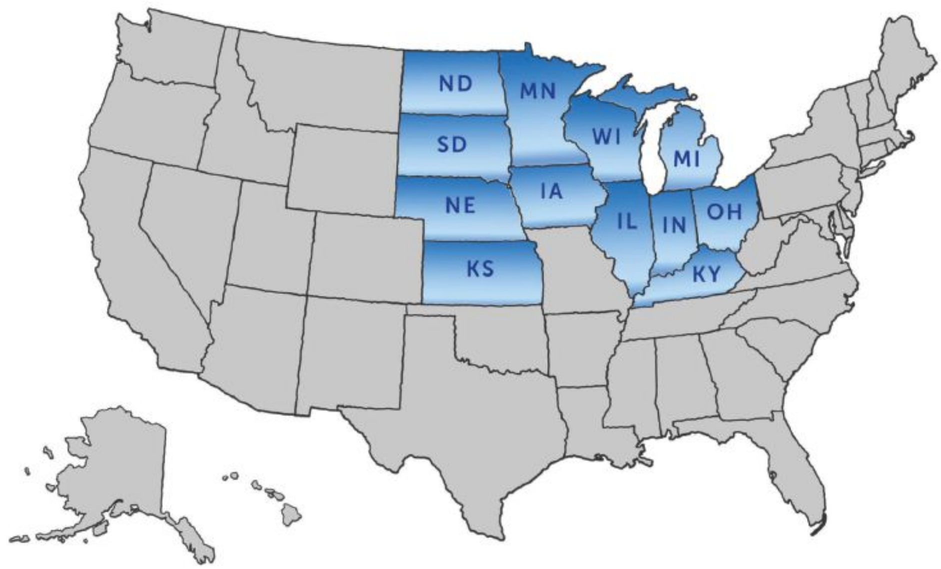
Bridge Component Deterioration Models for Midwest States

Advancements in predictive modeling of bridge component deterioration provides much-needed support for preserving concrete structures

by Philip Meinel, Wisconsin Department of Transportation Bureau of Structures

Starting in 2014, the Federal Highway Administration (FHWA) and numerous state departments of transportation began focusing on data-driven decision-making in transportation asset management. A strategy for systematically recommending the right work on the right structures at the right time had long been sought, but many state agencies did not have the tools to achieve this goal. When the FHWA initiated the collection of condition information for bridge elements according to the American Association of State Highway and Transportation Officials' (AASHTO's) *Manual for Bridge Element Inspection*,[1] state agencies started compiling detailed information to support automated bridge management systems (BMSs). These automated BMSs are now able to more accurately predict what work will be needed on each structure network wide; however, accurate predictions can only be built from a correct historical database.



Transportation Pooled Fund research program TPF-5(432) participating states. All Figures and Tables: Wisconsin Department of Transportation. Data source: *TPF-5(432): Bridge Element Deterioration for Midwest States*.[5]

The new requirements for AASHTO-specified bridge elements rendered historical databases obsolete and shifted the way that state agencies thought about component deterioration. Most data from before 2014 were not useful for estimating future deterioration of the current AASHTO bridge elements. Every state faced this issue, but with limited research, agencies were left to either manufacture theoretical deterioration models based on empirical engineering judgments or rely on general component-level models to determine when major work should be performed.

In 2016, the Wisconsin Department of Transportation (WisDOT) developed its own BMS software and quickly realized that more-refined, component-level deterioration models were needed. Two years later, WisDOT attempted to generate state-specific deterioration models with the limited data available to develop age-based deterioration projections using statistical averages and typical outlier analysis. This deterministic modeling allowed WisDOT's BMS to function, but more data were needed to perform the industry-standard probabilistic modeling that most BMS software uses. Some of the early deterministic models are highlighted in the Wisconsin case study in National Cooperative Highway Research Project Synthesis 585, *Bridge Element Data Collection and Use*.[2] They are also referenced in the Transportation Research Board webinar "Bridge Element Data Use in the U.S."[3]

Midwest Partnership

The AASHTO TSP 2 Midwest Bridge Preservation Partnership[4] enabled Midwest states to collectively discuss their bridge management needs. Reliable bridge component deterioration models were identified as the top priority. The relationships developed within the multistate partnership facilitated a greater level of collaboration, with states not only sharing resources and expertise but also opening state databases for evaluation. In addition to the partnership, the Transportation Pooled Fund (TPF) research program TPF-5(432): Bridge Element Deterioration for Midwest States[5] was instrumental in providing a funding mechanism for this collaborative research to ultimately achieve high-quality, data-driven decisions for transportation structures.

TPF-5(432) began in December 2019 and the final report was published in November 2022.[5] The study used Markov-Weibull probabilistic analysis to develop reliable deterioration models for National Bridge Inventory (NBI) general component ratings (GCRs), national bridge elements, bridge-management elements, and agency-defined elements (ADE). The results from this TPF research could be immediately implemented in each state's BMS software to better predict what structure work will be needed in the future throughout the Midwest highway network. The resulting models are offered in spreadsheets that can be customized to assign a more appropriate deterioration curve for a specific subset of structure types or environments.

General Component Rating Models

NBI GCR deterioration models were the first to be developed because they gauge the overall condition of the structure. The TPF study linked structure inventory data to the bridge component ratings, which allowed some refinement of the models. **Figure 1** shows projected deck deterioration based on average GCRs for the type of reinforcement. With this graph, state transportations validated that epoxy-coated reinforcement preserves bridge decks more effectively than uncoated reinforcement. If departments of transportation solely program deck replacements based on NBI deck rating, they can quantify the benefit of using epoxy-coated reinforcement as an approximate 20-year life extension. States with more advanced BMS will also consider element condition before programming deck replacements. The models can also be refined by specific structure type. **Figure 2** shows how the average NBI superstructure GCR based on superstructure type predicts deterioration. This figure supports the WisDOT preference to use concrete superstructures whenever practicable. In Wisconsin, prestressed concrete open-web girders (such as I-girders) are used on about 45% of state-owned structures and concrete slab spans are used on another 16%.

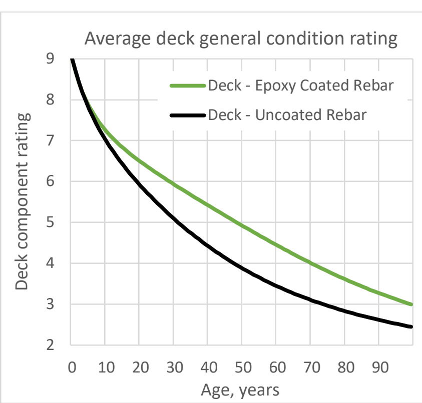


Figure 1. Model of deck deterioration as indicated by average general component ratings.

The focus of the TPF study quickly shifted to bridge elements, especially reinforced concrete decks and slabs. The AASHTO *Manual for Bridge Element Inspection*[1] defines deck elements as transmitting loads into superstructure elements and slab elements as transmitting load into the substructure elements. An advantage of having two condition evaluation systems—(a) GCR based on the NBI component data and (b) element condition states (CS) based on element-level bridge inspections and ranging from CS1 (the highest) to CS4 (the lowest)—is the ability to compare data between the two datasets. **Figure 3** compares deterioriation models for reinforced concrete deck and slab components that use NBI average deck GCRs or AASHTO measures of element deterioration, as shown by the Element Health Index.[5] The Element Health Index gives a representation of the condition states documented by an element-level inspection. It is defined as the fraction in CS1 plus two-thirds of the fraction in CS2, plus one-third of the fraction in CS3.

Figure 3 shows that the difference in the reinforced concrete slab and deck component deterioration is more pronounced in the model using the Element Health Index than in the GCR model due to the more detailed nature of the Element Health dataset.

Wearing surfaces are a key part to any bridge preservation strategy. In 2014, WisDOT established ADEs for each type of wearing surface. Many states use this data collection method, as they recognize that each type of wearing surface has a unique deterioration curve. When the Midwest data did not have an ADE assigned to each wearing surface type, the wearing surface was determined by translating the NBI item 108 code for deck surface.

Figure 4 compares deterioration of wearing surface types within the Midwest. It is important to note that every deck was assigned a wearing surface type—the "bare deck/sealed concrete" wearing surface represents the top surface of the original deck or slab component. **Figure 5**, which is from

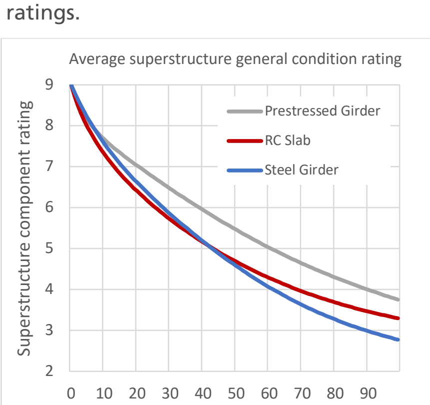


Figure 2. Model of superstructure deterioriation as indicated by average general component ratings.

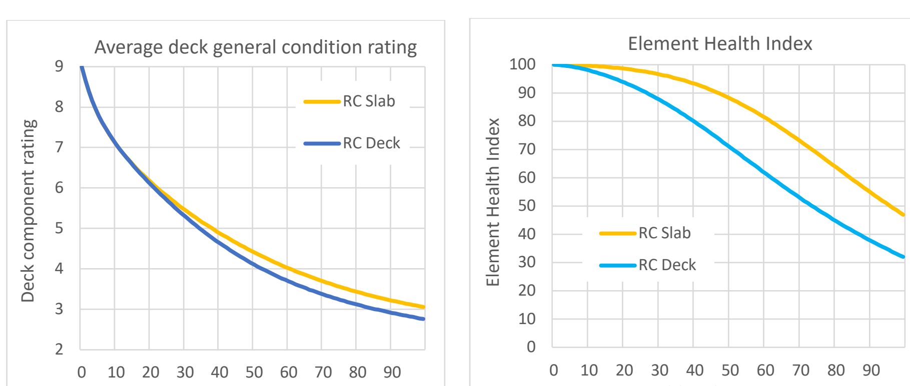


Figure 3. Comparison of reinfoced concrete (RC) deck and slab deterioration models using average general component ratings (left) and Element Health Index data (right).

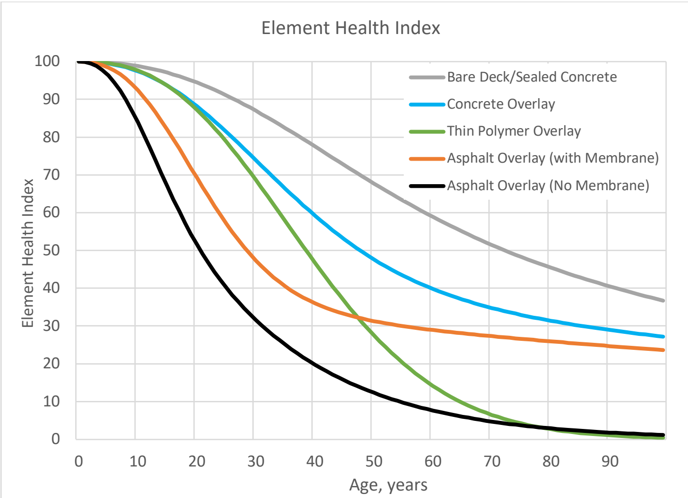


Figure 4. Wearing surface deterioration as indicated by Element Health Index data.

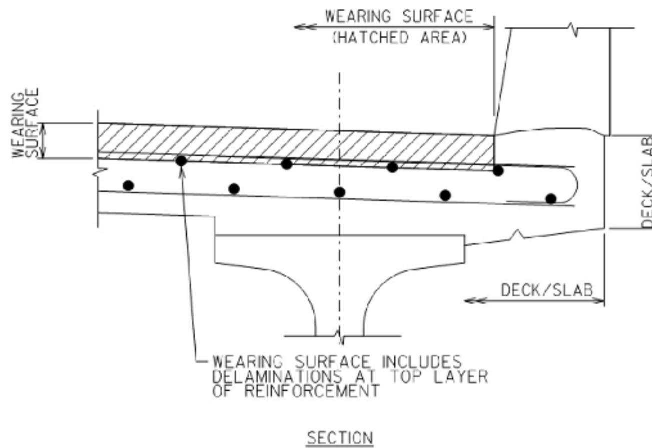


Figure 5. Wearing surface extent as defined by the Wisconsin Department of Transportation.

the WisDOT *Structure Inspection Field Manual*,[6] shows how Wisconsin defines the extent of the wearing surface. By tracking the condition of the original integral wearing surface separately from the underlying deck or slab component, WisDOT is better able to predict when the first overlay should be applied and which overlay type is most appropriate. The distinction between the top and bottom of the deck is also essential for determining when to perform an overlay and when to replace the entire deck.

Models Used to Develop Preservation Strategies

By comparing the deterioration models for various bridge components and quantifying the benefits of reinforcement types and overlay options, state transportation agencies can build an ideal preservation life cycle for each type of structure in their inventory. For example, combining the benefit of epoxy-coated reinforcing bars within a reinforced concrete deck and applying regular deck sealing or a thin polymer overlay early in the life cycle of the structure significantly extends the service life of the deck in a cost-effective manner. Bridge component deterioration models using in-service condition data and research projects to evaluate new materials and applications have helped WisDOT shape a robust preservation strategy, which is laid out in the *WisDOT Bridge Manual*.[7]

Although the TPF-5(432) study did not produce deterioration models for every component, it did establish the basis for component modeling, which can be repeated for any component of interest. The study did not evaluate prestressed concrete open-web girders, but WisDOT later created a component deterioration model from the shared Midwest data. The reason that this component was not included in the original study is the historically slow rate of deterioration overall and the significant correlation of advanced girder-end deterioration related to leaking joints above. The TPF-5(432) study focused more on deck and joint deterioration modeling to avoid exposure of the girder ends. Expansion joints were shown to deteriorate rapidly in the Midwest, a finding that supports the preservation strategy of eliminating joints whenever possible.

The TPF-5(432) study did evaluate common reinforced concrete substructure components (columns, pier caps, pier walls, and abutments). The method of data collection significanlty affected the analysis of component deterioration. Markov deterioration models rely heavily on the median transition times (that is, the time it takes for half of the quantity in a condition state to transition into the next condition state). **Table 1** compares the median transition time from CS1 to CS2 for reinforced concrete substructure elements. There is a noticeable difference between the findings for the columns, where the quantity used when collecting condition data is "each," (that is, per column), and findings for the other substructure elements, where condition data are collected per linear foot. There appears to be a consistent trend in which initial deterioration seems steeper when condition data are collected with less detail. The elements (columns) collected with less detail (using "each" instead of linear feet) transition more quickly to CS2 because any defect within the entire element height will classify the full element in CS2. State transportation agencies should strive to collect condition data in more detail (despite the minimum national standards) to produce improved deterioration models.

There was interest among the Midwest states to quantify the increased deterioration rate of components in harsh conditions as a part of the TPF-

Table 1. Median transition times from condition state 1 (CS1) to condition state 2 (CS2) for reinforced concrete substructure elements

Reinforced concrete substructure elements	Population	Median transition time from CS1 to CS2, years
Abutments, ft	33,799	40.9
Pier walls, ft	8172	50.3
Pier caps, ft	25,320	69.4
Columns, each	19,334	23.8

Table 2. Median transition times for reinforced concrete pier caps based on Average Daily Traffic (ADT) under the structure

ADT under the structure	Number of inspections with pier cap elements	Median transition times between condition states (CS), years		
		CS1 to CS2	CS2 to CS3	CS3 to CS4
ADT = 0	16,939	92.8	15.7	72.3
0 < ADT < 1000	1032	86.3	9.1	71.9
1000 ≤ ADT < 10,000	2225	67.4	10.4	89.4
1000 ≥ 10,000	5125	37.1	7.8	52.4
All	25,320	69.4	12.4	68.0

5(432) study. A significant correlation was found between traffic volume (represented by Average Daily Traffic) passing under the structure and the rate of deterioration. **Table 2** shows this correlation for reinforced concrete pier caps. When deterioration models are adapted to specific environments, both short-term project scoping and long-term funding scenarios are improved.

Refining the Asset Management Process

The asset management process is iterative: refine data collection, refine predictive modeling, and repeat. Throughout this process, data collection always serves the end goal of predictive modeling. When data collection processes are less robust—possibly due to anticipated workload or limited ability to accurately record detailed condition data—the predictive modeling is also less robust. Increased data refinement leads to increased bridge preservation activities because the refined data helps agencies identify treatments earlier in the life cycle and focus on the specific defects to be corrected to maintain the structure in good condition.

To promote more advanced data collection practices to support the desired BMS performance, the TPF-5(432) study summarized nondestructive evaluation (NDE) usage among the states, specifically NDE used on reinforced concrete decks and slabs. WisDOT has one of the few network-wide NDE programs for assessing wearing surface condition. These NDE data reveal wearing surface defects that are hidden and help WisDOT's automated BMS determine the best timing for an overlay, which is essential for an effective bridge preservation strategy. It is critical that the NDE data are recorded under a wearing surface ADE, so that BMS software can distinguish between the condition at the top of the deck component and the condition at the bottom of the deck component. That information is the difference between an overlay recommendation and a deck replacement recommendation. More information about Wisconsin's use of bridge deck NDE can be found in the *WisDOT Structure Inspection Manual*[8] and the FHWA NDE webinar "Systematic Thermography of Bridge Decks in Wisconsin."[9]

The Midwest states intend to continue to collaborate, merge inspection methods, and standardize data management practices to create a more consistent and reliable database for future bridge component modeling efforts. Specific areas of improvement as recommended in the TPF-5(432) report include the following:

- More uniform use of component defects
- More uniform use of ADEs, including wearing surface ADEs
- Improvement in the quality and consistency of construction activity data (repair and improvement history)

To the extent that Midwest states can accomplish these recommendations, dividends will be seen both in refining predictive modeling, and in refining asset management decisions throughout the region.

References

1. American Association of State Highway and Transportation Officials (AASHTO). 2019. *Manual for Bridge Element Inspection*. 2nd ed. Washington, DC: AASHTO.
2. Bektas, B. 2022. *Bridge Element Data Collection and Use*. National Cooperative Highway Research Project Synthesis 585. Washington, DC: National Academies Press. https://doi.org/10.17226/26724.
3. TRB. 2023. "TRB Webinar: Bridge Element Data Use in the U.S." Recorded March 29, 2023. https://vimeo.com/813260024/638bebd76f.
4. AASHTO Transportation System Preservation Technical Services Program. n.d. "Midwest Bridge Preservation Partnership." Accessed October 12, 2023. https://tsp2bridge.pavementpreservation.org/midwest-mwbpp.
5. Wisconsin Department of Transportation (WisDOT). 2022. *TPF-5(432): Bridge Element Deterioration for Midwest States*. Madison, WI: WisDOT. https://www.pooledfund.org/Document/Download?id=14072.
6. WisDOT. 2020. *Structure Inspection Field Manual*. Madison, WI: WisDOT. https://wisconsindot.gov/dtsdManuals/strct/inspection/insp-fm-2020.pdf.
7. WisDOT. 2023. *WisDOT Bridge Manual*. Madison, WI: WisDOT https://wisconsindot.gov/dtsdManuals/strct/manuals/bridge/ch-all.pdf.
8. WisDOT. 2017. *Structure Inspection Manual*. Madison, WI: WisDOT. https://wisconsindot.gov/dtsdManuals/strct/inspection/insp-sm.pdf.
9. Federal Highway Administration. 2023. "Systematic Thermography of Bridge Decks in Wisconsin" (webinar). https://usdot.zoomgov.com/rec/share/9DWnww1OEZVJcIQ-Meh9nXXgKvA4dpO8s0PJYq_lgeqRNOqvg3L8SywGq0v20zCt.fY_U3lo-jtZeGfXg?startTime=1679936630000 (passcode: &t*P3&SA).

Philip Meinel is a structures asset management engineer for the Wisconsin Department of Transportation Bureau of Structures in Madison, Wisc.