Significant Factors of Bridge Deterioration

by

Damon Fick
Senior Research Engineer

Matthew Bell
Research Associate

Western Transportation Institute
Montana State University - Bozeman

A proposal prepared for the

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

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PROBLEM STATEMENT

The proposed research is in response to the Federal Highway program's initiative to use state-based deterioration models to forecast bridge maintenance activity. To address this initiative and to improve these models, significant factors affecting bridge deterioration will be identified and evaluated to quantify their influence on bridge deterioration across the five transportation districts of Montana. The research will contribute to more accurate and reliable bridge management analyses through the following objectives: 1) Identify significant factors affecting bridge deterioration in Montana. 2) Determine refinements, based on the identified significant factors, to the recently established deterioration curves, and 3) Establish effective data collection, processing, and future research opportunities for improving the accuracy and consistency of Montana's ability to forecast bridge deterioration. A potential path for accomplishing these objectives is to align historical NBI component-level inspection data with historic precipitation, freeze-thaw cycles, and NWS or Snotel data. In-depth historic record review of bridge maintenance and rehabilitation records for common bridge types also holds potential for discovering significant factors affecting bridge deterioration and the reduction or acceleration of deterioration common to rehabilitation methods. Other factors may be identified and included, but the research will be generally limited to the most significant contributors of deterioration rate variation.

Historical National Bridge Inventory (NBI) component-level inspection data includes a rating scale from 0 to 9 compared with the more recent NBI element data that uses condition state (CS) ratings from CS-1 to CS-4 for an area of a particular element. The *Development of Deterioration Curves for Bridge Elements in Montana* research project concluded, consistent with the experience of other departments of transportation experience, that challenges associated with the element-level ratings are the narrow rating scale and low percentage of bridge element areas rated as CS-2 through CS-4. New analysis capabilities within the MDT's bridge management software, BrM, will enable a relevant comparison of the potentially improved deterioration trends using the historical NBI component-level inspection data.

This research is a logical continuation of the *Development of Deterioration Curves for Bridge Elements in Montana* research that is currently near completion. The proposed research will support MDT's use of AASHTOWare BrM and will increase the accuracy and confidence of bridge deterioration forecasts, performance gaps, and funding needs. Furthermore, the new National Bridge Inventory Standards (NBIS) and Specifications for the National Bridge Inventory (SNBI) released by the Federal Highway Administration in May 2022 provide an opportunity to integrate results of the proposed research with these new requirements.

Future State activity depends on the results of this research to more accurately and reliably schedule replacement, rehabilitation, and preservation projects on over 5000 state, county, and local municipality bridge structures.

BACKGROUND SUMMARY

The objective of the proposed research is to improve current deterioration curves for Montana bridges to more accurately determine the timing and type of work events that will reduce maintenance/rehabilitation expenditures and increase the service life of bridge structures. The literature review will focus on previous research and experience related to; 1) significant factors that influence deterioration rates, 2) component-level NBI data for deterioration modeling, and 3) deterioration modeling including maintenance activities. Related to the 2nd and 3rd topics, new requirements from the National Bridge Inventory Standard (NBIS) and the Specification for the National Bridge Inventory (SNBI) will be evaluated to ensure the research efforts align and are compatible.

Significant factors to bridge deterioration have been identified by several states. South Carolina concluded that overweight trucks cause exponentially increased damage to highway infrastructure [1]. Virginia found that the greatest deterioration in reinforced concrete decks were from the ingress of chloride ions and confirmed the need for low-permeability concrete, especially where uncoated reinforcing steel was present [2]. A survey of 29 departments of transportation found that age and average daily traffic were most frequently reported factors used to adjust deterioration rates [3]. Studies that include significant factors to improve deterioration modelling were limited in this preliminary literature search.

Studies using historical component-level NBI data to successfully create deterioration curves is also well-documented in the literature. Texas successfully modeled deterioration rates using NBI-component level data and concluded that these condition ratings are tried-and-true measures of bridge deterioration [4]. NBI component level data was used by North Carolina to developed a simplified and reliable probabilistic model [5] and Georgia divided bridges from three regional districts into five deck and five superstructure subgroups to improve the accuracy of their deterioration models [6]. Many of these studies focused on different aspects of the deterioration model itself, but in all cases, the historical NBI component data was determined to be a suitable representation of bridge deterioration.

The most common maintenance work event included by departments of transportation to improve deterioration modeling is surface treatments. Utah considered bituminous overlay, epoxy overlay, and latex-modified concrete overlay in each of their transportation regions. Their results concluded that certain treatments applied at certain times achieve higher inspection ratings than monolithic concrete and result in an apparent increase in bridge deck service life [7]. Texas researchers used a novel approach to infer past maintenance and rehabilitation type and timing based on changes in bridge condition ratings and concluded that transportation agencies can apply their approach using their own inspection data [8]. The same survey of 29 departments of transportation noted above found that deck overlays and deck wearing surface were the most frequently reported maintenance items used to adjust deterioration rates [3]. This same study also found that nearly one-half of the agencies accounted for bridge washing, deck seals and treatments, joint replacements, overlays, and rehabilitation. Six agencies developed an approach to isolate the benefit of specific bridge maintenance treatments and their impact on the deterioration rate. MDT's bridge management software, BrM also provides an adjustment factor for surface treatments in their deterioration analysis. Investigating the extent of MDT's surface treatment program will provide the necessary details to potentially apply these adjustment factors with confidence.

The Federal Highway Administration (FHWA) recently released updated National Bridge Inventory Standards (NBIS) and Specification for the National Bridge Inventory (SNBI). Relevant to the proposed research are the new component-level items rated on the same component level 0 to 9 rating scale. A second important change to the Standard and Specifications is the addition of work event items. The year the bridge was built, the year work was performed, and the work performed data entries provides a consistent attribute from which to create datasets from in BrM in the near future. These attributes and datasets will be implemented using the framework established as part of the proposed research.

Evidence from the published literature and publication of new NBIS and SNBI requirements provide a unique opportunity to implement a framework and understanding of significant factors that affect bridge deterioration in Montana. The proposed research will improve deterioration curves by considering contributing factors, NBI component-level data, and maintenance activities using methodologies from the literature to extend these approaches for climate, construction, maintenance, or bridge management practices in Montana.

BENEFITS AND BUSINESS CASE

The proposed research is important because it will improve the accuracy and efficacy of recently established deterioration curves of Montana bridges by identifying significant factors that influence these trends. The research is timely because results of the research will integrate requirements of the new Specification for the National Bridge Inventory (SNBI) published in May 2022.

Targeting significant factors that increase or decrease deterioration rates in Montana bridges will enable bridge management engineers to target specific bridge types, regions, and construction and maintenance practices that are reducing or increasing bridge service life. Cost effective solutions can be implemented locally and state-wide to ultimately reduce the maintenance and rehabilitation expenses of bridges and increase their service life through the following improvements.

- More accurate and reliable deterioration forecasting will improve bridge management analyses and maintenance programming.
- Maximize bridge investment through efficient selection of maintenance projects across the state, region, or by influencing factors.
- Prioritize maintenance activities to reduce life-cycle costs of bridge infrastructure.

Cost savings, efficiency gains, improved infrastructure, and increased service life will be benefits from the proposed research and realized by MDT and the travelling public.

OBJECTIVES

The overall objective of the proposed research is to increase the confidence of deterioration prediction models by applying weighted factors to reflect different environments, traffic characteristics, and bridge types in Montana. Specific objectives are to; 1) Identify significant factors affecting bridge deterioration in Montana. 2) Determine refinements, based on the identified significant factors, to the recently established deterioration curves, and 3) Establish effective data collection, processing, and future research opportunities for improving the accuracy and consistency of Montana's ability to forecast bridge deterioration.

RESEARCH PLAN

The research program described in this proposal will identify significant factors that influence the deterioration of bridges in Montana. Data sources to be investigated for their specific contribution to deterioration will be those suggested by MDT and those found in the literature review. The selected significant factors will be used with NBI component-level bridge data and general condition rating analyses in BrM to assess the refined deterioration trends. The timing, frequency, and efficacy of specific maintenance or rehabilitation practices will be evaluated for their effect on the service life of bridges. Recommendations to implementing a significant factors component to MDT's bridge management analyses will be consistent with the new Specification for the National Bridge Inventory (SNBI).

A project kick-off meeting will be held to introduce researchers to the Technical Panel and to summarize proposed activities. The research and project associate will review the contractual obligations, deliverables, project milestones, timetable, and other project elements. Technical issues or concerns will be discussed and clarified if necessary.

Information will be disseminated during the course of the project to the Technical Panel through quarterly and task reports. A meeting during the literature review (Task 1) is scheduled to discuss the new provisions of the SNBI and to make sure the task is considering these changes. Decision point meetings with the Technical Panel are included in the schedule after Task 2 and Task 3 to discuss the draft task reports. These meetings facilitate potential adjustments to the research path as MDT continues their efforts to configure and refine data used in the optimization analyses of BrM. 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, standards, and specification review
2. Significant factors data and maintenance records review
3. General Condition Rating (GCR) analyses
4. Final Reporting
5. Implementation

Task 1: Literature, Standards, and Specifications review.

A comprehensive literature search will identify factors used by other departments of transportation to improve the precision of the recently established deterioration curves for Montana Bridges. Examples include environmental conditions (precipitation, freeze-thaw cycles, NWS, Snotel data), de-icing practices, traffic characteristics (ADT, ADTT, overweight permits), and construction practices. Sources for information will include the Transportation Research Board, State departments of transportation, Universities, and national and international journals.

The second important component of Task 1 will be a review of the new National Bridge Inspection Standards (NBIS) and the Specification for the National Bridge Inventory (SNBI) coding guide, published in May 2022. Of particular relevance to the proposed research is the SNBI, which replaces the 1995 *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*. Any recommendations made to refining deterioration curves using significant factor data from component or element-level data must be compatible with new inspection data coding.

A mid-task meeting will be scheduled with the Technical Panel to discuss the effects of the NBIS and SNBI documents on the proposed research. A Task 1 Report will be submitted following the mid-task meeting. The Literature Review task will be updated for the final report.

Task 2: Significant Factors data and Maintenance Records Review

Identifying significant factors to Montana bridge deterioration is a primary objective to the proposed research and will be completed using a statistical analysis of the potential significant factor data. Data that will be reviewed includes freeze-thaw, NWS snowtel, deicer, overweight truck, and maintenance records. Additional significant factor data or review methodologies may be identified during the maintenance record and/or decision point meetings scheduled during Task 2. Generalized linear models, and other time series forecasting models, will be used to identify geographic areas in Montana that have local maximum and minimum significant factor values. Bridge datasets in these regions will be assembled and further divided into smaller datasets such as functional class and ADT. Deterioration curves will be calculated for these smaller datasets to determine if maximum or minimum significant factor data results in accelerated or slower deterioration. A method to quantify the increased or decreased deterioration (shape factor, median years, slope, etc) will be used to characterize the influence of all significant factor data considered.

Maintenance and rehabilitation actions on a bridge are second significant factor that will be obtained from construction plans or other data sources provided by MDT. A summary of work events, date completed, bridge ID, and component-level ratings before and after will be created to document the influence of specific maintenance actions. Due to the number of maintenance records available and the time span over which they exist, an analysis will be completed to determine an appropriate number of work events and bridge types required for a statistically relevant assessment. Patterns of deterioration and future maintenance needs on these bridge groups will provide the basis for interpreting bridge maintenance effects on bridge deterioration and service life.

Task 3: General Condition Rating Analysis

A general condition rating (GCR) analysis is an available deterioration profile within BrM that uses component-level inspection data. The GCR analysis is easier to customize within BrM and outlier data points can be more-easily removed. Task 3 of this research will use the GCR analysis profile to create a condition curve using the datasets created in Task 2 to investigate the influence of significant factors on bridge deterioration and service life. Results of the GCR analysis with NBI component-level data can be used to compare trends created with BrM's protective coating factor and other analysis scenarios in BrM. The objective of Task 3 is to quantify the influence of identified significant factors using the GCR profile and to explore alternatives to integrate the results within the larger BrM optimization framework.

Task 4: Final Reporting

A final report will be prepared to document all aspects of the research including a summary of each of the tasks, results, and conclusions. A cover picture will be included with the final report. 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 to MDT during the combined final presentation and implementation meeting. The second deliverable as part of the final reporting is a project summary report that addresses 1) what we did, 2) what we found, and 3) what the researchers conclude.

Task 5: Implementation

This task finalizes the implementation of the research results into MDT’s bridge management operations. Based on results of the research and BrM software configurations completed by MDT, implementation recommendations will be sent to the Technical Panel two-weeks prior to the final presentation and implementation meeting. A final presentation and implementation meeting will be scheduled three months before the project end date. The implementation recommendations from the completed research along with recommendations from the Technical Panel will be discussed during the meeting. Responses to the implementation recommendations will be recorded by the Principal Investigator and documented in the implementation report. Methods to quantify the performance of the completed research will be discussed during the implementation meeting and documented in the performance measures report. A poster, summarizing all aspects of the research, will be the final delivery of the research implementation.

INTELLECTUAL PROPERTY

This research does not include the creation or development of intellectual property.

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 BrM using MDT's license, and periodic updates on their ongoing bridge management configuration and input data.
- *Significant factor data*—MDT will provide de-icer, and overweight vehicle data and other potential significant factor information. Any others?
- *Bridge maintenance data*—MDT will provide relevant bridge maintenance/ rehabilitation documentation and guidance on their interpretation. MDT will provide contact information for personnel to assist with the details and practices of MDT maintenance.
- *BrM configuration*—MDT will provide updates on the configuration of BrM and cost and trigger data used to ensure significant factor analyses will be compatible.
- *Performance measures data*—MDT will provide baseline data or costs associated with their optimization analyses so that the performance of the proposed research can be quantified.
- *Review of deliverables*—MDT will review project deliverables and provide comments, suggestions, and guidance for current and future tasks of the research.
- Coordinate maintenance interview/discussion/feedback

OTHER COLLABORATORS, PARTNERS, AND STAKEHOLDERS

Mayvue Solutions, support contractor for AASHTOWare's Bridge Management software (BrM) will continue to provide technical assistance to researchers and MDT to develop and implement datasets and analyses identified in the proposed research.

PRODUCTS

Quarterly progress reports will be submitted during the proposed research timeline in addition to the following products:

1) Task 1 Report – Literature and SNBI review
2) Task 2 Report – Significant factors data and maintenance record review.
3) Task 3 Report – Significant factor/General Condition Rating (GCR) analyses
4) Final Report

   Project Summary Report
5) Implementation Report

   Performance Measures Report

   Poster
6) Journal and/or conference publications and presentations

RISKS

Identifying significant factors to improve the accuracy and reliability of the recently developed deterioration curves for Montana bridges has a high probability of success. The researchers are familiar with MDT's inspection data and experienced in running analyses and implementing research results into BrM. Risks to budget, schedule, and scope may exist if MDT's selection and refinement of BrM input data is delayed. The probability of this risk is low due to the proposed two-year duration of this project and the BrM implementation experience that exists with Technical Panel members.

IMPLEMENTATION

The proposed research is designed around implementation. Researchers are knowledgeable with MDT's bridge management software (BrM) and will be using the software to perform all general condition rating (GCR) and optimization analyses to evaluate the influence of significant factors on bridge deterioration. The research focuses on the parameters used by BrM to improve the accuracy of its optimization analyses.

There are many ways for transportation agencies to configure BrM to perform bridge management analyses and the results are a function of cost and trigger data. Depending on the final configuration selected by MDT and data used, the implementation of the significant factors research may vary. Successful implementation of the proposed research, therefore, must begin during the scheduled decision point meetings after submission of the Task 2 and 3 reports. These meetings and others scheduled as necessary, are expected to exchange updates on the configuration and data selected by MDT and parameters and adjustments made to deterioration curves in BrM used by researchers. Given researchers experience with BrM, MDT's progress on final configuration parameters, and bridge management expertise serving on the technical panel, implementation of the significant factors research is expected to be seamless.

SCHEDULE

The proposed work is scheduled to take 19 months to complete. The proposed project schedule is shown in Table 1: Project Time Schedule. The schedule is based on an anticipated start date of January 15, 2023, and an estimated completion date of August 15, 2024.

Table 1: Project Time Schedule

Activities	Dates	2023												2024							
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Kick-off Meeting	1/15/23																				
1 – Literature, standards, and specification review																					
SNBI Discussion	3/15/23																				
Task 1 Report	4/15/23																				
2 – Significant factors data and maintenance record review																					
Maintenance records review meeting	6/15/23																				
Task 2 Report	8/1/23																				
Decision Point Meeting	8/15/23																				
3 – Significant factors/General Condition Rating (GCR) analyses																					
Task 3 Report	12/1/23																				
Decision Point Meeting	12/15/23																				
4 – Final Reporting																					
4a – Draft Final Report (with cover picture)	3/1/24																				
4b – Project Summary Report	3/15/24																				
4c – Final Draft, Final Report	4/15/24																				
5 – Final Presentation and Implementation																					
5a – Final Presentation and Implementation Meeting	5/15/24																				
5b – Implementation Report	6/15/24																				
5c – Performance Measures Report	7/15/24																				
5d – Poster	7/31/24																				
Project End Date	8/15/24																				

= Milestone

= Quarterly Report Due

BUDGET

Project expenses of $98,705 are shown in Table 2. The in-state travel expenses support five project meetings in Helena that include the kickoff, Task 1-3 report, and final presentation and implementation meetings. Tasks, Meeting, and Deliverable Cost Breakout are shown in Table 3. Project expenditures during state fiscal years are shown in Table 4.

Table 2: Detailed Project Budget

Labor Expenses									
Person	Role	Kickoff Meeting	Task 1	Task 2	Task 3	Task 4	Task 5	Total	Total Cost
Damon Fick	Principal Investigator	-	-	-	-	-	-	-	-
Matthew Bell	Co-Principal Investigator	-	-	-	-	-	-	-	-
Student	Data Analysis and Processing	-	-	-	-	-	-	-	-
Business Mgr.	Budget Assistance	-	-	-	-	-	-	-	-
Admin Staff	Admin. Support	-	-	-	-	-	-	-	-
Total Labor Cost									**$77,964**
In-State Travel									$1,000
Indirect Cost @ 25%									$19,741
Total Labor Cost									**$98,705**

Table 3: Task, Meeting, and Deliverable Budget

Item	Labor	Travel	Total
Kickoff Meeting	$3,107	$200	$3,307
Task 1, Literature, Standards, and Spec. Review	$14,107		$14,107
Deliverable, Task 1 Report meeting		$200	
Task 2, Significant factors data and maintenance record review	$18,427		$18,427
Deliverable, Task 2 Report meeting		$200	
Task 3, General Condition Rating (GCR) Analyses	$14,107		$14,107
Deliverable, Task 3 Report meeting		$200	
Task 4, Final Reporting	$14,107		$14,107
Deliverable: Final Report, Project Summary Report			
Task 5, Final Presentation and Implementation	$14,107		$14,107
Deliverable: Implementation Report and meeting, Performance Measures Report, Poster		$200	
Total	**$77,964**	**$1,000**	**$78,164**

Table 4: State Fiscal Year (SFY) (7/1 – 6/30) Breakdown

Item	State Fiscal Year 2023	2024	2025	Total Cost
Salaries	$17,193	$34,386	$2,866	$54,445
Benefits	$7,427	$14,854	$1,238	$23,518
In-State Travel	$316	$632	$53	$1,000
Supplies	$0	$0	$0	$0
Total Direct Costs	$24,936	$49,872	$4,156	$78,964
Overhead	$6,234	$12,468	$1,039	$19,741
Total Project Cost	$31,170	$62,340	$5,195	$98,705

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 a Senior Research Engineer at the Western Transportation Institute at Montana State University and is licensed professional engineer in the state of Montana. He has over 14 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 MDT research project *Development of Deterioration Curves for Bridge Elements in Montana*. Final results of the research and implementation recommendations will be presented to MDT November 14.

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 [9] 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 [10]. Mr. Bell led the statistical analysis and software implementation of MDT's *Development of Deterioration Curves for Bridge Elements in Montana*. In addition to the prediction modeling used for bridge deterioration, his statistical analysis experience includes logistic regression on egg sizes to determine nest occupancy, population estimates for prairie dog colonies, random block designs for determining plant species growth along roadways using different types of erosion control blankets. In addition to analytical skills, he also has mechanical intelligence and is researching new designs for wildlife crossing infrastructure using composite materials. The results from these research areas were presented at international conferences and workshops.

A graduate or undergraduate student will support the project investigators during the Summer of 2023. They will be responsible for documenting maintenance history on Montana bridges and adding detailed maintenance records to relevant bridge datasets.

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 1	2	3	4	5	6	Total	Percent of Time vs. Total Project Hours (total hrs./person/ total project hrs.)	Percent of Time-Annual Basis (total hours/ person/ 2080 hr.)
Damon Fick	Principal Investigator	24	90	90	90	90	90	0	474	31.3%	22.8%
Matthew Bell	Co-Principal Investigator	24	150	150	150	150	150	0	774	51.2%	37.2%
Graduate Student	Data Analyiss and Processing	0	0	240	0	0	0	0	240	15.9%	11.5%
Business Mgr.	Budget Assistance	1.5	1.5	1.5	1.5	1.5	1.5	0	9	0.6%	0.4%
Admin Staff	Admin. Support	2.5	2.5	2.5	2.5	2.5	2.5	0	15	1.0%	0.7%
Total		52	244	484	244	244	244	0	1512		

Table 6 Availability

Team Member	Project/Work	Role	Percent Committed FY23	FY24
Damon Fick	Deterioration Modeling	Principal Investigator	5	0
	FRP Wildlife Crossings	Senior Research Engineer	10	10
	Consulting	Professional Engineer	15	15
		Total Commitments	**30**	**25**
Matthew Bell	**Deterioration Modeling**	**Co-Principal Investigator**	**5**	**0**
	FRP Wildlife Crossings	**Research Associate**	**10**	**10**
	DOI Roadkill observation and data systems	**Research Associate**	**10**	**10**
	Wildlife vehicle collision spatial analysis	**Principal Investigator**	**15**	**0**
		Total Commitments	**40**	**20**

FACILITIES

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

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