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Steel Bridge Coating Evaluation and Rating Criteria

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16. Abstract

The aim of the study is to gather information on three topics: (1) the evaluation and rating of steel bridge protective coatings, (2) coating systems used by various states throughout the United States, and (3) maintenance painting procedures employed by various state department of transportation agencies (DOTs). First, it was found that most state DOTs use either an Element Level type rating of the coating system or a 9–0 NBI type rating; many state DOTs use both methodologies, with one used for state bridges and the other for local bridges. Second, for coating systems, it was found that there is a great deal of uniformity of the steel bridge coating systems used in the United States, with three-coat paint systems being the most common. Third, it is believed that maintenance painting can extend the useful life of bridge coatings. However, many state DOTs report that the cost of maintenance painting has increased due to many factors that involve available personnel, proper training, and increased regulations on the removal and application of steel bridge coatings. Consequently, many DOTs no longer perform maintenance painting, other than emergency repairs, and simply wait until the entire bridge needs to be re-coated and contract the work out. Lastly, an NBI 9–0 type rating procedure for steel bridge coatings is proposed for possible consideration and implementation by INDOT.

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EXECUTIVE SUMMARY

Introduction

The integrity of the coating system used for steel bridge superstructures is critical for protecting the steel from deterioration. A three-coat paint system is used in Indiana that consist of a zinc-rich primer coat overlayed with two additional coats. It is well known that the paint system on the steel members acts as a barrier protecting the structure from moisture, oxygen, and deicing agents that can result in corrosion and eventual loss in cross section. Once the coating system is compromised then the structural condition can deteriorate. Consequently, it is important to properly evaluate and assess the condition of the coating system.

The *Indiana Department of Transportation (INDOT) Bridge Inspection Manual* from 2010 (INDOT, 2010) was recently superseded with a new edition in 2021. Unfortunately, the coating evaluation methodology that was included in the 2010 version of the manual was not included in the 2021 version of the manual. Hence, there are no steel bridge coating evaluation requirements in Indiana that are part of a current specification or standard. Consequently, a new rating standard is needed.

Two additional, but related, topics of interest include (1) information on steel bridge coating systems used by other state departments of transportation (DOTs) to assess the robustness of the coating system used in Indiana, and (2) information on maintenance painting procedures that are used by other state DOTs to extend the life of current coating systems.

This synthesis study examines three aspects of coating systems used in Indiana. The aim of the study is to gather information from other state DOTs regarding (1) the methodology used to evaluate and rate steel bridge structure coating systems, (2) the coating system used by the various state DOTs, with particular emphasis on states in the immediate geographic region, and (3) maintenance coating systems that are used by various state DOTs, again with emphasis on states with similar geographic environments.

Findings

- A wide variety of methods are employed by different states to evaluate their steel bridge coating systems. Most of the states in the Midwest use one or both of two methods for evaluating their coatings: (1) element level inspection with Condition States 1–4 and (2) National Bridge Inventory (NBI) inspection with ratings from 9–0. The element level inspection method is typically used for state-controlled or larger bridges, while the 9–0 inspection method is often used for non-state controlled or local bridges. For element level inspections, many appear to be based to some extent on the AASHTO element level inspection method for Element 515–Steel Protective Coatings.
- Several states use photographs in their element level inspection. Photographs provide example condition states for various coating defects, and it is believed that their use will help provide more consistent and accurate coating evaluations. Other documents, such as the ASTM D610-8 evaluation (ASTM, 2019b) of rust grade, can also be used to assist in the development of a rating system.
- Three-coat paint systems are widely used throughout the United States. The most common coating system used is an inorganic zinc rich primer, an epoxy intermediate coat, and some type of urethane finish coat. Some states use organic zinc-rich primers instead of inorganic zinc-rich primers to achieve faster drying times and more uniform surface thickness layers. But their use is not widespread due to the increased costs of organic primers.
- The most common methods used for maintenance painting are a complete removal and recoat and spot painting at localized areas of concern. Maintenance painting appears to be less common throughout the Midwest region due to several factors which increase costs. Several states simply wait to completely recoat the bridge. Overall, determining the optimal maintenance painting strategy relies heavily on several variables and changes on a state-to-state basis. In order to determine the best practices for maintenance painting for the State of Indiana, further research would need to be conducted on the topic.

Implementation

Based upon input from the research study advisory committee, an NBI-type 9–0 guide for coating evaluation was developed that can be implemented immediately to conduct steel bridge coating evaluations and rating (see Table 1.1). This procedure was based on requirements that are used in Minnesota and Pennsylvania, as well as a rust grade scale that is in ASTM D610-8. Moreover, the procedure can be further improved for bridge inspector use by adding sample photographs that illustrate various coating defects and corresponding condition states.

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1. INTRODUCTION

The integrity of the coating system used for steel bridge superstructures is critical for protecting the steel from deterioration. According to a previous version of the *INDOT Bridge Inspection Manual* (INDOT, 2010), "Paint acts as a physical barrier between the steel and the environment. By preventing oxygen, moisture, deicing chemicals, and pollutants from coming in contact with the steel, the paint coating prevents the rust-producing electrochemical reaction from starting. Two to four paint layers typically make up the coating system and include the prime coat and one or more top coats." However, there is little guidance given in the inspection manual for evaluating the condition of the coating system and determining the need for future work actions. A brief description is provided together with NBI condition states that range from 9 (excellent condition) to 0 (total paint failure) for rating the paint system condition. The system requires the bridge inspector to use considerable judgement when rating the coating system and, due to the vagueness of the rating method, suggests that there could be considerable variation in the ratings among various bridge inspectors. Table 1.1 offers a guide for coating evaluation.

The *INDOT Bridge Inspection Manual* (INDOT, 2020) was revised in 2021, and again in May 2022. The initial revised document contains sections that are dated from September 2020 through July 2021. However, the section that contained information on the evaluation of the bridge coating system was excluded. Consequently, there currently is not any guidance available to bridge inspectors on the evaluation methods used to rate the coating system for a steel bridge structure. While some condition states are obvious, such as the one shown in Figure 1.1, other condition states are not as clear, such as the one shown in Figure 1.2.

It is clear when examining the two versions of the *INDOT Bridge Inspection Manual* that there is not enough information to rate the coating system for steel bridge structures. Consequently, variability in the coating evaluation will result from the lack of information on how to rate the coating system.

In addition to the coating system evaluation, the coating system itself may vary over time and from one region to another. It is believed that there is a great variety in the types of coating systems used by DOTs throughout the US. This information may be useful as Indiana evaluates the robustness of their coating system for steel bridges. Comparisons can then be made between the coating system used in Indiana and the coating system used in other states.

Another issue of interest is possible remediation methods that can be recommended if there are some localized areas of the bridge that experience coating deterioration and, thereby, makes the bridge susceptible to corrosion deterioration at those locations. Information for options available for maintenance painting in localized regions would be extremely useful. Maintenance painting is a technique that some state DOTs use to extend the life of the coating system and protect the bridge until the entire coating system needs to be fully replaced.

This synthesis study examines three aspects of coating systems used in Indiana. The aim of the study is to gather information from other state DOTs regarding the (1) methodology used to evaluate and rate the bridge structure coating system, (2) the coating system used by the various state DOTs, with emphasis especially on states in the immediate geographic region, and (3) the maintenance coating systems that are used by various state DOTs, again with emphasis on states with similar geographic environments. The intent of this research is to provide information that can be used

TABLE 1.1
NBI-Type 9–0 Guide for Coating Evaluation

Rating	Condition	Description
N	Not applicable	No paint or weathering steel.
9	Excellent	Recently painted, good seal, no defects or rusting.
8	Very good	Very minor defects, paint is still intact, and no peeling is occurring; minor rusting, less than 0.3% surface area.
7	Good	Small defects in the paint system are beginning to form, preliminary stages of peeling; small amounts of surface rusting, up to 1% surface area.
6	Satisfactory	Some peeling and rusting, minor impact damage, rusting of up to 3% surface area, paint system still functioning overall.
5	Fair	Paint system beginning to show imminent signs of failure, surface rusting of up to 10%, significant spots of peeling and rust throughout.
4	Poor	Paint system is failing, major rusting and peeling, surface rust of up to 16%.
3	Very poor	Paint system has mostly failed, minor section loss at non-essential points, surface rust greater than 16%.
2	Severe	Paint system has failed, section loss at essential points, surface rust of up to 33%.
1	Total paint failure	Major section loss occurring throughout the structure at crucial points, repainting is not a viable option to repair, surface rust up to 50%.
0	Total paint failure	Surface rust greater than 50%, large areas of extremely heavy rust and section loss; remove damaged structure.

Figure 1.1 Steel bridge coating failure with most of the web thickness lost due to corrosion (NYDOT).

Figure 1.2 Steel bridge coating that is compromised with corrosion visually evident.

to recommend steel bridge coating evaluation methodologies, coating systems, and maintenance painting techniques for the State of Indiana, based upon methods used successfully in other states.

2. COATING EVALUATION AND RATING

The coating system used on steel bridges is crucial in deterring corrosion and member loss. Therefore, it is vital to have sufficient methods for evaluating the coating condition as well as determining cost effective maintenance strategies for the coating system. According to a 2017 scan report titled *Successful Preservation Practices for Steel Bridges,* the annual cost of corrosion on highway bridges alone is estimated to be between $6.43–$10.15 billion dollars (Vinik et al., 2016). Therefore, there is a need for a clear and detailed coating evaluation methodology so that INDOT can strategically plan their annual call for projects and budget for the optimal integrity of the steel bridges in Indiana. A good maintenance painting strategy may also be beneficial to prolong the coating service life and effectively stretch available DOT dollars.

2.1 Prior Indiana Rating Requirements for Coatings

The previous version of the *Indiana Bridge Inspection Manual* (INDOT, 2010) had some limited information on the rating of painted surfaces used on steel superstructures. This was located in Article 4.8 titled "Paint and Tonnage of Steel." The requirements were listed under Item 59B.01 and provided brief descriptions to assist in rating the painted surface. The rating recommendations from that publication are noted in Table 2.1.

As can be noted in the above rating requirements, the statements are quite general. There can certainly be some variability in the rating assigned by different bridge inspectors due to their interpretation of the requirements. Nevertheless, the above recommendations do provide some guidance on how to generally rate a painted surface. The current *Indiana Bridge Inspection Manual* (INDOT, 2022) did not include the section that contained the rating guidelines for painted surfaces. Hence, at present, there are not any recommended guidelines by INDOT for rating painted surfaces.

2.2 Coating Evaluation and Rating in Other States

This section is primarily focused on the evaluation of the coating (paint) system on steel bridges. The resources from which the documents within this analysis are obtained include state DOT bridge inspection manuals (BIMs), highway specifications, and various national standards from AASHTO, ASTM, and FHWA.

One of the key objectives that was established as part of this research was to acquire quantitative inspection standards. While qualitative descriptions and references images are a great help in understanding the paint system quality at each condition state, quantitative standards provide a very solid dividing line between different condition states and reduce ambiguity between different conditions.

2.2.1 National Standards

While there are slight differences at the state level that will be reviewed later in this report, there is a substantial amount of common ground that can be found between different states. Primarily, this involves element level inspection, which is a form of inspection that breaks the system into separate elements and analyzes the quality of each element. Each element has its own set of quality criteria and defects as issued by the American Association of State Highway and Transportation Officials, or AASHTO.

Contained within the *AASHTO Manual for Bridge Element Inspection* (AASHTO, 2019) are different charts which highlight a few common defects that occur for each bridge element, the condition of each of these defects, and their impact on the element's overall condition. There are about 100 different elements

TABLE 2.1
Previous INDOT Rating of Steel-Painted Surfaces

Rating	Condition	Description
N	Not applicable	No paint or weathering steel.
9	Excellent	Recently painted—good seal.
8	Very good	May be several years since painting—good seal, minor chalkiness.
7	Good	Few areas of light rust X some chalkiness and peeling.
6	Satisfactory	Light rust in many areas; extensive chalkiness and some peeling.
5	Fair	Light rust in many areas with localized areas of medium rust buildup; cracking, peeling, and blistering over a large area.
4	Poor	Many areas of medium rust and localized areas of heavy rust—significant peeling, cracking, and blistering.
3	Very poor	Many areas of heavy rust.
2	Very poor	Many areas of extremely heavy rust.
1	Total paint failure	Large areas of extremely heavy rust, little or no paint remains.
0	Total paint failure	Large areas of extremely heavy rust, little or no paint remains.

contained within the manual, and while every state does not have information on inspection that is consistent with what is included in the AASHTO manual, the bridge element system seems to remain consistent.

The element of interest for this document is Element 515–Steel Protective Coatings. This element can include several types of systems, including paint, oxide on weathering steel, and galvanization, among others. Shown in Figure 2.1 is the chart contained within the *Manual for Bridge Element Inspection* (AASHTO, 2019) that lists the common defects for steel protective coating and the condition states for each defect.

What is especially noticeable about the chart is that most of the descriptions for the defects are described qualitatively, not quantitatively. Some of the descriptions contained within this chart are somewhat subjective. Take the effectiveness defect, for example; the definitions of substantially effective and limited effectiveness can be quite subjective, and there is no further explanation as to what separates these categories from each other. Later in the document, we will see that some states do choose to expand upon these brief definitions.

The primary defects are split into five different categories: chalking, peeling, oxide film degradation color and texture, effectiveness, and damage. The definitions are as follows.

- Chalking is the formation of a powder on the surface of the paint film due to weathering and may appear as the color noticeably fades.
- Peeling, also labeled as cracking or bubbling, is the process of paint on the surface of steel peeling away, showing noticeable cracks and/or bubbles, which have the potential to leave the steel surface underneath exposed.
- Oxide film degradation (color/texture) is the success or failure of oxide on weathering steel as described by the proper color of the steel or the texture described on the steel.
- Effectiveness is the description of the overall effectiveness of a protective coating.
- Damage indicates whether the protective coating has picked up any other substantial physical damage, such as impact damage.

The AASHTO manual also displays several reference images that indicate the condition states for each defect and overall grade of the paint system. It is quite organized, going through each defect in order and showing photographs for each defect at each condition state level in order. What the AASHTO manual also contains that was not found for any of the other states were reference images for areas that displayed more than one type of condition state. These are referred to by the manual as Condition State (CS) 1–2, CS 2–3, CS 3–4, and so forth. An example for chalking is shown in Figure 2.2.

Another useful document is provided by the American Society of Testing Materials (ASTM). The ASTM D610 specification (2019b), which is titled *Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces*, provides some very useful quantitative data to determine the level of rusting on a surface, which can impact the paint system and the bridge's overall condition. The chart is shown in Figure 2.3 and correlates the rust grade condition rating with a percentage of surface rust deterioration.

Instead of four different condition states that could be potentially assigned in the AASHTO element level manual, the ASTM standard goes more into depth with 11 different grades. It also has specific ratings for the type of rusting that the steel is experiencing, whether that is spot, general, or pinpoint rusting. While this is in fact a national document, Florida is the only state to make mention of the contents within the document. Unfortunately, more detailed information is only present for the category of rust evaluation, and such a document is either not present or was not found for the other defects.

While these two documents are the primary sources of information that will be referenced herein, there are several other specifications that were found for

Element 515 – Steel Protective Coating – Condition State Definitions				
Defects	**CS 1 (Good)**	**CS 2 (Fair)**	**CS 3 (Poor)**	**CS 4 (Severe)**
Chalking (Steel Protective Coatings) (3410)	None.	Surface dulling.	Loss of pigment.	Not applicable.
Peeling / Bubbling / Cracking (Steel Protective Coatings) (3420)	None.	Finish coats only.	Finish and primer coats.	Exposure of bare metal.
Oxide Film Degradation Color / Texture Adherence (Steel Protective Coatings) (3430)	Yellow-orange or light brown for early development. Chocolate brown to purple-brown for fully developed. Tightly adhered, capable of withstanding hammering or vigorous wire brushing.	Granular texture.	Small flakes, less than ½-in. diameter.	Dark black color. Large flakes, ½-in. diameter or greater, or laminar sheets or nodules.
Effectiveness (Steel Protective Coatings) (3440)	Fully effective.	Substantially effective.	Limited effectiveness.	Failed; no protection of the underlying metal.
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in Condition State 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in Condition State 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in Condition State 4 under the appropriate material defect entry.

Figure 2.1 Condition state definitions for steel protective coatings as defined in the *AASHTO Manual for Bridge Element Inspection* (AASHTO, 2019).

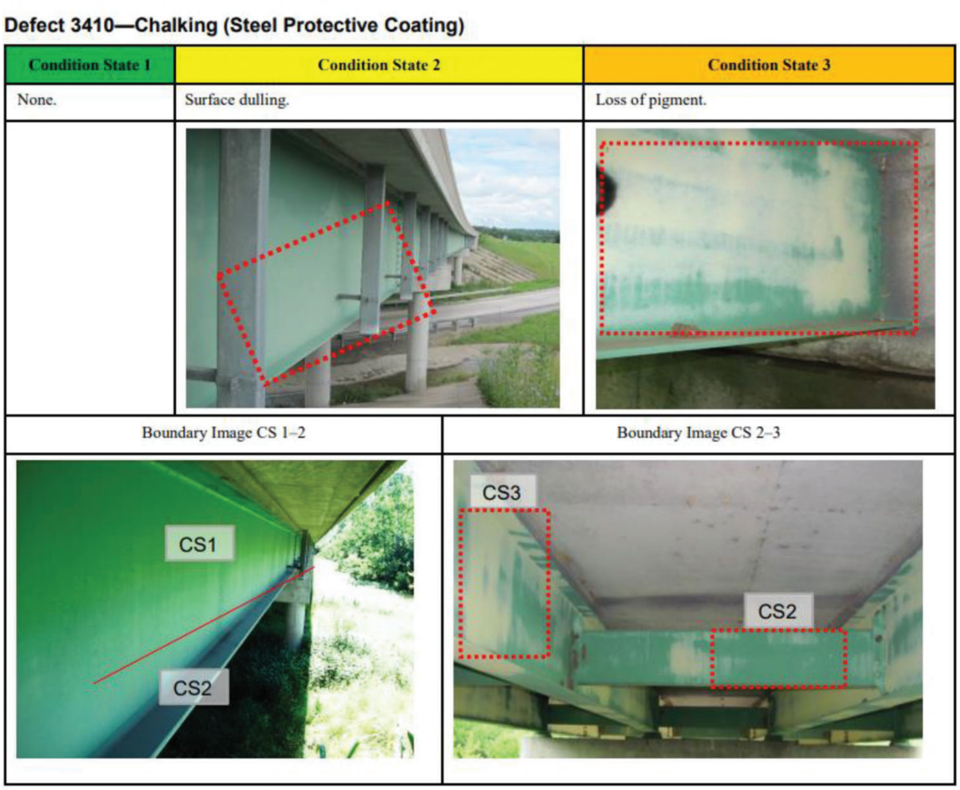

Figure 2.2 Reference images for chalking as displayed in the *AASHTO Manual for Bridge Element Inspection* (AASHTO, 2019).

Rust Grade	Percent of Surface Rusted	Spot	General	Pinpoint
10	Less than or equal to 0.01 percent		NONE	
9	Greater than 0.01 percent to 0.03 percent	9-S	9-G	9-P
8	Greater than 0.03 percent to 0.1 percent	8-S	8-G	8-P
7	Greater to 0.1 percent to 0.3 percent	7-S	7-G	7-P
6	Greater than 0.3 percent to 1 percent	6-S	6-G	6-P
5	Greater than 1 percent to 3 percent	5-S	5-G	5-P
4	Greater than 3 percent to 10 percent	4-S	4-G	4-P
3	Greater than 10 percent to 16 percent	3-S	3-G	3-P
2	Greater than 16 percent to 33 percent	2-S	2-G	2-P
1	Greater than 33 percent to 50 percent	1-S	1-G	1-P
0	Greater than 50 percent		NONE	

Figure 2.3 Rust grade versus percent rusted surface in ASTM D610 (2019b).

protective coating inspection as well. One of these documents is an SSPC publication found through the Association for Materials Protection and Performance (AAMP). AAMP is a recent merger of the Society for Protective Coatings (SSPC) and the National Association of Corrosion Engineers International (NACE). While not explicitly mentioned, these standards could still play a part in paint system inspection and evaluation. To start, SSPC-VIS2, a standard provided by the Society for Protective Coatings (SSPC), covers similar material to the ASTM D610 (2019b) above, and provides detailed images for different kinds of rusting and the severity of each, ranging from 0.03% rusting all the way up to 50% rusting. It also covers examples for general, pinpoint, and spot rusting, which can be found in Figure 2.4, Figure 2.5, and Figure 2.6.

Moreover, ASTM D660 (ASTM, 2011) introduces a new kind of potential defect known as checking. Checking is defined within the document as a "…phenomenon manifested in paint films by slight breaks in the film that do not penetrate through the last applied coating." These are essentially wrinkles in the paint system. An example of checking is shown in Figure 2.7. While checking may not present as much of a threat as defects such as corrosion or chalking, it is still important to look out for checking and identify its occurrence.

ASTM D714 (2017) is presented in a similar manner as ASTM D660 (ASTM, 2011). However, ASTM D714 (2017) gives details on a defect known as blistering. An example of blistering is shown in Figure 2.8. Blistering is similar to bubbling and, according to Corrosionpedia (2019), is identified by "…dome- or circular-shaped bubbles of the coating film held away from the substrate. Blisters can have irregular shapes, depending

Figure 2.4 An example of an area that is 0.03% rusted and of spot rusting type (SSPC-VIS2).

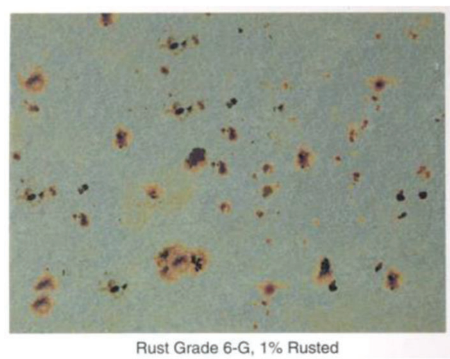

Figure 2.5 An example of an area that is 1% rusted and of general rusting type (SSPC-VIS2).

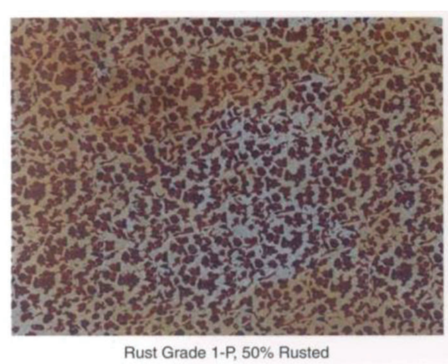

Figure 2.6 An example of an area that is 50% rusted and of pinpoint rusting type (SSPC-VIS2).

on the cause." "When adhesion is poor, blisters that form can remove the coating from the substrate, either isolated as blisters, or by total delamination of the coating." The Corrosionpedia (2019) article further states that to minimize blistering problems one should select a coating with very strong adhesion strength. Proper surface preparation is also a critical component to minimize blistering.

2.2.2 State-to-State Differences

There are a number of details and slight differences found while looking at the coating inspection standards

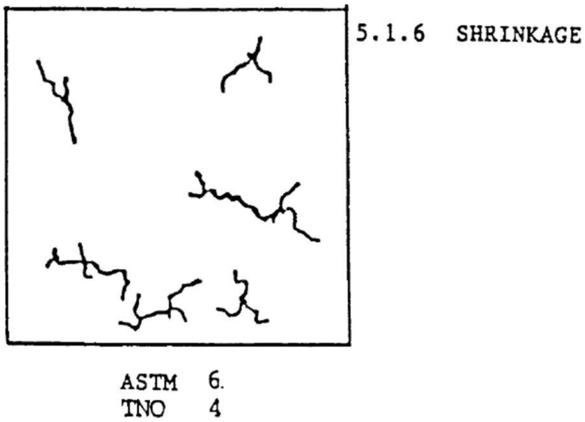

Figure 2.7 Detail on checking caused by shrinkage (ASTM, 2011).

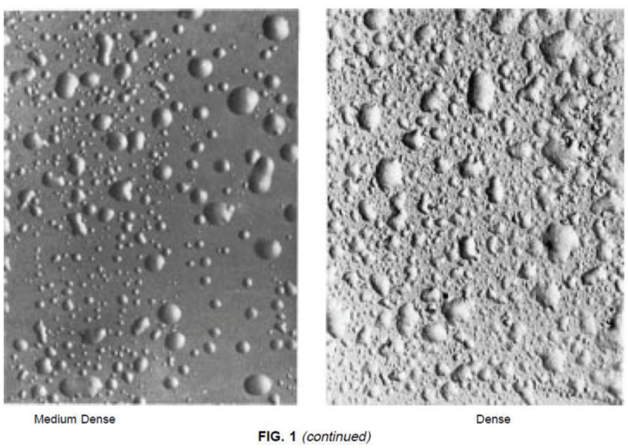

Figure 2.8 An example of different densities of blistering that may be found in a paint system, as detailed by ASTM D714 (2017).

from state to state. The information presented below was gathered primarily from the bridge inspection manuals of various state departments of transportation (DOTs). It should be noted, however, that information was not found on every single state, and that the ones listed below are not necessarily the only states where information was found.

A review of the requirements in several states indicates that the rating system used for steel protective coatings tends to be either an element level inspection with Condition States 1–4 or an National Bridge Inventory (NBI) inspection with condition ratings 9–0 (FHWA, 1995). A number of states indicate that they use both systems to some extent. Meetings with the Research Study Advisory Committee indicated that INDOT is primarily interested in an NBI inspection method with ratings 9–0. Nevertheless, the rating system(s) used by departments of transportation in other states were examined to glean information on what is commonly used and how that may be useful to Indiana.

Many states use both rating methods, but the preferred evaluation method may change when it is a state-owned bridge versus a private or local/county owned bridge. Although all methods were considered, specific emphasis was placed on the method specified in the state's official bridge inspection manual. Most states using the element level inspection method with Condition States 1–4 utilize a version very similar to the AASHTO bridge element inspection method for Element 515–Steel Protective Coatings (AASHTO, 2019), which is shown in Figure 2.1.

The chart itself has been found within state documents from the following states in some form, ensuring that these states follow these guidelines exactly—Alabama, California, Colorado, Hawaii, Montana, Nebraska, New Jersey, Oklahoma, South Carolina, South Dakota, and Wisconsin. Additionally, there also states that reference the use of the *AASHTO Element Inspection Manual*, though do not directly reference the chart above. The states include Louisiana, New Hampshire, North Dakota, Pennsylvania, and Texas. It is possible that there are more states that follow these exact guidelines, but sufficient evidence to support that claim has not yet been found.

Minnesota, for example, uses an element level inspection method with Condition States 1–4 for bridge coatings that is somewhat similar in appearance to the AASHTO bridge element level table—see Figure 2.9. Minnesota has a set of condition states listed from good to severe, just as AASHTO does. However, rather than listing the coating defects, Minnesota lists the coating systems used. A general description of deterioration is then provided under the condition states for each of the coating systems. There is also a defect listed as rusting steel with ranges of numerical values for each of the condition states. As noted in Figure 2.9, the percentages shown are based upon values in the SSPC-VIS 2 document (SSPC, 2004). Moreover, photographs accompany the condition states and can be used as reference points to assist in the inspection classification. An example of the reference images for weathering steel is shown in Figure 2.10.

It should be noted that Minnesota also uses a National Bridge Inventory (NBI) inspection method with ratings 9–0. According to Sarah Sondag, from the Minnesota Department of Transportation Bridge Office, both NBI condition ratings and element level condition states are used for inspections. Section B.2 in the *Bridge and Structure Inspection Program Manual (BSIPM)* (MnDOT, 2021) has information on the NBI condition ratings, and Section B.3 has information on the element level condition states. She stated that the NBI ratings describe the overall condition of a bridge, but the element level condition states ratings provide more detailed information regarding the condition of specific bridge elements, including coatings. Minnesota assesses coating condition with Element 515–Steel Protective Coatings based on guidance in Section B.3.8.4 of the BSIPM (MnDOT, 2021).

Oregon evaluates coating systems on their bridges with four different condition states, similar to the AASHTO element level condition states (good, fair, poor, severe), as shown in Figure 2.11. It should be

Item or Defect	Condition States			
	1 Good	2 Fair	3 Poor	4 Severe
Painted Steel Surfaces	Little or no paint deterioration.	Minor paint deterioration. Chalking and fading of finish coat.	Moderate paint deterioration. Finish coat failure (cracking, bubbling, or peeling) – prime coat remains mostly intact.	Paint system failure. Prime coat cracked, bubbling or peeling (steel exposed).
Rusting Steel Percentage (1 SF Coated Segment)	0.3% or less*	0.3% to 3%*	3% to 16%*	More than 16%*
	*Percentages are based upon The Society for Protective Coatings SSPC-VIS 2 (Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces)			
Galvanized Steel Surfaces	Little or no deterioration of galvanized coating.	Minor coating deterioration. Light chalking or fading of galvanized surface.	Moderate coating deterioration (coating remains mostly intact). Heavy chalking.	Galvanized coating system failure.
Duplex Coated (Galvanized and Painted) Steel Surfaces	Little or no deterioration.	Minor coating deterioration. Chalking or fading of finish coat – any exposed steel is very isolated.	Moderate coating deterioration. Finish coat failure (cracking, bubbling, or peeling) – galvanized coating remains mostly intact.	Extensive duplex coating system failure.
Unpainted Weathering Steel Surfaces (Protective Oxide Coating)	Protective oxide coating is uniform and tightly adhered (yellow, orange, or brown color)	Protective oxide coating is uneven or has minor deterioration. Dark brown color – the surface may be dusty or granular.	Protective oxide coating has moderate failure (small flakes, less than ½" diameter). Black color.	Protective oxide coating has failed. Large areas of the surface layer are flaking off.

Figure 2.9 Minnesota Department of Transportation bridge inspection field guide evaluation system for steel protective coatings (MnDOT, 2021).

noted, however, that even in the highest condition state that can be given to a coating system, the description still allows for slight flaws in the system, as opposed to the AASHTO standard, which requires there to be no flaws and a full effectiveness within the system.

Illinois also uses the element level inspection method with Condition States 1–4, although the descriptions for each condition state do not match the AASHTO manual's descriptions. Additionally, the descriptions are not broken up by category of defect but are instead listed as broad descriptions of the entire system. Feasible actions for each condition state are also given, which can include no action, washing and cleaning, blasting and painting, replacing the paint system, and replacing the entire unit.

Washington uses a National Bridge Inventory (NBI) inspection method with ratings 9–0 to evaluate coatings. The description for each of these ratings, however, only dictates how recently a given bridge has been painted or how soon a bridge will need to be painted. There was no evidence found that mentioned any descriptive evidence of deficiencies.

Wisconsin details different condition states for each defect in a paragraph format as opposed to the usual chart. Details for each condition state seem to be the same for most defects, and it also goes into detail for the effectiveness defect, indicating what might be found for each condition state. Figure 2.12 illustrates the effectiveness defect.

When comparing these descriptions of effectiveness versus the ones provided in the AASHTO manual, WisDOT provides much more of an explanation for each given level of effectiveness, and they provide a solid basis for determining the effectiveness of a given coating system.

Connecticut also appears to exhibit a different paint evaluation system than the AASHTO standard. The paint evaluation system condition is expressed for the whole system as opposed to breaking the condition down into each defect. Additionally, instead of having different Condition States 1–4, the condition states are ratings numbered 9–1, though only using the odd numbers, as shown in Figure 2.13. The ratings are listed from excellent all the way to failed. The only quantitative data that was found within this evaluation system was the percentage of surface area that was found to be rusting or peeling.

As mentioned earlier, Florida was the only state found to go into detail regarding the ASTM D610 document (ASTM, 2019b), showing the chart that detailed rust grades and percentages that corresponded to each grade. While Florida does not make any mention of the chart in the AASHTO manual or any other requirements, it does mention four main criteria that are used to assess a given coating system. These

Figure 2.10 Reference images provided by MnDOT for weathering steel condition states (MnDOT, 2021).

Painted Steel Bridge Element CS Definition

CS1 (Good)	CS2 (Fair)	CS3 (Poor)	CS4 (Severe)
Initiation of rust on edges, crevices and fasteners, or no rust present. Chalking peeling, or curling of coating maybe present	Rust is present on edges crevices and/or fasteners and may be spreading to webs flanges, and connection areas. No rust scale is present. Rusted area may be up to 15% of total surface.	Extensive rust is present on edges, crevices, joints, webs, and/or flanges. Rusted area is over 15% of the total surface. There is some rust scale, but with little pitting or metal loss.	Complete deterioration on edges, crevices, connections. Almost all surface

Figure 2.11 Oregon Department of Transportation condition state definitions for paint systems.

A.3.4.2 Effectiveness (3440)

This defect is the only defect to be used on all steel protective coatings other than Weathering Steel. The ability for the protective coatings to protect the steel element it is placed over is its effectiveness. A protective coating can lose effectiveness through wear, deterioration, and leakage.

Condition States

Condition State 1 indicates a protective coating which is fully effective. Coating system may have minor fading, chalking, dulling, but there is no active corrosion and primer coat is intact.

Condition State 2 indicates a protective coating which is substantially effective. Coating system may have moderate deterioration such as chalking, peeling, blistering or cracking to finish coat. Surface/freckle rust or staining may be present, but there is no pack rust.

Condition State 3 indicates a protective coating which is limited effectiveness. Coating system has extensive deterioration to finish and primer coats. There is loss of pigment, peeling, bubbling, or cracking to finish and primer coats. Surface rust is prevalent. Pack rust may be present.

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Condition State 4 indicates a protective coating which has failed or is non-existent and provides no protection of the underlying metal. There may be heavy corrosion and pack rust.

Figure 2.12 Wisconsin Department of Transportation description for effectiveness of paint systems.

four criteria include extent and severity of damage (such as peeling), adhesion of existing coating, thickness of existing coating, and the extent and severity of corrosion. Again, no mention of quantitative data was made within the document.

Michigan's Structure Inspection Manual (MDOT, 2019) details the different types of defects with brief descriptions which do differ from the defects listed in the AASHTO manual. Figure 2.14 illustrates the Michigan DOT list of defects and categories. Michigan also indicates that the presence of some of these defects has a bigger impact on the overall bridge condition than the presence of others. For example, beams with general or spot rusting do not present as serious of a priority for repainting as beams that exhibit chalking or pinpoint rusting might.

Michigan also gives percentages of surface area as a quantitative data measurement, measuring the surface area of a paint system that has rusted to evaluate the condition of a bridge coating system. Visual examples of each defect are also given to better explain the descriptions provided for each type of defect. Lastly, the condition state with defect descriptions is also provided in the *Michigan Bridge Element Inspection Manual* (MDOT, 2017).

Alaska utilizes the SSPC VIS-2 document for their coating evaluation. Though no extensive defect breakdown could be found such as the one in the AASHTO manual, the Alaska DOT did mention that bridges exhibiting a rust grade of above 4 or a surface area percentage above 10% (according to SSPC VIS-2) should be considered for repainting. This specific rust

Rating Guidelines

9	Excellent	No defects.
7	Good	Paint system is generally smooth and uniform. The system may exhibit isolated areas (less than 10%) of peeling or delaminations in the top or inner layers; however, the primer is still intact and able to protect against the environment. Isolated areas of cracking or excessive chalking may be present (less than 10%). Less than 5% of painted surfaces may exhibit rusting.
5	Fair	Paint system is showing signs of deterioration. Peeling or delamination in top or inner layers of the system is more prevalent. Less than 50% of painted surfaces are rusting. Most of the rusting is located at the beam ends and diaphragms where members have been subjected to leakage.
3	Serious	Paint system shows significant deteriorations. Greater than 50% of painted surfaces are rusted. Peeling is noted throughout the painted surfaces.
1	Failed	Paint system has fully deteriorated. Greater than 90% of painted surfaces are rusted and/or peeling.

Figure 2.13 Connecticut Department of Transportation coating system condition rating.

Category		Description	Reference Figure
Corrosion	Spot Rusting	Limited corrosion occurring to a small number of specific areas	5.14.01
	General Rusting	Intermittent corrosion occurring throughout the majority of surface areas	5.14.02
	Pinpoint Rusting	Widespread freckled corrosion occurring throughout the majority of surface areas	5.14.03
Degradation	Cracking/Peeling/Curling	Usually occurs from improper surface preparation, poor environmental conditions during application, or excessive film thickness.	5.14.04
	Chalking	Caused by ultraviolet light breakdown of the top coat which leads to a dull or white powdery surface	5.14.05

Figure 2.14 Michigan Department of Transportation list of defects and categories as found in the *Michigan Structure Inspection Manual* (MDOT, 2019).

grade was cited as being "aesthetically unacceptable and will lead to steel section loss."

Ohio DOT (ODOT, 2014) has a coating evaluation system, which is shown in Figure 2.15, that is broken down into different categories similar to the *AASHTO Manual for Bridge Element Inspection.* However, the categories and criteria for the system are slightly different than AASHTO's. They do provide quantitative data on the surface area percentage that has failed for the coating system, which appears to be different from other surface area criterion in terms on the percentage covered for each category.

While the criteria shown in Figure 2.15 are for an element level rating, which are from the *Ohio Manual of Bridge Inspection* (ODOT, 2014), Ohio also uses a 9–0 NBI rating. According to Tim Keller, Administrator of the Office of Structural Engineering for the Ohio DOT, the 9–0 rating is used for local bridges while the element level rating and the NBI 9–0 rating are both used for state bridges. He also indicated that photographs are used for the 9–0 rating, but the standard is not available online yet.

Vermont's coating evaluation standards are shown in Figure 2.16 and are in the form of numbered ratings. These are somewhat similar to the Connecticut evaluation system, though slightly differ from it.

Other states which did give information that hinted at the use of coating systems and the evaluation of them but did not provide any further information that could be located or deemed as useful, are noted below.

- Alabama made mention of different types of painting or repainting jobs and defined what each type of painting job was with regards to the percentage of the structure that would be cleaned and repainted. There are three different types: spot painting, partial painting, and complete painting. Spot painting consists of painting less than 25% of the structure, partial painting consists of painting between 25% to 75% of the structure, and complete painting consists of painting more than 75% of the structure.

Item - 30. Protective Coating System (PCS)

1-4 Rating	Degradation Problems			Workmanship Problems	Candidate for Recoating
	% Surface Area (SA) **Failed**	Issues	Surface Corrosion		
1-Good	**0 to 5%**		Light	Up to 10% failed SA, Multiple minor issues, Up to 10% finish coat failed	
2-Fair	**6 to 15%**	Not effective at Beam ends under joints	Prevalent	Up to 20%	Candidate for zone painting (fascias and under joints)
3-Poor	**16-30%**	Not effective	Prevalent	Large areas of old Paint Painted over	Candidate for total recoating
4-Failed	**More than 30%**				

Figure 2.15 Ohio Department of Transportation system for evaluating the paint system condition (ODOT, 2014).

State Item No. 211 - Rating of Paint **1 digit (A)**

This item indicates the rating of paint, code as follows:

Code	Description
8	Paint is in good condition
7	Spot painting or complete painting with minor cleaning required
6	Complete painting with general cleaning required
5	Complete painting w/ extensive cleaning required
N	Any structure w/ a non-paintable superstructure, such as: concrete slabs and T-beams; culverts; A-588 steel; etc.

Figure 2.16 Vermont Department of Transportation paint rating system.

- Maine indicates that, due to the overall climate of the region, certain protective coatings like paint are rarely used. They do list alternate methods and materials that are used, such as weathering steels, galvanized steel, metalizing, and polyuria elastomer coatings. However, no mention of evaluation of these systems was located.
- Delaware provides some examples of steel bridge elements containing defects and provides photographs to go along with them. However, no evidence of a rating scale or a breakdown of each defect was found.
- Iowa only makes mention of the condition of paint on a scale from 9–0, though no mention of specifics or descriptions come with the scale.
- Within Kansas's *Local Bridge Inspection Manual*, coating system condition is only briefly touched on when referring to the bridge superstructure condition.
- The only mention of coating inspection or procedures that *Kentucky's Bridge Inspection Manual* makes is in reference to noting any increases in corrosion of the bridge during its inspection.
- In Nevada's structures manual, a section that is dedicated to aspects of bridge inspection makes mention of a bridge inspection manual that exists, but no such document could be found.
- New York goes into detail on the inspection process, but only for weathering steel. There are several visual examples citing the condition states of coating systems, galvanized surfaces and weathering steel, but the photographs do not seem to be systematically organized.
- The closest thing to bridge inspection standards that could be found for Tennessee was the "Bridge Inspection and Repair" section listed on their DOT website. This only briefly touched on the bridge inspection process, and no document such as a bridge inspection manual was found.
- The most detail located from Utah talking about protective systems are found within the bridge management manual, in a section discussing ratings for substructure condition, which coating system typically falls under. Coating system is not mentioned explicitly in this section, however.
- Virginia's DOT has a document which supplements the AASHTO bridge manual. In addition to the element inspection of paint, Virginia also includes an element for the 5 feet of paint at the end of each steel member, with evaluation criteria similar to the chart in Figure 2.1.

2.3 Coating Evaluation and Rating in Nearby and Surrounding States

A number of states surrounding Indiana and geographically adjacent were selected to be examined. These specifically included: Illinois, Iowa, Kentucky, Michigan, Minnesota, Ohio, Pennsylvania, and Wisconsin. These states were chosen due to the similar environmental conditions and the common use of deicing chemicals such as salt.

Of the eight (8) Midwest states examined, five (5) of the states primarily utilize an element level inspection. These states are Illinois, Michigan, Minnesota, Ohio, and Wisconsin. Of these five, Michigan utilizes the exact same evaluation method as the AASHTO element level inspection method. Three states, Michigan, Minnesota, and Ohio included images as well as descriptions, while Illinois and Wisconsin only included descriptions.

Of these five states that use an element level inspection method, Minnesota's requirements contained the most in-depth descriptions (MnDOT, 2021). Images were also attached for each condition state. Based on these criteria, Minnesota appears to have the most advanced element level evaluation method of any state in the Midwest. Because of this, their scale was utilized as a guide when determining a recommendation for INDOT.

A specific feature of the Minnesota rating system that was believed to be desirable was the rusting steel percentage, which provided a strong quantitative method for evaluating the condition of a coating system. The descriptions provide more detail than the AASHTO evaluation method, which can be easily observed by comparing the length of descriptions for the two. Finally, as noted above, the Minnesota requirements contained images for each condition state. By connecting example photographs with each condition state, the bridge inspection should result in more consistent ratings amongst different inspectors. This in turn should aid in identifying the bridges with the most need for maintenance painting or repair, potentially saving money for the department of transportation.

There were two states in which neither scale nor criteria could be found for evaluating coatings. Kentucky contained a brief description, saying to "Inspect the paint on the structure and make a judgement on its condition. Document any increases in corrosion which has occurred since the previous inspection" (Kentucky Transportation Cabinet, 2017). Per examination of the Kentucky Transportation Cabinet's website, it appears that they default to the AASHTO Element 515 requirements described in Figure 2.1. The other state was Iowa, where they make mention of a rating system, but do not provide it anywhere for the public.

Two states, Pennsylvania and Iowa, contained a 9–0 rating scale, similar to what INDOT has requested for a recommendation. The *Iowa Department of Transportation Bridge Inspection Manual* (HDR, 2015) provided little detail on the scale, except to indicate that the ratings scale from 9–0. They also indicated that the rating is recorded in a software (HDR, 2015). Pennsylvania on the other hand contained some descriptions which were quite detailed. In the Pennsylvania manual, this is referred to as Item 6B36–Paint Condition Rating (PennDOT, 2022b). The requirements are shown in Figure 2.17.

Overall, the descriptions in the Pennsylvania requirements provided for each rating level are better than many that are utilized by other states. Each description provides sufficient detail for the coding condition, making establishing a rating very straightforward. The descriptions provide clear differences as the condition gets worse. Another potentially helpful part of this rating system was that each rating was associated with a maintenance painting strategy, as can be seen at the bottom of Figure 2.17. The rating system does leave some things to be desired. For one, there is no quantitative method for analyzing the coating condition. In addition, there are no images correlated to each condition rating level.

2.4 Discussion and Recommendations

It is clear that when looking at coating evaluation methods used by DOTs throughout the United States that there is no one method that is used. In general, however, the rating system used for coatings tends to be either an element level inspection method with Condition States 1–4 or a National Bridge Inventory (NBI) inspection method with ratings 9–0. Many states indicate that they use both systems to some extent. Meetings with the Research Study Advisory Committee indicated that INDOT is primarily interested in a National Bridge Inventory (NBI) inspection method with ratings 9–0.

With all of this background, it is believed that a recommendation could be made that draws upon helpful parts of other existing rating systems. From Minnesota, the descriptions and images were deemed beneficial to include in a rating system. From Pennsylvania, an outline of a sufficient 9–0 rating system was provided with detailed descriptions. Michigan and Ohio provided more images to be used in association with the rating system. Finally, ASTM D610-01 (2019a) provided a sound quantitative method to include in the evaluation system. By combining all of these existing pieces, a National Bridge Inventory (NBI) inspection method with ratings 9–0 was developed and is shown in Table 2.2.

An examination of the values shown in the proposed rating system shows that there is correlation between the condition rating and the percent of the surface area that has developed rusting. The correlation is based upon an approximate lining up of the values in ASTM D610-01 (2019a) and the condition rating. Also, the percent rusted surface area, as used in the condition states of the Minnesota element level inspection method, is approximately correlated with the rusted surface areas shown in the proposed National Bridge Inventory (NBI) inspection method with ratings 9–0 (see Figure 2.9).

No attempt was made to provide photographs of corrosion damage with the National Bridge Inventory

Coding:

N Not Applicable

9 New Condition

8 Good – That condition of the paint system where there may be minor spots of deterioration or cracking with virtually all of the paint system intact and not peeling. A few minor rust spots are acceptable.

7 Fair to Good – Conditions that fall between code 8 and code 6.

6 Fair – That condition of the paint system where a number of small rust areas or blisters may be noted and/or there may be loose rust formation pitting/peeling of the paint.

5 Poor to Fair – Conditions that fall between code 6 and code 4.

4 Poor – That condition of the paint system where the system has broken down and there may be major areas of peeling and cracking along with a high percentage of severely rusted areas with scales and/or flakes (need for painting is urgent).

3 Critical to Poor – That condition of the paint that caused the metal to corrode to such an extent of deep pitting and loss of section in non-critical areas and where the loss of section is considered to be minor.

2 Critical – The condition of the paint that caused corrosion of metal to such an extent that there is major loss of section and deep pitting on a large percentage of the area of the element or the loss of section which has materially affected the strength of the member and requires immediate correction.

1 Intolerable – Study should determine the feasibility for repair and merit of painting.

0 Painting will no longer help – Structure is generally in a hopeless condition

Summary Paint Condition Rating Codes

Coding	Indication
8, 7	Spot painting
6, 5	Program for painting
4	Urgently in need of painting
3, 2	Structure repair may be required before painting
1, 0	Beyond repair (painting is a waste of resources)

Figure 2.17 Pennsylvania Department of Transportation paint evaluation coding descriptions (PennDOT, 2022b).

TABLE 2.2
Proposed INDOT Rating of Steel-Painted Surfaces

Rating	Condition	Description
N	Not applicable	No paint or weathering steel.
9	Excellent	Recently painted, good seal, no defects or rusting.
8	Very good	Very minor defects, paint is still intact, and no peeling is occurring; minor rusting, less than 0.3% surface area.
7	Good	Small defects in the paint system are beginning to form, preliminary stages of peeling; small amounts of surface rusting, up to 1% surface area.
6	Satisfactory	Some peeling and rusting, minor impact damage, rusting of up to 3% surface area, paint system still functioning overall
5	Fair	Paint system beginning to show imminent signs of failure, surface rusting up to 10%, significant spots of peeling, and rust throughout.
4	Poor	Paint system is failing, major rusting and peeling, surface rust of up to 16%.
3	Very poor	Paint system has mostly failed, minor section loss at non-essential points, surface rust greater than 16%.
2	Severe	Paint system has failed, section loss at essential points, surface rust up to 33%.
1	Total paint failure	Major section loss occurring throughout the structure at crucial points, repainting is not a viable option of repair, surface rust of up to 50%.
0	Total paint failure	Surface rust greater than 50%, large areas of extremely heavy rust and section loss, remove damaged structure.

(NBI) inspection method with ratings 9–0. However, this is believed to be a very important step in providing an improved evaluation and rating system for a steel bridge coating system. Some sample photographs from other states are provided in Appendix B for general reference. However, the selection of appropriate INDOT photographs with sample corrosion damage is beyond the scope of this project.

3. COATING SYSTEMS FOR STATE DEPARTMENTS OF TRANSPORTATION

A second feature of this study is an examination of the coating systems used throughout the Midwest and the rest of the United States. This information may be useful as Indiana evaluates the robustness of their coating system for steel bridges. It was also suggested that the coating evaluation methods could be influenced by the coating system that that state primarily uses.

The country was divided up into several regions deemed to have similar environmental conditions. These regions were the Midwest, Southeast, Northeast, Western Coastal, Southwest, and Northwest. The coating system used in the various states and regions were examined. The bridge design manuals or specifications in various states were examined to determine the recommended coating systems used. Useful information on coating systems was also found in Stephens et al. (2019). A complete list of the number of coats used in the coating system for individual states is listed in Appendix A.

The Midwest region was inspected thoroughly since it contains Indiana. The Midwest region included Indiana, Illinois, Iowa, Ohio, Michigan, Minnesota, Kentucky, and Wisconsin. In the Midwest, every state utilized a three-coat system except for Minnesota, which included specifications for a 2–3 coat system. Several options for three coat systems were listed for each state, with very slight variations from state to state.

Starting in Indiana, the first coat is typically an inorganic zinc-rich primer. This is followed by an epoxy intermediate coat, and then a polyurethane finish coat—see *INDOT Standard Specifications* (INDOT, 2022). Specifications exist for an organic zinc-rich primer system, but this is very rarely used due to its higher cost compared to inorganic zinc. The typical practice in coating application is for the primer coat to be applied in the fabrication shop, followed by the intermediate and top coats applied in the field after the bridge girders have been erected. Looking at the qualified products list, the paint systems permitted have very little variation from company to company.

Throughout the Midwest, every state department of transportation contains specifications for a zinc-rich inorganic primer, followed by an epoxy intermediate coat, and some kind of urethane top protective coat. Some states in the Midwest also contain a few other systems which are approved to be used on structural steel for bridges. Minnesota has specifications for a two-coat system, which originally made it appear like there was some nonuniformity in the Midwest. However, after further research, it appears that this system is only used for maintenance painting, as the second coat.

One difference in the Midwest region is the predominant use of organic zinc-rich primers in Michigan. According to John Belcher, with the Michigan Department of Transportation, Michigan typically uses an organic zinc rich primer, rather than an inorganic zinc-rich primer coat. He stated that the inorganic zinc-rich primers take too long to cure and that they can proceed sooner if they use an organic zinc-rich primer. He also stated that the surface tends to be more uniform with organic zinc-rich primers. They only use inorganic zinc-rich primers if needed for the bolt faying surface.

According to Sarah Sondag, from the Minnesota Department of Transportation, Minnesota typically uses a 3-coat paint system with an inorganic zinc-rich primer coat for new construction. She also stated, however, that a three-coat paint system with an organic zinc-rich primer coat is used in the field for rehabilitation (i.e., removing the existing coating and repainting).

There are a few other three coat systems that appear in specifications for some states in the Midwest. One is a moisture cured urethane system which appears in Minnesota and Iowa specifications. The next is an aluminum epoxy mastic coating system which appears in Illinois and Iowa specifications. Finally, there is an acrylic paint system which appears in the Illinois and Iowa specifications as well.

Although there exists several different paint systems not included in the INDOT specifications, there is far more uniformity in the Midwest than it may appear to have. For example, three coat systems are utilized exclusively in every state in the Midwest region for new steel coatings. Not only is the same number of coats used in every state, but the primary coating system is the same as in Indiana: inorganic zinc-rich primer, epoxy intermediate coat, and some kind of urethane finish coat. Other paint systems exist in the region, but appear to only be utilized in special cases, such as maintenance painting or extreme environments.

Looking at the other regions throughout the United States, the trend of uniformity in a region remains common. In the Northeast, there is a regulating body which has its own qualified products list. This regulating body is called NEPCOAT, which stands for North East Protective Coating Committee. The states included in this are New York, Pennsylvania, Maine, Rhode Island, Connecticut, Delaware, Massachusetts, New Hampshire, New Jersey, and Vermont. Due to this organization, the Northeast region is incredibly uniform in terms of coating methods. The most common coats used in the Northeast are called List A and List B of the NEPCOAT qualified products list. List A utilizes an inorganic primer, epoxy intermediate coat, and polyurethane finish coat. List B is very similar, except it utilizes an organic primer (NEPCOAT, 2022).

Looking at the Southeast region, there is significantly more differences than in the Northeast and Midwest. While the three-coat system remains the standard across the region, specifications for two coat systems are much more common. In South Carolina, Tennessee, and Alabama, two and three coat systems are utilized. Whereas in North Carolina, only two coats are used. Throughout the rest of the region in Florida, Georgia, Mississippi, and Arkansas, only three coat systems are specified.

Moving to the Southwest, three-coat systems are the overwhelming standard utilized. Kansas utilizes just

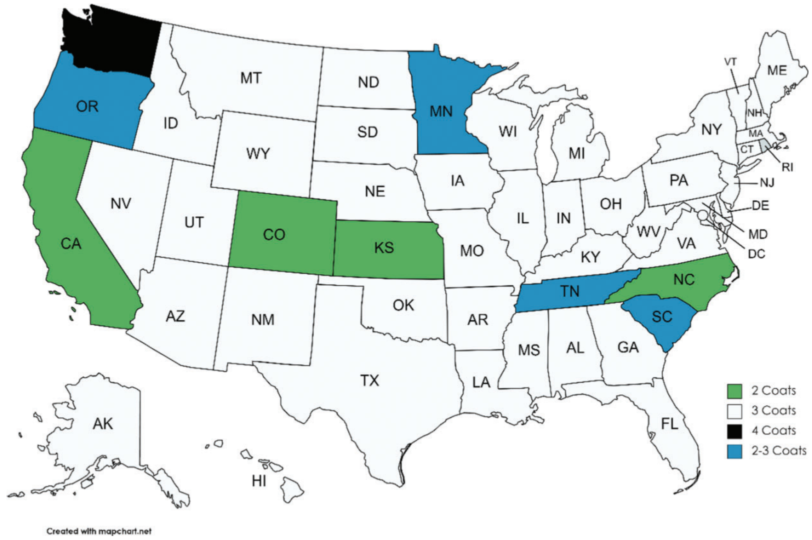

Figure 3.1 Number of paint coats used in coating systems for various states.

two coats, and Missouri allows for two to three coats. In the Northwest region, every state utilizes a three-coat method exclusively except for Colorado, which uses a two-coat method. In the western coastal region, we can see some more variety. Washington utilizes a four-coat method exclusively, which appears to be the only state in the United States who primarily uses a four-coat method. California exclusively utilizes a two-coat system, while Oregon has specifications for both a two and three coat method.

A map showing the number of coats used in the coating system for individual states is shown in Figure 3.1. Some important observations can be made from studying each region. For one, the greatest deviations from the standard three coat system are primarily seen in the western coastal and southeast region, both coastal regions. There are only two landlocked states who exclusively utilize a non-three-coat system, Kansas, and Colorado. Based on research, these two states appear to simply be outliers. Another important note comes from the Northeast region. Although every region appears to have some sort of committee to promote uniformity in coatings, NEPCOAT is the most prevalent and best organized. An organization such as this could ensure that the best practices are being used in regions with similar environmental conditions.

Another important note to consider is that although Figure 3.1 can be helpful for visualizing requirements in every state very quickly, it does not tell the full story. For example, states such as Minnesota, South Carolina, Tennessee, and all other states colored in blue may appear to have entirely different requirements than most of the nation; some, however, typically default to three coat systems. Without being able to interview all of these states it is difficult to know for sure. However, it was shown that in Minnesota the two-coat system was utilized rarely and only for maintenance painting, while all new steel was coated with a three-coat system. It appears that this is likely the same case in all or most of the states utilizing two to three coats. In addition to this, the "fourth" coat applied in Washington is simply a stripe coating, or an extra coat of paint applied to edges, welds, or other trouble areas. Therefore, there is not four coats on the entire bridge, and it would perhaps be better described as a three-coat system with added protection from corrosion at troublesome edge areas.

In reality, the only major discrepancy lies in states which only permit two coat systems. These states are California, Colorado, Kansas, and North Carolina. None of these states are close geographically to Indiana. The final conclusions reached by the research team on coating systems is that the Midwest and areas surrounding Indiana contain extreme uniformity and primarily use the same coating system described in INDOT specifications. In addition, no correlation was found between the coating system utilized and how the coating systems are evaluated.

4. MAINTENANCE PAINTING

4.1 Purpose of Maintenance Painting

One of the most important facets of maintaining protective steel coatings is maintenance painting. Maintenance painting refers to paint applications to existing steel that has deteriorated for some reason. The three most common methods of maintenance painting are spot painting, complete recoat, and overcoating. According to a scan performed by the Kentucky Transportation Cabinet in accordance with the National Cooperative Highway Research Program, of the 31 Department of Transportations who replied, 18 utilized spot painting, 25 utilized zone painting, 23 utilized overcoating, and 28 utilized total removal and recoat (Kentucky Transportation Cabinet, 2017; MnDOT, 2014). According to a scan performed by the Minnesota Department of Transportation in 2014, 54.8% utilized spot touch-up, 66.7% utilized zone painting, 50% utilized spot touch up and overcoat,

Surface Preparation Method	SSPC Number
Solvent Cleaning	SSPC-SP1
Hand Tool Cleaning	SSPC-SP2
Power Tool Cleaning	SSPC-SP3
White Metal Blast Clean	SSPC-SP5
Commercial Blast Cleaning	SSPC-SP6
Brush Off Blast Clean	SSPC-SP7
Near White Metal Blast Cleaning	SSPC-SP10

Figure 4.1 Standard surface preparation methods based on the Society for Protective Coatings (SSPC).

and 90.5% utilized complete removal and repaint (MnDOT, 2014). Both of these surveys indicate that complete removal and recoat is by far the most common method utilized throughout the country.

Although the aforementioned scans illustrate the prevalence of maintenance painting across the country, much more goes into maintenance painting than just applying a few coats of paint to some trouble areas. In order for paint applied to an existing steel structure to have any significant lifespan, proper surface preparation is required. The most commonly used surface preparation standards are governed by the Society for Protective Coatings, also known as the SSPC (as noted earlier, SSPC is now a part of the AAMP). There are several standards which are commonly utilized by state DOT specifications when specifying how to prepare a metal surface for maintenance painting. The most common surface preparation methods are listed in Figure 4.1.

4.2 Use of Maintenance Painting in Other State DOTs

When going through the bridge maintenance manuals for different state DOTs, most states make use of several different methods in order to ensure their maintenance coatings will maximize its life expectancy. For example, Pennsylvania states that for zone/spot painting, "Power tools shall be used to clean corroded spots to bright metal . . . Take measures to allay dust, if necessary" (PennDOT, 2022a). Although PennDOT states what their expectations are, they make no mention of specific SSPC standards. This is likely because several surface preparation methods are used and vary significantly based on the case. In *IOWADOT Office of Bridges and Structures Bridge Maintenance Manual*, it states, "Remove dirt and debris from bearings and bearing seats with hand tools. Power wash to remove debris trapped in crevices of bearing components." (HDR, 2014).

Minnesota's Bridge Maintenance Manual contains a specific chapter related entirely to bridge maintenance painting, which contains some thorough information regarding all bridge maintenance painting procedures. The surface preparation methods required for each maintenance painting method, in addition to the materials used in each system, is listed in Figure 4.2 (MnDOT, 2019).

Another important factor to consider with maintenance painting is who is conducting the surface preparation and maintenance painting itself. Depending on available personnel, this can either be performed by a contractor or by in-house personnel. According to a survey conducted by KTA-Tator in 2013 for the Minnesota Department of Transportation, out of 42 transportation agencies, 1 used only in-house forces, 27 used only contractors, and 14 utilized a mix of both (MnDOT, 2014). In Minnesota, in-house personnel do the majority of maintenance spot painting. Contractors, on the other hand, are typically used for a full repainting of a bridge.

Maintenance painting has the potential to expand life span of protective coating systems, but also requires a significant investment of money and time. Based on the results from the Minnesota Department of Transportation survey in 2014, it seems that very few state departments of transportation have the staff with the expertise to be able to perform maintenance painting in-house. With the added cost of using a contractor, the upfront investment for maintenance painting continues to increase. With the constrictive budget faced by many of these DOTs, maintenance painting seems to be becoming a less common practice throughout the country. When interviewing Josh Rogers, the Head of Bridge Maintenance at the Kentucky Transportation Cabinet, he stated that maintenance painting was performed very rarely. Rogers stated that they only use in-house personnel when repairing a damaged structure. The same approach is used in Michigan. John Belcher, who is with the Michigan DOT, indicated that they do zone painting if there is a repair or retrofit involved, such as at beam ends, pin/hanger joints and bolt repairs, but they always contract the work out. The exception is that there is one state-wide emergency crew that sometimes does painting if needed for a repair. Moreover, Tim Keller, an official from the Ohio Department of Transportation, stated essentially the same idea, that they very rarely performed maintenance painting. Keller noted that the exception to that is if there is deterioration at a bridge joint.

Maintenance Coating Systems: Years of Anticipated Service until 3%–5% and 5%–10% Coating Breakdown Reoccurs[7]

Coating System	Coating Materials	Surface Preparation	Years to 3%–5%	Years to 5%–10%
One Coat Touch-Up	1 Coat Surface Tolerant Polyamide Epoxy	SSPC-SP 3	5	7.5
Two-Coat Touch-Up and Overcoat	1 Coat Surface Tolerant Polyamide Epoxy 1 Coat Aliphatic Polyester Polyurethane	SSPC-SP 3	7	10.5
		SSPC-SP 6	9	13.5
New Three-Coat Replacement System	3 Coats- Zinc Rich Epoxy, High Build Epoxy and High Solids Polyester Aliphatic Polyurethane	SSPC-SP 10	14	21

Figure 4.2 Minnesota DOT maintenance coating systems (MnDOT, 2019).

In addition to having to hire contractors, environmental regulations developed in the past several years have added even more restrictions to maintenance painting methods while increasing costs. Several of these regulations developed by the EPA, such as the Clean Water Act and the Clean Air Act, have driven up costs by altering the methods that can be used for surface preparation. According to a 2017 scan report, "These new methods have produced a general increase in maintenance painting costs of 200% to 500% over the past decade." (Vinik et al., 2016). With this increase in costs, it would make sense that many state departments of transportation are passing on maintenance painting and waiting until the coating condition deteriorates enough to justify a complete recoat.

The Kentucky Transportation Center at the University of Kentucky has conducted substantial research on maintenance painting. When interviewing a representative of the Kentucky Maintenance group, he stated that this research initiative was more of an individual venture and has been struggling lately to carry the same momentum it once had. Partially because of this, implementation into state standards and practices has been almost nonexistent. With the recent addition of several obstacles such as environmental regulations which drive up costs, there exists a significant gap in research that is waiting to be filled. Whether this be through developing new techniques or improving upon old techniques, more research and work needs to be done on this subject. Although some promising research initiatives have been proposed, there is still much room to grow in order to draw important conclusions.

After reviewing state standards, bridge maintenance manuals, and research conducted on bridge maintenance painting, the overwhelming trend observed is that many of the decisions that go into maintenance painting are personnel dependent. There is not a lot of explicit information written down in state standards that state when to perform certain maintenance painting methods, meaning much of this comes down to the expertise of individual bridge inspectors. Although this method can work, it would be beneficial to have criteria written into state standards for when personnel retire or when new personnel are hired. This was further backed up by the interview with a Kentucky Transportation Cabinet official who stated that maintenance painting was performed very rarely, and only performed if specifically called out by bridge inspectors.

In terms of what is being conducted right now, it appears that complete removal and recoat is the most common method of maintenance painting throughout the country. Spot painting is performed on specific spots of accelerated corrosion but, in general, it is not a commonplace practice as shown by the scans conducted. Overall, determination of a maintenance painting strategy is a very fluid topic that is everchanging. Changing personnel, inflation, environmental regulations, and available funding for maintenance drastically alter the decision-making process. Consequently, due to these many factors, it is difficult to provide a recommendation on maintenance painting for Indiana without a more comprehensive study.

5. CONCLUSIONS, RECOMMENDATIONS, AND INDOT STRATEGIC GOALS

5.1 Summary and Conclusions

The goal of this study was to examine the coating evaluation criteria used by other state department of transportation agencies for steel bridges, collect information on the coating systems that they use, and collect a summary of procedures they may use for maintenance painting. A few conclusions were reached on each topic and they are summarized below.

For coating evaluations, there is a wide variety of methods employed by states to evaluate their steel bridge coatings. Looking specifically at the Midwest, most states have two methods for evaluating their coatings: an element level inspection method with Condition States 1–4 and a National Bridge Inventory (NBI) inspection method with ratings 9–0. Most states utilize their element level inspection method for state controlled and larger bridges, while the National Bridge Inventory (NBI) inspection method is used for non-state controlled or local bridges. For element level inspections, most appear to be based to some extent upon the AASHTO element level inspection method for Element 515–Steel Protective Coatings. Several states in the Midwest also utilize photographs in their element level inspection criteria. Photographs provide example Condition States for various coating defects, and it is believed that their use will help to provide for more consistent and accurate coating evaluations. Several other documents, such as the ASTM D610 (2019b) evaluation of rust grade also can be used to develop a rating system.

For steel bridge coating systems, the goal was to observe what other states around the country were using in comparison to Indiana. In the Midwest, the number coats for the coating systems used was very uniformly a three-coat system. Moreover, for the Midwest region the most common coating system used was an inorganic zinc rich primer, an epoxy intermediate coat, and some type of urethane finish coat; the same basic three-coat system is used in Indiana. In one state, and in certain circumstances in other states, an organic zinc rich primer was used instead of an inorganic zinc rich primer coat. However, the use of organic zinc rich primer coats in the fabrication shop are not common. Briefly looking at the rest of the country, the use of three-coat systems is by far the most popular coating method. The coating system that is used in Indiana is also commonplace throughout the rest of the country. Four states utilize exclusively a two-coat system, representing the only significant discrepancy throughout the country in terms of coating systems.

For maintenance painting, the most common methods used are complete removal and recoat and spot painting at trouble spots. Maintenance painting appears to be becoming less common throughout the Midwest region due to several restrictions which increase costs. Several states are instead waiting to completely recoat the bridge. Overall, determining the optimal maintenance painting strategy relies heavily on several variables and changes on a state-to-state basis. In order to determine the best practices of maintenance painting to be used in the State of Indiana, further research would need to be conducted on the topic.

5.2 Recommendations

The overall recommendation to the Indiana Department of Transportation would be to implement and utilize a National Bridge Inventory (NBI) inspection method with a 9–0 rating scale similar to the one provided in Section 2.4 for the evaluation and rating of steel bridge coatings. The descriptions in the rating procedure are detailed enough that they can be implemented and used directly. Moreover, it is recommended that the procedure be further improved by adding sample photographs from INDOT bridges that illustrate various coating defects and condition states. This would be a significant enhancement that would be beneficial and very useful for the bridge inspectors. It would also help to provide for more consistent rating evaluations.

5.3 INDOT Strategic Goals

The research in this study impacts the INDOT strategic goals (INDOT, 2019) related to *safety* and *asset sustainability*. The coating system in a steel bridge acts as a protective layer or shield for the steel substrate and prevents active development and deterioration from corrosion of the steel surface. When the coating is compromised there can be section loss which will lead to a reduction in the safe load capacity of the steel member. Moreover, accurate rating of the steel members will provide asset engineers with the information needed to plan for future work actions that could include recoating a steel bridge or, in extreme corrosion cases, replacement of selected bridge members or elements of the bridge. Implementation of the National Bridge Inventory (NBI) inspection method with a 9–0 rating scale similar to the one provided in Section 2.4 for the evaluation and rating of steel bridge coatings will help to improve the safety of steel bridges and assist in planning work actions to protect the steel bridge inventory, which is a valuable asset.

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APPENDICES

Appendix A. State Coating Systems

Appendix B. Example Photographs of Condition State with Element Level Ratings

APPENDIX A. STATE COATING SYSTEMS

The coating number of coats used in the coating system for various state departments of transportation is shown in the table below. Most state DOTs use a three-coat system as indicated in the table footnote. Additional notes are added to the table when other systems are used in particular states.

State	Region	Number of Coats	Notes
Alabama	SE	3	
Alaska	WC	3	Utilizes metalizing on remote sites
Arizona	SW	3	
Arkansas	SE	3	
California	WC	2	Inorganic/organic zinc-rich primer, exterior grade latex paint
Colorado	NW	2	Inorganic zinc-rich primer, high build urethane topcoat
Connecticut	NE	3	NEPCOAT QPL
Delaware	NE	3	NEPCOAT QPL
Florida	SE	3	
Georgia	SE	3	
Hawaii	WC	3	
Idaho	NW	3	NEPCOAT QPL
Illinois	MW	3	
Indiana	MW	3	
Iowa	MW	3	
Kansas	SW	2	Inorganic zinc-rich primer, acrylic or polyurethane finish coat
Kentucky	MW	3	
Louisiana	SE	3	
Maine	NE	3	NEPCOAT QPL
Maryland	NE	3	NEPCOAT QPL
Massachusetts	NE	3	NEPCOAT QPL
Michigan	MW	3	
Minnesota	MW	2–3	
Mississippi	SE	3	
Missouri	SW	3	
Montana	NW	3	
Nebraska	NW	3	
Nevada	NW	3	
New Hampshire	NE	3	NEPCOAT QPL
New Jersey	NE	3	NEPCOAT QPL
New Mexico	SW	3	Makes note to consider weathering steel opposed to painting
New York	NE	3	NEPCOAT QPL

North Carolina	SE	2	
North Dakota	NW	3	
Ohio	MW	3	
Oklahoma	SW	3	
Oregon	WC	2–3	
Pennsylvania	NE	3	NEPCOAT QPL
Rhode Island	NE	3	NEPCOAT QPL
South Carolina	SE	2–3	Inorganic zinc rich primer, followed by either aluminum epoxy top coat, acrylic latex top coat, or polyurethane top coat.
South Dakota	NW	3	
Tennessee	SE	2–3	Two coat system consists of organic zinc primer and fast cure epoxy coat
Texas	SW	3	
Utah	SW	3	
Vermont	NE	3	NEPCOAT QPL
Virginia	NE	3	
Washington	WC	4	Primer coat, intermediate coat, intermediate stripe coat, topcoat
West Virginia	NE	3	
Wisconsin	MW	3	
Wyoming	NW	3	

*All 3 coat systems (unless otherwise noted in table) consist of some variation of the following:

Coat 1: Organic or inorganic zinc-rich primer
Coat 2: Epoxy or urethane intermediate coating
Coat 3: Polyurethane or acrylic latex topcoat

**All information was obtained by each respective states' qualified products list and verified using Literature Review conducted by the University of Pittsburgh (Stephens et al., 2019).

***Geographic region

MW = Midwest
NE = Northeast
NW = Northwest
SE = Southeast
SW = Southwest
WC = Western Coastal

APPENDIX B. EXAMPLE PHOTOGRAPHS OF CONDITION STATE WITH ELEMENT LEVEL RATINGS

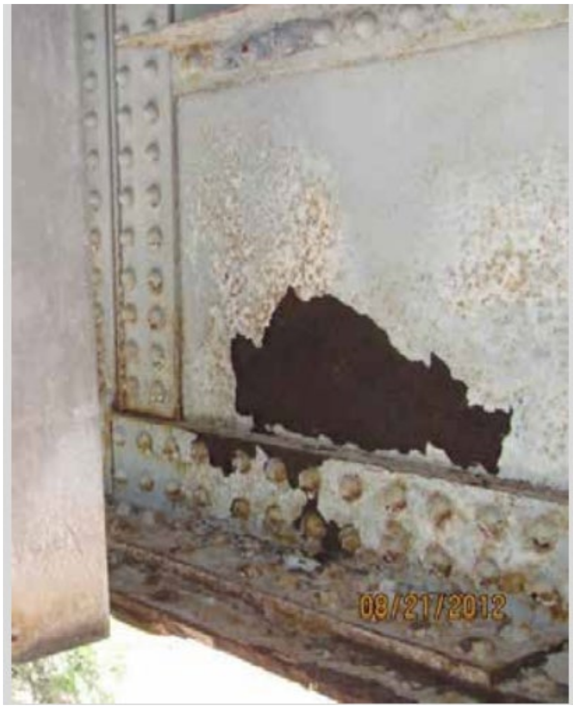

Figure B.1 Element Level 4 (Minnesota).


Figure B.2 Element Level 2 (Minnesota).

Figure B.3 Element Level 3 (Minnesota).

Figure B.4 Element Level 4 (Michigan).

Figure B.5 Element Level 4 (Ohio).

Figure B.6 Element Level 2 (Ohio).

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

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