improve the functional condition of the bridge. PM can generally be categorized into two separate groups, as shown in Figure 1. One group is made up of cyclical activities that are performed at predetermined intervals. Cyclical activities typically prevent or retard future deterioration but do not improve the condition of the bridge element. Typical cyclical PM actions include bridge washing, deck sealing, and joint cleaning.

The second group is made up of condition-based activities, which are implemented in response to a certain condition identified through inspection. Condition-based actions are intended to delay the deterioration of the bridge element and may also improve the functional condition of the element. Typical condition-based PM actions include crack sealing, joint seal replacement, and spot or zone painting.

In this report, both cyclical and condition-based PM actions are identified. Cyclical PM actions may also be performed based on condition by identifying needs through inspection; this strategy may be applied to reduce costs and/or adjust to anticipated budget fluctuations. Methods for obtaining additional data to support condition-based PM are discussed in Chapter 3.

2.2 Columbia's Bridge Population

The bridge population of Columbia, Missouri currently includes 29 bridges and 9 culverts, as listed in Table 1.

Table 1. Bridge population of Columbia, Missouri

No.	Bridge Federal ID	Design No.	Year built	# of Span	Superstructure Material	Deck Type	Wearing Surface	Recent Deck CS Rating	Recent Superstructure CS Rating	Recent Substructure CS Rating	Culvert rating
1	15392	**0930001**	1978	1	PrestConc	ReinConc	Asphalt	6	7	8	NA
2	15400	**0930002**	1982	1	PrestConc	ReinConc	Asphalt	5	5	6	NA
3	30593	**0930003**	2004	3	PrestConc	ReinConc	PlainConc	8	9	9	NA
4	15409	0930006	1981	2	PrestConc	ReinConc	Asphalt	5	6	7	NA
5	15413	**0930009**	1987	3	PrestConc	ReinConc	Asphalt	8	7	7	NA
6	15422	0930013	1979	1	PrestConc	ReinConc	Asphalt	8	7	8	NA
7	32732	0930010	2009	2	PrestConc	ReinConc	PlainConc	7	7	9	NA
8	15426	**0930016**	1928	4	PrestConc	ReinConc	Asphalt	7	7	7	NA
9	15427	**0930017**	1925	3	PrestConc	ReinConc	Asphalt	7	7	8	NA
10	15429	**0930018**	1982	2	PrestConc	ReinConc	PlainConc	7	7	6	NA
11	15436	0930023	1985	3	PrestConc	ReinConc	Asphalt	7	7	7	NA
12	15437	**0930024**	1990	2	PrestConc	ReinConc	PlainConc	7	7	7	NA
13	28793	**0930031**	1982	1	PrestConc	ReinConc	PlainConc	7	7	8	NA
14	31461	**0930032**	2005	3	PrestConc	ReinConc	PlainConc	7	9	8	NA
15	34416	0930039	2012	3	PrestConc	ReinConc	PlainConc	8	8	8	NA
16	34784	0930040	2014	4	PrestConc	ReinConc	NotApplic	9	9	9	NA
17	33734	**0930036**	2009	3	PrestConc	ReinConc	PlainConc	8	7	9	NA
18	15430	**0930019**	1984	2	PrestConc	ReinConc	Asphalt	6	6	7	NA
19	15442	**0930028**	1988	3	ReinConc	ReinConc	Asphalt	6	6	6	NA
20	34415	**0930038**	2012	3	ReinConc	ReinConc	NotApplic	7	7	7	NA
21	15406	**0930004**	1980	3	ReinConc	ReinConc	Asphalt	7	7	7	NA
22	33540	**0930005**	2009	3	Steel	ReinConc	NotApplic	8	9	7	NA
23	15417	**0930011**	1960	1	Steel	ReinConc	Asphalt	6	3	6	NA
24	15423	**0930014**	1935	1	Steel	ReinConc	PlainConc	7	5	8	NA
25	15425	**0930015**	1920	2	Steel	ReinConc	NotApplic	5	5	6	NA
26	28133	0930030	1950	3	GalvSteel	Earth Fill	Asphalt	NotApplic	7	5	NA
27	32428	**0930034**	2009	3	Steel	ReinConc	PlainConc	8	8	8	NA
28	15435	**0930022**	1986	3	Steel	ReinConc	Asphalt	7	7	7	NA

No.	Bridge Federal ID	Design No.	Year built	# of Span	Superstructure Material	Deck Type	Wearing Surface	Recent Deck CS Rating	Recent Superstructure CS Rating	Recent Substructure CS Rating	Culvert rating
29	33735	**0930037**	2009	3	Steel	ReinConc	PlainConc	9	9	8	NA
30	24139	0930041	1986	3	Steel	Earth Fill	Earth Fill	NotApplic	NotApplic	NotApplic	5
31	31917	0930033	2006	1	GalvSteel	Earth Fill	Earth Fill	NotApplic	NotApplic	NotApplic	6
32	15439	0930025	1990	3	ReinConc	ReinConc	PlainConc	NotApplic	NotApplic	NotApplic	6
33	15440	0930026	1990	2	ReinConc	Earth Fill	Earth Fill	NotApplic	NotApplic	NotApplic	7
34	15441	0930027	1990	2	ReinConc	Earth Fill	Earth Fill	NotApplic	NotApplic	NotApplic	5
35	15443	0930029	1994	2	ReinConc	Earth Fill	Earth Fill	NotApplic	NotApplic	NotApplic	7
36	15432	0930020	1986	2	ReinConc	ReinConc	Earth Fill	NotApplic	NotApplic	NotApplic	6
37	15434	**0930021**	1986	2	ReinConc	ReinConc	Asphalt	NotApplic	NotApplic	NotApplic	6
38	32773	0930035	2008	3	ReinConc	ReinConc	PlainConc	NotApplic	NotApplic	NotApplic	6

The 29 bridges were the focus of the study, although some PM activities apply equally well to culverts. The population of 29 bridges includes bridges containing different superstructure materials: 18 prestressed concrete superstructures, 7 steel superstructures, 3 reinforced concrete superstructures, and 1 galvanized steel superstructure. Of the 29 bridges, 15 have bare concrete decks and 14 have an asphalt overlay.

There are nine culverts in the inventory; the majority of these culverts (six) have an earth-fill driving surface, so many deck preservation actions are not relevant. Two culverts have concrete decks, and one culvert has an asphalt overlay.

Of the bare concrete decks in the inventory, 13 have a condition rating of 7 or higher, indicating that these decks are in good condition. These decks are suitable candidates for cyclical preservation activities, such as sealing the deck with silane, which is discussed later in the report. Maintaining these decks in good condition will extend their service lives and reduce future costs due to repair needs such as patching or application of an asphalt overlay.

As part of the research, field visits to many bridges in Columbia were completed to identify bridge preservation needs for particular bridges and to develop knowledge regarding the characteristics of bridges in Columbia. Field visits to 1 culvert and 22 bridges were conducted, and the bridge preservation needs and conditions of these bridges were observed to assist in developing recommendations. The design numbers of the bridges that were visited are highlighted in bold text in Table 1.

2.3 Common Bridge Preservation Activities

Bridge preservation activities are focused on reducing the rate of corrosion damage for the different bridge elements, such as the bridge deck, superstructure, and bearing areas. As previously mentioned, the primary driving forces of corrosion are moisture and chlorides. Consequently, PM activities generally consist of methods to prevent the intrusion of water and chlorides, divert water from contact with bridge elements, and remove debris and vegetation that can trap moisture against bridge elements. Typical bridge preservation activities are listed in Table 2. Typical frequencies at which the different tasks are implemented are also shown in the table. Activities are divided into two categories: cyclical activities to be completed at a preset interval and condition-based activities that are completed as a result of reported condition.

Table 2. Listing of typical bridge preservation activities and recommended cycles

Bridge Component	Preventive Maintenance Type	Description	Action Frequency (years)
All	Cyclical	Sweeping, power washing or flushing	1–2
Deck	Cyclical	Deck washing	1
		Deck sweeping	1
		Drainage cleaning / repair	1
		Joint Cleaning	1
		Deck sealing	7–10
		Crack sealing	4–5
	Condition Based	Deck Patching	1–2
		Asphalt Overlay with membrane	12–15
		Joint seal replacement	10
		Drainage repair	1
Superstructure	Cyclical	Bridge approach restoration	2
		Seat and beam end washing	2
	Condition based	Spot or Zone painting Debris removal	As needed
Substructure	Condition based	Scour counter measures	As needed
		Clearing debris	As needed

Through the research, it was found that there are a number of very common PM activities that are being applied across different state departments of transportation (DOTs), including MoDOT. Essentially, bridge preservation activities fall into the following categories:

- Cleaning bridge elements
  - Sweeping
  - Washing
  - Clearing debris
- Sealing concrete
  - Penetrating sealers
  - Crack sealing
- Minor repairs
  - Spot painting
  - Scour countermeasures
  - Drainage repair

These relatively few and simple activities are effective at extending the service lives of bridges, and most are very cost-effective. As shown in Table 2, washing and cleaning of all bridge elements is a PM activity that can be repeated on an annual or biannual basis to remove debris and chlorides, thereby extending the service life of a bridge. This applies to all bridge elements, but research has shown that this activity is usually focused on bridge decks, with other elements being cleaned less frequently. The following section will discuss this and other PM activities mentioned in Table 2.

2.4 Bridge Cleaning

One of the most important and lowest-cost actions that can be taken to support bridge preservation is the cleaning of bridge elements, in particular bridge decks, but also drainage and support bearing areas (beam seats). Debris accumulation on the surface of the concrete promotes corrosion by trapping moisture against the surface of the concrete. For example, Figure 2 shows debris accumulated on the deck of a culvert. As shown in the figure, dirt has accumulated below the concrete railing, and leaves have accumulated along a fence that traverses the bridge.

Figure 2. Debris accumulation on a deck (culvert 0930021)

In some cases, vegetation may grow from this debris. The debris traps moisture against the concrete and accelerates the deterioration of the concrete. Deck sweeping and/or mechanical removal (i.e., using a shovel) of this debris would reduce the long-term effect of this debris accumulation and slow the deterioration of the bridge elements. Cleaning and removal of debris should be completed on bridge decks, beam seats/bearing areas of bridges, and superstructure members, where appropriate. Removal of the accumulated debris is typically completed prior to bridge washing or deck flushing.

Debris accumulation in the beam seat area is particularly prevalent where deck joints are failing and can result in a significant increase in the rate of deterioration. Figure 3 shows an example of debris collected in the beam seat area as a result of a failed deck joint, which is allowing debris from the deck surface to accumulate on the beam seat.

Figure 3. Debris accumulated in the beam seat area as a result of a failed joint/seal in the deck above the bearing

High water events can also deposit debris in the beam seat area. Periodic cleaning of the beam seat area may not be required in areas where joints and seals are performing adequately if the bridge is not subject to periodic high water. When joints and seals are damaged, frequent cleaning of the bearing/beam seat area is necessary to clear debris and remove chlorides that typically drain from the bridge deck through the failed seal and directly onto the bridge bearings. Repair or replacement of joint seals and failing joints can reduce the need for cleaning.

2.5 Bridge Washing

Bridge washing consists of washing bridge elements with water to remove debris and reduce the level of chlorides present. Pressurized water is typically used for superstructure elements and drainage areas; bridge decks are commonly washed with either pressurized water or by flooding the deck with water from a water truck. One purpose of bridge washing is to remove the debris accumulated on the bridge after completion of the dry removal of debris (i.e., sweeping); however, washing may also be the sole medium for removing the debris. The second purpose of bridge washing is to remove or reduce chlorides that have accumulated over the winter months when deicing chemicals are applied to the deck.

Washing reduces debris, and this in turn reduces the moisture retained in contact with bridge elements. More importantly, washing reduces the level of chlorides present on the surfaces of bridge elements. Research has shown that washing leads to a reduction of chlorides, although one bridge owner found that chloride levels appeared to increase with washing. However, this was likely due to high levels of chlorides in the wash water (see Section 4.1). If this may be a concern, chloride levels in the source water should be examined to ensure that the wash water does not have a high level of chlorides. Generally, washing the surfaces of bridge elements will reduce the chloride levels present on the surface, which will then reduce the rate of corrosion damage to the bridge element.

The washing of steel bridge elements should be focused near beam ends, where deterioration of the coating and increased deterioration of weathering steel can be anticipated. In this case, the bridge washing is primarily focused on the removal of residual chlorides from the surface of the material. As noted previously, the washing of steel members has been shown to effectively reduce the chloride levels on the surface of the steel.

Based on surveys of state practices, deck washing using pressurized water is the most common form of bridge washing. Typically, washing pressures range from 1,500 to 3,000 psi. Research has indicated that pressures below 1,500 psi reduce the effectiveness of bridge washing. Flushing of the deck using a water truck is another common method of washing a bridge deck and is implemented by MoDOT. Deck flushing is used by MoDOT on an annual basis as a means of cleaning bridge decks to remove light debris and residual chlorides. Water drainage from the bridge deck through the existing drainage system helps clear debris from the drainage system and remove residual chlorides in the drains.

Traffic control is typically required for bridge deck washing. Deck flushing may require a lower level of traffic control than pressure washing if the flushing is done using a water truck; this lower level of traffic control reduces the exposure of individuals to the risk of working in the roadway.

2.5.1 Schedule and Costs of Bridge Washing

The appropriate schedule for bridge cleaning varies depending on the bridge element, with decks typically having the priority for cleaning and washing. This is rational because decks have the most direct exposure to chlorides applied during the winter months and are also most likely to accumulate debris. Typically, deck washing is specified as an annual activity completed in the spring. Superstructure washing can be specified at two-year or one-year intervals.

Bridge washing is a low-cost bridge preservation activity that can be undertaken using maintenance staff. Costs of bridge washing have been reported using data from surveys and some research projects, as described in Section 4.1.4. In some cases, bridge washing includes pressure washing of truss bridge members, which greatly increases the cost. Because Columbia does not have any truss bridges in its inventory, however, these data are not relevant. Typical costs of bridge washing by in-house staff range from an estimated \$0.1 to \$0.53 per ft^2, \$300 to \$800 per bridge, or \$50 per hour.

2.6 Bridge Deck Preservation

Bridge decks provide the driving surface for traffic and are therefore exposed to traffic loading, and damage to the bridge deck can have an immediate effect on the serviceability of the deck. Corrosion of reinforcing steel that leads to bridge deck spalling is a common form of deck deterioration that requires repair and reduces the service life of a bridge deck.

The exposure of a bridge deck to deicers is a primary cause of distress. The penetration of chlorides into the deck is typically modeled as a diffusion process that is dependent on the chloride gradient and the diffusion characteristics of the concrete itself. The chloride gradient is a function of the amount of chloride applied to the deck and the amount of chloride that remains in place on the deck. Increased chloride buildup on the deck surface increases the rate of diffusion through the concrete to the level of the reinforcing steel. Consequently, corrosion rates can be reduced if the surface concentrations of chlorides can be reduced by applying less deicer and/or by washing the bridge deck in the spring to remove residual chlorides that may remain on the concrete surface.

The diffusion properties of the concrete are a function of the quality of the concrete; typically, poor-quality concrete has a higher diffusivity and good-quality concrete has a lower diffusivity. High-performance concretes commonly have a lower diffusivity than traditional concrete mixes. Reduction of the diffusivity of existing concrete can be achieved through the use of sealers, which limits the diffusivity of the concrete and resists the ingress of moisture.

Cracking in concrete bridge decks typically extends from the surface of the deck to the level of the reinforcing steel. Cracks provide a direct pathway for water and chlorides to penetrate to the level of the reinforcing steel and initiate the corrosion process. Therefore, an important component of bridge deck preservation is sealing bridge deck cracks to limit the penetration of water and chlorides.

2.6.1 Penetrating Sealers

Penetrating sealers are effective at reducing the diffusivity of the concrete and sealing small cracks. The objective of penetrating sealers is to prevent capillary action at the surface and thereby reduce the penetration of water and chlorides. Penetrating sealers penetrate more deeply into the concrete than top coat crack sealers and may be hydrophobic (water repellent) or pore blocking. Penetrating sealers are typically applied three to six months after construction, before chlorides have an opportunity to penetrate the surface of the deck. However, research has shown that even if penetrating sealers are not applied immediately after construction, the application of sealers still has a positive effect on preventing the penetration of chlorides into the deck (see Section 4.2.2.3). A periodic reapplication procedure is necessary throughout the life of the structure for the sealer to be effective. Sealers are effective for decks that do not yet have chloride intrusion to the level of the rebar; if chlorides have already penetrated to the level of the reinforcing steel, the benefit of sealing the deck is significantly reduced.

Penetrating sealers include silanes, siloxenes, siliconates, and silocones. Linseed oil can also be used, though the use of linseed oil has been largely discontinued because of the frequent reapplication necessary to provide protection. Silane sealers are the most commonly used products. Penetrating sealers have some ability to seal tight cracks 0.010 in. wide or less (Krauss et al. 2009).

Sealers are typically applied beginning at the time of construction and reapplied at intervals of 5 to 10 years. MoDOT recommends that silane sealers be applied at a frequency of 7 to 10 years. Research has suggested that silane treatments applied at the time of construction remain sufficiently intact for as long as 12 years (Ley and Moradllo 2015).

Deteriorated and damaged decks with extensive cracking and/or ongoing corrosion are not good candidates for deck sealing because the intrusion of chlorides has already occurred, and therefore the benefits of sealing the deck against the intrusion of moisture and chlorides cannot be realized. Decks with an asphalt overlay are obviously not good candidates for concrete sealants; however, sealing of the asphalt through the application of a fog seal and by sealing cracks in the asphalt may have a positive effect.

There is a significant population of relatively new concrete bridge decks in Columbia that would be good candidates for deck sealing because they are currently in good condition and their future deterioration could be delayed through the cyclical use of sealers. Table 3 lists bridges in the Columbia inventory that have bare concrete decks in good condition. The application of sealers to these bridge decks would delay future repairs and extend the overall lives of the decks.

Table 3. Listing of concrete bridge decks in good condition in Columbia

No.	Bridge Federal ID	Design No.	Year Built	# of Spans	Deck Type	Wearing Surface	Recent Deck CS Rating
1	30593	0930003	2004	3	ReinConc	PlainConc	8
2	32732	0930010	2009	2	ReinConc	PlainConc	7
3	15429	0930018	1982	2	ReinConc	PlainConc	7
4	15437	0930024	1990	2	ReinConc	PlainConc	7
5	28793	0930031	1982	1	ReinConc	PlainConc	7
6	31461	0930032	2005	3	ReinConc	PlainConc	7
7	34416	0930039	2012	3	ReinConc	PlainConc	8
8	34784	0930040	2014	4	ReinConc	NotApplic	9
9	33734	0930036	2009	3	ReinConc	PlainConc	8
10	15423	0930014	1935	1	ReinConc	PlainConc	7
11	32428	0930034	2009	3	ReinConc	PlainConc	8
12	34415	0930038	2012	3	ReinConc	NotApplic	7
13	33540	0930005	2009	3	ReinConc	NotApplic	8
14	33735	0930037	2009	3	ReinConc	PlainConc	9

2.6.2 Crack Sealing

Sealing individual cracks, such as those shown in Figure 4, can be a cost-effective method of preserving a bridge deck.

Figure 4. Example of concrete bridge deck cracking

Local staff can apply the crack sealer using the bottle method. This is sometimes referred to as "crack chasing." Crack sealers include epoxies, topically applied repair resins such as high molecular weight methacrylate (HMWM), and other polymers. The crack sealing approach is usually effective if the spacing between cracks is 2 ft or greater. When cracks are more closely spaced, sealers applied by flooding the deck (i.e., flood coat) are typically more effective. Research described later in this report (Section 4.2.2) indicates that crack sealing is an effective method for protecting against the ingress of water and chlorides, thereby reducing deterioration due to corrosion damage to the reinforcing steel in concrete bridge decks.

Because cracks in the bridge deck provide direct pathways for moisture and chlorides to reach the reinforcing steel in the bridge deck, the sealing of cracks is an important PM strategy. The lifespan of crack sealers is less than that of penetrating deck sealers, and reapplication at a frequency of three to five years is typically necessary with crack sealers. Research has suggested that after three years the effectiveness of crack sealers may be reduced (Section 4.2.2.7).

MoDOT recommends the use of low-viscosity polymers for the sealing of narrow cracks in bridge decks. MoDOT currently has several crack sealers that could be described as "healer-sealers" that serve to both seal the deck and seal cracks, as suggested in Category 771 of the MoDOT EPG. The recommended treatment of bridge decks under the MoDOT EPG is shown in Table 4.

Table 4. MoDOT deck sealing recommendation table, EPG 771.15

Deck Condition	Recommended Treatment
New decks and decks with minimal cracking	EPG 771.16 Penetrating Concrete Sealer – Silane
Decks with hairline cracks < 1/128 in. (0.008 in.) wide	EPG 771.17 Concrete Crack Filler – Low-Viscosity Polymer (LVP)
Decks with cracks >1/128 in. (0.008 in.) wide	EPG 771.18 In-Deck Bridge Deck Crack Filler
Decks with cracks >1/64 in. (0.016 in.) wide	EPG 771.19 Chip Seal to Entire Deck

The MoDOT EPG recommends penetrating sealer, crack sealer, a healer-sealer-type crack sealer, and a chip seal for maintenance of concrete bridge decks. The recommendation depends on the width of existing cracks in the bridge deck. When crack widths are narrow, penetrating sealers may be effective in sealing the surface of the cracks and providing some preservation benefit. For larger cracks, a low-viscosity polymer is recommended. A variety of crack sealing products is available, and these crack sealers can be effective even for larger-width cracks.

Although the MoDOT EPG recommends a healer-sealer type of crack sealing when cracks are wide, the cost of applying such a healer-sealer may be prohibitive compared with the cost of simply chasing cracks using a low-viscosity polymer or other crack-sealing product. There are substantial benefits to sealing cracks in bridge decks, regardless of the widths of the cracks.

For bridges with an asphalt overlay, cracks in the asphalt overlay provide a pathway to the surface of the concrete, where moisture can become trapped and penetrate the concrete deck surface. Cracks in asphalt overlays can be sealed using asphalt products, and this should be considered for asphalt-covered decks. However, asphalt-covered decks are frequently decks at or near the end of their service lives and may be programmed for repair. Consequently, the benefits of sealing these cracks may be reduced, and the cost-effectiveness of sealing cracks should be assessed on a case-by-case basis.

2.6.3 Costs of Deck Sealing

A wide variety of products is available for deck and crack sealing, and these different products obviously have different costs. According to a survey completed by the Kentucky Transportation Cabinet, bridge owners reported that the cost of sealing decks with penetrating sealers is approximately \$1.00 per ft^2. The cost of flood coating with a healer-sealer is approximately \$1.50 per ft^2. The costs of crack chasing, i.e., sealing individual cracks, was reported as approximately \$4.44 per linear ft.

A life cycle cost analysis of the effect of implementing a sealing program demonstrated that the periodic application of sealers can result in significant savings over a bridge service life of 75 years (see Section 4.2.3). In the analysis cited, four different scenarios were considered, as shown in Table 5.

Table 5. Life cycle cost analysis for different PM scenarios for a bridge deck

Scenario	Description	Present Value ($/ft^2)
1	Seal deck at time of construction only	$80.63
2	Seal periodically throughout the life of the bridge, and no deck replacement required, overlay after 35 years	$43.30
3	Seal periodically and patch as required, overlay after 35 years, no deck replacement	$48.18
4	Seal periodically, overlay after 30 years, replace deck later in time than scenario 1	$59.96

The different scenarios considered the use of a sealer to extend the life of a bridge deck, as well as different maintenance activities, such as concrete patching, that may be required during the life of the bridge deck. The analysis shows that the present value was significantly reduced by the use of sealers throughout the life of the deck. This analysis demonstrates how periodic PM and maintenance activities can significantly reduce the life cycle cost of a bridge deck.

2.7 Spot Painting

Spot painting is a PM activity that has limited implementation within typical state preservation programs. However, this PM activity should be considered for cases where steel beam ends are deteriorating but not yet in serious condition. MoDOT typically uses a calcium sulphonate penetrating primer and a topcoat to fully recoat bearings and portions of steel beams near the bearings that have corrosion damage and failing coatings. However, virtually any coating would provide life extension relative to a do-nothing approach. Spot painting should not be completed where there is direct drainage onto the superstructure, such as beneath a leaking joint, unless the joint is repaired, because the spot painting will fail very quickly in such cases. Priority should be given to repairing the joint because the atmospheric corrosion rates of steel are very low, and therefore stopping the leakage from the joint will have a significant impact on slowing the rate of damage. If bridge washing is also being completed so that surface chlorides are being reduced, the corrosion damage may be significantly limited even without recoating the steel.

2.8 Joint Seal Repair

A significant issue in the deterioration of beam ends, bearings, and beam seats is leaking joints at the end of the bridge deck. Damage in the beam ends usually results from leaking joints in the bridge deck, which allow water to pass the joint and run onto the supporting structural elements. Figure 5 shows the type of damage that can result from leaking joint seals.

Figure 5. Corrosion damage at a beam end caused by a leaking joint

Corrosion on the flange, web, and bearing results from water leaking through the joint above the bearing. Joint seal repairs should be prioritized for weathering steel bridges, bridges with damaged or deteriorated coating, and concrete and prestressed girders.

3 RECOMMENDATIONS AND CONCLUSIONS

This chapter documents the recommendations and conclusions developed for the bridges in Columbia, Missouri based on the analysis of existing bridge preservation practices nationwide and the review of Columbia bridge data. These recommendations and conclusions include methods for collecting data for the purpose of identifying bridge preservation needs and specific recommendations and prioritization approaches for bridge preservation.

3.1 Bridge Condition Data

Data-driven PM activities can provide increased efficiency by identifying when condition-related activities should be completed. Currently, MoDOT conducts a biennial safety inspection of each bridge in Columbia and provides an inspection report containing inspector recommendations for maintenance and repair. These data are important input that can be used within the bridge preservation program to identify condition-related activities. A listing of actions from the MoDOT reports provided through the project has been summarized and is included as Appendix B of this report. The recommendations include a number of PM activities, such as deck sealing, clearing vegetation, and bank protection. Rehabilitation activities, such as deck or deck overlay replacements, are also included in the notes and could be considered for future programming.

However, the MoDOT inspections are conducted at 24-month intervals, and conditions may change between inspections. Additionally, the focus of the state inspection is bridge safety. Therefore, not all potential PM activities are included in the comments. For example, deck cracking, debris on the deck, or clogged drains may not be identified on the bridge inspection report. To enhance the data available for identifying preservation activities, the city may consider implementing a periodic BPIP as a practical, low-cost method of improving the data available to engineering staff regarding the PM needs of the bridge inventory. The following section describes what such an inspection program would include.

3.1.1 Bridge Preservation Inspection Program

A BPIP could be implemented to improve the efficiency and quality of bridge preservation activities. This inspection program would not replace the existing National Bridge Inspection Standards (NBIS) inspection program implemented by MoDOT, but rather enhance that program's inspections by providing additional data on specific items relevant to preservation. The rationale of a BPIP is to provide additional data on the current needs in the inventory in a practical, low-cost manner.

The BPIP could be implemented using temporary employees to visit each bridge in the inventory and complete a simple questionnaire. This questionnaire is focused on identifying condition-based PM activities that could be completed by maintenance personnel. The questionnaire is included in Appendix D and asks the following questions:

1. Is there any vegetation growing from deck drains, joints, or cracks?

2. Are there any unsealed cracks in the surface of the deck? (width)
3. Are there any spalls in the bridge deck that require patching?
4. Is there debris on the surface of the deck?
5. Is there water draining/leaking onto the bearing or substructure elements?
6. Are the deck drains impacted by debris?
7. Is there debris collected on the superstructure of the bridge?
8. Is there any debris accumulated on the substructure?
9. Is there debris collected in the waterway that would affect the flow of water?
10. Is there vegetation growing onto the superstructure/substructure?

As shown in Appendix D, the questionnaire includes a sample image of each condition. Generally, these images depict conditions found when examining city bridges during the course of the research.

The BPIP could be implemented by using a summer work force to visit each of the bridges to complete this simple questionnaire. It is envisioned that only a short training program would be required to teach staff how to identify the conditions that indicate the preservation activities needed and how to complete the BPIP questionnaire for each bridge. A typical inspection could be completed in one hour or less. The BPIP inspector could photograph conditions identified at the bridge that require PM activities. The BPIP would be low cost and would assist maintenance personnel with identifying where PM activities, such as deck washing, clearing debris, crack sealing, or deck patching, may be required.

3.2 Prioritization of Preventive Maintenance Activities

This portion of the report describes the recommended schedule and prioritization of PM activities for Columbia. The recommended scheduling and prioritization plan was developed based on a review of the available literature, a field review of a portion of the bridge inventory in Columbia, analysis, and practicality of implementation. A calendar of MoDOT bridge maintenance activities is provided in Appendix A.

3.2.1 Immediate Action for PM

Bridge PM activities were analyzed to determine the activities that should be prioritized for future application. A subjective risk analysis was completed that considered the potential impact of the PM activity, the cost, and the ease of implementation. In this analysis, the cost was rated as low, medium, or high; the impact was estimated based on the available literature and engineering judgement; and the ease of implementation was analyzed based on whether the activity could be completed by maintenance personnel or temporary workers or if it was likely to require a contract.

Based on this analysis, PM activities were prioritized for implementation in Columbia. Table 6 lists the PM activities that are recommended for implementation, starting with near-term activities and extending through future activities.

Table 6. Suggested PM activities, priority, rationale, and selection criteria

Scenario	Priority	Rationale	Selection Criteria
Seal cracks in bare concrete decks	ASAP	Open cracks in the surface of a bridge deck are the most direct pathway for moisture and chlorides to penetrate to reinforcing steel and cause corrosion damage. The sealing of cracks will have an immediate, positive effect on reducing the deterioration of bridges. The activity can be completed by current maintenance personnel.	BPIP / Inspection results
Clean decks and drains	12 months	Sweeping and cleaning of bridge decks will immediately have an effect on reducing the rate of corrosion by removing moisture trapped against the bridge materials. The activity can be completed by current maintenance personnel or by temporary staff.	BPIP / Inspection results
Clean beam seat areas of debris	12 months	Clearing beam seats of debris will immediately have an effect on reducing the rate of corrosion by removing moisture trapped against the materials. The activity can be completed by current maintenance personnel or by temporary staff.	BPIP / Inspection results
Implement bridge deck washing / flushing program	24 months	Deck washing will have a long-term benefit of reducing the rate of corrosion in bridge elements. The impact of deck washing may be less than impact of simply removing debris from the surface, and the cost is higher.	All bridge decks
Implement bridge superstructure washing	24 months	Superstructure washing will have a long-term benefit of reducing the rate of corrosion in bridge elements. The impact of superstructure washing is less than the impact of simply removing debris from the surface, and the cost is higher. Access to the areas of the bridge that require washing is also more difficult, and pressure washing is required.	Prioritize steel bridges and bridges with open or leaking joints
Implement a bridge deck sealing program	24 months	Sealing of concrete decks will extend the service life of the deck and have a positive long term effect on the deterioration rate of the deck. However, the costs are higher than other activities, and this may require contract forces to complete the work. Maintenance personal can seal decks with some modest training in procedures.	See Table 4
Clear vegetation	36 months	Removing vegetation surrounding or growing onto bridges will diminish the corrosive environment by improving air flow through the structure and not trapping moisture against the surface of the concrete. However, the impact of this activity is much smaller than removing debris or washing bridge elements. Costs are low and maintenance personnel or temporary workers can complete this task.	BPIP / Inspection results
Repair leaking joints	48 months	Repairing leaking joints in bridges will reduce deterioration at the beam ends by preventing water and chlorides from draining directly onto these elements. This will have the impact of extending the service life of the bridge. Requirements depend on the types of joints. Replacing leaking deck seals has a higher cost relative to other PM activities.	BPIP / Inspection results

In essence, activities that are simple to implement, low cost, and high benefit are prioritized over higher-cost actions that may be more difficult to implement. For example, bridge cleaning is recommended for the next 12 months because this action can be completed using simple hand tools to remove debris accumulating on decks, blocking drains, and resting on beam seats. Bridge washing is recommended for the next 24 months because this may require more planning and the use of tools such as a washing truck, pressure washers, etc. Practically, it may be that implementing the cleaning and washing activities simultaneously is more efficient if the resources to do so are available. The sealing of cracks is prioritized for immediate implementation because this activity will have a high impact on bridge maintenance by blocking the direct ingress of water and chlorides to the level of the reinforcing steel, thereby decreasing the rate of deterioration of the bridge deck. Removal of vegetation is given a low priority because its impact on reducing the deterioration of bridge elements is smaller than that of other PM activities.

In addition to these PM activities, removal of debris deposited along piers or abutments during high water events should be undertaken on an as-needed basis. Slopes should be repaired and scour countermeasures should be implemented on an as-needed basis. These activities are common bridge maintenance activities and therefore were not placed in the list of PM activities. Inspection reports can be used to identify areas where these activities should be undertaken.

As part of the research, field visits to a number of bridges in Columbia were undertaken. Based on the field review of the bridges, a number of immediate actions, based on conditions found at the bridge, were identified and are included in Appendix B. These data have been provided to assist in prioritizing particular bridges for PM actions.

3.2.2 Bridge Washing Prioritization

Bridge superstructure washing will remove debris and contaminants and help preserve bridges. For most bridges, bridge washing should focus on the beams ends, bearings, and beam seats. If a bridge has drains through the deck that are causing water from the deck to drain onto the superstructure, the area surrounding the drains should be considered for washing. Bridges with leaking joints should be prioritized over bridges with sound joints. Jointless bridges may not require periodic washing because chlorides from the surface of the bridge deck may not be leaking onto the superstructure and beam seat area. Weathering steel bridges will benefit significantly from bridge washing because chlorides on the surface of the steel can break down the patina intended to protect the bridge from rapid corrosion damage. During the initial program startup, bridges with accumulated debris on the beam seat and bridges with leaking joints should be prioritized for cleaning and washing. The suggested BPIP can provide data that can be used to select bridges for initial cleaning and washing of the beam ends.

Table 7 shows a preliminary listing of the bridges in Columbia in order of priority for bridge washing over the longer term.

Table 7. List showing bridge washing priority

No.	Bridge Federal ID	Design No.	Year built	# of Span	Superstructure Material	Wearing Surface	Recent Deck CS Rating	Recent Superstructure CS Rating
1	15435	930022	1986	3	Steel	Asphalt	7	7
2	33540	930005	2009	3	Steel	NotApplic	8	9
3	15417	930011	1960	1	Steel	Asphalt	6	3
4	15423	930014	1935	1	Steel	PlainConc	7	5
5	15425	930015	1920	2	Steel	NotApplic	5	5
6	33735*	930037	2009	3	Steel	PlainConc	9	9
7	32428	930034	2009	3	Steel	PlainConc	8	8
8	34784	930040	2014	4	PrestConc	NotApplic	9	9
9	15426	930016	1928	4	PrestConc	Asphalt	7	7
10	30593	930003	2004	3	PrestConc	PlainConc	8	9
11	15413	930009	1987	3	PrestConc	Asphalt	8	7
12	15427	930017	1925	3	PrestConc	Asphalt	7	7
13	31461	930032	2005	3	PrestConc	PlainConc	7	9
14	34416	930039	2012	3	PrestConc	PlainConc	8	8
15	33734	930036	2009	3	PrestConc	PlainConc	8	7
16	15436	930023	1985	3	PrestConc	Asphalt	7	7
17	15442	930028	1988	3	ReinConc	Asphalt	6	6
18	34415	930038	2012	3	ReinConc	NotApplic	7	7
19	15406	930004	1980	3	ReinConc	Asphalt	7	7
20	15409	930006	1981	2	PrestConc	Asphalt	5	6
21	15430	930019	1984	2	PrestConc	Asphalt	6	6
22	32732	930010	2009	2	PrestConc	PlainConc	7	7
23	15429	930018	1982	2	PrestConc	PlainConc	7	7
24	15437	930024	1990	2	PrestConc	PlainConc	7	7
25	28793	930031	1982	1	PrestConc	PlainConc	7	7
26	15392	930001	1978	1	PrestConc	ReinConc	6	7
27	15400	930002	1982	1	PrestConc	ReinConc	5	5
28	15422	930013	1979	1	PrestConc	Asphalt	8	7
29	28133	930030	1950	3	GalvSteel	Asphalt	NotApplic	7

This list was developed based on the following prioritization: weathering steel bridge with joints should be the first priority (Nos. 1 and 2), followed by other steel bridges (Nos. 3 through 5). Bridges with concrete superstructures are the second priority, and these have been further prioritized based on the number of spans in the bridges. This prioritization was based on the rationale that multi-span bridges are more likely to have a joint with the potential for leaking and deck runoff may be more significant. Two weathering steel bridges that are jointless are prioritized following other steel bridges (Nos. 6 and 7). However, some of the concrete bridges in the inventory are jointless bridges, and these bridges should have a lower priority for bridge washing than comparable bridges with joints. The BPIP could be utilized to improve the prioritization of bridges with concrete superstructures.

3.2.3 Periodic PM Actions

The previous section of the report described the priority action items for PM activities. In terms of longer-term PM activities, Table 8 records the PM activities that are recommended to be completed in the future, the expected service life of those activities, and the bridge selection criteria. Over the longer term, some PM actions need to be repeated at different intervals.

Table 8. Short term, mid-term and long-term preservation actions, expected service life, and bridge selection criteria

Time Period	PM Action	Expected Service Life (years)	Bridge Selection Criteria
Short Term (12–24 months)	Seal concrete cracks	3–5	Decks with cracking
	Drainage System Cleanout/repair	1	All bridge decks with drains
	Deck cleaning and washing	1	All bridges will benefit from cleaning and washing
	Clean and wash bridge beam ends, beam seats and bearings	1–2	Bridges with accumulated debris and leaking joints; prioritized as noted in the text
	Deck Sealing	10	Bare concrete decks in good condition
	Seal HMA cracks	3–5	Asphalt decks with cracking
Mid Term (25–72 months)	Seal Joints	7–10	Based on inspection results
	Spot Painting	7	Bridges with damage at the beam ends
	Reseal cracks after 3–5 years	3–5	Cyclical
Long Term (73–120 months)	Reseal decks after 7 to10 years		

For many of the PM activities identified, MoDOT provides engineering policy guidance that describes the activity. Table 9 shows the relevant MoDOT EPG categories for different PM activities.

Table 9. PM activities and relevant MoDOT engineering guidance

Preservation Action	MoDOT EPG
Superstructure Washing	771.2 Bridge Cleaning and Flushing
Deck Flushing/Washing	771.2 Bridge Cleaning and Flushing
Vegetation Control	771.20 Cut and Spray Brush and Vines
Debris Removal	771.8 Remove Drift
Drainage System Cleanout/repair	771.2 Bridge Cleaning and Flushing 771.4 Drain Basin Maintenance
Spot Painting	771.14 Spot Painting of Bearings and Piling
Deck Sealing	771.16 Penetrating Concrete Sealer – Silane
Seal concrete cracks	771.17 Concrete Crack Filler – Low-Viscosity Polymer 771.18 In-Deck Bridge Deck Crack Filler 771.19 Chip Seal to Entire Deck (R322 Bridge Seal Coats Maintenance Planning Guidelines)
Seal Joints	771.10 Bridge Joint Sealing – Hot Pour 771.11 Bridge Joint Sealing – Silicone 771.12 Bridge Joint Sealing – Polytite
Seal HMA cracks	413.5 Crack Treatment in Bituminous Pavements

3.3 Discussion

This portion of the report describes a recommended program for preventive maintenance for the city. The PM actions that were selected for implementation were chosen considering the practicality of implementation. Generally, activities that could be performed at a low cost and with in-house staff were the focus of the recommendations. These recommendations were developed based on a review of the literature, surveys of common practices by bridge owners, and interaction with other preservation specialists.

3.4 Conclusions

Highway bridges are a vital part of our nation's infrastructure. The implementation of a bridge preservation program helps agencies extend the service lives of their bridges and maximize the use of limited resources. By applying preventive maintenance procedures, agencies can achieve significant cost savings by avoiding costly major repairs and the reconstruction of bridges.

In this project, a bridge preservation program was developed for the Columbia to help the city effectively manage and maintain its inventory of 38 bridges. The program was developed based on a review of existing practices by other agencies, an informal risk analysis, and field visits to 14 bridges within the city. Key recommendations for this program are as follows:

- Focus on low-cost activities to prevent bridge deterioration and keep good bridges in good condition.

- Identify and prioritize PM activities, as shown in Table 6.

- Wash bridges periodically based on the priority shown in Table 7.

- Include a mix of short-term, mid-term, and long-term PM activities (Table 8).

- Identify preservation needs through the implementation of a BPIP that uses the questionnaire provided in Appendix D.

- Consult the maintenance notes in the MoDOT biennial inspection reports for additional guidance regarding short-term condition-based PM activities for each bridge.

- Utilize the MoDOT EPG and other resources for guidance regarding specific details and procedures for bridge PM activities.

As Columbia continues to grow, implementation of this bridge preservation program will help the city meet its future transportation demands by keeping its network of 38 bridges in good condition while using limited resources.

4 RESEARCH

4.1 Bridge Washing

4.1.1 Bridge Washing Description

This section of the report provides a summary of the literature search performed to explore the application of bridge washing. A summary of the results from the research is presented first, followed by more detailed summaries of relevant literature.

According to the FHWA Bridge Preservation Guide, bridge washing is a “cyclical preventive maintenance” activity that delays the deterioration of bridge elements (FHWA 2011). “Cyclical” in the context of “bridge preservation and maintenance” means that the activity is scheduled irrespective of the condition of the bridge elements to preserve their present condition, as previously discussed (FHWA 2011). Bridge washing has received more widespread attention in recent years because bridge preservation activities have become eligible for funding under FHWA programs.

4.1.2 Bridge Washing Purpose, Frequency and Concerns

Bridge washing is done for two different purposes and in two different ways. One purpose of bridge washing is to remove the debris accumulated on the bridge elements either after completion of the dry removal of debris or as the sole method for removing the debris. The second purpose of bridge washing is to remove chlorides from or reduce the amount of chlorides on bridges or their elements. The removal of chlorides is intended to reduce the rate of corrosion. This can be effective for bridge decks, steel bridge members, reinforced concrete, prestressed concrete, expansion joints, and bridge bearings and seats.

A number of surveys have been completed to record the implementation of bridge washing. The result of a survey by Berman et. al (2013) sent to 53 agencies (35 states, 1 Canadian province, 1 bridge agency, and 16 other bridge owners) showed that 19 of the responding agencies had bridge washing programs. Another survey sent by the Minnesota Department of Transportation (MnDOT) discovered that about 75% of the 22 respondents had bridge washing among their maintenance activities (CTC 2016).

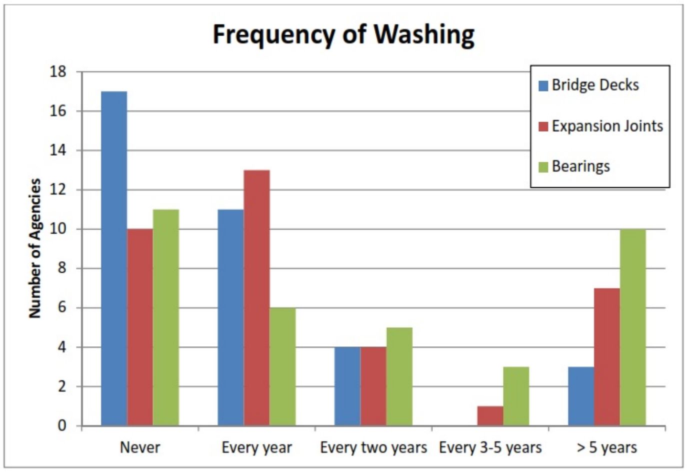
Bridge washing is accomplished at varying frequencies by different agencies. Table 10 shows the feedback provided in response to the survey sent out by Berman et al. (2013).

Table 10. Table showing the frequency of bridge washing done by responded agencies

Frequency	Agency	Comment
Biannually	New Jersey	N/A.
Annually	Indiana, Iowa, Kansas, Missouri, Washington, West Virginia	*Indiana.* Except for truss bridges, which are twice a year. *Iowa.* Only border bridges on an annual basis. *Kansas.* Yearly in some areas/districts, more frequently in others. *Missouri.* We prescribe cleaning/flushing decks in the fall and the entire bridges in the spring. In reality, we flush decks/drains at least once a year, but cleaning the substructure and superstructure occurs less frequently. *Washington.* Annually on steel truss bridges. *West Virginia.* We try every year, but it depends on manpower.
Every 2 years	New Hampshire, Vermont	*New Hampshire.* Target is annually.
As needed	Delaware, Michigan, North Carolina	*Delaware.* As needed according to a biannual bridge inspection.
Other	Oklahoma, Denmark	*Oklahoma.* Some of our field divisions have done this; once a year if at all. *Denmark.* Only few big bridges a few times a year.
Just Started	MDTA	N/A

As shown in the table, the most common frequency for bridge washing is annually, though some agencies are using a two-year interval or evaluating the need for bridge washing based on conditions (i.e., as needed). Missouri reports that bridge washing is an annual activity.

Figure 6 shows the frequency of washing for different agencies according to Burgdorfer et al. (2013). This includes the washing of bridge decks, expansion joints, and bearings. In this figure, it can be seen that there is a large variation in the washing frequency implemented by bridge owners.



Burgdorfer et al. 2013, WSDOT

Figure 6. Bridge washing frequency relative to bridge element need in the US

The reasons for the different bridge washing frequencies, to some extent, is provided by the respondents in Table 11, and Figure 6 shows the different bridge washing frequencies with respect to bridge elements.

Table 11. Midwest states' bridge washing frequency relative to bridge element type

	Deck Washing	Expansion Joint Washing	Bearing Washing	Steel Bridges	Mechanical Bearing Percentage	Older Expansion Joints
	Frequency (Years)				Percentage	
Illinois	Never	Never	Never	26–50		0–25
Indiana	1	1	1	26–50	51–75	26–50
Iowa	>5	>5	>5	0–25	26–50	0–25
Michigan	Never	Never	Never	51–75	51–75	0–25
Minnesota	1	1	1	0–25	26–50	0–25
Missouri	1	>5	>5	51–75	26–50	26–50
North Dakota	1	1	1	0–25	0–25	0–25
Oklahoma	Never	>5	Never	26–50	26–50	0–25
South Dakota	1	1	>5	26–50	51–75	0–25

Source: Burgdorfer et al. 2013, WSDOT

Other reasons cited in the literature that contribute to different bridge washing frequencies are as follows:

- Agencies' expectations for the "level of service" and their "program goals"(FHWA 2011)
- Availability of funds and resources for agencies (FHWA 2011, Burgdorfer et al. 2013)

- The environmental condition around the bridge, such as coldness and length of winter (necessitating application of deicers), amount of humidity, moisture presence, and distance of the bridge from a coastal environment (Kogler 2012, Burgdorfer et al. 2013)
- Type of structure, such as steel (weathering steel and painted steel), reinforced concrete, and prestressed concrete, and bridge elements (bridge deck, connections, bearings, expansion joints, and railing) (Sprinkel 2001, Burgdorfer et al. 2013)
- Strictness of state environmental regulations on collecting solid and liquid debris (Burgdorfer et al. 2013)

The frequency of bridge washing relative to the bridge elements shown in Figure 6 is differentiated in Burgdorfer et al. (2013) according to the geographic locations of the states, and only the Midwest states are shown in Table 11. The Midwest states are among those that wash their bridge decks most frequently due to the variable environmental conditions during the year. The column named Steel Bridges in Table 11 shows the percentage of steel bridges relative to the agency's bridge inventory, and it was determined that deck washing is more common among agencies with a higher percentage of steel bridges (Burgdorfer et al. 2013). A survey found that even states that do not wash bridge decks still clean expansion joints more frequently than bearings, which are deemed to be "less important" (Burgdorfer et al. 2013).

Some bridge owners do not commonly use washing as a preservation activity for their bridges. For example, Arizona does not wash its bridge decks, and the cleaning of expansion joints and bearings is accomplished at frequencies of greater than five years because "Arizona has a climate that is not conducive to corrosion growth" and deicing salt is rarely used there (Burgdorfer et al. 2013). Georgia does not wash bridge decks at all; expansion joints are washed at frequencies of once every three to five years, and bridge bearings are washed at intervals of greater than five years because officials "have determined [that] washing is not really needed in their state" (Burgdorfer et al. 2013). Likewise, bridge decks, expansion joints, and bearings are cleaned in intervals greater than five years in Iowa due to "insufficient funds and resources" (Burgdorfer et al. 2013). In Maryland and Tennessee, bridge decks, expansion joints, and bearings are not washed at all because of "restrictive environmental regulations to maintain the integrity of Chesapeake Bay" and "environmental regulations," respectively (Burgdorfer et al. 2013). In Michigan, except for one district that washes bridge decks and expansion joints, bridge decks, expansion joints, and bearings are not washed now. However, the state "had a specification for washing superstructures for 10 years" that "was discontinued due to environmental regulations that were enacted" (Burgdorfer et al. 2013). Bridge decks and bearings are not washed in Oklahoma at all, and expansion joints are washed no more than every five years due to "lack of sufficient resources" (Burgdorfer et al. 2013).

There is a general consensus that bridge washing can minimize the corrosion rate of bridges and their elements, but there is no quantitative data to back up the frequencies practiced by the above-mentioned agencies. A research project was completed by the Oregon Department of Transportation in 2005 to study the efficiency of bridge washing on reinforced concrete bridge decks. This study examined the ability of bridge washing to minimize the chloride content and chloride ion absorption both in the laboratory and on in-service bridges. After two years of experiments, the research concluded that annual and biannual washing is ineffective in reducing the existing “chloride ion content” and “chloride ion penetration in reinforced concrete decks” (Soltesz 2005).

As mentioned by several state DOTs, environmental regulations can hinder bridge washing. The following environmental concerns regarding bridge washing require attention: debris management before washing, wash water source selection, wash water disposal and collection, lead- and asbestos-based paint and flaky rust removal and collection, and disturbance of migratory birds. Regulatory rules related to the above-mentioned concerns should be followed prior to any bridge washing schedule. A separate section in this report will cover these issues, and the respective sources are available in the references section.

Bridge washing, even with limited literature to quantify its effectiveness or justify it financially, is deemed by several state DOTs to be an activity that lengthens the useful life of bridges and bridge elements and is a recommendation of the FHWA Bridge Preservation Guide.

4.1.3 Literature Review

This portion of the report summarizes key references describing the effectiveness of bridge washing. The primary focus of previous research has been the effectiveness of bridge washing for steel bridge members.

4.1.3.1 Hara et al. (2005)

Hara et al. (2005) completed a three-year long (June 2001 to April 2004) bridge washing experiment on two bridges to find the effect of bridge washing on the inhibition of “deicing salt corrosion of weathering steel bridges” in Japan (Hara et al. 2005). The two bridges, named S-bridge and U-bridge, are located on an expressway that traverses mountainous terrain in Japan. The bridges have been in service since 1992. The selected portions of the bridges were washed using pressurized tap water at the beginning of April during the project period. The authors selected the bottom flanges of the steel bridge for performing measurements because these are areas where chlorides are expected to be found in high concentrations and where corrosion is most commonly found. Small steel samples were also placed at different positions on the steel bridge members, which allowed for these samples to be removed periodically for analysis of the corrosion products formed and to complete section loss analysis.

The study determined that the concentration of chloride ions in the rust is at a maximum during the deicer application months and is at a minimum otherwise. During the summer, the rust build-up process is positive and occurs when chloride concentrations of not less than 0.2% by mass remain from the previous winter.

The steel test specimens positioned close to the S-bridge girder bottom flange showed that washing the specimens with 2 MPa pressure compared to no wash had reduced section loss. It was also found that chloride remnants from the winter that remain in the summer reduce the effectiveness of the weathering steel patina by enlarging the particle sizes of the corrosion products. It was concluded that washing, even with the low pressures used for this research, was effective at inhibiting the rate of corrosion damage for weathering steel.

4.1.3.2 Johnson et al. (2003)

This study examined three sets of bridges located in different environments: urban, suburban, and rural. Each set consisted of two bridges that were in close proximity to each other. The study attempted to quantify the steel surface contamination by chlorides, nitrates, and sulfate salts prior to surface preparation and after pressure washing. In all three sets, one bridge was washed using water and the counterpart was washed using a mixture of water and a chemical salt remover.

The bridges located in the urban area were two side-by-side steel bridges separated by an open joint along the girders. The bridges had high traffic volumes. Both bridges exhibited corrosion damage. In total, 144 test samples were collected from the center of the span and tested for chloride, sulfate, and nitrate. A water washing pressure of 3,000 psi was used, and the water was taken from a local potable source with no prior property or content test.

The rural bridges were two moderately traveled bridges located about a mile away from each other on the same route and in the same environment. The corrosion area for these two bridges was located at the bottom of the bottom flange. For these bridges, 40 test samples were taken to test the chlorides, sulfates, and nitrates.

The suburban bridges were located on a heavily traveled route and were located a mile away from each other in about the same environment. The bridges were painted with a lead-based paint. The corroded area located in the webs of the fascia beam and the bottom and top faces of the bottom flanges were washed at 3,000 psi pressure. A total of 80 test samples was collected to test chlorides, sulfates, and nitrates. Table 12 shows the test results for the pre-wash, water wash, and salt remover wash.

Table 12. Summary of results averaged over all six bridges

	Pre-wash ($\mu g/cm^2$)	**Water Wash ($\mu g/cm^2$)**	**Salt Remover Wash ($\mu g/cm^2$)**
Chlorides	33	20	8
Nitrates	13	8	2
Sulfates	10	4	2
Total Salt	56	32	13

Source: Johnson and Kowalski 2003

The study concluded that sulfates and nitrates are present in all environments and that sulfate ions can be removed more easily in the presence of chlorides and nitrates. It was also found that a large amount of salts stay on the coated surfaces of the bridge after pressurized water washing. Generally, it was found that the total amount of salts was reduced by the washing process and that more salts were removed if a salt remover was used in the wash water. The researchers also indicated that salts were removed if the washing nozzle was kept perpendicular to the surface within a distance of 1 ½ ft.

4.1.3.3 Alland et al. (2013)

The bridge washing procedures of the Pennsylvania Department of Transportation (PennDOT) were studied in Alland et al. (2013) to evaluate the effectiveness of bridge washing. One of the purposes of this study was to measure the concentration of salts on the surface of bridges. This was accomplished by measurement of the salt concentration on three bridges to determine the amount of salt concentration prior to washing and to determine the effectiveness of current bridge washing procedures that PennDOT used for removing the salts. The after-wash water from all three bridges was also collected to measure the effectiveness of the washing procedure and to check if it was safe to let the water drain into a stream. Five different spots on a truss bridge, five spots on a steel I beam bridge, and six spots on a plate girder bridge were washed using a washing pressure of 1,500 psi. The results of the truss bridge washing for only one location are shown in Table 13.

Table 13. Bridge washing salt concentration result of truss bridge (one location only)

	Salt Concentration, mg/m^2 (x 10^{-3} grains/ft^2)	
Reading	**Pre-Wash**	**Post-Wash**
1	12(17)	7(10)
2	15(22)	7(10)
3	15(22)	6(9)
4	13(19)	3(4)
5	8(11)	6(9)
6	15(22)	6(9)
7	11(16)	7(10)
8	7(10)	3(4)
9	15(22)	1(1)
10	18(26)	7(10)
11	7(10)	6(9)
12	16(23)	1(1)

Source: Alland et al. 2013

The following results were found from this test:

- River water removes an appreciable amount of salt from undamaged coating of steel bridges (61% reduction in this test).
- Rusty surfaces retain more chlorides than undamaged surfaces because the chlorides reside in the corrosion pitting and are, therefore, hard to remove.

The wash water was tested for turbidity, zinc, lead, and copper content and yields. The results are documented in Table 14 and Table 15. Comparison between the wash water volume from the bridge washing activity in a day with the amount of water that would flow into a small stream suggests that the calculated turbidity can be neglected. Generally, these results show that the wash water would not have a negative environmental impact.

Table 14. Wash water turbidity for tested bridges

Bridge	Sample	Turbidity
Van Port	Tanker water before wash	54
	Tanker water after wash	55
	Runoff water 1	82
	Runoff water 2, 2	60.5
	Runoff water 3	89
Hassam Road over Montour Run	Tanker water before wash	0.32
	Tanker water after wash	0.31
	Runoff water 1	102
	Runoff water 2, 3	115
	Runoff water 4	95
Interstate 79 over Thomas Run	Tanker water before wash 1	0.64
	Tanker water before wash 2	0.64
	Tanker water before wash 3	0.64
	Tanker water after wash 1	0.64
	Tanker water after wash 2	0.64
	Tanker water after wash 3	0.64
	Runoff water 1	160
	Runoff water 2, 2	165
	Runoff water 3	167

Source: Alland et al. 2013

Table 15. Wash water zinc, lead, and copper content

Bridge	Sample	Total Zn	Total Pb	Total Cu
Van port	Wash water before wash	ND	ND	ND
	Wash water after wash	ND	ND	ND
	Runoff 1	1	ND	ND
	Runoff 2	2	ND	ND
	Runoff 3	2	ND	ND
Hassam Road over Montour Rub	Wash water before wash	ND	ND	ND
	Wash water after wash	ND	ND	ND
	Runoff 1	24	ND	ND
	Runoff 2	20	ND	ND
	Runoff 3	22	ND	ND
Interstate 79 over Thomas Run Road	Wash water before wash 1	ND	ND	ND
	Wash water before wash 2	ND	ND	ND
	Wash water before wash 3	ND	ND	ND
	Wash water after wash 1	ND	ND	ND
	Wash water after wash 2	ND	ND	ND
	Wash water after wash 3	ND	ND	ND
	Runoff 1	15	ND	ND
	Runoff 2	22	ND	ND
	Runoff 3	23	ND	ND

ND = None detected, PPM
Source: Alland et al. 2013

Based on the results of salt concentration and wash water analysis from the bridge washing experiment, two types of recommendations, “programming and procedural,” were provided for PennDOT that would make bridge washing more effective (Alland et al. 2013).

For programming recommendations, the tests prior to washing revealed different salt concentrations on different bridge members or parts of bridge members, indicating that spot-specific bridge washing could minimize the bridge washing budget. Based on the results obtained from under the leaking expansion joint before and after washing, washing the area under a damaged expansion joint was recommended once a year until the expansion joint could be fixed. Flushing of bridge joints should be completed because residual chlorides could be reintroduced into areas below the joint during rain events. Connections were found to have higher chloride concentrations than other parts of the bridges; therefore, they should be washed. Also, because removing salts from fully damaged and corroded parts of a bridge using pressurized washing is difficult, recoating such areas of the bridge is recommended as an alternative to bridge washing.

For procedural recommendations, ensuring that the pressure washer is fully functional prior to washing would make the washing more effective because the procedure would remove a higher percentage of the surface salt. Water pressures of a least 1,500 psi were found to be effective; pressures below 1,500 psi were found to be less effective. Use of a pressure gauge to ensure that adequate pressure is available during operation was recommended. Generally, bridge washing is effective when technicians use access equipment to reach bridge members and position the washing nozzle near every bridge member at close range and at an angle of less than 20 degrees from normal.

4.1.3.4 Palle et al. (2003)

This research was completed to assess the presence of soluble salt on the surface of bridge paints in Kentucky. The study examined how soluble salt levels were affected by available bridge cleaning options and tested the effectiveness of commercially available salt removers for removing salts, avoiding paint damage, and reducing rust back. Testing was completed at several locations on three different types of bridges: a girder bridge, a tied arch bridge, and a through truss bridge. The soluble salt amount was measured before washing, after cleaning using power tools, and after pressure washing using 3,500 psi at a distance of 6 to 12 in. from the surface being washed. Some of the results are shown in Table 16.

Table 16. Amount of salt before and after salt removal

Bridge ID	Test area	Item tested	Existing condition (μg/ml)	After power tool cleaning (μg/ml)	After washing (μg/ml)
I-471	A1	Chloride	30	45	15
		Nitrate	2.5	0	2.5
		Sulfate	24	3	0
	2A	Chloride	0	7	
		Nitrate	2.5	2.5	
		Sulfate	0	0	
	3A	Chloride	10	5	
		Nitrate	2.5	2.5	
		Sulfate	0	0	
I-71	A*	Chloride	0		0
		Nitrate	15.5		2
		Sulfate	0.5		0.25
	C*	Chloride	0		0
		Nitrate	9.5		0.75
		Sulfate	0.75		0.5

A* and C* are averaged amount of several spots in test area A and C
Blank cells indicate unavailability of data on those test areas.
Source: Palle et al. 2003

These tests also indicated that bridge washing was effective for removing chlorides from steel bridge members. Chloride remover was tested at one location and was found to be effective for eliminating soluble salts.

4.1.3.5 Crampton et al. (2013)

A bridge washing experiment was carried out by Wiss, Janney, Elstner Associates, Inc. on five bridges to determine the effectiveness of bridge washing for removing chloride from weathering steel patinas and for removing loose, thick, flaky rusts and other accumulated debris from weathering steel bridges (Crampton et al. 2013). The tests were done using chemical salt removers mixed with water and drinking water only, with a pressure of 3,500 psi at a distance of about 12 in. from the surfaces being washed. The results of the study show that chlorides can be minimized in the patina of weathering steel bridges by washing. During the test, two nozzles, one with a 0° spraying angle and one with a 40° spraying angle, were used to measure the effectiveness of the procedure. The test revealed that the 0° nozzle performed better than the 40° nozzle, but the researchers recommended a 15° nozzle because it provided "more uniform coverage of the wash area." Other recommendations of this study included the following: washing using a pressure of 3,500 to 5,000 psi, a "wash rate" of about 3 to 6 ft^2 per gallon, spot-specific washing, "higher pressure or extended wash times" for more damaged areas, and washing the bridges just after the end of the winter in order to remove chloride before it penetrates down to the patina. Also, this study recommended bridge washing frequencies based on the location of the bridge in terms of urban, rural, and suburban environment; whether a driveway was below the bridge; and the road type. These recommendations are shown in Table 17.

Table 17. Recommended washing priority and frequency for Iowa weathering steel bridges

	Environment		
Structure Type	**Urban**	**Suburban**	**Rural**
Grade Separation, Interstate below	Priority 1 1 to 2 years	Priority 2 3 to 4 years	Priority 3 5 to 7 years
Grade separation, arterial or local road below	Priority 2 3 to 4 years	Priority 3 5 to 7 years	Priority 4 7 to 10 years
Stream crossing, rail crossing, or limited access road below	Priority 3 5 to 7 years	Priority 4 7 to 10 years	Priority 4 7 to 10 years

Source: Crampton et al. 2012

4.1.3.6 Hopwood et al. (2015)

Part of the research for Hopwood (2015) involved overseeing the washing of 13 bridges done by contractors in five counties in Kentucky. Chloride content and conductivity were tested using post-washing water sampled from the bridges. During the observation, the researchers noticed several problems during and after washing: absence of Kentucky Transportation Cabinet inspectors sometimes during the contractor operation, the leaving of paint chips (possibly lead-based due to their orange color) around the bridges after bridge cleaning, labor safety ignorance by contractors, and no job site verification/check of the washing pressure of 3,500 psi specified in the contract. Also, the contractor used a ladder as access equipment to bridge elements or worked from the pier caps, which affected the proper distance and alignments of the nozzle relative to the washing surface. The contractor sometimes washed lower bridge elements first and then the upper elements, which contaminated the lower elements again. The bridge washing effectiveness in reducing chloride concentrations at beam ends was tested using the Bresle method. The contractors used local drinking water for washing bridges. The results shown in Table 18 indicate that washing the bridges using drinking water raised the chloride concentration of the bridge element surfaces. These results indicate that care should be taken to ensure that the wash water does not contain chlorides.

Table 18. Table showing the chloride concentrations before and after washing using drinking water

Location	Pre-Wash (μS/cm)	Surface Chloride Level (μg/cm2)	Post-Wash (μS/cm)	Surface Chloride Level (μg/cm2)
KY 453 over P&L RR	101	12.1	174	20.9
	41	4.9	54	6.5
US 641 over Purchase Pkwy	58	7.0	59	7.1
	53	6.4	158	19.0
	27	3.2	58	7.0
	46	5.5	52	6.2
US 131 over East Fork	15	1.8	10	1.2
	13	1.6	6	0.7
	21	2.5	20	2.4
	30	3.6	45	5.4
US 45 over Ohio River	5	0.6	5	0.6
	4	0.5	5	0.6
	23	2.8	34	4.1
	23	2.8	101	12.1
	11	1.3	63	7.6
	8	1.0	8	1.0
	9	1.1	10	1.2

Source: Hopwood et al. 2015

4.1.4 Bridge Washing Cost

This portion of the report provides summaries of bridge washing cost data from available research to provide exemplar values of the experiences of different bridge owners regarding the cost of bridge washing. These data are obviously affected by the administrative and regulatory environments under which the bridge owners operate.

4.1.4.1 Hopwood et al. (2015)

In a survey that was done as part of a study by Hopwood et al. (2015), the respondents provided the following costs for bridge deck cleaning/flushing:

- Two DOTs reported $300 to $800 per bridge using the in-house staff.

- Michigan reported $50 per hour using in-house staff.
- Iowa reported $12,500 per bridge using contractors.

4.1.4.2 Keegan and Peterson (2013)

Keegan and Peterson (2013) reported the bridge washing costs from 2010 to 2013 shown in Table 19, which indicates a significant reduction in costs on a per-bridge basis over the course of the time period reported (Keegan and Peterson 2013).

Table 19. Total and average bridge washing costs from 2010–2013

Year	No. of Bridges	Total Cost	Cost per bridge
2010	7	$98,289	$14,041
2011	8.5	$91,219	$10,731
2012	12	$87,350	$7,279
2013	16	$93,600	$5,850

Source: Keegan and Peterson 2013

Bridge washing cost breakdowns for the region of Olympic, Washington, for 2012 to 2013 are shown in Table 20 and Table 21, respectively.

Table 20. Costs of bridge washing only and of hand cleaning and washing in 2012, region of Olympic, Washington

	Bridge #	Bridge Name	Hand Clean Then Flush	Flush Only	Traffic Control	Cleaning 1922	Total	Hand clean Then Flush Cost	Flush Only cost
1	101/150	Humptulips River	X		$ 1,763.50	$ 6,315.55	$ 8,079.05	$ 8,079.05	
2	101/308	Calawah River		X	$ 1,015.51	$ 4,022.76	$ 5,038.27		$ 5,038.27
3	101/310	Sol Duc River #1	X		$ 1,964.66	$ 6,808.21	$ 8, 770.87	$ 8,770.87	
4	101/314	Sol Duc River #2	X		$ 2,345.82	$ 8,920.47	$ 11,266.29	$ 11,266.29	
5	101/316	Sol Duc River #3		X	$ 719.09	$ 4,174.87	$ 4,893.96		$ 4,893.96
6	101/320	Sol Duc River #4		X	$ 829.59	$ 4, 243.90	$ 5,073.49		$ 5,073.49
7	101/322	Sol Duc River #5		X	$ 382.40	$ 3,481.30	$ 3,843.70		$ 3,843.70
8	12/25	Wynoochee River		X	$ 2,549.64	$ 7, 291.89	$ 9,841.53		$ 9,841.53
9	12/51 N	Satsop River		X	$ 2,284.70	$ 7,133.09	$ 9,397.79		$ 9,397.79
10	12/51 S	Satsop River		X	$ 2,284.70	$ 5,801.34	$ 8,066.04		$ 8,066.04
11	12/76	Black River		X	$ 794.30	$ 3,554.43	$ 4,384.73		$ 4,348.73
12	109/10	Humptulips River	X		$ 699.51	$ 8,030.49	$ 8,730.00	$ 8,730.00	
			Totals		**$ 17,573.42**	**$ 69,776.30**	**$ 87,349.72**	**$ 36,846.21**	**$ 50,503.51**
			Average		**$ 1,464.45**	**$ 5,814.69**	**$ 7,279.14**		
						Average cost to hand clean and flush		**$ 9,211.55**	
						Average cost just to flush			**$ 6,312.94**

Source: Keegan and Peterson 2013

Table 21. Costs of bridge washing only and of hand cleaning and washing in 2013, region of Olympic, Washington

	Bridge #	Bridge name	Hand clean then flush	Flush only	Traffic control	Cleaning 1922	Total	Hand clean then flush cost	Flush only cost	ft^2 cost
1	101/150	Humptulips River		X	$ 742.20	$ 3,693.76	$ 4,435.96		$ 4,435.96	$ 0.38
2	101/308	Calawah River		X	$ 1,091.61	$ 4,772.35	$ 5,863.96		$ 5,863.96	$ 0.72
3	101/310	Sol Duc River #1		X	$ 754.04	$ 3,772.35	$ 4,519.82		$ 4,519.82	$ 0.59
4	101/314	Sol Duc River #2		X	$ 807.15	$ 1,667.63	$ 2,474.78		$ 2,474.78	$ 0.32
5	101/316	Sol Duc River #3		X	$ 486.51	$ 2,939.80	$ 3,426.31		$ 3,474.78	$ 0.47
6	101/320	Sol Duc River #4		X	$ 1,475.41	$ 4, 236.61	$ 5,712.02		$ 5,712.02	$ 0.71
7	101/322	Sol Duc River #5		X	$ 606.10	$ 3,796.21	$ 4,401.31		$ 4,401.31	$ 0.55
8	12/25	Wynoochee River		X	$ 3,928.26	$ 6, 224.95	$ 10,153.21		$ 10,153.21	
9	12/51 N	Satsop River		X	$ 1,280.82	$ 2,634.54	$ 3,915.36		$ 3,915.35	$ 0.32
10	12/51 S	Satsop River		X	$ 2,344.00	$ 3,552.27	$ 5,896.27		$ 5,896.27	$ 0.48
11	12/76	Black River		X	$ 641.50	$ 3,047.83	$ 3,689.33		$ 3,689.33	$ 0.74
12	109/10	Humptulips River		X	$ 1,097.80	$ 4,211.15	$ 5,308.95		$ 5,308.95	
		Chehalis River	X		$ 1,318.00	$ 4,426.20	$ 5,744.20	$ 5,744.20		$ 0.60
		Carbon River	X		$ 1,227.00	$ 5,931.76	$ 7,158.76	$ 7,158.76		$ 2.23
		Hoh River	X		$ 5,724.78	$ 8,988.65	$ 14,713.43	$ 14,713.43		$ 1.84
		Big Quilcene	X					$ 6,183.67		
			Totals		**$ 24,852.98**	**$ 68,744.35**	**$ 93,597.34**	**$ 33,800.06**	**$ 59,797.28**	
			Average		**$ 2,071.08**	**$ 5,728.70**	**$ 7,799.78**			**$ 0.91**
					Average cost to hand clean and flush			**$ 8,450.02**		
					Average cost to flush only				**$ 4,893.11**	
						Clean and flush		Cost per ft^2		$ 1.43
						Flush only		Cost per ft^2		$ 0.53

Source: Keegan and Peterson 2013

These data indicate that as the bridge washing programs became established and the number of bridges being washed increased, costs were reduced significantly. These data also illustrate that hand cleaning of the deck, in addition to flushing, significantly increased the cost of the bridge washing operation. However, hand cleaning for several of these bridges included pressure cleaning truss bridge elements, and flushing of the deck only was obviously a much smaller operation.

4.1.4.3 Rhode Island Department of Transportation (2002)

The Rhode Island Department of Transportation (RIDOT) performed an analysis of the effect of bridge washing based on deterioration models used in the PONTIS bridge management program. This bridge management program has been used by many state DOTs to store inspection data and perform future planning based on an assumed deterioration model known as the Markov model. This model predicts future deterioration of bridge elements based on the likelihood of the element transitioning from one condition state (CS) to the next lower condition state during a given two-year interval. This model is applied to bridge elements in different condition states, where CS 1 is an element without deterioration and CS 5 is an element (or portion of the element) in severe or failed condition.

To show the effect of bridge washing from a financial standpoint, an analysis of different PONTIS-recommended actions for element 107-Painted Steel open girder was performed. The recommended actions are common actions that might be taken to address the condition state of the subject element so as to improve the condition of the element or reduce its deterioration rate.

The recommended actions for this element in CS 1 is to “do nothing” or “surface clean.” In CS 2, the recommended actions are “do nothing,” “surface clean,” and “surface clean and restore top coat.” For bridges in CS 3, recommended actions include “do nothing” and “spot blast, clean, and paint,” and for CS 4, the recommended actions include “spot blast, clean, and paint” and “replace coating system.” Recommended actions for bridges in CS 5 are “major rehab” or “replace.” In the study, 13 bridges in CS 1 and 32 bridges in CS 2 were analyzed to measure the effect of different actions that could be taken, specifically the effect of surface cleaning. Element condition states are typically applied on a linear ft basis; it was assumed in this analysis that the bridge element unit of measure was 1 bridge, apparently to simplify the analysis. The analysis considered the expected deterioration pattern, based on expert opinion, for the “do nothing” approach; for “surface cleaning,” it was assumed that no deterioration would occur. If “do nothing” was selected for the eight years, the 13 bridges that were in CS 1 would be expected to transition to the following CSs at the end of the eight years:

- CS 1: 5 bridges
- CS 2: 5 bridges
- CS 3: 3 bridges

Likewise, the CS distribution of the 32 bridges now in CS 2 at the end of eight years with a “do nothing” action would be as follows:

- CS 2: 11 bridges
- CS 3: 13 bridges
- CS 4: 6 bridges
- CS 5: 2 bridges

The total number of bridges in each CS after eight years with a "do nothing" action was as follows:

- CS 1: 5 bridges
- CS 2: 16 bridges
- CS 3: 16 bridges
- CS 4: 6 bridges
- CS 5: 2 bridges

Based on these data, it would be expected that bridge coating deterioration for two bridges would be severe at the end of the eight-year period, requiring replacement to correct the deficiency, and six bridges would require at least spot cleaning and painting. To assess the financial impact of "do nothing" compared to a cleaning program executed every two years, the costs shown in Table 22 were assumed.

Table 22. Assumed costs for actions based on condition state

CS	Recommended Action	Cost
	Do nothing	No cost
CS 1, CS 2	Wash and clean steel	\$0.10 per ft^2: say \$2,000 per bridge
CS 3	Spot blast, clean and paint	\$2.00 per ft^2: say \$40,000 per bridge
CS 4	Spot blast, clean and paint	\$3.00 per ft^2: say \$60,000 per bridge
CS 5	Major rehabilitations	\$5.00 per ft^2: say \$100,000 per bridge

Source: RIDOT 2002

As mentioned earlier, all bridges were either in CS 1 or CS 2 at the start of the eight-year evaluation period, and if the "wash and clean" action had been chosen and all bridges were washed biannually, the total cost of washing 45 bridges would have been as follows:

45 bridges × \$2,000 / bridge × 4 = \$360,000

Based on the assumption that deterioration will not occur if washing is completed, the bridges would have been in much better condition states compared to the "do nothing" action. Also, if "do nothing" had been chosen during the eight years, the expenses of the recommended actions at the end of eight years would have been as follows:

CS 1: 5 bridges × \$2,000 / bridge = \$10,000 (bridge washing)

CS 2: 16 bridges × $ 2,000 / bridge = $32,000 (bridge washing)

CS 3: 16 bridges × $40,000 / bridge = $640,000 (spot blast, clean, and paint)

CS 4: 6 bridges × $60,000 / bridge = $360,000 (spot blast, clean, and paint)

CS 5: 2 bridges × $100,000 / bridge =$ 200,000 (major rehabilitation)

Total price of the actions = $1,242,000

These data illustrate that a cost savings of $882,000 could be realized if bridge cleaning had been performed throughout the eight-year period, as compared with a "do nothing" approach. Although this analysis had several simplifying assumptions that may cause the quantitative cost savings to overestimate the total savings that could be realized, the overall concept of cost savings through bridge washing to prevent the deterioration of bridge elements is illustrated.

4.1.5 Bridge Washing Steps and Best Practices

A bridge washing practice might be defined as a "best practice" if the activities fulfill the defined level of service for the agency's bridges, observe all applicable state and federal laws and regulations concerning the environment, observe all applicable work safety procedures for the staff, and complete the activities within the budget of the agency.

In order for the activities to fulfill the defined level of service for the agency's bridges, the following must be true:

- The staff should be skilled and trained.
- The water should be selected from the most suitable sources with the minimum possible chloride content.
- Equipment used should be operational and safe.

The MoDOT EPG Category: 771.2 Bridge Cleaning and Flushing provides guidance for the implementation of bridge cleaning and washing. Selected elements from the guide include the following:

- For dry cleaning or sweeping of accumulated debris on a bridge, elements thereof, or the vicinity of the bridge prior to washing, the content of MoDOT EPG Category: 127.25.1.4 Street Sweepings shall be followed for proper handling and disposal of debris. If bridge element damage is expected from using a metal shovel for removing the debris, the shovel can be replaced with a plastic counterpart.
- "If Asbestos Containing Material (ACM) is present in a bridge," the content of MoDOT EPG Category: 127.25.1.1.1 Asbestos and Bridge Maintenance shall be followed.

- For bridge cleaning/washing scheduling, the EPG Category: 771 Bridge Preventive Maintenance Guidelines attachment (Bridge Maintenance Calendar) shall be followed. The calendar is presented in Appendix A.
- To observe the jobsite safety of drivers and others in the vicinity of a bridge being washed, the provision of EPG Category: 616.23 Traffic Control for Field Operation shall be followed as necessary.
- To ensure the safety of the staff involved in bridge washing, the applicable provisions of EPG Category: 771 Bridge Preventive Maintenance Guidelines and the attachment (Policies, Rules & Regulations – Employee Handbook) shall be followed.
- To avoid the transport and spreading of "aquatic invasive species," the provision of EPG Category: 771.2 Bridge Cleaning and Flushing, "Guidance on Aquatic Invasive Species Control BMPs," shall be followed for selecting the water source for bridge washing and handling and treatment of equipment previously contaminated with "aquatic invasive species."
- The provisions of the federal Migratory Bird Treaty Act of 1918 (MBTA) shall be followed in order to protect birds listed under this law.

4.2 Deck and Crack Sealing

Deck sealing is a common PM action used to extend the life of bridge decks, and there is general consensus across the literature and within the preservation community that sealing concrete is an effective PM action. A wide variety of sealing products is currently available, and these generally fall into three categories. Penetrating sealers, such as silane, are used to prevent moisture penetration and chloride intrusion through the concrete. These sealers have some ability to seal cracks in the deck but are generally applied over the entire surface of the concrete. Crack sealers, such as epoxy, are used to fill and seal cracks to prevent the direct intrusion of water and chlorides through open cracks in the deck surface. These products are typically applied by hand to fill and seal the cracks. This process is sometimes referred to as "crack chasing." Healer-sealers both fill cracks and seal the deck itself and may be applied over the entire deck surface by flooding the deck or by applying the substance across the surface area of the crack and the surrounding area Materials used for crack sealing are sometimes used as healer-sealers, particularly if crack density is high.

Applying penetrating sealers just after deck construction is completed and applying crack sealers after cracks are formed are two ways to prevent the intrusion of water and chlorides into the concrete and thereby prevent deterioration of embedded reinforcing steel. Penetrating sealers, such as linseed oil, silane, and siloxane sealers, have been used historically, but more recently the spectrum of available products has increased and different agencies have found different products most useful for their purposes. Agencies using silane and siloxane are shown in Table 23 based on a recent survey (CTC 2016).

Table 23. Deck silane/siloxane sealing

Frequency	Agency	Comment
New Bridges	Hawaii, Missouri, Oklahoma	*Hawaii:* Only recently with new bridge projects. *Missouri:* Silane is applied on all new concrete bridge decks. If additional cracking occurs, reapplication is considered in the first 3 years. Additional applications are recommended at 7 to 10-year intervals. *Oklahoma:* New bridges receive silane treatment the summer following the construction. Research shows that silane treatments last 15 years. In order to seal the bridge decks on our post tensioned box girders, we are doing a shot blast, followed by a silane treatment followed by a flood coat (about 35 structures)
Every five years	New Hampshire, Vermont	N/A.
Every 10 years	Delaware	Just beginning program; every 10 years planned.
As needed	MDTA	Per condition inspection.
Other	Arizona	Project opportunity (tag along with pavement preservation.
Potential Use	Iowa	We are investigating sealing decks with silane.

Source: CTC 2016

Currently, MoDOT is using silane as a sealer for new bridge decks, as noted in the table. Resealing is being completed at 7- to 10-year intervals. Table 23 shows that the reapplication of sealers during the service life of a bridge is completed at different intervals by different bridge owners.

The following parameters are used to choose a crack sealer application method: “size of the deck, traffic control, cost,” distance of the cracks from each other, cause of the cracks (whether they are due to shrinkage of the concrete, change in weather, or “stress in the deck”), and surface roughness of the deck (Rogers et al. 2011). Research has shown that treatment of bridge decks with sealers immediately after construction, but without periodic reapplication, is not effective in reducing chloride penetration in the long run. Even bridge decks that were not treated with sealers at the end of construction but were sealed periodically had lower chloride concentrations throughout the service life of the deck (Pritzl et al. 2015). Several studies have recommended that to prevent the concrete from reaching an increased chloride concentration and to prevent cracks from being contaminated, bridge decks should be treated with sealers as soon as the construction is done.

Several researchers have explored the anticipated service life of penetrating sealers. A summary of previous results is shown in Table 24.

Table 24. Service life of penetrating sealers found by different researchers

Researchers	Service life for penetrating sealer (years)
Weyers et al. (1993) – SHRP	5 to 7
Sherman et al. (1993) – Texas DOT	5
Zemajtis and Weyers (1996) – Virginia Tech	7
NYSDOT (1997)	4
Meggers (1998) – Kansas DOT	8 to 11
Soriano (2002) – South Dakota DOT	4 to 10
Sohanghpurwala (2006) – NCHRP 558	5 to 7
Mamaghani (2007) – North Dakota DOT	5
Wenzlic (2007) – Missouri DOT	3 to 10
Filice et al. (2008) – Alberta DOT	4
Kraus et al. (2009) – NCHRP 20-07	5 to 10
Morse (2009) – Illinois DOT	4 to 5

Source: Bowman and Moran 2015

As shown in the table, there is diversity in the anticipated service lives of sealers. Generally, the anticipated service life trends towards 7 to 10 years, and these data could be used as a rationale for the reapplication interval for sealers.

Crack sealing sometimes occurs at shorter intervals than the application of penetrating sealers or in response to specific inspection results indicating the need for crack sealing. Table 25 tabulates the frequency of crack sealing reported by some bridge owners. In Missouri, MoDOT reports that crack sealing is commonly completed in three- to five-year intervals, but this depends on the expected service life of the particular product being used.

Table 25. Crack sealing application frequency

Frequency	Agency	Comment
Annually	Golden Gate Bridge, Denmark	N/A
Every five years	New Hampshire	N/A
10 years	California	Once at 10 years unless required again
As needed	Delaware, Hawaii, Kansas, MDTA, Michigan, Montana, New Jersey, North Carolina, Vermont	*Delaware.* As needed according to biannual bridge inspection *Kansas:* On an as-needed basis. There is no official crack sealing effort or policy. *MDTA:* Per condition inspection
Other	Arizona, Missouri, Oklahoma, Washington	*Arizona:* Project opportunity (tag along with pavement preservation) *Missouri:* Crack sealing occurs on a three- to five-year cycle depending on the product. *Oklahoma.* We seal the cracks on all new on system bridges the summer after construction. *Washington:* Just started to do select bridges
Plan to start	Indiana	N/A

Source: CTC 2016

Notably, MoDOT currently has several crack sealers that could be described as "healer-sealers" that serve to both seal the deck and seal cracks, as suggested in EPG Category: 771. The recommended treatment of bridge decks under the MoDOT EPG is shown in Table 26.

Table 26. MoDOT deck sealing recommendations, EPG 771.15

Deck Condition	Recommended Treatment
New decks and decks with minimal cracking	EPG 771.16 Penetrating Concrete Sealer – Silane
Decks with hairline cracks < 1/128 in. (0.008 in.) wide	EPG 771.17 Concrete Crack Filler – Low-Viscosity Polymer
Decks with cracks > 1/128 in. (0.008 in.) wide	EPG 771.18 In-Deck Bridge Deck Crack Filler
Decks with cracks > 1/64 in. (0.016 in.) wide	EPG 771.19 Chip Seal to Entire Deck

The MoDOT EPG recommends penetrating sealer, crack sealer, a healer-sealer-type crack sealer, and a chip seal for maintenance of concrete bridge decks. The recommendation depends on the width of existing cracks in the bridge deck.

4.2.1 Fog Seal Programs

A fog seal is a diluted asphalt emulsion used for several remedial purposes on existing asphalt pavements. The remedial capabilities of fog seal range from sealing cracks and waterproofing the pavement to preventing “further stone loss by holding aggregate in place” to improving pavement appearance (Shatnawi and Toepfer 2003).

The successful completion of a fog seal program is dependent on the quality of the emulsion, the current condition and quality of the surface being sealed, and the environmental conditions, such as temperature, rain, and wind. These controlling factors of a successful fog seal project completion are discussed in the following sections.

4.2.1.1 Fog Seal Project Selection

Visual inspection is the most common method for selecting a project for a fog seal. Using visual inspection, a pavement’s condition can be assessed in terms of its aging, whether the pavement is the right candidate for fog seal application, and whether this is the right time for fog seal. Asphalt pavements age differently depending on the binder type; some may age faster and some may age slower. For example, rubber- and polymer-modified asphalt age more slowly than ordinary asphalt. Aging and binder hardness are interrelated; hardened binder pavement ages faster, and as an asphalt pavement ages, the binder hardens.

Other factors that play a role in asphalt pavement aging include oxidation, “volatile loss,” “access of air and temperature condition of the pavement,” and the surface texture. The surface texture of the pavement also determines if it is suitable for fog seal application. Generally, open-graded surfaces, “aged and raveled” surfaces, and chip seal surfaces are suitable for fog seal application, because these types of surfaces allow the emulsion to reach down into the surface (Shatnawi and Toepfer 2003). Generally, open-graded surfaces age faster than dense-graded surfaces. Fog seal can be used for hot mix asphalt (HMA) surfaces that are older than one year or that show significant stone loss within a year to prevent air and water penetration into the pavement. Fog seals are suitable for open-graded surfaces but not dense-graded surfaces because the emulsion accumulates on the surface and makes the surface slippery.

Generally, fog seal efforts are focused on asphalt pavements and would therefore be suitable for bridge decks with asphalt overlays as a maintenance practice for the asphalt itself. This practice may have an impact on reducing the inflow of water through the pavement to the deck, which may serve as a preservation action. However, research has not shown that bridge owners use fog seal programs for bridge decks without asphalt overlays.

4.2.2 Literature Search on Deck and Crack Sealing

The following sections describe state-of-the-art research on the topic of deck and crack sealers.

4.2.2.1 Liang et al. (2014)

This study was completed on the deck of a steel box girder bridge in Colorado. The aim of the study was to determine which of four sealers inhibit moisture-assisted chloride penetration longer than the others and how the application of sealers affects the skid resistance of the bridge deck. The following four sealers were included in the study: Sika Pronto 19, a type of HMWM, super-low-viscosity low-modulus epoxy (named Epoxy 1 in Table 27), a low-viscosity high-modulus epoxy (named Epoxy 2 in Table 27), and Tamms Baracade 244-Silane Sealer. The sealers were applied to four areas of equal dimensions located in close proximity to each other on the bridge; a fifth area was identified as a control for comparison purposes. The parameters investigated in this study were the sealers' skid resistance, the sealers' ability to maintain the concrete's internal temperature and "internal pore relative humidity," and the amount of chloride concentrated along the thickness of the bridge deck (Liang et al. 2014). The effect of the use of sealers on the skid resistance of the bridge deck was compared with the skid resistance of raw untreated areas of the bridge deck; this was measured for two different scenarios, as shown in Table 27. Scenario A shows the results of the study right after the application of the sealers, and Scenario B shows the results of the study after one year of use.

Table 27. Sealers' skid resistance ranking for Scenarios (A) and (B)

			Scenario A		
Sealer	**Epoxy 1**	**HMWM**	**Epoxy 2**	**Silane**	**No Sealer**
Number	57.4	86.35	96.1	96.15	100.07
Ranking	5	4	3	2	1
			Scenario B		
Sealer	**Epoxy 1**	**HMWM**	**Epoxy 2**	**Silane**	**No Sealer**
Number	61.2	73.9	82.9	88	91.2
Ranking	5	4	3	2	1

Source: Liang et al. 2014

As shown in Table 27, the skid resistance of the bridge deck is lowered by the application of sealers; silane sealers have the smallest effect on skid resistance. The same result of lower skid resistance of the areas treated with sealers was obtained when the areas were retested after one year.

The results of testing the "internal relative humidity" of the bridge deck showed that the sealers inhibit post-rain and post-snow moisture penetration into the deck.

In terms of the ability of the different sealers to inhibit chloride penetration into the deck, HMWM, Epoxy 1, and Epoxy 2 each performed better than silane. Tests done one year later showed reductions in chloride inhibition for Epoxy 1 and Epoxy 2, while HMWM "was still effective" (Liang et al. 2014). The test results after three and a half years indicated that each of the sealers was still providing a protective barrier, although the researchers concluded that the HMWM performed better than the other sealers.

The cost of these sealers depends on the size of the projects; the cost of these sealers per square yard for this project was $19.80 for HMWM, $13.50 for Epoxy 1, $15.75 for Epoxy 2, and $13.50 for silane.

4.2.2.2 Wenzlick (2007)

To qualify some crack sealers for use on newly built bridge decks, MoDOT completed a study that assessed four different crack sealers against linseed oil, which has traditionally been used by MoDOT. The four crack sealers, reactive silicate 1 with the brand name of Chem Tech One, reactive silicate 2 with the brand name of Radcon # 7, a water soluble 1:1 sealer with the brand name of STAR MACRO-DECK, and silane 55 with the brand name of Sil-At ATS-55, were tested against linseed oil with the brand name of 50/50 Double-Boiled Linseed Oil/Mineral Spirits. These sealers were compared to an untreated concrete surface. The tests were completed on specimens cast with a concrete mix that is similar in design to bridge decks poured by MoDOT. Table 28 shows whether a sealer passed the AASHTO T259 modified test.

Table 28. Table shows the result of AASHTO T259 modified crack sealing test

Sample Number	Surface Treatment	Average Crack Width	Elapsed Time Unsealed	Elapsed Time Sealed	Sealed Time/Unsealed Time =(>2 to pass)	Pass
5RVWA033	Linseed Oil	0.0767 mm	21 seconds	53 seconds	2.52	yes
5RVWA019	Reactive Sillicate 1	0.187 mm	9 seconds	3 seconds	0.33	No
5RVWA006	Reactive Sillicate 2	0.300 mm	3 seconds	2 seconds	0.66	No
5RVWA080	Water Soluble 1:1	0.060 mm	9 seconds	59 seconds	6.55	yes
5RVWA048	Silane 55	0.050 mm	12 seconds	777600 sec. 9 days (stopped test)	64800	yes
5RVWA061	Control	0.323 mm	6 seconds	N/A	N/A	N/A

Source: Wenzlick 2007

AASHTO T259, Resistance of Concrete to Chloride Penetration, is a 90-day ponding test and is sometimes called the 90-day salt ponding test. In these tests, specimens are cracked to assess the ability of the sealers to seal cracks, and the results are based on the time it takes for water to pass through the specimen. The results in Wenzlick (2007) showed that linseed oil, silane, and STAR MACRO-DECK passed the modified test, while the reactive silicate products did not pass the test. The researchers identified the varying crack widths between the specimens as a possible factor in sealers not passing the test. The cracks in the specimens tested with reactive silicates were much larger than the other specimens, which may have contributed to the results.

Table 29 indicates the expected service life, coverage area, and costs of the materials studied. The cost indicated is the cost for the materials without labor or installation costs.

Table 29. Crack sealers' expected service life, coverage area, and cost

Product Name	Manufacturer expected service life	Sealer appearance or color	Coverage ft²/gallon	Cost/ft²
50/50 Linseed Oil / Mineral Spirits	5 years	Clear	200	$0.02
STAR MACRO	3 years	Clear	200	$0.08
Silane 55	10 years	Clear	150	$0.18
Reactive Silicate 1	10 years	Clear	50 (apply twice @ 100)	$0.18
High Molecular Weight Methacrylate	5 years	Clear	180	$0.45
Reactive Silicate 2	10 years	Clear	NA	$0.70

Source: Wenzlick 2007

These cost data indicate that silane is a moderate-cost alternative with a good anticipated service life. Based on the test results, the research approved STAR MACRO-DECK to be included in the "Pre Qualified List if the Material Special Provision is adopted" (Wenzlick 2007). Additional study was recommended for silane. Currently, MoDOT recommends the use of silane for bridge decks.

4.2.2.3 Pritzl et al. (2015)

The chloride profiles of nine bridges treated with three different types of corrosion inhibitors and one penetrating sealer was investigated in Pritzl et al. (2015) to determine the long term effects of these chemicals on bridge decks. The nine bridges, located in Wisconsin, had been in service for 12 to 16 years, and deicing salt had been applied to these bridges during this period.

Two out of the nine bridges were treated with tri-siloxane penetrating sealer just after completion of construction with no retreatment afterward. Two other bridges were repeatedly treated with tri-siloxane four years after construction, two bridge decks were partly treated with "corrosion inhibiting admixtures" and were left as "control segments," and the remaining three bridges were left without any treatment at all (Pritzl et al. 2015).

The results of this study show that bridge decks treated with sealers only after construction but not periodically sealed thereafter were not effective in reducing chloride penetration in the long run. Bridge decks that were not treated with sealers at the end of construction but were sealed several years after construction and periodically thereafter had lower chloride concentrations compared to untreated decks. These results indicate that bridge decks should be treated as soon as practical after construction and periodically thereafter to prevent the intrusion of chlorides into concrete.

4.2.2.4 Rahim et al. (2010)

Rahim et al. (2010) studied HMWM crack sealers for concrete bridge decks. The research consisted of a survey of state DOTs and a review of previous experiments with and applications of HMWM. A total of 41 state DOTs responded to the survey. It was found that HMWM is used by 42.5%, epoxy is used by 52.5%, polyesters are used by 7.5%, and other types of sealers, such as urethanes, silane, siloxane, linseed oil, and bituminous membranes, are used by 37.5% of the responding state DOTs. Of those states using HMWM, 59% only use it for sealing cracks, 6% only use it for sealing surfaces, and 37% use it for both purposes. Also, of those using HMWM, 82% apply it after cracks have formed and spread on the deck and 18% apply it just after construction is completed.

In terms of surface preparation of decks prior to the application of HMWM, respondents indicated that they use various methods: 35% use a power broom, 65% use forced air, 12% use pressurized water, and 29% use sandblasting, shot blasting, and/or the supplier's surface preparation recommendations. Based on previous studies and applications, the researchers recommend the following when using HMWM:

- To prevent a bridge deck from reaching the chloride concentration threshold and to keep cracks from being contaminated, bridge decks should be treated with sealers soon after construction is completed.
- In order for a bridge deck sealing application to be successful, deck preparation, deck cleaning, and crack cleaning of old decks should be done carefully.
- The recommended temperature for sealer application is 7° to 29° C.
- Because HMWM functions both for surface sealing and crack sealing, its application is recommended "three to six months after construction" (Rahim et al. 2010).
- HMWM can be applied to seal cracks that range from 0.05 mm to 12.7 mm.

4.2.2.5 Rogers et al. (2011)

Bridge deck flood coating has been implemented in Michigan since the 1990s. The term "flood coating" means to pour the sealing material onto a bridge deck and spread it out to the entire deck using a broom or similar means to seal the cracks in order to prevent moisture penetration.

Based on this report, the parameters to account for when choosing a crack sealer application method are deck size, traffic control, cost, distance of the cracks from each other, cause of the cracks (whether they are due to shrinkage of the concrete, changes in weather, or "stress in the deck"), and the surface roughness of the deck (Rogers et al. 2011). For example, if the distance between cracks is more than 2 ft, chasing the cracks pays off more than flood coating, while if the distance between the cracks is less than 2 ft, flood coating is the optimum application method. Rogers et al. (2011) also stated that the flood coat method will seal both visible and invisible cracks, while crack chasing only works for visible cracks. The report also provides information on how to prepare and clean bridge deck surfaces for flood coating or healer-sealer application.

4.2.2.6 Krauss et al. (2009)

A survey conducted as part of NCHRP 20-07, Task 234, Guidelines for the Selection Of Bridge Deck Overlays, Sealers, and Treatments, revealed the approach of 46 agencies regarding bridge deck preservation (Krauss et al. 2009). The Task 234 report details several procedures and methods for the preventive maintenance and rehabilitation of bridge decks. The report also documents the types of sealers used by 28 different bridge-owning agencies, as shown in Table 30. The results of this study indicated that silane sealers are the most common type of deck sealer currently in use.

Table 30. Number of agencies using different types of sealers

Sealer Type/Use	New or Experimental	Current Common Practice	Historic Experience (Not Current Practice)	Never
Silane Sealers	4	15	9	12
Siloxane sealers	7	5	13	13
Epoxy sealers	11	13	5	13
Methacrylate sealers	10	11	9	10
Polyurethane sealers	8	4	8	18

Source: Krauss et al. 2009

The expected service life of sealers by these agencies was also documented, and it was shown that 61% of respondents expected their sealers to have a service life of about 5 years, 18% expected a service life in the range of 5 to 10 years, and 21% expected more than 10 years of service life.

The survey also asked respondents to identify the common types of materials being used for crack repair. The survey results showed that HMWM was the most common form of crack repair, as shown in Table 31.

Table 31. Number of agencies repairing cracks using different materials

Rehabilitation Method/Use	New or Experimental	Current Common Practice	Historic Experience (Not Current Practice)	Never
Epoxy injection crack repair	4	22	8	9
Polyurethane crack repair	5	4	2	26
HMWM crack repair	7	15	9	10
Lithium salts	4	1	1	34
Cathodic protection	10	6	16	10
Corrosion inhibitors	14	6	8	14

Source: Krauss et al. 2009

Out of 27 agencies, 67% expect a service life of 10 years or less for crack repairs and 33% expect a service life in excess of 10 years (Krauss et al. 2009).

Chapter 4 of Krauss et al. (2009) contains information about controlling parameters when choosing the appropriate option for bridge deck repair. These controlling parameters include deck characterization, which is discussed in detail in Chapter 5 of the Task 234 report, and appropriate material selection (Krauss et al. 2009). The deck characterization information covers topics such as "preliminary planning, inspection for percent deck deterioration, deck condition rating, time to corrosion initiation, deck surface conditions, concrete quality, and other evaluation methods (special cases)" (Krauss et al. 2009). The material selection information covers topics such as "do nothing, maintenance, and partial or full deck replacement" (Krauss et al. 2009).

4.2.2.7 Oman (2014)

In Oman (2014), 12 types of crack sealing products from 8 manufacturers, as shown in Table 32, and six untreated control sections were tested on a single bridge in Minnesota for three years from 2011 to 2013.

Table 32. Crack sealing products list

Product	Manufacturer	Type	Application method
Accuflex Coating	Gel-Seal	Silicate	Flood
TK Products	TK-9030	Epoxy	Bottle
	TK-2110	Epoxy	Flood
	TK-2414	MMA	Flood
BASF	Epoxeal GS Structural	Epoxy	Flood (cracks)
	Degadeck sealer plus	MMA	Flood
Viking Paints, Inc.	Paulco TE 3008-1	Epoxy	Bottle
	Paulco TE 2501	Epoxy	Bottle
Sika Corp	Sikadur 55 SLV	Epoxy	Pump (cracks)
Euclid Chemical	Dural 50 LM	Epoxy	Flood, Flood (cracks)
Kwik Bond	KBP 204 P	HMWM	Flood
Transpo Industries	T70-MX-30	HMWM	Flood

Source: Oman 2014

The different crack sealing products included epoxy, methyl methacrylates (MMA), HMWM, and a single silicate. The different sealers were applied either as a flood seal or by bottle or pump, as shown in Table 32. Different cleaning procedures were also used before the sealer products were applied. Either sand blasting, shot blasting, or compressed air (via air hose) were utilized for cleaning prior to the application of each sealer.

Three different methods were used to measure the performance of the crack sealants studied. These included a permeability test, visual observation, and petrography of samples removed from the decks. The testing for permeability was accomplished using a field permeameter that measures the loss in the head of a water column and is commonly used for pavement assessment.

The outlet of the water column is sealed against the surface of the material being tested, and the water loss is monitored. This provides a measure of the permeability of a pavement or, in this case, areas of a concrete deck.

The bridge deck was sampled in 40 places and tested prior to the application of the crack sealers using a National Center for Asphalt Technology (NCAT) field permeameter that measured pass/fail criteria. The permeability tests done after one year at the same locations on the deck revealed that, except for the Accuflex product, all sealants showed lower head loss relative to the permeability tests done prior to sealant application. The Accuflex product was not found to be present in the test section where it was specified and, as such, could not be studied.

The results of testing after one year indicated that the sealers were effectively inhibiting the ingress of moisture into the deck. Increased permeability was observed in three of the six control sections, which had not been treated with sealers, possibly indicating deterioration over this time period. Also, a comparison of the permeability tests done at one year to the tests done after sealant application showed that, except for the Accuflex product, "four of the test locations showed no change, nine of the test locations showed further reduction in head loss, and another nine test locations showed an increase in head loss over one winter" (Oman 2014). The change in permeability results can be attributed to factors such as air temperature, cloud cover, and surface temperature. These factors were accounted for during the tests but were not studied in this experiment (Oman 2014).

Staff from the MnDOT bridge office and Braun Intertec performed visual observation of the sections of the bridge deck that had been treated with crack sealers each spring during the project period. The visual observations were rated subjectively on a scale of 3 to 1, as follows:

- "Effective (3): Sealant fully intact or essentially intact with a hairline crack.
- Semi-effective (2): Sealant mostly intact, but exhibiting small cracks, holes, or debonding.
- Ineffective (1): No evidence of sealant or some sealant present, but larger cracks and/or holes present" (Oman 2014).

After the first winter, a visual inspection of the deck showed that the KBP 204 P, Sikadur 55 SLV, and Dural 50 LM sealers showed "cracking or at least preliminary signs of cracking" (Oman 2014). The one exception was TK-9030. The visual observation after the second winter showed that, except for one of the two sections treated with Sikadur 55 SLV, which was rated effective, other sealed sections were semi-effective or ineffective. Visual observation after three winters revealed that none of the products in this research were rated "effective" after being on the bridge for three years, and only seven products were rated "semi-effective."

The petrographic observations and tests done after two winters on every sealed section of the bridge deck provided the additional information about the sealants (Oman 2014). It was noted that the cracks were full of debris accumulated from the surface preparation, and two different types of "failure modes" were detected: either the sealant did not fully "bridge the original crack" or the sealant was "detached from the crack face." In some cases, there was no evidence of sealer in the cracks assessed through petrography (Oman 2014).

Overall, the research indicated that the sealers were not fully effective after three years, and, as such, reapplication after three years would be appropriate for the sealers studied. Due to the large number of variables affecting the different sealers and sealer applications, an analysis was completed based on key parameters and a weighting system. This analysis considered the surface cleaning method, the cost of the product, and the performance results from the study. The results of this analysis were summarized for the selection of epoxy and MMA products, their application methods, and their approximate service lives, as shown in Table 33 for epoxy products and Table 34 for MMA products.

Table 33. Epoxy Products, application, and performance summary

Product	Test	Surf. Prep	Application	Additional Details	Visual Observations* 1 Year	2 Year	3 Year	Petrography	Estimated Service Life
TK-2110	9A	Air Blown	Flood	--	E	SE	SE	Free of cracks. Not detached.	3 to 4+ years
Paulco TE- 2501	24A	Air Blown	Bottle	3 applications	E	SE	SE	Free of cracks. Not detached.	3 to 4+ years
	35A	Air Blown	Bottle	3 applications	E	SE	SE	Free of cracks. Not detached.	3 to 4+ years
Dural 50 LM	25A	Air Blown	Flood	Pre-treated cracks	E	SE	I	Free of cracks. Not detached. Does not "bridge" crack.	2 to 3 years
Epoxeal GS Structural	17A	Air Blown	Flood	--	E	SE	I	Free of cracks. Detached.	2 to 3 years

*E = Effective, SE = Semi-effective, I = Ineffective
Source: Oman 2014

Table 34. MMA products, application and performance summary

Product	Test	Surf Prep	Application	Additional Details	Visual Observations* 1 year	2 year	3 year	Petrography	Estimated Service Life
KBP 204 P	20A	Air Blown	Flood	--	E	SE	SE	Free of cracks. Detached.	3 to 4+ years
T-70-MX-30	27A	Air Blown	Flood	--	E	SE	SE	Free of cracks. Detached.	3 to 4+ years
Degadeck CSP	21A	Air Blown	Flood	Pre-treated cracks	E	SE	SE	Free of cracks. Detached.	3 to 4+ years

*E = Effective, SE = Semi-effective, I = Ineffective
Source: Oman 2014

4.2.2.8 Ley and Moradllo (2015)

To determine the durability of silane in concrete bridges, 60 bridges were investigated in Ley and Moradllo (2015). The bridges had been in service for 6 to 20 years in Oklahoma and had an average annual daily traffic (AADT) of 3,600 to 18,000. Three cores were removed from the driving lane and three cores were removed from the shoulder area of each bridge, such that a total of 360 samples were removed during the course of the study. The silane products commonly used in Oklahoma contain 40% to 50% alcohol, and the minimum specified penetration depth, as specified by the Oklahoma Department of Transportation, was 1/8 in. at the time the bridges were constructed (Ley and Moradllo 2015). Although not directly reported, it was believed that silane sealer was applied at the time of construction of the bridge decks, and there was no reapplication of sealer later in the service life of the bridge. Table 35 shows the results of the study.

Table 35. Durability of silane for drive lane and shoulder of three different bridge ages

	Years of Service	6–12 years	15 years	17–20 years
	Total No. of bridges	**29**	**12**	**19**
Travel lane	Silane depth ≥ 1/8 in.	29 (100%)	8 (66.7%)	4 (21%)
	Silane depth < 1/8 in.	0 (0%)	4 (33.3%)	15 (79%)
Shoulder	Silane depth ≥ 1/8v	29 (100%)	8 (66.7%)	3 (16%)
	Silane depth < 1/8 in.	0 (0%)	4 (33.3%)	16 (84%)
Travel lane	Average silane depth ± std (in.)	0.24 ± 0.06	0.19 ± 0.13	0.07 ± 0.11
Shoulder	Average silane depth ± std (in.)	0.25 ± 0.06	0.19 ± 0.13	0.06 ± 0.10
Average difference in silane depth in shoulder and in the travel lane ± std (in.)		0.05 ± 0.03	0.03 ± 0.02	0.04 ± 0.04

Source: Ley and Moradllo 2015

As shown in the table, the results were divided into three different groups based on years of service: 6 to 12 years, 15 years, and 17 to 20 years. It was determined that 100% of the bridges in the 6 to 12 years group had a silane depth of greater than the recommended 1/8 in. depth. After 17 to 20 years of service, only 18% had a 1/8 in. depth of silane. After 15 years of service, only 68% of bridges had at least a 1/8 in. depth of silane, indicating that the silane had deteriorated. The similarity of silane depth between the driving lane and shoulder samples indicated that abrasion was not a factor in the deterioration of the silane depth. These data indicate that the service life for the silane sealer was approximately 12 to 15 years when analyzed by the depth of the silane layer.

4.2.3 Life Cycle Cost Analysis of Deck Sealing

A sample life cycle cost analysis of a bridge deck was calculated by Bowman and Moran (2015) using present value (PV). The analysis studied four different scenarios to determine the cost-effectiveness of treating bridge decks. Scenario 1 was based on the current Indiana Department of Transportation approach, i.e., no deck maintenance during the service life of the bridge. Scenarios 2 through 4 assumed that maintenance activities were performed, such as periodic sealing, patching, and overlay of the deck. The activities included in these scenarios and their respective costs are shown in Table 36.

Table 36. Activities and their cost for PV calculations

Activity	Cost ($/ft^2)
Deck construction	22.04
Sealing	1.14
Overlay	60.00
Deck replacement	95.00
Partial deck patching	2.70

Source: Bowman and Moran 2015

In the analysis, it was assumed that treatment of the deck with a sealer prevented deterioration to some extent, and the different scenarios (2 through 4) represented different levels of assumed effectiveness of the sealer. The calculation was completed for 75 years of bridge service life with a 4% discount rate.

Scenario 1: In this scenario, there is no maintenance. The deck is sealed at the time of construction, but no other PM actions are taken. In the analysis, the deck is treated with an overlay at 18.75 years and requires replacement after 37.5 years. The new bridge deck is sealed, and an overlay is applied 18.75 years after the new deck is installed (56.25 years calculated from the day of construction). By using PV calculations, the cost of this scenario ($80.63/ft^2) is as follows:

$$PV = \frac{FV_n}{(1+r)^n}$$

$$PV = 22.04 + 1.14 + \frac{60.00}{(1.04)^{18.75}} + \frac{95.00}{(1.04)^{37.5}} + \frac{1.14}{(1.04)^{37.5}} + \frac{60.00}{(1.04)^{56.25}}$$

$$PV = 80.63\$ / ft^2$$

Scenario 2: In this scenario, the deck is sealed every 5 years beginning with the completion of the deck construction, and the deck is treated with an overlay after 35 years. Due to the effectiveness of the sealer, deck replacement is not required. The PV for this scenario, calculated the PV equation above, would result in *PV*=\$43.30/ft^2.

Scenario 3: In this scenario, the bridge deck is sealed every 5 years beginning with the completion of the deck construction, 10% of the total area of the deck is patched once every 10 years, and the deck is treated with an overlay after 35 years. This scenario assumes that the sealer is not totally effective, but deterioration in the bridge deck does not exceed 10% in 10 years. Calculation of this scenarios using the PV equation above yields *PV*=\$48.18/ft^2.

Scenario 4: In this scenario, the deck is sealed every 5 years beginning with the completion of the deck construction, the deck is treated with an overlay at 30 years, and the deck is replaced at 50 years. In this scenario, the sealer only extends the service life of the deck, so deck replacement is still required. However, this replacement occurs later in time due to the use of a sealer. Calculation of this scenario using the PV equation above yields *PV*=\$59.96/ft^2.

Based on the above calculations, Bowman and Moran (2015) recommend bridge maintenance and state that “it is more cost-effective to perform a concrete deck maintenance program” that includes deck crack sealing, partial patching, treatment of the deck with penetrating sealer after 3 to 6 months of construction, and repetition of the maintenance every 5 years (Bowman and Moran 2015). Overall, this analysis illustrates that the application of deck sealers is very cost-effective over the service life of a bridge because it will delay the onset of damage and thereby delay necessary bridge deck replacements in the future.

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APPENDIX A: MODOT CALENDAR OF BRIDGE MAINTENANCE ACTIVITIES

Table 37. MoDOT calendar of bridge maintenance activities

	Bridge Maintenance Calendar											
Work Item	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
CLEANING												
Sweep deck to remove loose material	■	■	■	■	■	■	■	■	■	■	■	■
Clean and flush deck		■	■	■	■				■	■	■	
Thorough cleaning, lower chords, bearing, caps, etc.			■	■	■				■	■	■	
SLOPE & STREAMBANK												
Cut brush	■	■	■								■	■
Spray vegetation (see Herbicide Application Handbook)		■	■	■	■	■	■	■	■	■	■	
Shave approach shoulders			■	■	■	■			■	■	■	
Mat gutter maintenance					■	■	■	■	■	■		
Drain basin maintenance			■	■	■				■	■	■	
BRIDGE DECK												
Seal cracks with in-deck				■	■				■	■		
Total deck treatment-seal with in-deck					■	■	■	■	■	■		

	Bridge Maintenance Calendar											
Work Item	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Total deck treatment-asphalt chip seal						■	■	■				
Total deck treatment-seal with linseed oil								■	■			
Temporary bridge deck repair	■	■	■	■	■	■	■	■	■	■	■	■
BRIDGE JOINTS												
Hot pour bridge joint		■	■	■					■	■		
Seal bridge joint with silicone				■	■	■	■		■	■	■	
Seal bridge joint “poltytite”	■	■	■							■	■	■
STREAM												
Remove drift (remove anytime available)				■	■	■	■	■	■			
Repair stream banks – install gablons		During periods of low stream flow										
Repair stream banks – install rock blanket		During periods of low stream flow										
MISC.												
Seal abutment and pier caps			■	■	■	■	■	■	■	■		
Paint bearing and pilling				■	■	■	■	■	■	■	■	
Mudjack bridge approach slab	■	■	■	■	■					■	■	■

APPENDIX B: IDENTIFIED PM ACTIONS FOR BRIDGES IN COLUMBIA

This appendix documents PM actions identified through a survey of a portion of the bridge inventory for bridges in the City of Columbia, Missouri.

Table 38. Identified preservation actions for City of Columbia bridges

Bridge No.	Actions Required
930038	Bridge deck has extensive, long cracks. These cracks should be sealed. 
930019	Debris accumulated on sidewalks is causing corrosion of the railing and spalling. Clean the debris accumulated in both sidewalks of the bridge. Correct drainage issue at abutment. 

Bridge No.	Actions Required
930009	Clean the debris accumulated along the handrail of the bridge. Remove and clean the bridge water drains that are filled with debris. Remove the vegetation covering the sidewalk soffit. 
930034	Remove the vegetation that has climbed on the bridge. 
930004	Remove and clean debris accumulated along the railing of the bridge.

Bridge No.	Actions Required
930018	Remove and clean debris accumulated in the approach slabs. Remove the trees and branches stacked in pier wall on the upstream. 
930024	Fix the damaged expansion joint on one side of the bridge. Remove the trees and branches stacked in the pier wall on the upstream. 
930031	Clean the debris from the deck.
930001	Clean the sand and debris accumulated along one of the bridge railings. Remove the stacked trees from one of the abutments. Fill the bridge joints.

Bridge No.	Actions Required
930021	Remove and clean the accumated debris from sidewalk and bridge deck. The cracks should be sealed and the damaged pourable seal should be fixed. 
930017	Clean the accumulated debris from the deck. Fix the damaged pourable joint seal. 

APPENDIX C: MODOT WORK COMMENTS FOR CITY OF COLUMBIA BRIDGES

This portion of the report documents work notes provided through the MoDOT National Bridge Inspection Standards (NBIS) inspection results.

Table 39. MoDOT work comments for City of Columbia bridges

No.	Bridge Federal ID	Design No.	Inspection Date	Work Comment
1	15392	0930001	04/14/2015	Place bank protection along the north abutment and bank. Repair the deck.
2	15400	0930002	04/23/2015	Repair the driving surface, waterproof, and place an asphalt wearing surface on the deck. Place rock along the north abutment. Consider replacing the superstructure.
3	30593	0930003	04/23/2015	
4	15409	0930006	4/23/2015	Hydrodemolition candidate. Repair the deck and replace the wearing surface. Seal the edge of the deck and beams.
5	15413	0930009	4/23/2015	Clean out the deck scuppers. Consider replacing the wearing surface.
6	15422	0930013	4/27/2015	
7	32732	0930010	4/27/2015	Consider sealing the deck with silane.
8	15426	0930016	4/23/2015	Replace the wearing surface.
9	15427	0930017	4/27/2015	Repair the north bank protection
10	15429	0930018	4/23/2015	Consider sealing the deck with silane and painting the deck edges with an epoxy paint.
11	15436	0930023	4/16/2015	Replace the wearing surface. Place bank protection on the west bank. Clear the brush from the slopes.
12	15437	0930024	4/23/2015	Remove the drift. Clean out the channel. Consider sealing the deck with silane.
13	28793	0930031	4/23/2015	Clean out the channel. Consider sealing the deck with silane.
14	31461	0930032	5/4/2015	Clear the brush and vegetation from the banks. Consider sealing the deck with silane.
15	34416	0930039	4/16/2015	Consider sealing the deck with silane.
16	34784	0930040	4/6/2015	
17	33734	0930036	4/27/2015	Consider sealing the deck with silane.
18	15430	0930019	5/5/2015	Remove the chip seal. Repair the delaminations and place a new wearing surface on the deck. Seal the approach pavement joints and the south edge/sidewalk joint with elastomeric hot pour joint sealant.
19	15442	0930028	4/27/2015	Clean out all barrels. Patch and seal the deck with Indeck. Consider replacing the wearing surface.
20	34415	0930038	5/4/2015	Clean out the channel. Consider sealing the deck with silane.
21	15406	0930004	4/23/2015	Place bank protection along the upstream north bank and realign the channel.
22	33540	0930005	4/27/2015	Place bank protection along the channel bank. Seal the deck with some type of sealer, possibly silane. Clean the road debris from the bent caps and expansion device.
23	15417	0930011	4/27/2015	Place bank protection at the NW wingwall and bank.
24	15423	0930014	5/4/2015	Rock the west wall. Clean and paint bridge.
25	15425	0930015	5/4/2013	Clean and paint the exposed steel girders.
26	28133	0930030	4/27/2015	Place rock around the north and south pier footing.
27	32428	0930034	4/23/2015	Consider sealing the deck and sidewalks with silane.

No.	Bridge Federal ID	Design No.	Inspection Date	Work Comment
28	15435	0930022	4/27/2015	Remove the drift on the east pier. Cut and spray the vegetation growing under the bridge. Clean and paint the grinder ends and bearing. Replace the wearing surface. Clean and paint the deck edges with an epoxy paint. Repair the expansion joints. The deck is a good candidate for an epoxy polymer wearing surface. Consider making the abutments integral and removing the expansion joints.
29	33735	0930037	4/27/2015	Consider sealing the deck with silane.
30	24139	0930041	4/7/2015	Clean out the channel and realign the channel. Replace the pipes or place concrete in all pipes' flowlines.
31	31917	0930033	4/27/2015	Cut and spray the brush in the channel. Place bank protection along the north upstream bank.
32	15439	0930025	4/27/2015	Place rock at the downstream end consider sealing the deck with Indeck or star macro deck.
33	15440	0930026	4/23/2015	Cut and spray brush in the channel.
34	15441	0930027	5/4/2015	
35	15443	0930029	4/27/2015	
36	15432	0930020	4/27/2015	
37	15434	0930021	4/27/2015	Seal the deck with Indeck or star macro deck. Consider replacing the wearing surface.
38	32773	0930035	4/27/2015	

APPENDIX D: BRIDGE PRESERVATION INSPECTION FORM

Bridge Preservation Inspection Form
City of Columbia, MO

Is the bridge jointless? Y/N

	Question	Image of Typical Condition
1	Are there any unsealed cracks in the surface of the deck? Y/N Notes	
2	Are there any spalls in the bridge deck that require patching? Y/N Notes	
3	Is there debris on the surface of the deck? Y/N Notes	

	Question	Image of Typical Condition
4	Are the deck drains impacted by debris? Y/N Notes	
5	Is there debris collected on the superstructure of the bridge? Y/N Notes	
6	Is there water draining/leaking onto the bearing or substructure elements? Y/N Notes	

	Question	Image of Typical Condition
7	Is there any debris accumulated on the beam seat or on other substructure elements? Y/N Notes	
8	Is there debris collected in the waterway that would affect the flow of water? Y/N Notes	
9	Is there vegetation growing onto the superstructure/substructure? Y/N Notes