Significant Factors of Bridge Deterioration

Task 1 Report: Literature Review

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1 Introduction

Bridges structures deteriorate over time due to various factors such as environmental conditions, traffic loads, and age. Understanding the variables that affect bridge deterioration rates is necessary for state agencies to maintain the safety and functionality of bridges during their design service life.

The first section of this Task Report reviews the new Specification for National Bridge Inventory (SNBI) and documents new span types, bridge types, and materials for recording bridge component conditions that will be available for deterioration modeling in 2026. The second section summarizes published research identifying bridge characteristics that influence deterioration rates. The objective of this Task report is to provide an efficient starting point from which to review Montana bridge inspection data and inspection records to determine and quantify the influence of deterioration factors specific to the environment, traffic, and maintenance practices in Montana.

2 Specification for the National Bridge Inventory

The Specification for the National Bridge Inventory (SNBI) provides the framework and requirements for reporting highway bridge condition data for the National Bridge Inventory (NBI). The SNBI will replace the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (Coding Guide). The SNBI includes new designations for bridge components (decks, superstructures, substructures), materials (type, age, condition), and performance (load capacity, structural integrity, safety). The following subsections documents the new codes for span materials, span types, and deck materials included in the SNBI.

2.1 Span Material

The span material designates materials used for the bridge superstructure such as girders, beams, trusses, arches, and pipes. The span material is no longer a written description and is reported using the new SNBI codes that were expanded from 10 to 29 different materials shown in Table 1. Descriptions and examples can be found in Section B.SP.04 of the SNBI (FHWA, 2022).

2.2 Span Types

The span type defines the superstructure system of the bridge and similar to the span material, will be reported using the new codes that were expanded from 23 to 43 designations shown in Table 2. Additional information and examples for coding span types can be found in Section B.SP.06 of the SNBI (FHWA, 2022).

2.3 Deck Material and Type

Expanded designations for deck material and type in the SNBI are shown in Table 3. Descriptions and examples for coding bridge deck material and type, are found in Section B.SP.09 of the SNBI (FHWA, 2022).

Table 1: Comparison of the old NBI span materials and the new SNBI span material description and codes.

Old NBI Span Materials	New SNBI Span Materials (B.SP.04)	
Description	Code	Description
Aluminum, wrought iron, or cast iron	A01	Aluminum
	I01	Iron - cast
	I02	Iron - wrought
Concrete	C01	Reinforced concrete - cast-in-place
Concrete continuous	C02	Reinforced concrete - precast
Prestressed concrete	C03	Prestressed concrete - pre-tensioned
Prestressed concrete continuous	C04	Prestressed concrete - cast-in-place post-tensioned
	C05	Prestressed concrete - precast post-tensioned
	CX	Concrete - other
	F01	FRP composite - aramid fiber
	F02	FRP composite - carbon fiber
	F03	FRP composite - glass fiber
	FX	FRP composite - other
Masonry	M01	Masonry - block
	M02	Masonry - stone
	P01	Plastic - polyethylene
	PX	Plastic - other
Steel	S01	Steel - rolled shapes
Steel continuous	S02	Steel - welded shapes
	S03	Steel - bolted shapes
	S04	Steel - riveted shapes
	S05	Steel - bolted and riveted shapes
	SX	Steel - other
Wood or timber	T01	Timber - glue laminated
	T02	Timber - nail laminated
	T03	Timber - solid sawn
	T04	Timber - stress laminated
	TX	Timber - other
Other	X	Other

2.4 Summary

The new SNBI designations provide more specific descriptions of the bridge superstructure, decks, and materials which will enable a more granular analysis of bridge component deterioration. One challenge with the new codes included in the SNBI is the required training needed for inspectors to correctly identify the new codes shown in Table 1-3. Forty-three designations under the old system are now represented by 96 new codes. The initial NBI data submittal using the SNBI will likely create inconsistent or conflicting condition data in the short-term, however the long-term benefit of monitoring deterioration of more specific bridge components and materials will be realized through more efficient bridge maintenance and rehabilitation operations.

3 Review of Published Literature

The objective of the literature review was to identify significant factors and methods used by other departments of transportation and researchers that influence the deterioration rates of bridges. Several investigations have considered the factors shown in Table 4 to predict bridge component deteriorations more accurately.

Many of the papers focus on the statistical methods and analyses used to evaluate and identify deterioration factors. Other researchers focused on factors that caused overall bridge deterioration and others limited their study to the deterioration of a single bridge element. The methods and results from the researchers shown in Table 5 are summarized below.

Table 2: Comparison of the old NBI span types and the new SNBI span type descriptions and codes.

Old NBI Span Type	New SNBI Span Type (B.SP.06)	
Description	Code	Description
Arch - deck	A01	Arch - under fill without spandrel
Arch - thru	A02	Arch - open spandrel
	A03	Arch - closed spandrel
	A04	Arch - through
	A05	Arch - tied
Box beam or girders (single or spread)	B01	Box girder/beam - single
Box beam or girders (multiple)	B02	Box girder/beam - multiple adjacent
	B03	Box girder/beam - multiple spread
Segmental box girder	B04	Box girder/beam - segmental
Frame (except frame culverts)	F01	Frame - three-sided
Culvert (include frame culverts)	F02	Frame - four-sided
	F03	Frame - K-shaped
	F04	Frame - delta-shaped
Stringer/multi-beam or girder	G01	Girder/beam - I-Shaped adjacent
Stayed girder	G02	Girder/beam - I-Shaped spread
Tee beam	G03	Girder/beam - tee-beam
	G04	Girder/beam - inverted tee-beam
	G05	Girder/beam - double-tee adjacent
	G06	Girder/beam - double-tee spread
Channel beam	G07	Girder/beam - channel adjacent
	G08	Girder/beam - channel spread
Girder and floor beam system	G09	Girder/beam - girder & floor beam
	G10	Girder/beam - through girder
	GX	Girder/beam - other
Suspension	L01	Cable - suspension
	L02	Cable - cable-stayed
	L03	Cable - extradosed
	LX	Cable - other
Movable lift	M01	Movable - vertical lift
Movable - bascule	M02	Movable - bascule
Movable - swing	M03	Movable - swing
	MX	Movable - other
	P01	Pipe - rigid
	P02	Pipe - flexible
Slab	S01	Slab - solid
	S02	Slab - voided
Truss - deck	T01	Truss - deck
Truss - thru	T02	Truss - through
	T03	Truss - pony
Orthotropic	X01	Other - railroad flat car
Tunnel	X02	Other - ferry transfer
Mixed types	X03	Other - floating
Other	X	Other

Table 3: Comparison of the old NBI deck material and type to the new SNBI deck material and type descriptions and codes.

Old NBI Deck Material and Type	New SNBI Deck Material and Type (B.SP.09)	
Description	Code	Description
Not applicable	0	None
Aluminum	A01	Aluminum
Concrete cast-in-place	C01	Reinforced concrete - cast-in-place
Concrete precast panel	C02	Reinforced concrete - precast
	C03	Prestressed concrete - pre-tensioned
	C04	Prestressed concrete - cast-in-place post-tensioned
	C05	Prestressed concrete - precast post-tensioned
	CX	Concrete
	F01	FRP composite - aramid fiber
	F02	FRP composite - carbon fiber
	F03	FRP composite - glass fiber
	FX	FRP composite - other
Open grating	S01	Steel - open grid
Closed grating	S02	Steel - filled or partially filled grid
Steel plate (includes orthotropic)	S03	Steel - plate
	S04	Steel - orthotropic
Corrugated steel	S05	Steel - corrugated
	SX	Steel - other
Wood or timber	T01	Timber - glue laminated
	T02	Timber - nail laminated
	T03	Timber - solid sawn
	T04	Timber - stress laminated
	TX	Timber - other
Other	X	Other

3.1 Steel Coatings

3.1.1 *Analyzing Coating Conditions of Steel Bridges: A Data-Driven Approach*

Rahman et al. (2023) used machine learning-based regression models with historical inspection data for steel girder/beam elements to predict the coating conditions of steel bridges in Florida. The analytical models estimated the bridge features that had the highest importance related to coating failure. Both the decision tree and random forest regression models predicted similar feature importance. The study's conclusions identified the mean absolute errors of the models and their applicability to other bridge elements. The results from their random forest regression models are shown Figure 1.

3.2 Concrete bridge decks

3.2.1 *Bridge Deck Deterioration: Reasons and Patterns*

Kong et al., (2022) investigated factors influencing the deterioration of concrete decks using a Shapley additive explanation (SHAP) machine learning framework. An XGBoost model was trained to perform binary classifications of heavily imbalanced datasets to classify bridges less than 20 years old with poor/fair deck conditions and older bridges (30-40 years old) with good deck conditions from the national bridge inventory database. Features identified as important to the deterioration of concrete bridge decks were wearing surface, structure width, ADT, number of snow days, span length, and ADTT. Conversely, bituminous and epoxy overlay wearing surfaces were highly associated with relatively old bridges with good deck conditions. Features identified as important to the deterioration of concrete bridge decks are shown in Figure 2.

Table 4: Significant factors investigated by other researchers.

Category	Deterioration factor
Current bridge condition	Age
	Current NBI rating
	Maintenance history
Design	Design load
	Rebar protection
	Deck/structure material
	Structure type
	Wearing surface
Geometry	Deck/structure length
	Deck/structure width
	Deck/structure area
	Number of spans
	Roadway width
	Bridge skew
Service conditions	Average daily traffic
	Average daily truck traffic
	Functional class
	Service under the bridge
Environment	District/location
	Climate
	Number of cold/hot days
	Number of freeze-thaw cycles
	Precipitation

Table 5: Deterioration components considered by researchers.

Deterioration component	Researcher
Steel coatings	Rahman et al., 2023
Concrete decks	Kong et al., 2022 Phares, Liu and Abdalla, 2022 Manafpour et al., 2018 Huang, 2010 Huang et al., (2010) Kim and Yoon, 2010 James, Zimmerman and McCreary, 1987
Concrete bridges	Srikanth and Arockiasamy, 2021
General	Ilbeigi and Ebrahimi Meimand, 2020 Moomen et al., 2017
Superstructure	Hasan and Elwakil, 2019 Veshosky et al., 1994

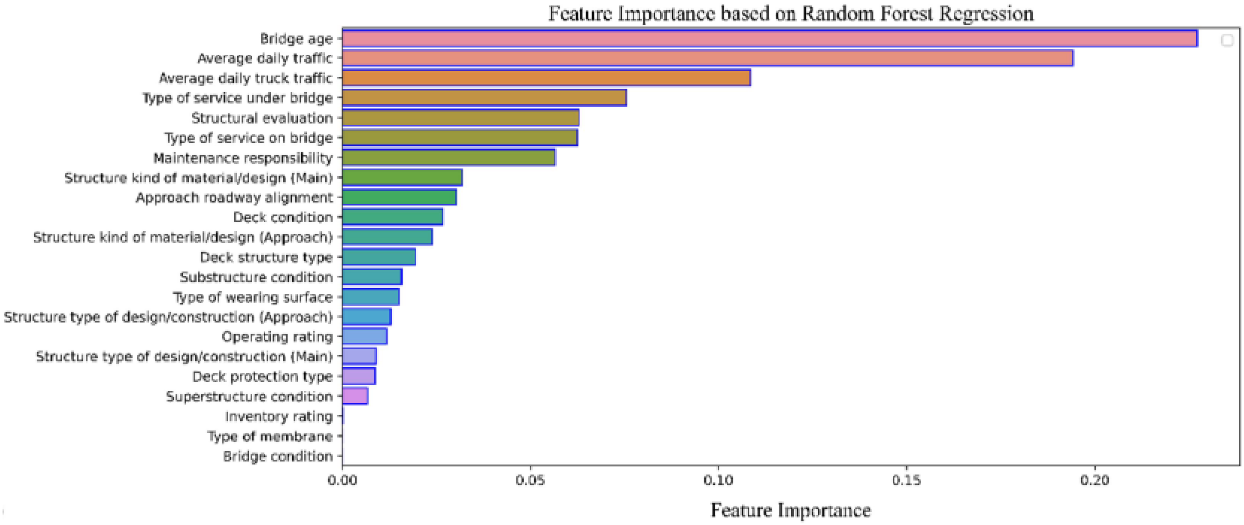

Figure 1: Feature importance by applying random forest regression (Rahman et al., 2023).

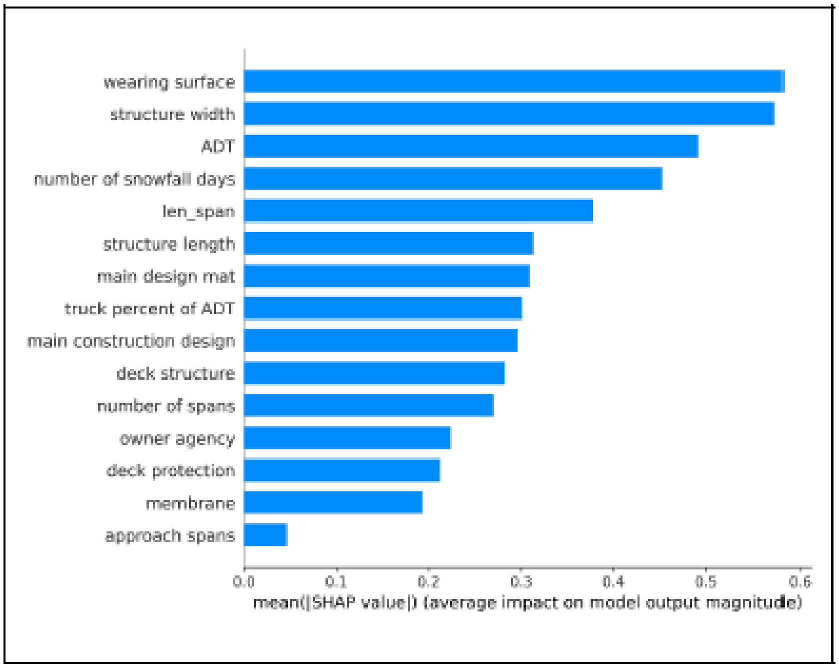

Figure 2: Feature importance based on SHAP values (Kong et al., 2022).

3.2.2 *Investigation of the Causes of Transverse Bridge Deck Cracking*

Phares et al., (2022) investigated transverse cracking in concrete bridge decks that initiated in the early stages of a bridge service life. Accelerated reinforcement corrosion, concrete deterioration, and increased maintenance costs were the motivation for their study. Observations for transverse deck cracking related to six bridge parameters are summarized in Table 6.

3.2.3 *Bridge Deck Cracking Evaluation*

Research by Nelson et al., 2021 included a field inspection, materials testing, and analytical modeling of Montana bridges to diagnose and recommend actions to mitigate the causes of transverse cracking in bridge decks. Based on studies completed by nine other State Departments of Transportation (including Montana in 2016) likely causes of bridge deck cracking were grouped into five different factors with their effect on cracking shown in Table 7. Effects from concrete mixture design, concrete strength, and construction practices are consistent with observations from Phares et al., 2022 for their parameters cement type, concrete type, and evaporation during placement (Table 6).

Table 6: Research observations from Phares et al., (2022)

Bridge Parameter	Observation
Location	Southwest and east Iowa had a higher propensity for deck cracking
Girder type	Precast, pretensioned concrete beams showed a higher chance of deck cracking than steel beam bridges
Cement type	Type 1 and IP (Portland-pozzolan) cement showed a higher chance of deck cracking compared to that for Type 2 cement
Concrete type	High performance concrete (HPC) bridge decks showed a higher chance of cracking compared to non-HPC bridge decks.
Bridge age	Bridges constructed between 1960 and 1980 showed a higher chance of deck cracking.
Evaporation during placement	Higher evaporation rates from six recorded concrete bridge deck placements resulted in a higher chance of deck cracking.

3.2.4 *Stochastic Analysis and Time-Based Modeling of Concrete Bridge Deck Deterioration*

Manafpour et al., (2018) investigated stochastic analysis for time-based modeling of concrete bridge deck deterioration using Markov chain models. The investigation assessed the effectiveness of preventive maintenance strategies by incorporating the stochastic deterioration processes of bridge decks into the decision-making process. The researchers developed a time-based Markov chain model to predict the transition probabilities of different deck states for bridges with different characteristics. Based on the model, a cost-benefit analysis was conducted to evaluate various preventive maintenance strategies. The study concluded that the model could effectively predict the deck's deterioration process and support cost-effective maintenance decision-making.

3.2.5 *Artificial Neural Network Model of Bridge Deterioration*

Huang (2010) used a statistical analysis to identify significant factors that influenced deterioration and developed an application model for estimating the future condition of bridges. Based on data derived from historical maintenance and inspection records of concrete decks in Wisconsin, the study identified 11 significant factors (county, district, design load, deck length, deck area, number of lanes, functional class, ADT, environment, degree of skew, number of spans) and developed an artificial neural network (ANN) model to predict associated deterioration.

3.2.6 *Exploring the Deterioration Factors of RC Bridge Decks: A Rough Set Approach*

Huang et al., (2010) investigated 29 bridge characteristics to determine their influence on reinforced concrete deck deterioration using the Rough Set Theory (RST) data mining technique. They grouped the factors into six common types and identified the factors causing the most significant impact using inspection data from 2,128 bridges in the Taiwan National Freeway System. The major factors contributing to two types of deterioration are shown in Table 8.

Table 7: Summary of Factors affecting bridge deck cracking, adapted from Nelson et al., 2021

Factor	Effect on Bridge Deck Cracking
Concrete mixture design	• Thermal and autogenous shrinkage are influenced by cement type; using Type II cements can help reduce thermal stresses, while using fly ash and slag can reduce both thermal stresses and shrinkage stresses. Finely ground cements, such as Type III cements, may increase heat of hydration and associated thermal stresses. • Using high volume of coarse aggregates with low coefficient of thermal expansion can reduce both shrinkage and thermal stresses. • Reducing paste content can reduce thermal stresses. • Conflicting recommendations have been provided in the literature regarding recommended w/cm. Some researchers recommend a minimum w/cm of 0.40, while others recommend a maximum of 0.40. Recommending a minimum w/cm of 0.40 ignores the potential for increased autogenous shrinkage at these ratios.
Concrete strength	• High strength concrete has a greater tendency to crack due to its higher modulus of elasticity (i.e., larger stresses associated with thermal or shrinkage strains). • Modulus of elasticity develops faster than tensile strength for the first 3 to 5 hours after initial set of the concrete.
Restraint conditions	• Restraint is greatest in interior spans (due to intermediate supports) and at integral abutments (due to fixed-end conditions). • Simply-supported or pin connections can reduce crack tendency. • Curved girders and skew can increase restraint.
Element design	• Cracking increases when girders provide more stiffness than the deck. This includes designs with thin decks (< 8.5 inches), composite steel plate girders, wide flanges, and cross framing. Larger spacing and thicker decks can reduce crack tendency. • Concrete girders can provide less restraint than steel girders due to their lower coefficient of thermal expansion. • Offsetting the top and bottom transverse reinforcing bars can reduce the risk of full-depth crack formation. • Increased cover will increase crack widths but will reduce crack frequency.
Construction practices	• Practices that limit evaporation from freshly placed concrete surfaces can reduce the potential for early plastic shrinkage cracking. • Mechanical vibration can close plastic shrinkage cracks; however, roller screeding may increase the risk of cracking due to local increases in near-surface paste content. • Large temperature variations during placement can exacerbate thermal stresses.

3.2.7 Identifying Critical Sources of Bridge Deterioration in Cold Regions through the Constructed Bridges in North Dakota

Kim and Yoon (2010) studied the source of bridge deck deterioration in cold regions using condition ratings from 2,801 concrete decks inspected between 2006-2007. Their unique approach combined multiple regression and geographic information system technology to evaluate physical, material, and environmental factors associated with the condition of existing bridge decks. The most significant parameter contributing to bridge deterioration was the year built, followed by ADT and the type of structural system. Decks on major interstate highways had lower condition ratings than other decks. The presence of water was also found to be critical to the deterioration in cold regions, and steel bridges were the most vulnerable bridge type in cold regions.

Table 8: Significant deterioration factors for RC bridge deck from Huang et al., (2010).

Deterioration Type	Significant Factor
Cracking	Peak monthly rainfall
	Max. rainy days in a month
	Type of girder material
	No. of lanes
	Expansion joints
	Type of pier
	Water crossing
	Design live load
Corrosion of Rebar	Area of main span deck
	Number of spans

3.2.8 *Effects of Overloads on Deterioration of Concrete Bridges*

James et al., (1987) investigated the interaction between physical damage from wheel loads and other damage mechanisms through a field study that documented the variation in cracking across the width of a bridge deck. Control structures with similar supports, age, construction, and traffic characteristics were used to compare the damage levels due to heavy truck traffic on the test bridges that carried outbound traffic from several aggregate quarries. The differential heavy truck traffic from the quarries was estimated to be 180 vehicles per hour and was thought to have lasted for approximately 26 years. Results of their research are summarized in Table 9.

Table 9: Research observations from (James et al., 1987).

Parameter	Observation
Flexural cracking	May occur at tensile stresses below the assumed $7.5\sqrt{f'_c}$.
Crack density	Increased densities of longitudinal and transverse cracking were observed in the overloaded concrete bridge decks.
Bridge type	Bridges supported by steel girders are more susceptible to progressive overload-induced damage than decks on prestressed concrete girders.

3.3 Concrete bridges

3.3.1 *Remaining Service Life Prediction of Aging Concrete Bridges Based on Multiple Relevant Explanatory Variables*

Srikanth and Arockiasamy (2021) studied explanatory variables using multivariate regression analysis based on the ordinary least square's technique. NBI data from 1992 to 2013 were used to develop the deterioration models. Conclusions from the investigation of eight variables organized into two categories are shown in Table 10.

Table 10: Explanatory variables considered by Srikanth and Arockiasamy (2021).

Category	Explanatory variable	Conclusions
Operation-related	Age	Deterioration rate varies with age during the service life of concrete bridge components. Bridges nearing their design life service life are more sensitive to faster deterioration.
	ADT	The effect of ADT on deterioration rate varies across different bridge components
	Functional class	Concrete bridge decks in urban locations deteriorate faster than rural areas.
Structure-related	Area of main span deck	Larger deck areas of the main span increase the deterioration rate of reinforced concrete bridge decks. Prestressed deck slabs were not affected.
	Number of spans	Deterioration increases with the number of spans and is attributed to an increase in number of joints
	Skewness	No statistically significant influence on bridge deterioration
	Wearing surface	Reduces deterioration rate, especially in concrete solid slab bridges
	Continuity of spans	No statistically significant influence on bridge deterioration

3.4 General

3.4.1 Statistical Forecasting of Bridge Deterioration Conditions

Ilbeigi and Ebrahimi Meimand (2020) performed statistical forecasting of bridge deterioration conditions using historical data of more than 28,000 bridges in Ohio from 1992 to 2017. Results of the ordinal regression analysis identified the explanatory variables for operation- and structure-related categories shown in Table 11. Truck ADT was not found to be statistically significant. Results of the validation and forecasting process showed that the model has a significantly high prediction power, and the forecasted transitions were statistically identical with actual transitions at a 1% significance level.

3.4.2 Bridge Deterioration Models to Support Indiana's Bridge Management System

Moomen et al., (2017) modeled families of curves representing deterioration models for bridge deck, superstructure, and the substructure for Indiana's bridge management system. Deterministic and probabilistic models were used to investigate traffic volume, truck traffic, design type, and climatic conditions on bridge deterioration rates. Conclusions from their investigation are shown in Table 12.

3.5 Superstructure

3.5.1 Stochastic regression deterioration models for superstructure of prestressed concrete bridges in California

Hasan and Elwakil (2019) studied the effect of non-periodic maintenance on NBI condition ratings. They identified the variables affecting superstructure deterioration and built models for predicting the superstructure condition. Their literature review identified a suite of variables shown in Table 13 have been previously studied and were identified as significant factors for bridge deterioration. Using NBI data from California, models were built to predict the superstructure condition of slab,-stringer, multibeam or girder, T-beam, and box beam or girder structure types using regression technique and Monte Carlo simulations. Age and ADT were identified as significant factors for increasing the rate of bridge deterioration. Span length, structure length, deck width, high degree of skew, ADTT, and roadway width were also associated with higher superstructure deterioration rates.

Table 11: Statistically significant variables from an ordinal regression analysis performed by Ilbeigi and Ebrahimi Meimand (2020).

Category	Explanatory Variable
Operation-related	Age
	ADT
	Deck area
	Current Condition
	Age from reconstruction
Structure-related	Area of main span deck
	Number of spans
	Skewness
	Wearing surface
	Continuity of spans

Table 12: Research observations from Phares et al., (2022).

Parameter	Observation
Climate variables	Freeze index, number of freeze-thaw cycles, and average precipitation were found to influenced bridge deck and substructure deterioration more than the superstructure.
Traffic loading	Concrete deck deterioration was much more sensitive to traffic
Location	General deterioration differences across maintenance districts in Indiana were observed, but the differences were not consistent.

3.5.2 Comparative Analysis of Bridge Superstructure Deterioration

Veshosky et al., (1994) selected homogeneous groups of bridges with similar structural material and type, maximum span length, maintenance responsibility, and other factors to evaluate superstructure deterioration. A regression analysis was used to estimate deterioration rates for homogeneous groups of steel and prestressed concrete bridges. Age and ADT were included as independent variables and superstructure condition ratings were the dependent variable. Statistical problems due to the multicollinearity of ADTT with ADT resulted in ADTT being excluded from the analysis. The bridge sample included 10,053 steel and 5705 prestressed concrete bridges built after 1950. Results of the investigation found no statistically significant differences in the rates of deterioration of steel and prestressed concrete bridge superstructures. Age and ADT were the primary determinant of superstructure deterioration.

Table 13: Significant factors in bridge deterioration research identified by Hasan and Elwakil (2019).

	Veshosky et al. (1994)	Kim & Yoon (2009)	Morcous (2011)	Tang et al. (2012)	Nieto (2014)	Chang et al. (2017)	Saeed et al., 2017),	Nieto et al. (2018)	Nabizadeh et al. (2018)
Age	o	o	o	o	o	o	o	o	o
Average Daily Traffic	o	o	o	o	o	o	o	o	o
Degree of Skew						o	o		
Max. Span Length				o	o	o	o	o	o
Structure Length		o			o	o		o	
Roadway Width						o			
Deck Width		o				o	o		
Percent Average Daily Truck Traffic		o	o			o	o		
Structure Type			o		o				o
Service on Bridge		o				o			
Service under Bridge		o				o	o		
Surface Wear Type			o	o		o			
Weather Conditions		o				o	o		
Maintenance Records									
Frequency of Inspection				o					

3.6 Literature Review Summary

Several significant factors influencing the deterioration of bridges were identified from published research. Some of the research focused on statistical methods and analyses to evaluate and identify deterioration factors, while other researchers focused on historical condition ratings using NBI data. The studies summarized in this review considered the general deterioration of bridge components in addition to specific deterioration of steel coatings, concrete bridge decks, concrete bridges, and the deterioration of superstructure members. The analytical tools used by researchers included data-driven approaches, machine learning frameworks, data mining techniques, and statistical analyses. A summary of the factors considered or identified by at least two of the researchers included in this literature review are shown in Figure 3.

4 Recommendations and Next Steps

The following tasks of this research will expand on the findings from the literature reviewed in this Task Report to identify specific factors that influence the deterioration of bridges in Montana. Two variables absent from the recent literature are the influence of overweight truck permits and the volume of deicing products applied to bridge decks. This research will determine if these are meaningful contributors to bridge deterioration or if they are adequately represented indirectly by ADTT and climate factors.

Two methods of analysis are currently being considered. The first analysis method is a time-based model which would assess the effectiveness of preventative maintenance strategies. This analysis will focus on a specific element deterioration and will be used to identify the influence of maintenance activities s on the deterioration rates. The second analysis method is a multivariate regression and/or random forest regression model. This analysis will focus on individual factors and their contribution to bridge deterioration rates. The analysis methods will provide an efficient process to consider the significant factors shown in Figure 3 along with other factors recommended by MDT bridge engineers that may be more specific or more influential for Montana bridges and maintenance operations.

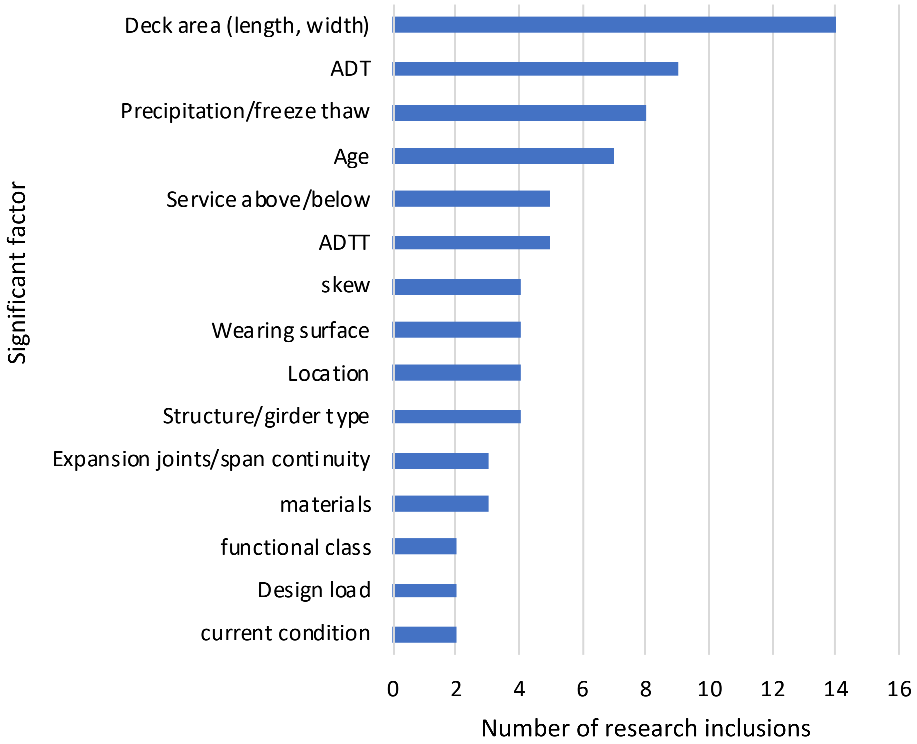

Figure 3: Significant factors considered by researchers.

An important first step in this research is to identify a smaller subset of bridges that represent the study variable and a comparable dataset of bridges that would represent a control group. A travel corridor through Montana that experiences large volumes of permitted truck traffic will be used to first evaluate the impact of heavy truck traffic. Subsequent datasets are expected to include bridge datasets in varying climates, of various ages, and with different ADT volumes.

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