STRATEGIC PRIORITIZATION AND PLANNING OF FOR MULTI-ASSET TRANSPORTATION INFRASTRUCTURE MAINTENANCE, REHABILITATION, AND IMPROVEMENTS: PHASE 1 – PRIORITIZATION THROUGH OPTIMIZATION

This document is a technical summary of the CIAMTIS technical report, *Strategic Prioritization and Planning of Multi-Asset Transportation Infrastructure Maintenance, Rehabilitation, and Improvements: Phase 1 – Prioritization through Optimization* (2021).

INTRODUCTION

The objectives of the first phase of this project are to explore and develop:

- Condition monitoring and forecasting capabilities.
- Algorithms for prioritizing and planning maintenance, repair, and rehabilitation options for multiple assets.
- Methods that explicitly account for uncertainty in state predictions.
- Understanding the context for implementing such tools.

METHODOLOGY

The research methodology for Phase 1 is summarized in Figure 1.

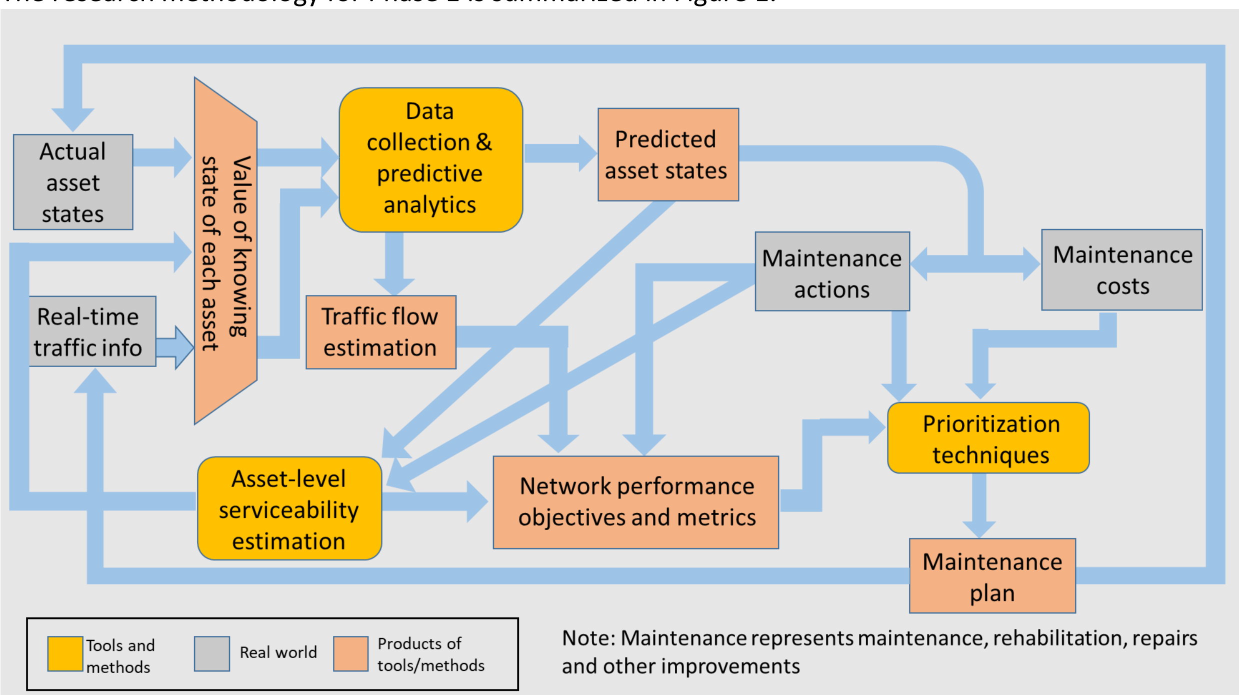

Figure 1. Project Methodology

Key features include:

- Conducting the research in the context of an asset management framework as shown in Figure 1.
- Exploring crowdsourced vehicle response data for condition assessment including the development of a framework for data processing and interpretation.
- Development of a detailed, realistic deterioration modeling framework.
- Assembly of real data on maintenance costs and actions, and the reliability and cost of inspection data.

- Formulation and solution of a multi-asset class roadway improvement scheduling problem that considers capacity loss during improvement actions (i.e., downtimes), traffic impacts of improved serviceability after the actions are complete, and uncertain deterioration mechanisms jointly across multiple asset classes.
- Assessment of the Value of Information (VoI) and the Value of Structural Health Monitoring (VoSHM) in this context.
- Application to an example problem and definition of next steps to be completed in Phase 2.

PRODUCTS

Products include:

- Artificial intelligence methods for extracting roadway quality metrics from crowdsourced smartphone data, which provide the ability to track roadway performance metrics over time for predictive purposes.
- Predictive models for multi-asset (pavement and bridge deck) condition metrics and network performance considering maintenance and rehabilitation actions, as well as monitoring data and their precision.
- Multi-asset infrastructure system management for scheduling actions through dynamic programming approaches and deep reinforcement learning. The solution uses a bilevel, stochastic mathematical program with embedded Markov decision process (MDP) concept and traffic system representation that enables assessment of state-based maintenance strategies and development of a priori prioritization and scheduling.
- A framework for assessing the Value of Information to support structural health monitoring.

EVALUATION RESULTS

Asset management is a data-driven process aimed at delivering the best levels of service for roadway assets given the available resources. Current practices vary in sophistication, so there are many opportunities to improve the data collection process, the models used to support decisions that select actions, and the process used to determine the most appropriate action at any point in time for an asset. However, there are also significant barriers to implementation, including the role played by proprietary data and software in the asset management process, skepticism of agencies toward complex optimization results, and the organizational structures that silo decision making by asset type.

This project demonstrated the applicability of new types of data, including processing; models for asset deterioration and activity cost and duration that reflect current practices; strategies for assessing the value of information; and an optimization model for scheduling activities that captures uncertainty in deterioration, disruption to users, and cross asset tradeoffs.

The use of crowdsourced vehicle response data shows promise as a low-cost way to collect asset data at high frequency. An unsupervised learning framework that combines Pareto-optimized wavelet featurization with clustering is developed to provide low-cost pavement condition data using methods that are general and scalable. For example, Figure 2 shows two roads where the vehicle response data labeled the roads as having patching. While there may be some limitation regarding fine-grained pavement defects, the framework can be extended to capture data from multiple vehicles over time.

A detailed, realistic deterioration modeling framework, following principles of Markov decision processes and partially observable MDPs (POMDPs), is developed for both pavements and bridges. The framework uses common condition measures (IRI and CCI for pavements, and deck condition for bridges) and four maintenance categories (Do Nothing, Minor Repair, Major Repair, and Reconstruction) to determine state transition probabilities and costs. Condition data are also dependent on the inspection type: no inspection, low-fidelity, and high-fidelity inspections. The accuracy of the information and the cost of inspection are associated with each inspection type.

Figure 2. Two Roads with Patching Labels

A methodology to compute the Value of Information (VoI) and the Value of Structural Health Monitoring (VoSHM) within the context of MDP/POMDPs is presented. Respective stepwise and long-term value-based information metrics are analyzed, and their relations to the POMDP decision-making framework are provided. These results provide quantitative answers to the practical question of how much condition information is worth and how that information affects decisions.

A multi-asset class roadway improvement scheduling problem that considers capacity loss during improvement actions (i.e., downtimes), traffic impacts of improved serviceability after the actions are complete, and uncertain deterioration mechanisms jointly across multiple asset classes is formulated and solved. The solution found using a cutting-edge, deep reinforcement learning method for an illustrative example shows the value of decisions integrated over asset classes (in this case, pavements and bridge decks) and the importance of user disruption. Figure 3 shows the difference between stochastic and deterministic models for an example network.

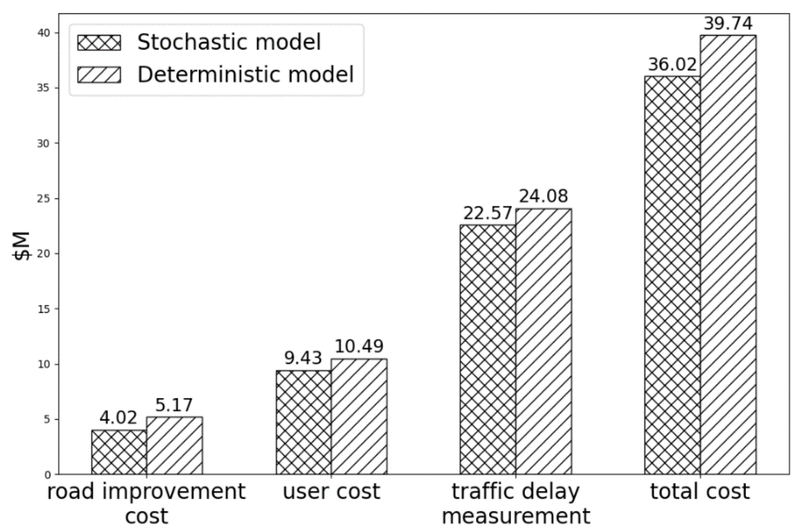

Figure 3. Influence of Stochasticity on Optimal Improvement Cost Schedule

CONCLUSION AND IMPLEMENTATION

The project results show promise. Phase 2 of the research will extend the results of Phase 1 to:

- Extend developed condition monitoring and forecasting capabilities to exploit continuously sensed, multi-sourced data technologies for persistent condition updates on multiple assets from varying vehicle types.
- Extend methods from Phase 1 for capturing roadway characteristics from sensed data for continuous, multi-vehicle sensing implementations.
- Extend the MDP upper-level conceptualization of the prioritization problem to a POMDP model to incorporate data uncertainty and continuously sensed and updated-predicted asset condition states.
- Create methods that explicitly account for uncertainty in state predictions with data updates.
- Develop a solution algorithm for adapting decisions that exploit updated information as captured in the stochastic, bi-level program with POMDP at the upper level and user equilibrium (UE) at the lower level.
- Employ developed methods to evaluate and demonstrate the potential benefits for updated prioritization and policy options.
- Create simpler, intuitive tools, prescriptive guidelines, and/or implementable policies based on knowledge gained from earlier tasks that can be deployed in complex roadway networks.

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