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Project Title

Development of Age and State Dependent Stochastic Model for Improved Bridge Deterioration Prediction

University

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Research Needs

Reliable and accurate assessment and prediction of the condition deterioration of bridges is critical for effective bridge preservation, which can help extend the service life of bridges. Bridge inspection serves as an important task in assessing the current condition of bridges. The inspection data over time can also help establish condition deterioration models to predict bridge conditions in the future. The deterioration models combined with the information on the current condition can help guide inspection, maintenance, repair, and rehabilitation planning, and can also be incorporated for risk and life-cycle analysis. Therefore, it is very important to develop deterioration models that can better predict the condition deterioration of bridges and bridge elements.

Bridge deterioration is influenced by many factors and is usually a result of many complex (deterioration) processes, e.g., corrosion, concrete degradation, cracking, fatigue (Agrawal et al. 2010). In the absence of good mechanistic-based deterioration models, deterioration models (e.g., Markov chains, Weibull-based models) established based on bridge inspection data are commonly used by state DOTs for bridge asset management and have been incorporated in bridge management systems such as AASHTOWare Bridge (Agrawal et al. 2010). Existing Markov deterioration models in bridge management systems usually assume stationary transition probability matrix (i.e., assuming homogenous deterioration process), while in reality the deterioration process is non-homogeneous (Dinesh Devaraj 2009) and the deterioration rate could be different for each bridge or bridge element, considering the differences in influencing factors (or explanatory variables) such as age, climate environment, protective systems, and other external conditions (e.g., traffic conditions). Also, it is assumed that the condition does not improve (i.e., the “do nothing” assumption) and there is no jumping in condition states (which could happen depending on the inspection interval and the deterioration rate) (Kallen 2009). Typically, optimization approaches are used to establish the transition probability matrix;

however, they suffer from drawbacks such as noninvertible matrix and negative transition probabilities (Wellalage et al. 2013). More general stochastic models that can capture the non-homogeneous nature of the deterioration process are needed, and so are calibration approaches that can establish proper transition probability matrices.

In terms of inspection data, most of the states have been collecting some element-level bridge condition data (Rehm 2013). Although there is more than a decade of inspection data (Farrar and Newton 2014; Rehm 2013), the data have not been fully utilized. One key issue that needs to be addressed is the large variability/uncertainty in the inspection data (stemming from various sources). One contributing source is the subjectivity of the inspection process. For example, it has been reported in (Graybeal et al. 2003) that out of the assigned condition ratings for the same structure by 49 bridge inspectors from 25 state departments only 68% of them fall within ±1 interval around the mean while an interval of ±2 would be needed to capture 95% of the assigned ratings. How to incorporate the uncertainties in the inspection data in a systematic way is an important issue that needs to be addressed to establish more robust deterioration models. This aspect has not been explicitly considered. Research is needed in how to effectively leverage the inspection data to establish better deterioration models and to predict bridge conditions at the element-level to guide cost-effective maintenance decision making.

Overall, there is a need to develop systematic and robust approaches that can extract useful and accurate information from the inspection data and can accommodate more general models for the deterioration process.

To address the above challenges, this project aims to develop general age and state-dependent stochastic deterioration models using inspection data for improved element-level condition deterioration prediction of bridges. Also, a Bayesian framework will be established to facilitate systematic and robust calibration of the deterioration models incorporating the inspection data and various uncertainties.

Research Objectives

The project will pursue the following objectives:

1) Proper probability models will be established to explicitly quantify the variability/uncertainty (measurement errors) in the visual inspection data for each condition rating through analyzing data in the literature. Different probability models will be investigated and the one that can best capture the variability will be adopted.

2) Non-homogeneous age and state-dependent Markov deterioration models will be established that can explicitly consider the impact of age, condition history, environment, traffic conditions, and other important factors.

3) A Bayesian framework will be developed for calibration of the non-homogeneous Markov deterioration models based on inspection data with explicit modeling of the model error and measurement error in the inspection data.

4) The calibrated deterioration models will be validated using actual inspection data and compared with existing models. In the end, the deterioration model and the calibration (including stochastic sampling) will be packaged into a GUI tool that can be easily adopted.

Research Methods

Early stages of this project will focus on obtaining, organizing, and preprocessing the bridge inspection data. Condition ratings for different elements and components will be collected for bridges in Colorado. Preprocessing of the raw inventory data will be carried out. The preprocessing of the inspection data is an important step to obtain proper and usable data for calibration of deterioration models.

Although the condition ratings in the inspection data are deterministic, there is large variability associated with them. Next, through analyzing data in the literature on condition ratings for same bridges from different inspectors, different probability models will be investigated and proper models will be established to best quantify and capture the uncertainty in the inspection data.

To develop the stochastic Markov deterioration model, the transition probability matrix needs to be established. While homogeneous Markov model has been studied, it cannot capture the impact of age, condition history (e.g., the amount of time in a certain condition rating), climate environment, protective systems, and other external conditions (e.g., traffic conditions), which have been shown in literature to have a big impact on the deterioration rate. Therefore, non-homogeneous Markov model will be explored to capture the nonstationarity in the transition probabilities. Specifically, the transition probabilities will be modeled as functions of the above factors to explicitly consider their impact. Instead of specifying the model forms, surrogate models will be established for the transition probabilities. The optimal model form will be determined through Bayesian updating and model selection.

Next, a Bayesian approach will be developed to calibrate the stochastic deterioration model. Since the observation (inspection data) is at the condition rating level, Bayesian hierarchical model will be established for calibration of the parameters in the surrogate model for the transition probabilities. This approach will allow explicit consideration of the uncertainties in measurement error (i.e., uncertainties in inspection data) and model error (i.e., error in the deterioration model). Advanced stochastic sampling (e.g., Markov Chain Monte Carlo or MCMC) will be adopted to establish the posterior distribution of the model parameters. This is more beneficial compared to optimization or maximum likelihood estimates since it could provide the confidence interval for the estimates. The condition prediction using the established model will have a probabilistic nature too and can provide confidence interval for the condition estimation. This information can be directly further integrated into risk and life-cycle analysis.

In the end, the performance of proposed deterioration models will be assessed through real bridge inspection data in Colorado. Comparison with existing models will also be conducted to show the advantages of the proposed models.

Expected Outcomes

This project will provide non-homogenous Markov deterioration models that can better predict bridge conditions and capture the impact of various important factors (explanatory variables). It will also provide a general approach for establishing improved element-level deterioration models using inspection data and incorporating the associated uncertainties. The developed deterioration models can be incorporated in existing bridge management systems and the condition prediction results can be further used to guide risk-informed cost-effective maintenance and inspection decision making for better preservation of bridges.

Relevance to Strategic Goals

State of Good Repair
It will provide deterioration models that can predict the condition of bridge elements more accurately; and the improved condition prediction information can be used to better guide or establish optimal cost effective maintenance planning to help preserve and extend the service life of the transportation system in the long-term.

Educational Benefits

A graduate research assistant will be hired to conduct the research described in this proposal.

Tech Transfer

The research findings will be disseminated through presentations in conferences and seminars. Also, a graphical user interface will be developed to facilitate adoption of the developed approach by bridge asset management personnel and a workshop will be organized to help the implementation.

Work Plan

The specific tasks below will be completed as part of this project.

1) Inspection data collection and preprocessing. This task includes collecting condition ratings (inspection data) for different elements and components for bridges in Colorado, and preprocessing of inspection data. The expected completion date for this task is 4 months from the project start date.

2) Literature review and establish model for quantification of uncertainty in bridge inspection data. The expected completion date for this task is 8 months from the project start date.

3) Develop non-homogeneous Markov deterioration models. This task include: identify the important factors to consider in the model; establish surrogate model for the transition probabilities as function of the identified important factors; establish the stochastic deterioration model. The expected completion date for this task is 12 months from the project start date.

4) Develop the Bayesian framework for calibration of the deterioration models. Markov Chain Monte Carlo Simulation will be used to generate posterior samples for the model parameters. The expected completion date for this task is 20 months from the project start date.

5) Validate the models using actual inspection data and compare the models with existing deterioration models. The expected completion date for this task is 20 months from the project start date.

6) Disseminate the project findings through final report, journal publications. The expected completion date for this task is 24 months from the project start date.

Project Cost

Total Project Costs:	$106,000
MPC Funds Requested:	$ 53,000
Matching Funds:	$ 53,000
Source of Matching Funds:	Faculty time and effort and faculty start-up funds

References

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