Literature Search 607: Quantifying Benefits of Bridge Maintenance
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Resources searched: TRID (includes RiP and MnDOT TRSs); Transport, Academic Search Premier, Google Scholar

Summary: Most results were listed by the champion in the Need Statement, and I provided full citations as requested. I added 5 other completed studies denoted by ** (pp. 3-5). Results are organized into In Progress Research and Completed Research.

Results

In Progress Research

Project Title: Bridge Element Deterioration for Midwest States
Source: Pooled Fund TPF-5(432)
Summary: The objective of this pooled fund research is to have multiple Midwest departments of transportation (DOTs) pool resources and historic Midwest DOT bridge data related to element level deterioration, operation practices, maintenance activities, and historic design/construction details. This data will provide the basis for research to determine deterioration curves.
Start date: April 24, 2020
Note: Currently in the data gathering and literature review stage.
Project page: https://rip.trb.org/view/1632303

Project Title: NCHRP 14-36: Proposed AASHTO Guide for Preservation of Highway Bridge Decks
Source: University of Colorado Boulder
Summary: The objective of this research was to develop bridge and deck preservation guides for possible adoption by AASHTO. The proposed AASHTO guides shall be developed based on data to be collected from representative agencies. At the minimum, the guide shall include: (1) a catalog of bridge element preservation actions and (2) the criteria and selection methodology of bridge preservation actions with associated costs and benefits for use in life cycle cost analysis and possible integration into a bridge management system.
Note: Currently in the final review stage for AAHSTO; may be postponed to 2021 Ballot for Approval.

Project Title: Protocols for Concrete Bridge Deck Protections and Treatments
Source: Wisconsin DOT
Summary: The objective is to develop recommendations and guidelines for bridge deck treatments that would maximize the condition and longevity.
Project page: https://rip.trb.org/View/1442345
**Completed Research**

Title: Quantifying the Impact of Bridge Maintenance Activities on Deterioration: A Survey of Practice and Related Resources (TRS 1509)
Source and date: MnDOT (2016)
Abstract: MnDOT is interested in learning about practices to quantify the benefits of various bridge maintenance treatments in relation to remaining service life and bridge life-cycle costs. In addition, the agency is interested in knowing how maintenance treatments may be incorporated into deterioration models. To support this effort, CTC & Associates conducted a literature search and a survey of domestic and international transportation agencies to learn about the type and frequency of bridge maintenance activities, practices for quantifying the impact of bridge maintenance activities on deterioration, and the use of deterioration models to examine the benefits of bridge maintenance. This document includes a summary of findings from the online survey, related documents, the full text survey responses, and three of the related documents in full in the appendices.

Title: Remaining Asset Service Life, Phase 1
Source: MnDOT (2018)
Summary: This research identified that currently the remaining service life of bridges are not updated to account for preservation actions. The research team also recommended exploring additional metrics: Asset Sustainability Ratio and Deferred Preservation Liability. The Deferred Preservation Liability metric would attempt to estimate the impacts of deferred maintenance by identifying the higher costs required as assets deteriorate and require more extensive repairs prematurely because preventive maintenance was not performed. The proposed research could potentially use the selected data to evaluate the impacts of deferred maintenance in conjunction with evaluating the benefits of performing maintenance.

Title: Bridge Deck Preservation Portal, Phase 1
Summary: The project’s goal was to develop a framework to assist engineers in selecting the optimum bridge deck preservation options. They developed a probabilistic algorithm to provide estimates for service life extension of bridge deck maintenance actions. Since there was limited empirical basis for the reduction factors used in the estimated service life calculations, the study recommends a parametric study to validate the parameters. A short description of the need for a parametric study is included in section 5.1.1, Optional Task A.1 and Section 5.2 Discussion and Next Steps.

Title: NCHRP Report 859: Consequences of Delayed Maintenance of Highway Assets
Source: TRB (2017)
Summary: The handbook was developed to assist DOTs in making bridge preservation investment decisions.
Full text via [http://www.trb.org/NCHRP/Blurbs/176740.aspx](http://www.trb.org/NCHRP/Blurbs/176740.aspx)
See also Appendix D to NCHRP 859, Procedure to Quantify Consequences of Delayed Maintenance of Bridges. This appendix indicates that “evaluating the consequences of delayed maintenance on bridges demands the evaluation of individual bridge components or elements” and “life extension provided by these [cyclical maintenance] actions is not well established in the literature”. There are examples provided, but I haven’t had a chance to review in detail.
Title: Bridge Preservation Treatments and Best Practices  
Source: Indiana DOT, Purdue University (2015)  
Summary: This research identified cost effective maintenance treatments and recommendations for timing based on results and procedures implemented by other agencies or developed through previous research. The study performed life cycle cost analyses of four alternatives to determine the cost-effectiveness of maintenance and cited previous research to identify expected service life extensions of the alternatives.  
Full text: https://doi.org/10.5703/12888284316007

Title: Deterioration Rates of Minnesota Concrete Bridge Decks  
Source: MnDOT (2014)  
Summary: Section 6.2 of the research report suggests further study could include maintenance records in order to compare general condition performance of Districts with maintenance consistency.  
Full text: http://www.lrrb.org/media/reports/201440.pdf

Title: Quantifying the Benefits of Routine and Preventive Maintenance: Survey of Practice (Preliminary Investigation, PI-0244)  
Source: Caltrans (2020)  
Summary: Caltrans surveyed other DOTs regarding methodologies for quantifying the benefits of routine and preventive maintenance.  

Title: NCHRP 14-23, Practical Bridge Preservation Actions and Investment Strategies and Appendices (Handbook for Practical Bridge Preservation Actions and Investment Strategies, Sample Catalog of Bridge Preservation Actions, Impacts and Metrics)  
Source: TRB (2014)  
Summary: This report was referenced in the Caltrans Survey of Practice. The summary indicated that the report contained feasible preservation actions, estimated cost, expected element life extension and metrics that can be used to analyze the effectiveness of bridge preservation actions.  

Title: NCHRP Report 668: Framework for a National Database System for Maintenance Actions on Highway Bridges  
Source: TRB (2010)  
Summary: May be applicable with regard to what bridge data should be collected and/or used in the proposed research.  
Full text via http://www.trb.org/Publications/Blurbs/164203.aspx

**Title: Comparative Study of Data Mining Models for Prediction of Bridge Future Conditions**  
Abstract: Highway and bridge agencies use several systematic inspection approaches to ensure an acceptable standard for their assets in terms of safety, convenience, and economic value. The Bridge Condition Index (BCI), used by the Ontario Ministry of Transportation, is defined as the weighted condition of all bridge elements to determine the rehabilitation priority for the bridge. Therefore, accurate forecasting of BCI is essential for bridge rehabilitation budgeting and planning. The large amount of data available about bridge conditions for several years enables the use of different mathematical models to predict future BCI. This research focuses on investigating different classification models developed to predict the BCI in the province of Ontario, Canada, based on the publicly available historical data for 2,802 bridges over a period of more than 10 years. Predictive models used in this study include k-nearest neighbors (k-NN), decision trees (DTs), linear regression (LR), artificial neural networks (ANN), and deep learning neural networks (DLN). These models are compared and statistically validated via cross validation and paired t-test. The decision tree
model showed acceptable predictive results (within 0.25% mean relative error) when predicting the future BCI and is the recommended option based on its performance and certainty in posterior maintenance decision making for the selected case study.

Full text within MnDOT’s firewall: https://ascelibrary.org/doi/full/10.1061/%28ASCE%29CF.1943-5509.0001395

**Title: Maintenance intervention predictions using entity-embedding neural networks**


Abstract: In this paper, we show that the historical and operational data, readily available at the agencies, is of vital importance and can be used effectively for the recommendations of maintenance advises for bridges. This is achieved by developing a machine learning system that is trained on the past asset management data and provide support to the decision-makers in the condition assessment, risk analysis, and maintenance planning tasks. We have evaluated several traditional learning algorithms as well as the deep neural networks with entity embedding to find the optimal predictive models in terms of predictive capability. Additionally, we have explored the multi-task learning framework that has a shared representation of related prediction tasks to develop a powerful unified model. The analysis of results shows that a unified multi-task learning model performed best for the considered problems followed by task-specific neural networks with entity embedding and class weights. The results of models are further evaluated by instance-level explanations, which provide insights about essential features and explain the importance of data attributes for a particular task.

Full text (open access): https://doi.org/10.1016/j.autcon.2020.103202

**Title: Optimization of Life-Cycle Maintenance of Deteriorating Bridges with Respect to Expected Annual System Failure Rate and Expected Cumulative Cost**


Abstract: Civil infrastructure systems are subjected to progressive deterioration resulting from multiple mechanical and environmental stressors. This deterioration process is developed under uncertainties related to load effects, structural resistance, and inspection outcomes, among others. In this context, life-cycle optimization techniques provide a rational approach to manage these systems considering uncertainties and several budgetary and safety constraints. This paper proposes a novel optimization procedure for life-cycle inspection and maintenance planning of aging structures. In this procedure, the structural system effects are accounted for by modeling the structure as a series, parallel, or a series-parallel system whose components are subjected to time-dependent deterioration phenomena. Different possible repair options are considered depending on the damage state and the outcomes of each inspection. For each component, essential or preventive maintenance aiming at reducing the system failure rate are performed when inspection results indicate that the prescribed threshold damage levels have been reached or violated. Otherwise, no repair is performed. Optimum inspection and maintenance plans are formulated by minimizing both the expected system failure rate and expected cumulative inspection and maintenance cost over the life-cycle of the structure. The proposed approach is applied to an existing bridge.

Full text within MnDOT’s firewall: https://ascelibrary.org/doi/full/10.1061/%28ASCE%29ST.1943-541X.0000812

**Title: Synthesis of Service Life Prediction for Bridges in Texas**

Source: University of Houston and TxDOT (2019)

Abstract: In procurement requirements for design-build project contracts for bridge structures, the Texas Department of Transportation (TxDOT) may implement a 100-year service life requirement. However, there are no indicated measures or any technical recommendations that provide directions to satisfy the given requirement of service life. In addition, TxDOT and consultants use TxDOT recommendations for durability to improve performance during service life of design-bid-build and design-build projects but no quantitative methods or codified guidance is available to validate how the enhanced service life requirements are met. Further, the state of Texas has large number of existing old bridge thus the evaluation of the remaining service life of these bridges is a very important economic issue for TxDOT. The
replacement of all these bridges is not possible since the available financial resources are limited. Therefore, it is very essential to prioritize the repair works based on the estimated remaining service life. As a result, this research study has been conducted to obtain information about state-of-the-art and state-of practice of bridge service life prediction. The research team gathered and analyzed the relevant information on various topics related to service life prediction which can be utilized as guidelines while dealing with the determination of service life of old as well as new bridges. The extensive literature survey conducted by the research team provides valuable information for TxDOT which can be helpful for service life prediction of bridges in the state of Texas. By utilizing the collected information under the scope of the project, the following benefits can be achieved: (1) This project would provide guidance on managing available funds efficiently for the required repair activities using the data on condition of the bridges. (2) The review of the available information obtained from different sources would provide better understanding of various deterioration models used for predicting service life, inspection checks and methods, maintenance practices and rehabilitation or replacement requirements for bridges, and would enhance the knowledge on achieving and extending the service life of bridges in Texas. (3) The output from this research project would be beneficial for maintaining the existing bridges in a good condition, improving their service life to make them economically efficient and determining strategies to achieve design service life for newly constructed bridges.

Full text: https://library.ctr.utexas.edu/hostedpdfs/uh/0-6938-1.pdf

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**Title:** Bridge maintenance prioritization using analytic hierarchy process and fusion tables  

Abstract: Due to budget constraints of Departments of Transportation (DOTs) and a significant number of deficient bridges around the U.S., there is a need for a systematic approach to more efficiently and optimally allocate limited resources for bridge maintenance efforts. This paper presents a GIS-integrated decision-making framework to prioritize bridge maintenance by using aggregated bridge ratings and average daily traffic (ADT). The aggregated bridge ratings were the weighted average of deck, substructure, superstructure, and scour ratings; the weights were determined by analyzing a group of bridge experts' comparisons of the relative importance of deck, substructure, superstructure, and scour with respect to bridge resiliency, riding comfort, safety, and serviceability using the Analytic Hierarchy Process (AHP). Then, a geographical information system (GIS) user interface that integrated Google™ Fusion Tables, Google Maps, and the decision-making criteria was created to visualize the priority of the bridges for maintenance. Through a case study and validation with a division bridge engineer at Oklahoma DOT (ODOT), the developed framework was proven to be a robust and reliable approach. This study contributes to industry practice by providing a systematic and implementable approach to facilitate state DOTs' decision-making for bridge maintenance without requiring extra bridge data collection effort. Highlights • Developed an integrated GIS for bridge maintenance prioritization decisions • An aggregated bridge rating was determined through a multi-criteria AHP • Safety was the top criteria for decision-making • Deck rating received the highest weight for non-water-crossing bridges • Substructure rating received the highest weight for water-crossing bridges

Full text available upon request