Development of Deterioration Curves for Bridge Elements in Montana

Draft Report

Task 2: Inspection Data Review and Processing

by

Damon Fick

Assistant Professor

Matthew Bell

Research Associate

Western Transportation Institute

College of Engineering

Montana State University

Prepared for the

Montana Department of Transportation

2701 Prospect Avenue

P.O. Box 201001

Helena, MT 59620-1001

March 2021

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This task report summarizes a review of inspection data from MDT's Structural Management System and the Federal Highway Administration's (FHWA) National Bridge Inventory. Processing routines were investigated for efficiently creating datasets by filtering relevant bridge attributes available from the bridge inspection datasets.

Inspection data from MDT's Structure Management System (SMS) was used to identify an approach for creating datasets of different bridge types and in different regions to produce reliable bridge deterioration trends. With input from MDT, selected bridge attributes will continue to be refined and computer routines developed based on results of these iterations. Plots of bridge element ratings vs. age were created for different bridge groups to demonstrate the process and for further analysis.

The product of Task 2 is an efficient strategy to create desired datasets and plots that reveal general deterioration characteristics of Montana bridges. This framework will be applied to the statistical analysis (Task 3) where bridge maintenance, rehabilitation, or construction activities will be used to establish a general bound of bridge condition improvements and deterioration over time. The baseline data created in Task 2 will be compared with trends from similar regions of the country that were identified in the literature review to determine the best approach for developing deterioration models. The data will be organized into families of datasets that represent conditions specific to Montana and may include geographic location, traffic volume, climate conditions, and/or bridge design features. The deterioration models will be created in a format that can be fully integrated into MDT's Bridge Management System (BrM).

PRELIMINARY INSPECTION DATA REVIEWED

Several data files were reviewed as part of this research task to assess the content and format of bridge inspection data from MDT and the FHWA. The datasets reviewed included attributes that may be used for further analysis, however, other attributes may be identified and implemented. Details of the datasets reviewed are provided below.

Selected Attribute Data for All Bridges in Montana

A dataset created by the Technical Panel from MDT's SMS contained 5,039 bridges with construction dates going back to 1970. Attributes included in this dataset are included in Table 1. MDT maintains approximately 2,938 of these bridges with locations across Montana shown in Figure 1. The inspection ratings for the bridge decks in this dataset range from 0 to 9 and are defined in Table 2.

Historical Bridge Deck Ratings

A second dataset created by the Technical Panel from MDT's SMS contained all bridge deck ratings from 1970. Approximately 75,000 rows of data exist for the approximately 5,039 bridges, each row representing a different inspection year. The selected attributes included in this dataset from Table 1 were bridge number, latitude and longitude, inspection item name/number, rating, date archived, and comments. The multiple inspection year data for individual bridges was used to explore computer routines to extract individual or groups of bridges with selected characteristics and time periods to create smaller datasets for further analysis.

Table 1 MDT Structural Management System Data Attributes

Bridge Number	Latitude	Longitude	NBI Structure No.	Feature Intersected
Location	Inspection District	Administrative District	Functional Classification	Facility carried by structure
Owner	Maintenance Responsibility	Maintenance Section	Year Built	Year Reconstructed
Bridge Roadway Width	Structure Length	Average Daily Traffic	Average Daily Truck Traffic	Year Rehabilitated
On/Off System	Type of Service on Bridge	Type of Service Under Bridge	Deck Rating	Superstructure
Culvert	Next Inspection Date	NHS Indicator	County Code	Deck Structure Type
Type of Wearing Surface	Main Span Material	Main Span Design Type	Inventory Route-Record Type	Rout Number

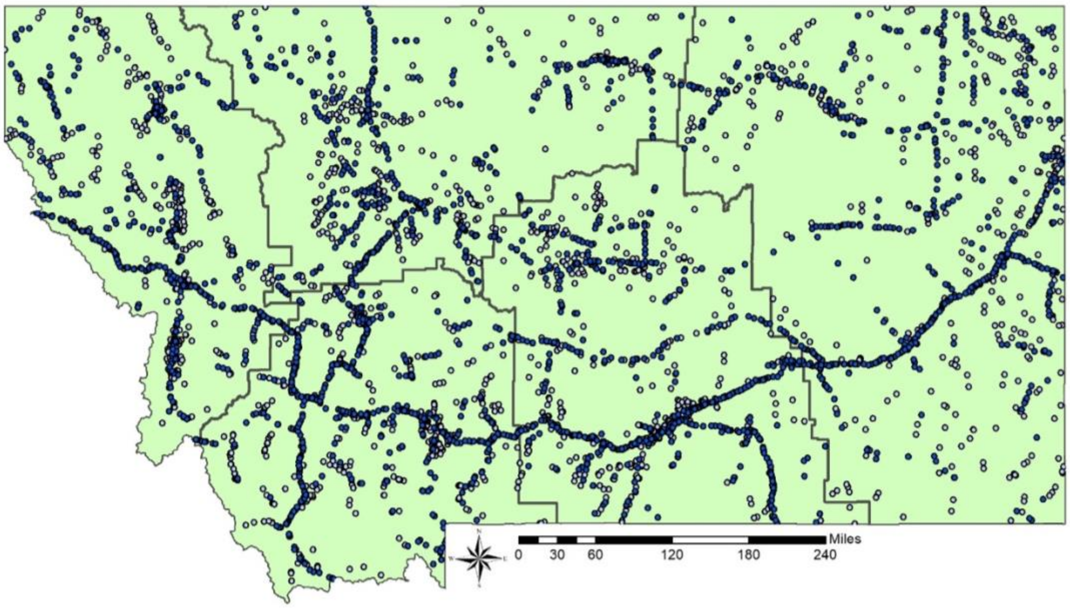

Figure 1: Locations of all the bridges in Montana. The bridges maintained by MDT are identified as blue/dark colored dots; other bridges are identified as grey/light colored dots.

National Bridge Inventory Data

National Bridge Inventory (NBI) data is available from the FHWA website (https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm) for years 1992-present. This data includes condition ratings of 1 through 9 (Table 2) for bridge decks, superstructure, substructure, channels, and culverts.

Table 2 Condition Ratings 1-9 for bridge deck, superstructure, substructure, channel, and culvert items.

Code	Description
N	Not Applicable
9	Excellent Condition
8	Very Good Condition - no problems noted
7	Good Condition - some minor problems
6	Satisfactory Condition - structural elements show some minor deterioration
5	Fair Condition - all primary structural elements are sound, but may have minor section loss, cracking, spalling or scour.
4	Poor Condition - advanced section loss, deterioration, spalling or scour.
3	Serious Condition - loss of section, deterioration, spalling or scour have seriously affected primary structural components
2	Critical Condition - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	Imminent Failure Condition - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	Failed Condition - out of service - beyond corrective action.

National Bridge Inventory (NBI) Element Data

National Bridge Element (NBE) data is available for years 2015-present from the FHWA website (https://www.fhwa.dot.gov/bridge/nbi/element.cfm). In 2015 State departments of transportation were required to submit inspection data that subdivided the quantity of a bridge element into different condition state ratings shown in Table 3. Bridge element data assembled by the FHWA are shown in Table 4 [1]. The attributes for this data include Structure Number, Element Number (Table 4), Total Element Quantity, and the Element Quantity rated as Condition State 1, 2, 3, or 4.

Table 3 Condition State definitions

Condition State 1	Good
Condition State 2	Fair
Condition State 3	Poor
Condition State 4	Severe

National Weather System Daily Data for 1876 to 2011

National Weather data were obtained from the Technical Panel and includes over 200,000 rows of historical snow fall amounts by county in Montana. Totals and averages will be calculated for the different counties by year to assess their influence on deterioration rates of bridges with different snowfall totals.

Montana Deicer Data for 2020

Deicer data received from the Technical Panel contains application rates for 116 counties in Montana with the attributes shown in Table 5.

Table 4 Federal Highway Administration Bridge Elements [1]

Element	Units	Element Number: Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
Deck/Slab							
Deck	SF		13	12	31		60
Open Grid Deck	SF	28					
Concrete Filled Grid Deck	SF	29					
Corrugated or Orthotropic Deck	SF	30					
Slab	SF			38	54		65
Top Flange	SF		15	16			
Substructure							
Closed Web/Box Girder	LF	102	104	105			106
Girder/Beam	LF	107	109	110	111		112
Stringer	LF	113	115	116	117		118
Truss	LF	120			135		136
Arch	LF	141	143	144	146	145	142
Main Cable	LF	147					
Secondary Cable	EA	148					149
Floor Beam	LF	152	154	155	156		157
Pin, Pin and Hanger Assembly	EA	161					
Gusset Plate	EA	162					
Substructure							
Column	EA	202	204	205	206		203
Column Tower (Trestle)	LF	207			208		
Pier Wall	LF			210	212	213	211
Abutment	LF	219		215	216	217	218
Pile Cap/Footing	LF			220			
Pile	EA	225	226	227	228		229
Pier Cap	LF	231	233	234	235		236
Culvert							
Culvert	LF	240	245	241	242	244	243
Bridge Rail							
Bridge Rail	LF	330*		331	332	334	333
Joint							
Strip Seal	LF			300			
Pourable	LF			301			
Compression	LF			302			
Assembly with Seal (Modular)	LF			303			
Open	LF			304			
Assembly without Seal	LF			305			
Other	LF			306			
Bearing							
Elastomeric	EA			310			
Movable (roller, sliding, etc.)	EA			311			
Enclosed/Concealed	EA			312			
Fixed	EA			313			
Pot	EA			314			
Disk	EA			315			
Other	EA			316			
Wearing Surfaces and Protective Coatings							
Wearing Surfaces	SF			510			
Steel Protective Coating	SF			515			
Concrete Protective Coating	SF			521			

Table 5 Montana Deicer Data Attributes

Name	Item Number	Longitude	Latitude	Type
Type Number	Date Archive	Active Status	Comments	Last Modified

INSPECTION RATING INTEGRATION STRATEGY

Combining the condition state rating system implemented in 2015 (Table 3) for bridge elements (Table 4) with inspection data collected prior to 2015 using the 1-9 rating scale for bridge items must be done carefully. There are currently no established, or agreed upon, methods to convert the NBI condition states to the element level condition rating that was started in 2015. Because different condition states are assigned for smaller quantities (e.g. square or lineal foot) of a bridge element, a direct mapping of 'Good' in Condition State 1 is not consistent with a rating of 'Good' or '7' using the old system. If a robust method of combining the rating systems is not identified, the historical data will be evaluated independently and used to validate deterioration predictions made with the more recent Condition State ratings.

PRELIMINARY DATA PROCESSING

Simple regression lines for the NBI concrete bridge deck rating and age were created for the 'selected attribute data for all bridges' dataset provided by the Technical Panel. **Figure 2** shows these regressions for all 5,039 bridges included in this dataset. The figure illustrates the importance of creating smaller, more specific groups of bridge rating datasets, where trends between bridge deck rating and bridge age can be more insightful. As the bridge datasets get smaller, such as concrete bridges in the Billings region or bridges with average daily traffic (ADT) of 10,000-19,999 as shown in **Figure 3** and **Figure 4** respectively, it is possible to more clearly see deterioration trends within a group.

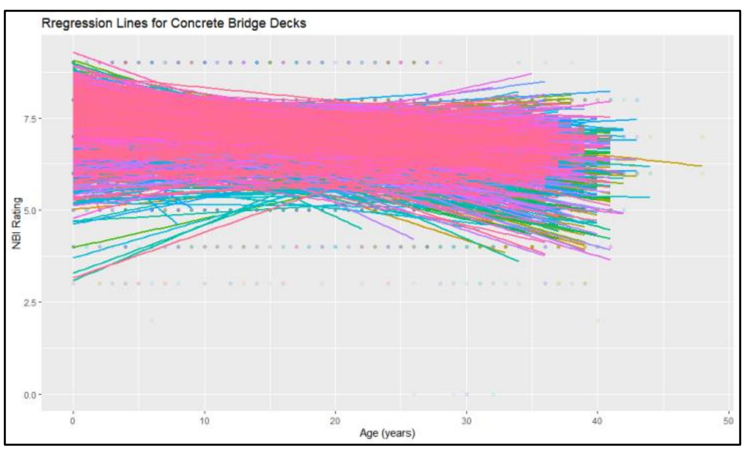

Figure 2: Regression lines for NBI values vs. age for decks of concrete bridges in Montana.

Another data analysis tool reviewed was density charts, where groups of bridges with the same rating at a certain age can be seen graphically. A density plot for the state maintained concrete bridge deck ratings is shown in **Figure 5**. This type of grouping and analysis is able to identify bridges that may have incomplete or unique data, such as outlying values of zeros for the four bridges between 25 and 32 years old in **Figure 5**. These types of visual representations reveal inconsistencies that can be further investigated to ensure data is complete and accurate before performing the statistical analysis (Task 3) and creating deterioration curves (Task 4) for the selected groups of bridges.

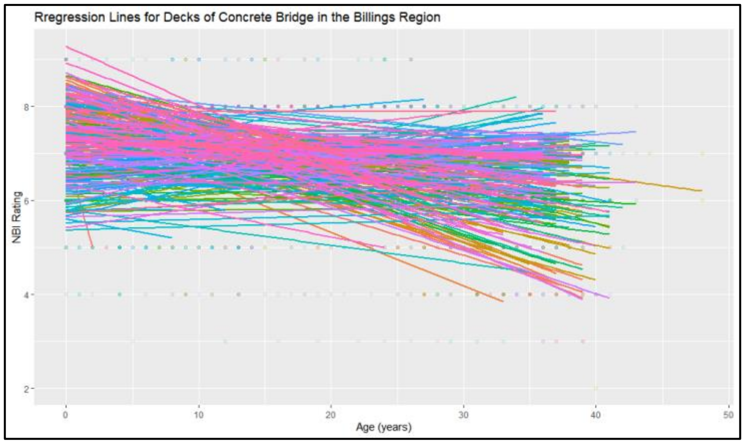

Figure 3: Regression lines for NBI values vs. age for decks of concrete bridges in Billings, Montana.

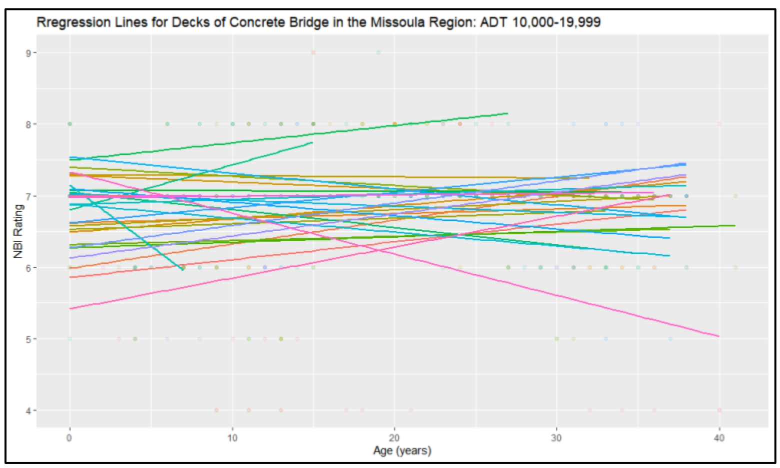

Figure 4: Regression lines for NBI values vs. age for decks of concrete bridges in Missoula, with an ADT of 10,000-19,999 vehicles.

ANALYSIS APPROACH

After reviewing published literature on the development of deterioration curves for different State departments of transportation, the following analysis approach has been developed for Task 3 (Statistical Analysis).

1. Filter the data.
    a. Remove bridges with significantly incomplete and/or outlying data entries and bridges under two years old.
    b. Filter datasets for bridges maintained by MDT.

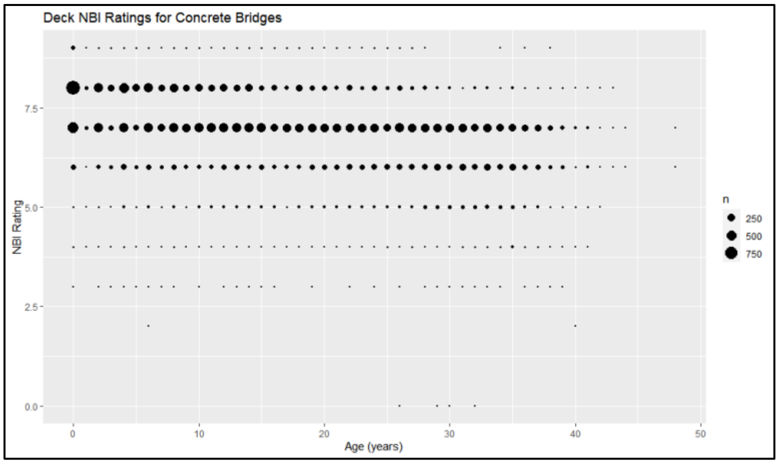

Figure 5: Density chart for NBI values vs. age for bridge decks of concrete bridges in Montana. The larger the black dot, the more bridges that have that value at that age.

c. Divide bridges into groups with similar attributes.
    i. Location, functional class, material type, span length, maintenance activity, etc.
d. Add data fields for deicer application rates and historical weather data.
e. Divide data randomly to have 80% as a training set used for creating the models and the other 20% as a validation set used to test the accuracy of the models.

2. Evaluate maintenance, rehabilitation, and replacement of bridges.
    a. Determine from the bridge condition data whether any of the three bridge intervention categories (repair, rehabilitation, and replacement/reconstruction) occurred at any specific year, what type of intervention, and the effectiveness of such interventions in terms of increases of the condition ratings of the bridge components.
3. Identify the variables to include for each bridge group.
    b. Apply stochastic, and deterministic, regression models to a Least Absolute Shrinkage and Selector Operator (Lasso) regularization to help with variable selection and to identify which predictor variables are most applicable to each group and which approach works better for bridges in Montana.
        i. Preliminary variables that will be considered include: ADT, percent truck traffic, functional class, deck structure type, bridge material type, structural type, structural length, roadway width, wearing surface, freeze/thaw cycles, average precipitation, deicer application rates, year built, year reconstructed, and type of service on/under bridge.
4. Introduce the selected variables into Weibull-based deterioration models and develop families of predictive matrices for different bridge elements.
5. Format that the developed matrices for compatibility with MDT’s Bridge Management Software (BrM).

The uncertainties of the results of this analysis approach will likely require additional input and guidance from the Technical Panel. This exchange of information will be coordinated by the Technical Panel Chair. Results of the statistical analysis will be validated with historical data, published research, and professional judgement from MDT transportation professionals.

SUMMARY

The analysis process described in this task report will be used to create select families of bridge groups for the statistical analysis that will be completed in Task 3. An iterative process of creating datasets and performing the statistical analysis will be required to refine the deterioration trends that will be used to formally develop the deterioration curves for Montana bridges in Task 4.

REFERENCES

1. Federal Highway Administration, *Specification for the national Bridge Inventory Bridge Elements*, U.S. Department of Transportation, Editor. 2014.