Development of Deterioration Curves for Bridge Elements in Montana

by

Damon Fick
Assistant Professor

Matthew Bell
Research Associate

Western Transportation Institute
Civil Engineering
Montana State University - Bozeman

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Montana Department of Transportation
2701 Prospect Avenue
P.O. Box 201001 Helena, MT 59620-1001

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PROBLEM STATEMENT

The Federal Highway Administration (FHWA) has established measures for State departments of transportation to use for implementing the National Highway Performance Program (NHPP), which includes bridges that carry the National Highway System (NHS). Each State is required to develop an asset management plan to improve or preserve bridge conditions [1] and operation of a bridge management system that includes deterioration forecasting. The objective is to assist bridge owners in prioritizing and efficiently performing maintenance, preservation, and/or re-construction on bridges. Achieving this objective requires the use of bridge inspection data to estimate bridge deterioration over time and to identify bridge work that will maximize service life and returns on investment.

The MDT Bridge Management staff is currently testing the Federal Highway Administration's National Bridge Investment Analysis System (NBIAS) as a tool to forecast bridge deteriorations, evaluate life cycle costs, identify short and long-term budget needs, and identify optimal work strategies and schedules [2]. To forecast bridge deterioration, accurate trends representing the probability of a condition to deteriorate to a lower rating or score are required. MDT is exploring deterioration curve alternatives for use in this analysis. One option uses inspection data reported by States, Federal Agencies, and Tribal governments in the National Bridge Inventory (NBI). The component-level condition ratings for bridge decks, superstructures, and substructures does not consider different environmental conditions, traffic characteristics, or recent bridge improvements. Deterioration curves generated with this data produce highly variable results when applied to bridges that fall outside of 'average' conditions present in the NBI. In addition, the component-level (deck, superstructure, and substructure) condition ratings indirectly account for the deterioration of more specific bridge elements and can be unreliable indicators for bridge management decisions.

Representative deterioration curves specific to Montana's climate, operation practices, and bridge design details are required to more accurately perform state-wide investment optimization alternatives. In addition, changes to deterioration trends based on maintenance, rehabilitation, or construction practices should be captured to reflect changes to bridge service life. The integration of the refined deterioration curves for Montana bridges must be compatible with a selected bridge management system.

BACKGROUND SUMMARY

Several states have recently or are currently performing research related to deterioration modeling, the development of new analytical tools, and the development of deterioration curves for bridge elements using inspection data from bridges in their own state. A pooled fund study of 12 Midwest states is currently in progress to investigate element-level deterioration, operation practices, maintenance activities, and historic design/construction details [3]. The study objective is to develop a select number of deterioration curves for the time-dependent deterioration of bridge elements that reflect Midwest environments.

Recently completed research by the Nebraska Department of Roads investigated developing state-specific deterioration models for use in AASHTOware's Bridge Management Software (BrM) [4]. Results of the investigation identified deterioration trends related to concrete decks in different transportation districts, AADT, epoxy coated rebar, and structure type. The state of Wyoming developed deterioration models using both stochastic and deterministic models using the National Bridge Inventory inspection data and inspection data from WYDOT [5]. Two deterioration models were created for different bridge ages; one for the first 30 years and a second model for 30+ years. Results of this investigation found that LASSO regression is able to reduce human influence from the selection of explanatory variables. For applying stochastic models to small datasets, researchers suggest using component-level inspection [5]. The Indiana Department of Transportation developed families of deterioration curves using the National Bridge Inventory (NBI) database [6]. The NBI condition ratings were used as the response variable and families were categorized by administration region, functional class, and superstructure material type. The explanatory variables were traffic volume, truck traffic, climatic condition, and design type and features. The study concluded that environmental variables contribute significantly to bridge deterioration and freeze index, freeze-thaw cycles, and average precipitation were found to be major predictors [6].

Markov models are a commonly used stochastic technique for analyzing the deterioration of road bridges [7]. These models are developed by assuming bridges are inspected at fixed time intervals and the future bridge condition does not depend on past conditions [8]. One of the advantages of Markov models is their ability to include uncertainty from variations in the initial condition, applied stresses, inspection ratings, and the deterioration process itself. Other advantages include predicting future conditions based on present conditions and their computational efficiency [8].

Each Markov chain consists of an initial distribution matrix created from inspection data and a probability transition matrix which represents the probability of moving from one condition state to the next. The first step to implementing a Markov chain model is to develop the transition probability matrix, P, as shown in Figure 1, where n is the number of condition states and the values $p_{i,j}$ represents the probability of a bridge element transitioning from one condition state i to a lower condition state j.

$$P = \begin{matrix} p_{1,1} & p_{1,2} & \cdots & p_1, n \\ p_{2,1} & p_{2,2} & \cdots & p_2, n \\ . & . & \cdots & . \\ p_{n,1} & p_{n,2} & \cdots & p_{n,n} \end{matrix}$$

Figure 1 Transition probability matrix form

An example of a transition probability matrix is shown in Figure 2, where the number of rows and columns represent the number of condition states. The zero values in the matrix are the probability of moving from a lower condition state to a higher state.

$$P = \begin{bmatrix} 0.57 & 0.09 & 0.32 & 0.02 & 0 \\ 0 & 0.52 & 0.27 & 0.17 & 0.04 \\ 0 & 0 & 0.85 & 0.11 & 0.04 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Figure 2 Transition probability matrix (adapted from Mohseni et al. [9])

With the initial distribution matrix vector, $P(0)$, that represents the current condition of a bridge element, the future condition vector $P(t)$ at any number of transition periods (t) can be calculated using the following expression [4].

$$P(t) = P(0) \cdot P^t$$

Transition probability matrices can be generated using an expert judgment process with several experienced bridge engineers or by using multiple years of inspection data. One method to solve the nonlinear problem using inspection data is through regression-based optimization. This method minimizes the sum of absolute differences between the regression curve that best fits the data and the conditions predicted using the Markov-chain model using the following equation from Butt et al. [10]

$$Minimize \sum_{t=1}^{N} |C(t) - E(t)|$$

where *N* = total number of transition periods,

C(t) = condition at transition period number t based on regression curve,

E(t) = expected value of bridge condition at transition period number *t*.

The expected condition at transition period *t* is based on a Markov chain, which is calculated by:

$$E(t) = P(t) \cdot S$$

where *S* = vector of condition states

Because the regression model is influenced by maintenance actions performed in previous years, often without available records in the bridge management systems, the percentage prediction method can be used. This second method to determine the transition probability matrix calculates the transition matrix values using the following from Jiang et al. [11].

$$p_{i,j=} {}^{n_{i,j}}/_{n_i}$$

where $n_{i,j}$ = number of transitions from state *i* to state *j* within a given timer period

n_i = total number of bridges in state *i* before the transition

This method requires at least two consecutive condition records without any maintenance activity for a large number of bridge elements at different condition states to create representative transition probabilities.

The proposed research will expand on the published literature to identify the appropriate analysis tools and methods that will be used to develop a family of deterioration curves for Montana bridges.

BENEFITS AND BUSINESS CASE

The proposed research is important and timely because of the Federal initiative for State departments of transportation to develop and operate a bridge management system that includes deterioration forecasting for all National Highway System (NHS) bridge assets. MDT currently uses generic deterioration curves developed using component-level condition ratings for the deck, superstructure, and substructure from the National Bridge Inventory database. Results of this research will be based on bridge element-level inspections for Montana bridges and will be compatible with MDT's bridge management software. Bridge Bureau engineers will be able to more accurately identify bridges for maintenance, rehabilitation, or replacement projects. Future State activity depends on the results of this research to schedule replacement, rehabilitation, and preservation projects on over 5000 state, county, and local municipality bridge structures. Benefits of the research include:

- Efficient selection of maintenance projects will maximize the impact of limited resources to ensure functional and safe bridge structures.
- Ability to monitor maintenance activities to determine their effectiveness and their contribution toward increasing the service-life of the bridge structure.
- Prioritize maintenance activities for bridges in different transportation and different traffic characteristics through an understanding of unique deterioration characteristics.

Opportunities to quantify these benefits will be identified during implementation (Task 6), where deterioration modeling can be performed and compared with historical maintenance, rehabilitation, and construction practices. Possible metrics include the overall functionality of the developed deterioration curves with MDT's selected bridge management software and the flexibility to modify parameters to customize desired results.

OBJECTIVES

The overall objective of the research is to develop deterioration curves for bridge elements in Montana. Specific objectives are to 1) Create families of deterioration curves for Montana bridges in different geographic locations using explanatory variables such as traffic volume, climate conditions, and design type, 2) Establish modifications to the deterioration curves to represent ‘performance jumps’ in bridge conditions created after maintenance or rehabilitation activities take place, and 3) Create a process to easily revise and implement the data with MDT’s bridge management software.

RESEARCH PLAN

The research program described in this proposal will develop deterioration curves for bridges in Montana. The development of these curves will be based on a thorough review of current bridge deterioration modeling methods, which will be adapted to the specific characteristics of Montana bridges and inspection data. Information will be disseminated during the course of the project to the technical panel through quarterly and task reports. Project meetings are included in the schedule with the Technical Panel at decision points after the completion of each task. These meetings will discuss results and will allow flexibility as the research proceeds and to ensure the overall objective of the project is accomplished. Details of the following task will be discussed and defined prior to starting the next task. An implementation report, final report, and project summary report will be delivered, followed by a presentation to summarize the results of this research. The specific work tasks include:

1) Literature review
2) Inspection data review and processing
3) Statistical analysis
4) Deterioration curve development
5) Final reporting
6) Implementation and performances measures

Task 1: Literature Review

A comprehensive literature search will be performed to summarize relevant practices related to the development of deterioration curves that include state-specific inspection data, bridge characteristics and maintenance practices. Three sub-tasks of the literature review include; 1) Identify deterioration trends of bridge elements based on historical bridge data collected by Departments of Transportation and published research available in the literature, 2) Summarize available software and capabilities for including state-specific bridge inspection data for asset management, and 3) Review current methods established by other State departments of transportation and trends toward implementing a reliable bridge management system. The 2nd and 3rd sub-tasks will include surveys of software developers and transportation officials in other states to understand the challenges and data analyses required for success. Limitations of more complicated deterioration models will be compared with simplified approaches. Sources for information will include the Transportation Research Board, State departments of transportation, Universities, and national and international journals. A Task 1 Report is included as a deliverable and will be followed by a decision point meeting with the Technical Panel. This meeting will discuss the available methods and confidence levels for creating, using, and modifying deterioration curves. A focused selection of alternatives will be made for further consideration. The Literature Review task will be updated for the final report.

Task 2: Inspection Data Review and Processing

Inspection data from MDT's Structure Management System (SMS) will be reviewed to identify and organize data that will most accurately identify bridge element-level deterioration. With input from MDT, search parameters will be established and computer routines developed to extract meaningful bridge inspection data. Plots of bridge element condition states (scale of 1-4) vs. time will be compared with National Bridge Inventory data (scale of 1-9) to identify similarities and differences in the two data sets. Bridge activities that cause an increase in condition state or rating will be used to establish a general bound to condition improvements caused by maintenance, rehabilitation or construction practices over time. This baseline data will be compared with trends identified in the literature review to determine if Montana bridge deterioration is comparable with bridges studied in other regions. The data will be further 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 product of Task 2 will be an efficient method to create desired datasets and plots that reveal general deterioration characteristics of Montana bridges and will be documented in the Task 2 Report. A decision point meeting will be held to determine specifically which families of datasets should be created for further consideration. A strategy will be established by the Technical Panel and researchers during this meeting for performing the initial statistical analysis and methods to validate the results. Acceptable confidence levels will be defined for the families of datasets selected.

Task 3: Statistical Analysis

Using results from the literature review task and a method to create desired datasets established in Task 2, a statistical analysis will be performed to generate the data required for implementation with a MDT's selected bridge management software. Due to the common use of Markov models by State departments of transportation and bridge management software platforms, they will be considered for the present study along with less complicated models identified in the Literature Review Task. A comparison of analyses methods and their confidence levels will be included for the preliminary datasets selected and summarized in the Task 3 report. Each model will be calibrated to determine parameters that produce consistent results relative to the selected dataset. A decision point meeting will be held at the conclusion of Task 3 to select the appropriate statistical analysis (or combination of analyses) to be implemented for developing the deterioration curves in Task 4. It is likely that results of the statistical analysis will require new datasets to be selected by the Technical Panel and researchers for analysis to further validate the results.

Task 4: Deterioration Curve Development

Using the selected statistical analysis determined from Task 3, deterioration curves will be developed for a baseline group of bridges. Different explanatory variables such as traffic characteristics, bridge type, and environmental conditions will be incrementally added so that changes in the deterioration curves can be assessed. The developed deterioration curves will be compared with plots of condition ratings and/or states vs. time that were developed in Task 2 and also with equations for deterioration curves identified in Task 1 to assess their reliability. After establishing the limits of the selected model for the different bridge datasets, improvements to deterioration trends as a result of maintenance, rehabilitation, and/or construction activities will be added to the model. A second method that will be used to estimate the reliability of the curves will be historical modeling to the present time (rather than future modeling) which will be compared with the actual condition or rating of the bridge element. A summary of calculated deterioration curves, confidence intervals, and limits to their applicability, will be documented in the Task 4 Report. The content and details of implementing the developed deterioration curves with MDT's selected bridge management software will be finalized at the decision point following Task 4. Outcomes of this meeting will be documented in the Implementation Report.

Task 5: Final Reporting

A final report will be prepared to document all aspects of the research including a summary of each of the tasks, pertinent results, and implementation recommendations. The final report will provide the detailed results of the literature review. An executive summary will be prepared to concisely communicate the purpose, general approach, and results of the study. The format of the report will follow MDT's *Report Writing Requirements*. A draft of the final report will be sent to the Technical Panel allowing two months to review, followed by a two-week period where revisions are made. The Principal Investigator will present the results of the research in a final presentation to MDT and will be followed by the implementation meeting and presentation.

Task 6: Implementation and Performance Measures

This task includes implementing the developed deterioration curves into MDT's bridge management system. Different scenarios of bridge maintenance, rehabilitation, and construction operations will be explored for different datasets and compared with historical costs and bridge element performance. Representative scenarios will be documented in a performance measures report. In addition to the deterioration models generated in Task 4, tools and results from Tasks 2 and 3 will be used to change the parameters of the bridge management analysis. Task 6 will be documented in a stand-alone implementation report. A meeting facilitated by the Principal Investigator to review implementation recommendations will be combined with the final report and presentation described in Task 5.

MDT AND TECHNICAL PANEL INVOLVEMENT

The following information will be necessary from MDT for the successful completion of the proposed research.

- *Bridge management software*—MDT will provide access to the software, data, and background information on MDT's recent deterioration modeling efforts.
- *Inspection data and supporting information*—MDT will provide the bridge inspection database and qualitative information related to interpreting the data.
- *Bridge selection*—MDT will recommend representative bridge types, structural elements, locations, traffic characteristics, environmental conditions and maintenance activities to include in the deterioration curve development.
- *Bridge Maintenance data*—MDT will provide a reasonable level of support to identify a representative collection of completed bridge maintenance activities and timelines that can be used during the calibration process.
- *Review of deliverables*—MDT will review project deliverables and provide comments, suggestions, and guidance for current and future tasks of the research.

PRODUCTS

The following products will be produced as a result of the proposed research:

1) Quarterly progress reports
2) Task 1 report – literature review
3) Task 2 report – inspection data review and processing
4) Task 3 report – statistical analysis
5) Task 4 report – deterioration curve development
6) Final Report
7) Final Project Summary Report
8) Final Performance Measures Report
9) Final Implementation Report
10) Project Poster
11) Journal and/or conference publications and presentations

IMPLEMENTATION

Results of the research will be ready to implement at the conclusion of the research. The findings will consist of processed data that includes the ability to create plots of MDT inspection data vs. time for selected bridge elements. A program such as Matlab, R, or Excel will be used to perform the statistical analysis that will determine the probability of the bridge to move from one condition level to the next lower condition level. In the case of maintenance or rehabilitation, the bridge condition would move to a higher level. The deterioration curves will be formatted to meet the requirements of the MDT's bridge management software where MDT personnel can continue using the same procedures for managing bridge assets with more accurate and representative deterioration curves. A detailed step-by-step process to apply the products of this research will be included in the implementation report.

Necessary activities for the successful implementation of the proposed research include an initial assessment by MDT to determine the applicability of the deterioration curves. Results obtained from the bridge management software will be reviewed to determine if recommendations are relative and reasonable with historical experience. Refinements will be necessary to obtain data that can be reliably used for asset management purposes.

MDT is currently making decisions on maintenance activities based largely on historical data and experience. Implementation costs for this research in the short term will include additional personnel time to perform the modeling and review the results and make refinements. In the longer-term, the implementation of the proposed research will reduce the costs of bridge asset management through the efficient selection of bridges and maintenance operations.

SCHEDULE

The proposed work is scheduled to take 28 months to complete. The proposed project schedule is shown in Table 1. The schedule is based on an anticipated start date of April 1, 2020, and an estimated completion date of July 15, 2022.

Table 1: Project Time Schedule

Activities	Dates
Kick-off Meeting	4/1/20
1 – Literature Review	
Task 1 Report	7/15/20
Decision Point Meeting	7/31/20
2 – Inspection Data Review and Processing	
Task 2 Report	10/15/20
Decision Point Meeting	10/31/20
3 – Statistical Analysis	
Task 3 Report	2/15/21
Decision Point Meeting	2/28/20
4 – Deterioration Curve Development	
Task 4 Report	6/15/21
Decision Point Meeting	6/30/21
5 – Final Reporting	
6a – Draft Final Report (with cover picture)	9/30/21
6b – Draft Project Summary and Performance Measures Reports and Draft Poster	11/15/21
6c – Final Draft, Final Report	12/31/21
6d – Final Project Summary and Performance Measures Reports and Final Poster	2/15/22
6 – Implementation and Performance Measures	
7a – Implementation Meeting and Final Presentation	12/15/21 - 1/15/22
7b – Draft Implementation Report	1/31/22
7c – Final Implementation Report	4/30/22
7 – Webinar	5/15/22 - 7/15/22
Project End Date	7/15/22

BUDGET

The project expenses are shown in Table 2. The in-state travel expenses support project meetings in Helena that include the kickoff, coordination meetings, final presentation and implementation meetings. Tasks, Meeting, and Deliverable Cost Breakout are shown in Table 3. The principal investigator (Damon Fick) is a faculty member from the Civil Engineering Department and the Co-Principal investigator (Matthew Bell) is research associate from the Western Transportation Institute. Project expenditures during state fiscal years are shown in Table 4.

Table 2 Expenses

Labor Expenses															
			Task												
Person	Role	Kickoff Meeting	1	2	3	4	5	6	Total	Hourly Rate	Total Wages	Hourly Benefit Rate	Total Benefits	Total Cost
Damon Fick	Principal Investigator													
Matthew Bell	Co-Principal Investigator													
Graduate Student	Data Analysis and Processing													
Business Mgr.	Budget Assistance													
Admin Staff	Admin. Support													
Total		**54**	**223**	**463**	**263**	**263**	**183**	**103**	**1552**		**$41,008**		**$18,432**	**$59,440**
Indirect Cost @ 25%														$14,860
Total Labor Cost														$74,300
Direct Expenses														
In-State Travel														$600
Total Project Cost														$74,900

Table 3 Task, Meeting, and Deliverable Cost Breakout

Task, Meeting, and Deliverable Cost Breakout			
Item	Labor	Travel	Total
Kickoff Meeting	$2,724	$200	$2,924
Task 1, Literature Review	$9,330		$9,330
Task 2, Inspection Data Review and Processing	$13,650		$13,650
Deliverable, Task 1&2 Report			
Task 3, Statistical Analysis	$10,050	$200	$10,250
Task 4, Deterioration Curve Development	$10,050		$10,050
Deliverable, Task 3&4 Report			
Task 5, Final Report and Presentation	$8,610		$8,610
Task 6, Implementation and Performance Measures	$5,027	$200	$5,227
Total	**$59,440**	**$600**	**$60,040**

Table 4 Project expenditures during state fiscal years

	State Fiscal Year				
Item	2020	2021	2022	2023	Total Cost
Salaries	$4,904	$19,616	$19,616	$1,635	$45,771
Benefits	$1,464	$5,858	$5,858	$488	$13,669
In-State Travel	$64	$257	$257	$21	$600
Supplies	$0	$0	$0	$0	$0
Total Direct Costs	$6,433	$25,731	$25,731	$2,144	$60,040
Overhead	$1,592	$6,369	$6,369	$531	$14,860
Total Project Cost	$8,025	$32,100	$32,100	$2,675	$74,900

STAFFING

The Western Transportation Institute (WTI) is the nation's largest transportation institute focusing on rural transportation issues. The Institute was established in 1994 by the Montana and California Departments of Transportation, in cooperation with Montana State University–Bozeman. WTI is part of the College of Engineering at Montana State University (MSU) and has a multidisciplinary research staff of professionals, students, and associated faculty from engineering (civil/mechanical/industrial/electrical), computer science, psychology, fish and wildlife, business, biology and economics.

Damon Fick will serve as PI on this project. Dr. Fick is an Assistant Professor in the Civil Engineering Department at Montana State University and is licensed professional engineer in the state of Montana. He has over 11 years of research experience in the areas of reinforced concrete, timber, and masonry structures, earthquake engineering, bridge structures, and alternative civil engineering materials. Dr. Fick is currently PI on the project *Performance of Asphalt Concrete Crack Sealants in South Dakota*, funded by the South Dakota Department of Transportation. The overall objective is to evaluate eight different sealant materials at two different South Dakota test sites. Documentation of the sealant installation and site visits during the past two years have been completed and a final assessment is in progress. Recommendations will be made to South Dakota's Standard Specification and their process of selecting crack sealants materials for SDDOT's Approved Products List.

Dr. Fick recently completed the *Investigation of Prefabricated Steel-Truss Bridge Deck Systems* project, funded by the Montana Department of Transportation. A prototype of a welded steel truss constructed with an integral concrete deck was proposed by a Montana steel fabricator as a potential alternative for accelerated bridge construction (ABC) projects. A new truss connection was designed to meet fatigue requirements and results of the investigation suggest materials, fabrication, and construction could be up to 26% less than a common plate girder structure. Results of the research were published in the proceedings of the National Accelerated Bridge Construction Conference [12] and will be presented in a poster session at the 2020 Transportation Research Board's annual meeting.

Matthew Bell is a Research Associate at the Western Transportation Institute and will serve as Co-PI on this project. He received his M.S. degree from Montana State University where he spatially modeled the risk of wildlife-vehicle collisions along Montana's road network [13]. Mr. Bell's research experience is in the area of transportation engineering, and is currently investigating the use of fiber-reinforced polymers for use in wildlife crossing infrastructure. In addition, he has a wide range of statistical analysis experience: logistic regression on egg sizes to determine nest occupancy, population estimates for prairie dog colonies, and random block designs for determining plant species growth along roadways using different types of erosion control blankets. Mr. Bell will be the primary source of effort for reviewing relevant research documents, designing the statistical analysis methods, and creating the deterioration curves.

A Graduate Research Assistant will support the project investigators during the Summer of 2020. They will be primarily responsible for reviewing the MDT inspection database and developing routines to select, organize, and process relevant data for the statistical analysis. The Research Assistant will also assist with the literature review, statistical analysis, and deterioration curve efforts.

The projected level of effort by project personnel is summarized in Table 5. As shown in Table 6, Dr. Fick and Mr. Bell have the available time necessary to complete this work in a timely and deliberate manner. Professional members of the research team will not be changed without written consent of MDT.

Table 5: Project Staffing

Person	Role	Kickoff Meeting	Task							Percent of Time vs. Total Project Hours (total hrs./person/ total project hrs.)	Percent of Time - Annual Basis (total hours/ person/ 2080 hr.)
			1	2	3	4	5	6	Total		
Damon Fick	Principal Investigator	24	60	60	60	60	60	40	364	23.5%	17.5%
Matthew Bell	Co-Principal Investigator	30	120	120	120	120	120	60	690	44.5%	33.2%
Graduate Student	Data Analyiss and Processing	0	40	280	80	80	0	0	480	30.9%	23.1%
Business Mgr.	Budget Assistance	0	1	1	1	1	1	1	6	0.4%	0.3%
Admin Staff	Admin. Support	0	2	2	2	2	2	2	12	0.8%	0.6%
Total		54	223	463	263	263	183	103	1552		

Table 6 Availability

Team Member	Project/Work	Role	Percent Committed FY20	Percent Committed FY21
Damon Fick	Civil Engineering Department	Instructor	40	40
	Deterioration Modeling	Principal Investigator	18	18
	SDDOT - Crack Sealing	Principal Investigator	5	0
	FRP Wildlife Crossings	Co-Principal Investigator	20	20
		Total Commitments	**83**	**78**
Matthew Bell	FRP Wildlife Crossings	Research Associate	25	40
	Deterioration Modeling	Co-Principal Investigator	25	30
	Roadkill Observation and Data System	Research Associate	30	0
	CDOT Friction Performance Measurement Tool	Research Associate	5	10
	CDOT Ag-Based Deicing Additives	Research Associate	10	0
		Total Commitments	**95**	**80**

FACILITIES

The proposed research does not include laboratory equipment or testing. The MSU library will provide access to published journal materials for review and necessary computing resources and software for the analysis portion are available through MSU Information Technology.

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