UTC Project Information	
Project Title	MPC-536 – Development of Age and State Dependent Stochastic Model for Improved Bridge Deterioration Prediction
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Brief Description of Research Project	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: 1. Establish proper probability models to explicitly quantify the variability in the visual inspection data 2. Establish non-homogeneous age and state dependent Markov deterioration models

	3. Develop a Bayesian framework for calibration of non-homogeneous Markov deterioration models based on inspection data 4. Validate the deterioration models using actual inspection data The project will pursue the following objectives. First, 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. Second, 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. Then 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. 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.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	
Impacts/Benefits of Implementation (actual, not anticipated)	
Web Links • Reports • Project Website	