ABSTRACT

Efficient pavement management is critical for ensuring roadway safety, extending pavement service life, and optimizing maintenance investments. However, current pavement management systems (PMS) often face limitations in pavement performance modeling, cost-effectiveness evaluation, and safety integration, especially under conditions of data scarcity and uncertainty. This dissertation addresses these challenges by applying Bayesian inference with Markov Chain Monte Carlo (MCMC) methods across three interrelated studies: deterioration forecasting, life-cycle cost analysis, and crash risk modeling. Chapter 2 enhances traditional Markov chain models by incorporating Bayesian MCMC to generate posterior transition probability matrices under sparse data conditions. This approach improves the reliability of pavement condition forecasts by integrating prior assumptions with observed data, enabling uncertainty quantification and long-term service life prediction with credible intervals. Chapter 3 evaluates the performance and cost-effectiveness of two preventive maintenance overlay types: Stone Matrix Asphalt (SMA) and Hot Mix Asphalt (HMA). Using both deterministic and probabilistic life-cycle cost analysis (LCCA), the study shows that SMA overlays typically provide longer service life and greater cost savings, particularly on pavement sections in fair to poor pre-overlay condition. A decision-support probability index is introduced to account for variability in performance and cost inputs, offering a more robust framework for treatment selection. Chapter 4 investigates the relationship between pavement condition and crash frequency and severity using a Multicategory Negative Binomial (MNB) model integrated with Bayesian MCMC methods. The analysis reveals that deteriorated pavement surfaces significantly amplify the effects of traffic volume, speed, and geometric features on crash risk. The Bayesian modeling approach proves especially valuable in data-sparse conditions, supporting more accurate and interpretable inference for safety-related decision-making. Collectively, the dissertation presents a unified framework that advances PMS by improving pavement performance modeling, enabling probabilistic cost assessments, and incorporating safety risk into maintenance prioritization. The findings support risk-based, data-informed strategies that help transportation agencies allocate resources more effectively and enhance the roadway network’s economic and safety performance.