Mechanistic Load Restriction Decision Platform for Pavement Systems Prone to Moisture Variations

National Road Research Alliance

MnDOT Contract 1034192 Task 1: Initial Memorandum on Expected Benefits and Potential Implementation Steps

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TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 RESEARCH PROJECT ABSTRACT AND OBJECTIVES

Excess moisture in base and subgrade soil has detrimental impacts on longevity and serviceability of pavements. Seasonal ground water level fluctuations, inundations due to storms and post-storm recess, frost penetrations and freeze-thaw effects lead to continuous moisture hysteresis and change of stress states in pavement foundation. Reliance of current analysis and design procedures on approximate empirical approaches limits their ability to incorporate moisture-dependent material response and to conduct real-time and forecasted pavement capacity and load restriction analyses. To reliably evaluate pavement bearing capacity and performance and to provide tools for pavement engineers to assess vulnerability to damage and make traffic allowance decision during and after periods of excessive moisture, a load restriction decision-platform is proposed. This platform encompasses three core attributes: (1) A mechanics-based model that correctly captures soil and base response to saturated and unsaturated soil states. It will be validated using actual field pavement tests such as MnROAD and can be further enhanced through the use of physically modelled scaled pavement sections; (2) A system-based approach to integrate impacts of various stressors (soil moisture state, vehicular loads and volume, climatic conditions etc.), current pavement conditions, subgrade properties, hydro-geology, and short-term climate forecast. Due to large number of variables and their inter-dependencies, a system dynamics modelling approach can holistically capture all significant variables and provide a user-friendly system for pavement load restriction decision making; and (3) A policy-informed decision-platform that incorporates inputs from transportation agencies and users to facilitate its implementation and to realize the cost-effectiveness of such mechanistic approach.

1.2 ORGANIZATION OF THE MEMO

This memorandum is organized in three chapters. The subsequent two chapters provide information on expected benefits of this study as well as the planned implementation steps.

CHAPTER 2: EXPECTED RESEARCH BENEFITS

2.1 HOW DOES THIS RESEARCH BENEFIT TAXPAYERS OF THE NRRA MEMBER STATES?

At present, a majority of roadway load restriction (LR) protocols in NRRA state DOTs depend on either use of subsurface soil information, historic seasonal moisture data, or observational post-flooding evaluation. In addition, neither of these methodologies provide robust estimate of actual pavement structural load carrying capacity and these approaches do not account for climate variations within the assessment of roadways in post-storm scenarios. Due to empirically driven nature of the LR protocols there is potential for imposing either over- or under- restriction on roadways. When over-restriction is used it results in losses to businesses due to limits imposed on trucking and other mean of freight transport. When there is under-restriction scenario, it substantially limits the life-span of roadway infrastructure resulting in excessive pavement repair, rehabilitation and reconstruction costs. Thus, both of these scenarios would result in substantial economic loss to National Road Research Alliance (NRRA) member state entities.

The proposed research will develop a mechanistic framework to improve robustness of the load restriction decision process. Through use of mechanistic relationships within a system dynamics framework, the proposed research will enhance the pavement load capacity assessment. The system dynamics framework allows for a flexible platform that can incorporate multi-variant effects and provide a tool with ability for forecasting. This tool will allow transportation officials to plan for storm-related and seasonal load restrictions into future. Finally, due to incorporation of both geo-mechanics and climate data, the tool will also have ability to aid in making decisions regarding post-flooding road opening. This ability will have tremendous impact on NRRA state DOTs' taxpayers as it directly impacts post-flooding access to affected areas.

2.2 INITIAL PROJECTION OF EXPECTED BENEFITS

The following benefits are currently identified to be achieved upon completion of the project:

- **Decrease Engineering/Administrative Costs:** The proposed decision toolkit will facilitate and accelerate decision making process by state DOTs with regards to when the road should be opened after flooding or after seasonal thawing. This will result in less personnel time for both field assessments and analytical evaluations.
- **Lifecycle:** The research will provide more accurate evaluation of pavement performance both under current condition and short-term future forecasted climatic (precipitation, temperature, etc. within a week), which would increase the lifespan of roadways while maintaining higher quality pavements for a longer time. Furthermore, by imposing load restrictions during vulnerable states, pavement longevity will be extended.

- **Operation and Maintenance Saving**: The results of this project including the sensitivity analysis, pavement performance assessment, and the toolkit will reduce the maintenance costs of roadways by providing a decision platform for load and traffic restrictions when the roads are in their vulnerable state. Both of these aspects will result in lowering of maintenance needs and costs.
- **Reduce Risk:** The results from system dynamics sensitivity analysis through a holistic, multi-variable and mechanistic pavement response assessment will increase the reliability of the end product, which will reduce the risk of substantial damage to roadways.

2.3 EXPECTED TECHNICAL OUTCOME

The following list summarized the expected benefits of this research as discussed with TAP members during 10/31/2019 kick-off web meeting:

- Develop a mechanistic framework to improve robustness of the load restriction decision process.
- Improve post-flooding and seasonal pavement capacity assessment.
- Implement a flexible platform that incorporates multi-variant effects with forecasting capability. This will be achieved through system dynamics modeling and analysis.
- Develop a toolkit, this is validated using field data, for load restriction decision, especially for post-flooding road restrictions.

CHAPTER 3: POTENTIAL IMPLEMENTATION STEPS

3.1 SUMMARY OF RESEARCH METHODOLOGY (SCOPE)

This project will develop a mechanistic pavement load restriction decision framework using system dynamics approach. The main outcome of this project will be a toolkit for pavement engineers to make decisions regarding load restrictions due to storm-related and seasonal soil moisture variations, including those during post-flooding instances. The use of system-based approach is necessary to integrate impacts of various stressors (soil moisture state, vehicular loads and volume, climatic conditions etc.), current pavement conditions, subgrade properties, hydro-geology, and short-term climate forecast. Due to very large number of variables and their inter-dependencies, a system dynamics modelling approach can holistically capture all significant variables and provide a user-friendly tool for pavement load restriction (both in current time and for future forecasting) decision making. The proposed research is divided into 10 tasks. In addition, to further enhance the developed decision framework with more detailed mechanistic pavement performance data and to incorporate systematically controlled and monitored pavement response, a subsequent project phase could include series of physically modeled and tested, scaled and full scale pavement sections

3.2 RESEARCH IMPLEMENTATION STEPS

The implementation strategy and project flow chart is schematically shown in Figure 3-1.

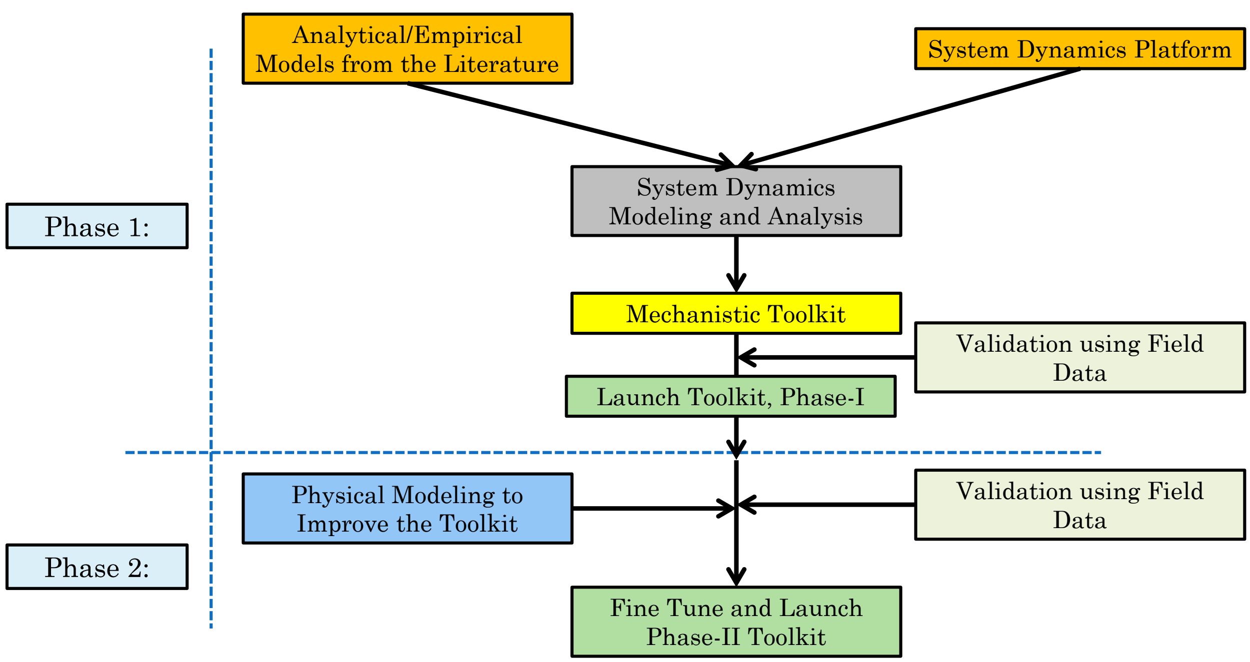

Figure 3-1 Implementation Flow Chart

The proposed comprehensive pavement assessment platform incorporates various components with major effects on pavement systems including:

- Pavement structural properties such as pavement layer types, modulus, Poisson's ratio, and thickness.
- Climatic conditions such as rainfall induced water infiltration in unsaturated soil zone.
- Soil properties such as type, density, plasticity, resilient modulus, and soil-water retention characteristics.
- Loading conditions such as vehicle type and load repetition.

Systems dynamics will be implemented using a computer software, i.e. Vensim. The goal is to run a sensitivity analysis and refine the LR implementation strategies based on key players. Vensim is a simulation software for improving the performance of real systems. It is capable of conducting sensitivity analysis, reality checks, statistical modeling, and instant outputting. Different models/equations that are planned to be reviewed in Task 2 will be included in this model.

After completing the system dynamics modeling and analysis, the information will be used for developing a user-friendly toolkit for load restriction decision. This toolkit is expected to facilitate user interface with different expertise level and different output formats. Then, the toolkit will be calibrated based on available MnROAD data or other post-flooding road assessment studies. This will complete this project and a Phase-I version of the toolkit will be launched for community input and assessment. As shown in Figure 3-1, Phase 2 of the project is expected to involve physical modeling of inundated pavements, which would include both scaled and full-scale models. These will be very helpful in better evaluation of the toolkit, improve the system, and refine some of the underlying constitutive and material models, which would contribute to Phase 2 toolkit launch.

3.3 BENEFIT IMPLEMENTATION AND QUANTIFICATION

The benefits listed in Section 2.2 will be implemented and quantified through the following approaches:

- Task 2 will provide a comprehensive assessment of current state-of-the knowledge and practice. This would be important in identifying the need for better models to **reduce risk**, which will be discussed in the Task 2 Deliverable.

- Task 4 will identify key factors in post-inundation pavement response (with a focus on post-flooded conditions) through a system dynamics sensitivity analysis. The results will provide a quantifiable measure of how a mechanistic model will improve the current approaches by state DOTs. Thus, the outcome would clarify how the **lifecycle** can be impacted by such model, **maintenance costs** will be saved, and the **risk** of damage to roadways will be reduced.

- Task 5 will generate a toolkit that can be used by state DOTs to decrease the **engineering/administrative costs**. The calibration/validation step that is scheduled for Task 6, in comparison with currently available field or lab data, will shed light and quantify the role of such toolkit in achieving the listed benefits including **lifecycle**, **maintenance saving**, and **reducing risk**.