Partnered Pavement Research Center

Annual Report

Fiscal Year 2020-2021

California Department of Transportation/

University of California Pavement Research Center

Caltrans

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About the Partnered Pavement Research Center

The Partnered Pavement Research Center (PPRC) is operated by the California Department of Transportation (Caltrans) and the University of California Pavement Research Center (UCPRC).

Caltrans Mission

Provide a safe and reliable transportation network that serves all people and respects the environment.

UCPRC Mission

Research, development, and implementation to support decision-making by Caltrans and other partners to provide economically and environmentally sustainable, equitably distributed, multifunctional pavement systems.

Caltrans Vision

A brighter future for all through a world-class transportation network.

UCPRC Vision

Caltrans and other partners will have continuously improving state-of-the-art pavement technology to maximize the level of service to all users of California's pavements, while optimizing the results from expenditures on pavement infrastructure and minimizing the environmental impacts. These goals will be accomplished by strategic planning for current and future challenges and opportunities, and by execution of projects from idea to implementation through conceptual studies, research, development, implementation support, and operational support.

Welcome to the FY 2020-2021 Annual Report for the Partnered Pavement Research Center!

The following are highlights of work that the Caltrans/UCPRC Partnered Pavement Research Center (PPRC) implemented during the last fiscal year:

Updated mechanistic-empirical pavement design methods for asphalt (*CalME*) and concrete (*Pavement ME*) surfaced pavements by calibration with Caltrans field performance data.

The calibrations took a new "big data" approach developed by the UCPRC that made use of Caltrans investments in improved data for the pavement management system (*PaveM*).

Guidance for selection of projects, design, and construction for full-depth and partial-depth in-place recycling.

These guidelines are tied to an intensive effort by Caltrans to increase recycling for projects where it will provide life cycle cost and environmental benefits.

Release of the new web-based version of *CalME* (version 3.0), the mechanistic-empirical pavement design software for asphalt surfaced pavements.

CalME was developed by the UCPRC with Caltrans funding, and it is being used on large pavement rehabilitation and reconstruction projects around the state.

Use of performance-related specifications (PRS) and new testing methods for asphalt materials for the reconstruction of Interstate 5 through Sacramento.

An asphalt mix with 25% recycled asphalt pavement content was used for the main structural layer. Life cycle cost savings of $37 million to Caltrans were identified from use of the innovative and PRS-specified materials as part of the Road Repair and Accountability Act of 2017 (SB 1). The UCPRC was given a Special Recognition and Appreciation Award as a Caltrans Efficiency Champion for supporting this project.

Implementation of concrete overlay on asphalt pavement by Caltrans on a pilot project on State Route 113 in Yolo County.

The project used guidance from research and accelerated pavement testing by the UCPRC that checked this strategy, which has been used in states with wet and humid climates but not in California's dry environment.

Updated environmental Life Cycle Assessment for Pavement (*eLCAP*) web-based software from the UCPRC.

eLCAP was reviewed by external reviewers, and preparations were made for piloting the software. *eLCAP* is a web-based tool to calculate the project-level environmental impacts (following the US Environmental Protection Agency's TRACI indicators) of the materials, construction, maintenance, rehabilitation, use, and end-of-life stages of pavement infrastructure.

Case studies demonstrating an approach developed by the UCPRC for multi-criteria decision support of alternative strategies for reducing greenhouse gas emissions.

This approach uses environmental life cycle assessment and life cycle cost analysis to calculate "bang for the buck" for each strategy and help prioritize a set of strategies to maximize investments. A parallel project funded by Caltrans through the National Center for Sustainable Transportation demonstrated use of the approach for local government decision-making through case studies in Los Angeles and Yolo counties.

New performance models for cracking and smoothness for the Caltrans pavement management system.

Performance models used to predict pavement conduction for use in planning of future maintenance and rehabilitation were updated using three more years of pavement condition data and new modeling methods.

Technical support to Caltrans for implementation of environmental product declarations (EPDs) for transportation materials as called for in the Buy Clean California Act (AB 262).

The UCPRC provided technical support for implementation of this legislation, which requires materials producers to provide EPDs, declarations of environmental impacts based on cradle-to-gate life cycle assessment. Support included help in creating the framework, database, and process documents and review of the quality and consistency of data in the EPDs.

Field data collection and analysis to understand the effects of pavement structure type on the fuel use of vehicles.

Field data were used to develop empirical models for fuel use. Mechanistic structural response models and software code were also developed.

Updates to the *Caltrans Highway Design Manual* by the UCPRC.

These updates reflect the transition to mechanistic-empirical design methods, the use of performance-related specifications, and research on in-place recycling and other improvements in pavement technology and practice.

Continued support to Caltrans operations of the pavement management system, mechanistic-empirical design, life cycle assessment, and life cycle cost analysis software and guidance.

This support task provides real-time help with questions from software users, updating of software in response to user comments, and development and periodic updating of guidance documents and training.

Continued operation of the calibration and certification centers for Caltrans and industry smoothness and falling weight deflectometer (FWD) testing personnel and equipment.

The UCPRC provided staff for testing, calibration data analysis, and certifications of profilers at the profiler certification test section in Sacramento and the FWD certification center at the UCPRC research site in Davis.

This fiscal year's research, development, and implementation support is from both the 2017-2020 PPRC contract, completed in September 2020, and from the current 2020-2023 contract. The following sections of this annual report include updates on current projects and summaries of reports published this fiscal year.

The UCPRC staff, students, and faculty and Caltrans staff will continue to work together to improve pavements, enhance their contributions to the quality of life across California, and reduce their environmental impacts.

John Harvey, Director and Principal Investigator, UCPRC
David J. Jones, Associate Director and Co-Principal Investigator, UCPRC
Jeremy D. Lea, Co-Principal Investigator, UCPRC
Angel Mateos, UC Berkeley Director and Co-Principal Investigator, UCPRC
UCPRC staff and students

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Introduction: Pavement Research Processes and Status

This annual report provides an overview of the strategic plan, research roadmaps, current research areas, and projects for the Caltrans/UCPRC Partnered Pavement Research Center (PPRC) and progress over FY 2020-2021.

Strategic Planning and Contract Development Process and Documents

Caltrans and the UCPRC have a robust process for working with industry and other partners to strategically identify, prioritize, plan, and communicate how to solve current and future challenges and take advantage of opportunities. The main strategic planning process is conducted as part of the preparation of each PPRC contract, typically every three years. The strategic planning documents are reviewed and updated as needed on an interim basis during the three-year contracts.

Strategic Planning Elements

The **Strategic Planning Process** is managed by the Caltrans Division of Research, Innovation and System Information (DRISI); the Caltrans Division of Maintenance/Office of Pavement; and the UCPRC. The outcomes of this process include updated and new Pavement Research Roadmaps and a prioritized list of projects for inclusion in the three-year contract.

The **Pavement Research Roadmaps** include one roadmap for each Caltrans strategic goal. Each roadmap identifies the scope and vision of the strategic goal; projects needed for conceptual studies, research, development, and implementation support to achieve the vision; and progress toward the vision in terms of completed, current, and next projects.

The **Partnered Pavement Research Center Contract** shows all research, development and implementation projects, support tasks for Caltrans operations, and project support tasks.

Current Pavement Research Roadmaps[1]

- Mechanistic-Empirical Design of Asphalt Pavement
- Mechanistic-Empirical Design of Concrete Pavement
- In-Place and Cold Central Plant Recycling
- Performance-Related Specifications for Concrete Including Construction Quality Assurance/ Quality Control (QA/QC)

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[1] The complete Pavement Research Roadmaps are included in Appendix B.

- Performance-Related Specifications for Asphalt Superpave and Quality Assurance/ Quality Control (QA/QC)
- Surface Treatments and Noise, Grind and Groove (GnG) and Open-Graded Friction Course (OGFC)
- Multi-Functional Pavements for Climate Resilience, Urban Environments, and Active Transportation
- Life Cycle Cost Analysis (LCCA)
- Roadway Life Cycle Assessment (LCA)
- Rubberized Asphalt
- Recycled Asphalt Pavement (RAP) and Recycled Asphalt Shingles (RAS)
- Smoothness
- Pavement Management System (PMS)
- New Concepts for Materials and Structures
- New Technologies and Integrated Frameworks

Strategic Planning and Contract Development

The strategic planning and contract development processes involve the following steps:

Caltrans and the UCPRC continually scan for current and future challenges to the department and for potential opportunities—from ongoing communication with all stakeholders; review of work and ideas from outside California; and work the UCPRC does with other federal, state, and local agencies, industry, and other universities.

DRISI and the UCPRC meet with Caltrans domain area stakeholders in the Office of Pavement (Concrete Pavement, Asphalt Pavement, Pavement Management System); Materials Engineering and Testing Services (METS); Construction; Planning; Sustainability; areas such as Asset Management, Traffic Operations, Environmental Analysis, and Aeronautics; and other offices depending on current strategic issues and opportunities. In coordination with the Office of Pavement, DRISI and the UCPRC also visit with district staff working on pavement to discuss the research program, review research results, and listen to needs.

DRISI and the UCPRC meet with industry groups to discuss challenges and needs and brief the Office of Pavement on the discussions.

The UCPRC prepares new Pavement Research Roadmaps as needed and retires and archives research roadmaps whose visions have been completed.

The UCPRC prepares conceptual project ideas for next projects based on the discussions, the updated Pavement Research Roadmaps, and any new Pavement Research Roadmaps.

The UCPRC holds briefings on the updated set of roadmaps and conceptual project ideas with the Office of Pavement in consultation with METS, Construction, and any other interested stakeholders and gets initial feedback. Also discussed are needs for Office of Pavement operations support tasks.

The UCPRC updates the conceptual project ideas and roadmaps and submits them to the Office of Pavement.

The Office of Pavement—with input from other divisions—reviews, comments on, and prioritizes project ideas.

The UCPRC submits updated roadmaps and a prioritized project list to the State Pavement Engineer for approval.

Based on the prioritization and feedback, DRISI and the UCPRC prepare contract documents, including budgets for each project and support task.

If a new challenge or opportunity is identified during the course of the contract by the Office of Pavement or other Caltrans stakeholders and funding is available, DRISI and the UCPRC prepare a new project work plan (and new roadmap, if needed) and submit it to State Pavement Engineer for inclusion in the roadmaps and approval for funding in the contract.

All projects must have a Caltrans "champion" assigned by Caltrans as the technical reviewer for the project or support task. The Caltrans champion is responsible for working with other Caltrans stakeholders, industry, and the UCPRC on preparing for and supporting implementation, in addition to technical review. If a project or support task does not have a champion, it is not funded by DRISI. If circumstances or priorities change and the purpose of the project or support task no longer exists or if the project or support task is no longer of sufficient priority to continue, the project or task is immediately halted by DRISI.

Work Plan Development Process and Documents

Once the contract is in place, the UCPRC prepares a detailed work plan for each project and submits the plan to that project's Caltrans technical reviewer. The technical reviewer solicits comments within Caltrans, which are incorporated into the final detailed work plan. The detailed work plan[2] includes:

- Background
- Problem statement
- Objectives and tasks
- Scope
- Schedule

The work plan is updated as needed during execution of the project, including review by the Caltrans technical manager. The budget is managed by DRISI and the UCPRC in consultation with the State Pavement Engineer or, for some projects, another Caltrans official who acts as the sponsor for the project or task.

Reporting Processes and Documents

The reporting process includes quarterly reports and specified project deliverables from the UCPRC.

Quarterly Reporting

In addition to periodic technical meetings organized with the technical reviewer and others, the overall progress is reported quarterly in the form of a detailed quarterly report showing progress on scope and spending. The UCPRC submits the quarterly report to DRISI, and DRISI reviews and shares it with the Office of Pavement. Delivery of the quarterly report is followed by quarterly update meetings on all projects with the domain offices in the Office of Pavement and METS, and biannually with the task groups of the Pavement Materials Partnering Committee, comprising Caltrans and industry.

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[2] Available from the UCPRC (contact Camille Fink at cnyfink@ucdavis.edu) and Caltrans DRISI (contact Joe Holland at t.joseph.holland@dot.ca.gov).

Project Deliverables

Periodic meetings are held during projects to present and get feedback and direction regarding interim results. Project reports and technical memoranda move through a formal five-step technical review process led by the Caltrans technical reviewer and the UCPRC project manager and managed by the UCPRC publications manager with DRISI. The technical reviewer solicits additional technical input from within Caltrans and industry as part of the initial steps. The UCPRC then responds to all comments and submits a revised version to Caltrans for final approval before publication. All reports can be accessed through the **UCPRC publications page**, the **DRISI research publications page**, or the **University of California eScholarship website**.

In addition to written documentation of research results, most reports, technical memoranda, and software results are presented at meetings with Caltrans, which sometimes include industry and other stakeholders.

Current Status of Contract

The current PPRC contract began in September 2020 and finishes in September 2023. Strategic planning and preparation of the next contract will begin in the summer of 2022.

Implementation and Research Projects in the PPRC 2020-2023 contract, organized by research area with their Caltrans project IDs (4-digit number) and UCPRC project numbers, are shown in the following section. The following chapter provides details of each project and progress this fiscal year. Summaries of FY 2020-2021 publications are presented in Appendix A.

Mechanistic-Empirical Design

Caltrans committed to replacing historical empirical pavement design methods with mechanistic-empirical (ME) methods in 2005. ME methods and design tools are periodically updated to reflect new materials, changes in specifications, new structure types, updates in reliability calculation approaches, policy changes, and changes in climate. They are also periodically recalibrated using improved performance databases from the pavement management system and new statistical techniques. ME simulation is the primary method of evaluating new materials and structures.

CalME Materials Library for Flexible Pavements (3809 | 3.51)

Further Improvement of CalME and Integration with Performance-Related Specifications (PRS) Into Routine Practice (3810 | 3.52)

Rubberized Hot Mix Asphalt-Gap Graded (RHMA-G) Layer Thickness Limits (3760 | 4.75)

New Rubberized Hot Mix Asphalt (RHMA) with Recycled Asphalt Pavement (RAP)/Recycled Asphalt Shingles (RAS) Part A: For Structural Layers in Flexible Pavements (3761 | 4.76A)

New Rubberized Hot Mix Asphalt (RHMA) with Recycled Asphalt Pavement (RAP)/Recycled Asphalt Shingles (RAS) Part B: For Interlayers and Base for Rigid Pavements (3977 | 4.76B)

Updated Caltrans Rigid Pavement Design Catalog Using Pavement ME (3811 | 3.53)

Monitoring Performance of Concrete Overlay Projects (3812 | 3.54)

Performance-Related Specifications

Performance-related specifications use performance-related tests to tie the assumptions regarding materials used in mechanistic-empirical design to the properties that the materials must have when placed in the pavement by the contractor during construction. This requires performance-related tests, specification approaches and limits, and quality control/quality assurance processes.

Asphalt Rubber Binder Specifications (3816 | 4.77)

Recycling

Recycling of existing pavement into new pavement materials and recycling of waste products and co-products from other supply chains can have economic and environmental benefits—but not always and only if tests, specifications, quality assurance, structural design, and materials design methods are available. To be beneficial, recycling must be safe, produce the same or better life cycle costs, produce the same or better life cycle environmental impacts, be practically feasible at desired scale, and not break the chain of repeated recycling of pavement materials.

Updated Guidance and Specifications for In-Place Recycling (3817 | 4.78)

Guidance, Tests, and Specifications for High Recycled Asphalt Pavement/Recycled Asphalt Shingle Contents in Hot Mix Asphalt (HMA) and Rubberized Hot Mix Asphalt (RHMA) Mixes (3819 | 4.79)

Sustainability

Sustainability considers economic, social, and environmental impacts and ways to reduce or eliminate those impacts. Research includes development of data, methods, and tools for quantifying impacts and use of the information in decision support.

Environmental Life Cycle Analysis (LCA) Updates and Applications (3820 | 4.80)

Implementation of Environmental Life Cycle Assessment (LCA) Data and Models for Project-Level Use in the eLCAP Software (3821 | 3.55)

Multi-Criteria Decision Support for Prioritization of Strategies to Reduce Environmental Impacts (3822 | 3.56)

Pavement Management System

The pavement management system is used for decision support in asset management of the Caltrans pavement network. Work in this area includes improvement of data, models, use of results in decision support, and use of the information in life cycle cost analysis.

Tri-Annual Performance Model Update (3814 | 3.57)

Continued Calibration of Mechanistic-Empirical Design Models with Pavement Management System Data (3764 | 3.58)

Improved Traffic Models for PaveM and Mechanistic-Empirical Design (3765 | 4.81)

Potential for Advanced Image Evaluation in Automated Pavement Condition Surveys (APCS) (3766 | 4.82)

Updates and Improvements to RealCost-CA (3815 | 3.59)

Support Tasks

Support tasks include tasks that support Caltrans operations (the follow-on to successful implementation for tasks where Caltrans has found it cost efficient to have the UCPRC provide the support) and tasks that support research, development, and implementation projects.

Develop and Manage Partnered Pavement Research Program (3823 | 2.01)

Provide Advice to State Government on Pavement Technology (3829 | 2.02)

Provide Support for Pavement Management System (PaveM) Operations (3832 | 2.03)

Provide Support for CalME, PavementME, and CalBack (3831 | 2.04)

Provide Support for eLCAP and RealCost-CA (3779 | 2.05)

Maintain Laboratory Testing AASHTO Re:source Certification (3828 | 2.06)

Maintain Laboratory and Field-Testing Equipment Capability (3826 | 2.07)

Maintain Heavy Vehicle Simulator Equipment (3827 | 2.08)

Operate Falling Weight Deflectometer and Profiler Calibration Centers (3825 | 2.09)

Update/Maintain Research Support Space (3824 | 2.10)

Provide Support to Division of Aeronautics (3780 | 2.11)

Conduct Advanced Pavement Research for Long-Term Future Needs (3830 | 2.12)

Mechanistic-Empirical Design

CalME Materials Library for Flexible Pavements

DRISI Project ID: 3809 | **UCPRC Project Number:** 3.51
Caltrans Technical Lead: Tom Pyle and Raghubar Shrestha, Office of Asphalt Pavement
UCPRC Project Manager: Rongzong Wu

Research Needs

The current *CalME* Standard Materials Library has limited regional materials and does not adequately cover certain material types listed in *CalME,* including but not limited to the following:

- Partial-depth recycled materials
- Full-depth recycled materials
- Asphalt mixes with higher recycled asphalt pavement contents
- Dense-graded asphalt materials with small amounts of recycled tire rubber (referred to as PG+X mixes)

The asphalt concrete specimen production procedures for performance-related testing need to be more standardized, and the fatigue life determination of asphalt concrete mixes with polymer- or rubber-modified binders is not well defined following current ASTM or AASHTO test methods. Performance-related test methods require further refinement to be more practical and implementable.

Objective/Goals

This study is a continuation of PPRC Project 3.51 (CalME Materials Library for Flexible Pavements). The objective of this project is to update the Standard Materials Library for *CalME.*

Deliverables

Task 1: Updated strategy for collecting and testing regional materials

- PowerPoint presentation on the development of a strategy for collecting and testing regional materials

Task 2: Material sampling and testing

- Updated *CalME* Standard Materials Library
- Technical memorandum summarizing the materials tested

Task 3: **Development of an asphalt concrete specimen production procedure**

- Technical memorandum describing the standard test procedure for producing asphalt concrete specimens for performance testing for use in performance-related specifications

Task 4: **Development of fatigue testing procedures for polymer- and rubber-modified mixes**

- Technical memorandum describing the procedure for evaluating fatigue performance of asphalt concrete mixes with polymer- or rubber-modified binders

Task 5: **Refinement of new performance testing methods for asphalt binder, fine aggregate matrix mixes, and asphalt concrete mixes**

- Technical memorandum summarizing the recommendations for various performance tests
- Draft of new or updated test methods

Task 6: **Preparation of project reports**

- Internal laboratory database tracking the production, testing, and analysis
- Quarterly presentation to Caltrans regarding research progress
- Technical memoranda listed in Tasks 2, 3, 4, and 5, and new and updated test methods from Task 5

Summary of Progress FY 2020-2021

Some gaps in the current Standard Materials Library have been identified, such as polymer-modified mixes and mixes with PG 70 binders. Most of the backlog of testing for materials sampled in the last contract has been completed. The sampling and testing of new mixes, including the Interstate 5 Sacramento AC Long Life project mixes, have started. The evaluation of a new compaction device as an alternative to the rolling wheel compactor has started as well as the development of procedures to address the aging effects on performance test results in pavement design, job mix formula approval, and quality control/quality assurance settings. A literature review of various fatigue life determination processes is complete, and a potential procedure has been proposed for use in polymer and rubber-modified mixes testing. A report on surrogate tests for asphalt mix fatigue and fatigue performance is undergoing review.

Further Improvement of CalME and Integration with Performance-Related Specifications (PRS) Into Routine Practice

DRISI Project ID: 3810 | **UCPRC Project Number:** 3.52

Caltrans Technical Lead: Tom Pyle and Raghubar Shrestha, Office of Asphalt Pavement

UCPRC Project Manager: Rongzong Wu

Research Needs

New features that can significantly improve *CalME* in terms of design workflow and efficiency have been identified and need to be developed and/or implemented. Some models in *CalME*, such as the aging model for asphalt materials, and consideration of the effects of wandering on pavement rutting need to be further improved. Some additional pavement behavior parameters need to be modeled in *CalME*, such as the effects of moisture on the mechanical properties of unbound and partially bound layers. Consideration and use of the significant amount of new accelerated pavement testing data collected in recent years is needed to improve the damage models used in *CalME*. These tests cover topics such as recycled asphalt pavement in rubberized hot mix asphalt-gap graded (RHMA-G) mixes, thicker RHMA-G layers, alternative RHMA-G mixes, full-depth reclamation materials, and cold central plant recycling materials. Performance tests need to be further refined and improved for more practical use in *CalME* designs and construction specifications. Finally, there is no centralized database that integrates both performance test data and mix volumetrics for Caltrans highway construction projects.

Objective/Goals

This study is a continuation of PPRC Project 3.41 (M-E Algorithms and Field Calibrations). The objective of this project is to deliver updated *CalME* software to Caltrans.

Deliverables

Task 1: Development/implementation of new *CalME* features

- Quarterly PowerPoint presentations to update Caltrans on progress of the new features
- Online documentation on how to use these new features

Task 2: Updated and new *CalME* models

- Quarterly PowerPoint presentations to update Caltrans on progress of model updates
- Implementation of the new models in *CalME*
- Online documentation on how to use these updated or new models

Task 3: **Calibration of *CalME* damage models with recently collected data**

- Technical memorandum on data cleaning, model selection, and calibration

Task 4: **Updated performance tests for design and construction**

- Technical memorandum detailing updated specimen preparation performance tests for developing *CalME* design inputs, performance tests for performance-related construction specifications, and a summary of performance test data collected from AC Long Life and performance-related specifications projects

Task 5: **Integration of *CalME* and Caltrans Data Interchange for Materials Engineering (DIME) database**

- Technical memorandum on recommended procedures for incorporating performance test results into Caltrans Materials Engineering and Testing Services (METS) and district materials laboratory operations and loading of results into the DIME database

Task 6: **Preparation of project documentation**

- Quarterly presentation to Caltrans regarding research progress
- Technical memoranda listed in Task 3, 4, and 5

Summary of Progress FY 2020-2021

New features to add to *CalME*—such as maintenance and rehabilitation schedules, automatic design, and integration with site investigation—have been identified. An initial guess button has been added to provide a rough design for given traffic, climate, and subgrade. Models for cemented materials have been updated. Some recycled materials (FDR-FA and FDR-C) damage models have been updated using Heavy Vehicle Simulator test results. This project supported the Interstate 5 Sacramento AC Long Life project on job mix formula approval and quality control/quality assurance testing and provided a summary on correlations between volumetrics and performance test results. An initial meeting was held with the DIME team about potential integrations between *CalME* and *PaveM*.

Rubberized Hot Mix Asphalt-Gap Graded (RHMA-G) Layer Thickness Limits

DRISI Project ID: 3760 | **UCPRC Project Number:** 4.75
Caltrans Technical Lead: Tom Pyle and Raghubar Shrestha, Office of Asphalt Pavement
UCPRC Project Manager: David Jones

Research Needs

The decision criteria for thickness limits of rubberized hot mix asphalt-gap graded (RHMA-G) layers—whether 1/2 in. nominal maximum aggregate size mixes can be used in 0.2 ft thick layers and whether RHMA-G layers can be used in layers other than surface layers—are dated. These criteria need to be updated based on life cycle cost analysis, environmental life cycle assessment, and expected performance based on mechanistic-empirical design simulations using *CalME.*

Objective/Goals

This study is a continuation of PPRC Project 4.63 (Performance-Related Specifications for Rubberized Asphalt Binder). The objective of this project is to develop updated criteria for determining thickness limits of RHMA-G layers and whether RHMA-G layers can be used in layers other than surface layers.

Deliverables

Task 1: **Heavy Vehicle Simulator (HVS) and associated laboratory testing of RHMA-G mixes**

- Research report covering first-level analysis of HVS and associated laboratory testing

Task 2: ***CalME* simulations using data collected during Task 1**

- PowerPoint presentation of Task 2 results

Task 3: **Revision of life cycle cost analysis and life cycle assessment information for RHMA-G applications and case study evaluations of the effects of implementing preliminary recommendations**

- PowerPoint presentation of Task 3 results

Task 4: **Research report and recommendations for updated *Highway Design Manual* language for RHMA-G design and use criteria**

- Research report documenting work done in Task 2 and Task 3 with recommendations for updated *Highway Design Manual* language for RHMA-G design and use criteria, if justified

Summary of Progress FY 2020-2021

This project is behind schedule due to delays caused by breakdowns of the two HVS machines and problems with obtaining spare parts that originate in Europe, where manufacturers and suppliers have had extended shutdowns due to COVID-19. HVS testing on three of the seven sections (Task 1) was completed and a first-level analysis report of the results was prepared, reviewed, and finalized. Laboratory characterization testing on plant mixed, laboratory-compacted specimens for each of the four mixes was completed. Periodic dynamic modulus testing on cores removed from the track is in progress to track aging of the mixes. Preliminary findings from the HVS testing have shown that performance of the three mixes was satisfactory in terms of the level of trafficking required to reach a terminal average maximum rut of 0.5 in., no significant damage was caused by the loading, and blending of the recycled asphalt pavement binder may have stiffened the mix. No work can be started on Tasks 2 and 3 until HVS testing has been completed.

New Rubberized Hot Mix Asphalt (RHMA) with Recycled Asphalt Pavement (RAP)/ Recycled Asphalt Shingles (RAS) Part A: For Structural Layers in Flexible Pavements

DRISI Project ID: 3761 | **UCPRC Project Number:** 4.76A

Caltrans Technical Lead: Raghubar Shresthra, Office of Asphalt Pavement

UCPRC Project Manager: Mohamad Elkashef (to August 15, 2021) and John Harvey

Research Needs

Previous research has shown that rubberized binders age at a slower rate than conventional binders. The effects of aging on rubberized binders and rubberized hot mix asphalt-gap graded (RHMA-G) and other RHMA mixes containing both fine- and coarse-graded recycled asphalt pavement (RAP) are not fully understood and need to be investigated. The performance of RHMA-G and other RHMA mixes produced with fine RAP (binder replacement is likely), coarse RAP (binder replacement is unlikely), recycled asphalt shingles (RAS), or RAP with RAS in different structural layers within different types of flexible pavement structures needs to be assessed in the laboratory and with mechanistic-empirical analysis. Whether rich bottom layers age deep in the pavement is of particular interest.

If RHMA-G layers and potentially RHMA layers with other gradations—with RAP, RAS, or RAP with RAS—used within pavement structures appear to result in a notable improvement in performance and pavement life, validation and calibration of results using accelerated pavement testing should be considered. For those applications that appear promising, guidance needs to be developed regarding how and where to use RHMA with and without RAP and/or RAS beyond current applications and an initial framework of properties and tests for use in performance-related specifications.

Objective/Goals

This research is a continuation of two previous CalRecycle-funded studies to investigate the use of RAP in RHMA. The objective of this phase of the study is to develop guidance on the use of RHMA (gap and other gradation) mixes containing RAP, RAS, or RAP with RAS in pavement structures, with special focus on use in structural layers, including rich bottom layers, in flexible pavements.

Deliverables

Task A.1: Updated literature review to include recently completed research

- PowerPoint presentation on the literature review results
- Summary of the literature review to be included in the research report prepared after completion of Task A.4

Task A.2: Initial *CalME* simulations in various structural layer applications in flexible pavements

- PowerPoint presentation on the results of the initial simulations and how they will be used to refine the Task A.3 laboratory testing plan

Task A.3: Laboratory testing of RHMA mixes with fine and coarse RAP, RAS, or RAP with RAS

- PowerPoint presentation on Task A.3 results
- Laboratory test results and analysis to be included in the research report prepared after completion of Task A.4

Task A.4: Refined *CalME* simulations using RHMA with RAP, RAS, or RAP with RAS in various structural layer applications in flexible pavements

- Research report documenting the findings from Tasks A.1 through A.4 with recommendations for further validation and calibration of results from the study if warranted, including pilot studies and/or Heavy Vehicle Simulator (HVS) testing to calibrate and verify the mechanistic simulations conducted in this task
- If justified, interim recommended language for the *Highway Design Manual* and for non-standard specifications covering the use of RHMA layers containing RAP, RAS, or RAP with RAS in structural layers
- Interim framework for the development of performance-related specifications for RHMA mixes containing RAP, RAS, or RAP with RAS for each application

Task A.5: If results from the first four tasks warrant, pilot studies and/or HVS testing to verify simulations

- Research report documenting pilot study and/or test track design and construction and pilot study and/or HVS test results and first-level analysis
- Updated *CalME* models
- Updated recommended language for the *Highway Design Manual* and for non-standard specifications covering the use of RHMA layers containing RAP, RAS, or RAP with RAS in structural layers in flexible pavements
- Updated framework for the development of performance-related specifications for RHMA layers containing RAP, RAS, or RAP with RAS

Summary of Progress FY 2020-2021

The literature review has been continually updated. Significant progress has been made this year on the laboratory testing of RHMA mixes with fine and coarse RAP and RAS. Some initial *CalME* simulations have been made using materials with different amounts of RAP versus conventional mixes and RHMA-G mixes. Additional simulations will be done once laboratory testing is completed.

New Rubberized Hot Mix Asphalt (RHMA) with Recycled Asphalt Pavement (RAP)/ Recycled Asphalt Shingles (RAS) Part B: For Interlayers and Base for Rigid Pavements

DRISI Project ID: 3977 | **UCPRC Project Number:** 4.76B

Caltrans Technical Lead: Deepak Maskey, Office of Concrete Pavement

UCPRC Project Manager: Angel Mateos

Research Needs

Asphalt bases currently being used under concrete are optimized for use as asphalt pavement surface layers, not as a base for concrete. Also, while the use of lean concrete base (LCB) presents some economic and ambient advantages compared to hot mix asphalt (HMA) bases, jointed plain concrete pavement (JPCP) performs worse with LCB than with HMA bases in terms of cracking. There is little knowledge about the mechanical properties that an asphalt mix should have to constitute a good base for a concrete pavement. In particular, no validated tests exist to evaluate the performance of an asphaltic material as a base for concrete pavement. There is also little knowledge about the interaction between the JPCP slab and its base. The simplistic conception of this problem in current mechanistic-empirical design methods fails to reproduce observed performance. While the use of rubberized hot mix asphalt-gap graded (RHMA-G) mixes—with or without recycled asphalt pavement (RAP), recycled asphalt shingles (RAS), or RAP with RAS—as a base for concrete pavements may provide technical, economic, and ambient benefits compared to currently used HMA, further research is required to determine these potential benefits.

Objective/Goals

The objective of Part B of PPRC Project 4.76 is to develop guidance on the use of RHMA mixes—with or without RAP, RAS, or RAP with RAS—as a base for rigid pavements and as a very thin interlayer between LCB and JPCP.

Deliverables

Task B.1: Completion of literature review

- PowerPoint presentation on the literature review results
- Summary of the literature review to be included in the research report prepared after completion of Task B.4

Task B.2: Laboratory testing of RHMA-G as JPCP base or JPCP slab-LCB interlayer

- PowerPoint presentation about Task B.2 results
- Laboratory test results and analysis to be included in the research report prepared after completion of Task B.4

Task B.3: Field evaluation of JPCP slab-base interaction

- PowerPoint presentation about Task B.3 results
- Field evaluation results and analysis to be included in the research report prepared after completion of Task B.4

Task B.4: Preparation of research report

- Research report detailing the study and including a set of performance-related tests and their corresponding performance limits to evaluate asphalt materials as a base or slab-base interlayer for JPCP
- Updated recommended language for the *Highway Design Manual* and for non-standard specifications covering the use of RHMA—with and without RAP, RAS, or RAP with RAS—as a base for rigid pavements and the use of engineered interlayers between LCB and JPCP

Summary of Progress FY 2020-2021

Different alternative materials have been explored as an asphaltic base of jointed plain concrete pavement and continuously reinforced concrete pavement and as an interlayer ("bond breaker") between the concrete pavement and LCB. The materials explored as asphaltic base include RHMA-G and rubberized hot mix asphalt-dense (RHMA-D), both with RAP. As interlayer materials, geotextile and microsurfacing have been explored. Several meetings have been held with the materials producers and several materials have been sampled for laboratory testing. Part of this project has focused on the development of a testing procedure that can be used to evaluate the suitability of a material as an asphaltic base of a concrete pavement or as an interlayer between the concrete pavement and LCB. A finite-element model is being developed as well.

Updated Caltrans Rigid Pavement Design Catalog Using Pavement ME

DRISI Project ID: 3811 | **UCPRC Project Number:** 3.53

Caltrans Technical Lead: Dulce Rufino Feldman, Office of Concrete Pavement

UCPRC Project Manager: Angel Mateos

Research Needs

The concrete pavement design catalog in the current Caltrans *Highway Design Manual* was implemented in 2007. The jointed plain concrete pavement (JPCP) catalog tables are based on calculations conducted with *Mechanistic-Empirical Pavement Design Guide* (version 0.8) in 2005 and 2006 and later adjustments based on design catalogs from other states. The tables do not acknowledge the changes that the AASHTO mechanistic-empirical design method (*MEPDG* in the past, *Pavement ME* now) has undergone over the past 15 years or the validation, calibration, and catalog development efforts conducted as part of PPRC Project 3.49 (Implement Concrete ME Design Tools). In addition, the current *Highway Design Manual* concrete pavement design catalog does not include concrete overlay on asphalt (COA), and the continuously reinforced concrete pavement (CRCP) thickness values have not been updated since the 2007 implementation.

Objective/Goals

The primary goal of Project 3.53 is to develop and implement a new *Highway Design Manual* concrete pavement design catalog using *Pavement ME* (version 2.5.5). This research will consider climate, traffic, materials, design, and construction practices and standards applicable to the Caltrans road network.

Deliverables

Task 1: **Finalized JPCP design catalog tables**

- JPCP design catalog tables

Task 2: **Finalized COA design catalog tables**

- COA design catalog tables

Task 3: **Development of CRCP design catalog tables**

- CRCP design catalog tables

Task 4: **Implementation of design catalog tables in a web-based tool**

- Online catalog and documentation

Summary of Progress FY 2020-2021

The design tables of thin COA and regular JPCP have been prepared. The tables consider the different COA and JPCP structures that are expected to perform properly on the Caltrans road network. Summary reports have been produced for both COA and JPCP outlining the hypothesis and design values adopted in *Pavement ME* to develop the design tables. The tables were developed using *Pavement ME* (version 2.5.5) with the nationally calibrated cracking models. The JPCP sections were also verified in terms of faulting and the International Roughness Index. The development of the CRCP design tables is pending. A database was created with the *Pavement ME* outputs required to run a web version of the design catalog. The mechanistic-empirical algorithms required to run the web catalog have been formulated and included in the two reports. The functionality of the web catalog has been drafted and sent to Caltrans for review.

Monitoring Performance of Concrete Overlay Projects

DRISI Project ID: 3812 | **UCPRC Project Number:** 3.54

Caltrans Technical Lead: Dulce Rufino Feldman, Office of Concrete Pavement

UCPRC Project Manager: Angel Mateos

Research Needs

While concrete overlay on asphalt (COA) and concrete overlay on concrete (COC) can be regarded as mature technologies, their increasing use results in the need to evaluate their performance, optimize their design, and potentially improve their construction. The relevance of concrete overlays is emphasized by the Targeted Overlay Pavement Solutions (TOPS) initiative launched by the Federal Highway Administration's Every Day Counts program (EDC-6) for the 2021-2022 cycle.

Although the performance of most concrete overlay alternatives is not very different from the performance of standard jointed plain concrete pavement (JPCP) or continuously reinforced concrete pavement (CRCP), a number of factors and phenomena deserve special study, including the reduced slab thickness of some concrete overlay alternatives, the interaction between the concrete overlay and the existing pavement, and the risk of distresses that result from the bottom-up propagation of the distresses in the existing pavement. From the construction point of view, one of the main differences between concrete overlay and regular JPCP and CRCP are the preparation of the existing asphalt or concrete surface prior to placing the concrete overlay and the possible use of an interlayer between the concrete overlay and the existing surface. The study of COA with short transverse joint spacing deserves special attention since this rehabilitation alternative is relatively new to the Caltrans road network and has mostly been used in colder, wetter climates than California that experience much less drying shrinkage.

Objective/Goals

The primary goal of Project 3.54 is to develop guidance for COA design and construction in California. This goal is be achieved through the evaluation of concrete overlay projects to determine performance under different climate, traffic, and existing site conditions and identification of current best and improved practices and standards applicable to California's climate, materials, and construction work zone practices.

Deliverables

Task 1: Continued monitoring of the State Route 113 COA pilot project

- Summary of updated observations on the early performance of the State Route 113 COA pilot project to be included in the final project report

Task 2: Evaluation of the condition of concrete overlay projects in California

- Summary of observations that will be included in the final project report

Task 3: Monitoring of the construction and initial performance of new concrete overlay projects

- Construction report for each project

Task 4: Preparation of research report

- Final research report

Summary of Progress FY 2020-2021

The monitoring of the Caltrans thin COA pilot on State Route 113 in Woodland has continued. The monitoring began during the construction of the pilot in October 2018. The monitoring includes continuous measurement of concrete temperature and strain with embedded sensors, periodic evaluation of the smoothness and surface texture, and occasional evaluation of the structural response under traffic loading. A report detailing the initial performance of the project to September 2020 has been produced. Support to Caltrans for the EDC-6 TOPS initiative is included in this research project. The performance of a list of COA and COC projects identified by Caltrans is being analyzed. The analysis is based on pavement management system data, and the main outcome of the initial part of the research is the development of the software code required to query the data and summarize the data in an appropriate format.

Performance-Related Specifications

Asphalt Rubber Binder Specifications

DRISI Project ID: 3816 | **UCPRC Project Number:** 4.77

Caltrans Technical Lead: Tom Pyle and Kee Foo, Office of Asphalt Pavement

UCPRC Project Manager: David Jones

Research Needs

Precision and bias statements need to be developed for the recommended performance grading (PG) testing procedures to make the PG binder specification applicable to asphalt rubber. Base binder selection criteria for asphalt rubber binders need to be reviewed, especially for inland valley and desert applications. New developments in fine rubber preparation and pelletizing of rubber particles to improve digestion need to be reviewed and recommendations made for their use in California, if applicable. Binders made with these products will typically meet Caltrans performance grading-modified (PG-M) specifications (except for solubility) and can be considered for wider use in dense-graded mixes where *CalME* evaluations indicate potential benefits.

Objective/Goals

This study is a continuation of PPRC Project 4.45 and Projects 4.50/4.63 (Performance-Related Specifications for Rubberized Asphalt Binder). The objective of this project is to finalize PG testing procedures for asphalt rubber binders.

Deliverables

Task 1: Completion of outstanding testing on field-produced binders, delayed because of COVID-19 restrictions, and finalized draft PG testing method

- Research report detailing Phase 3 PG testing of asphalt rubber binders
- Updated proposed draft of PG testing procedure for asphalt rubber binders
- Provisional PG map for asphalt rubber binders

Task 2: Preparation and implementation of statewide round robin study to develop precision and bias statements for the proposed PG testing procedure

- Technical memorandum documenting the design, analysis, and results of the round robin study
- Provisional precision and bias statements for PG testing of asphalt rubber binders

Task 3: Review and, if appropriate, updating of base binder selection criteria for asphalt rubber binders

- Technical memorandum documenting the findings of the review
- If laboratory testing is justified, research report documenting laboratory testing with recommendations for revising base binder selection procedures

Task 4: **Investigation of use of fine dry rubber and polymerized/pelletized, soluble rubber for use in asphalt mixes, primarily dense graded**

- Technical memorandum documenting results of the literature review and *CalME* simulations
- If further laboratory testing is justified, research report documenting laboratory testing with recommendations for implementation in pilot studies

Summary of Progress FY 2020-2021

Task 1 of this project is nearing completion. Research focused on the testing of binders after larger, incompletely digested rubber particles had been removed using a simple centrifuging process. Earlier phases of the study had determined that these incompletely digested particles were influencing the test results and leading to unrealistically high PGs. Results for the binders with larger particles removed appear to be consistent with expected performance. Work on Task 2, if required by Caltrans, cannot be started until Task 1 has been completed and the testing approach is provisionally adopted by Caltrans. As results become available, they are being analyzed in terms of preparing recommended base binder and asphalt rubber binder PG maps for the different climatic regions of California (Task 3). The literature on and testing of fine, dry rubber and polymerized/pelletized, soluble rubber in asphalt rubber binder applications continues, but no testing of these binders will be undertaken unless directed by Caltrans.

Recycling

Updated Guidance and Specifications for In-Place Recycling

DRISI Project ID: 3817 | **UCPRC Project Number:** 4.78
Caltrans Technical Lead: Allen King and Tom Pyle, Office of Asphalt Pavement
UCPRC Project Manager: David Jones

Research Needs

The following problem statements are still outstanding or require refinement/calibration for California conditions:

- Mechanistic-empirical parameters for in-place recycling (IPR) projects need to be finalized.
- Consistent mix design procedures for all IPR strategies need to be developed and laboratory performance testing needs to be done to refine mechanistic-empirical design and performance modeling parameters. Mix design procedures should include raveling tests, given that recycled layers are exposed to traffic for up to 15 days before the asphalt surfacing is placed.
- Partial-depth recycling (PDR) and cold central plant recycling (CCPR) materials produced with only recycled asphalt pavement typically have coarse gradations, which leads to compacted layers having relatively high air-void contents. The use of supplemental fines to improve gradations needs to be investigated. Use of fines derived from forest waste biomass materials should also be considered.
- Time limits for stockpiling of CCPR materials need to be established.
- The effects on construction and performance of rubberized hot mix asphalt and fabrics in the recycled layer are not fully understood and need to be further evaluated.
- Current PDR construction techniques are not conducive to the application of tack coats between the recycled and underlying layers. Consequently, debonding of these two layers is often observed in cores removed from the pavement. Recent developments in spray pavers need to be assessed to see if this equipment can be effectively used in PDR applications to improve long-term performance.
- The long-term performance of deep-lift full-depth recycling (FDR-C) projects has not been quantified. Although this strategy is being used on city and county roads with reported success, to date there are no published studies documenting longer-term performance on roads carrying traffic volumes typical of those on Caltrans roads where FDR-C may be considered. Concerns regarding the compaction of thicker layers on weak/moist subgrades, the potential for cracking resulting from drying shrinkage and/or differential compaction over the thickness of the layer, and the applicability of shrinkage crack mitigation of these thicker layers need to be investigated.

- The use of rejuvenating agents and other stabilizers (e.g., synthetic polymer emulsions) has not been investigated in IPR projects to date.
- Preliminary international research on the use of nano-stabilizers to improve emulsified asphalt performance in recycled layers has shown promising early results and warrants further investigation.
- Preliminary national research on the use of geosynthetics between subgrades and recycled layers and between recycled layers and asphalt concrete surfacings has also shown positive results, especially in the former application where the recycled layer material is processed through a cold central plant. The use of geosynthetics provides a potential alternative to subgrade stabilization and/or can provide a barrier to prevent fines contaminating the recycled layer. Geosynthetics between an FDR-C layer and the asphalt concrete surface may limit shrinkage cracks in the FDR-C layer from reflecting through the asphalt.
- Guidance has not been developed to identify when in-place recycling of material that is primarily subgrade soils, as opposed to primarily recycled asphalt concrete and aggregate base, should be modeled and designed as FDR and when it should be modeled and designed as stabilized subgrade or subbase.

Objective/Goals

This study is a continuation of PPRC Projects 4.65 (FDR Microcracking), 4.69 (FDR Emulsion and Field), and 4.70 (PDR Guidance). The objective of this project is to update guidance and mechanistic-empirical design procedures for in-place recycling.

Deliverables

Task 1: **Continued long-term monitoring of existing and new field IPR pilot projects to assess stiffness, cracking, rutting/densification, freeze-thaw, moisture sensitivity, and other observed distresses**

- Updated list of IPR projects evaluated/suitable for future evaluations
- Database of observations and measurements for *CalME* modeling
- Summary of observations and measurements from field monitoring, with recommendations for updating IPR guidance and *CalME* models and for adopting NCHRP 9-62 quality control/quality assurance procedures

Task 2: **Completion of Heavy Vehicle Simulator (HVS) and associated laboratory testing to assess mechanistic behavior and performance properties of CCPR materials**

- Research report documenting HVS testing, with recommendations for updating IPR guidance and *CalME* models

Task 3: **Literature reviews and laboratory testing to refine mix design procedures**

- Research report documenting laboratory testing, with recommendations for updating IPR guidance and *CalME* models

Task 4: **Field monitoring and associated laboratory testing of deep-lift FDR-C projects**

- Research report documenting task findings, with recommendations for updating IPR guidance, relevant *Highway Design Manual* chapters, and *CalME* models

Task 5: **Updated guidance, CalME models, and CalME materials library**

- Updated IPR guidance
- Updated *CalME* models and materials library
- Revised *Highway Design Manual* and specification language, if applicable
- High-level summary report documenting IPR research undertaken by the UCPRC since 2008

Summary of Progress FY 2020-2021

Progress on all tasks is on schedule. Field projects (Task 1, construction and long-term performance) continue to be monitored, with specific focus on projects where procedures are being adapted for specific circumstances. HVS testing of CCPR materials (Task 2) was delayed. However, testing on two sections (one with asphaltic emulsion and one with foamed asphalt) was completed in the review period. Satisfactory performance was observed on both sections. Laboratory testing (Task 3) continued according to the work plan, with primary focus during this review period on adding supplemental fines to PDR and CCRP projects to improve gradation and, as a result, reduce air-void content and improve strength and raveling resistance. Specimens cored from the test track at periodic intervals have also been tested for dynamic modulus to track aging of recycled layers. The expected behavior of deep-lift FDR pavements stabilized with cement (Task 4) was modeled, with initial findings indicating that shrinkage cracking is likely if full compaction and pre-cracking (i.e., microcracking) to the bottom of the layer are not achieved. Field projects are being sought to assess these findings. A new, comprehensive guideline on IPR was published, and the UCPRC participated in statewide training on IPR.

Guidance, Tests, and Specifications for High Recycled Asphalt Pavement/ Recycled Asphalt Shingle Contents in Hot Mix Asphalt (HMA) and Rubberized Hot Mix Asphalt (RHMA) Mixes

DRISI Project ID: 3819 | **UCPRC Project Number:** 4.79

Caltrans Technical Lead: Allen King, Office of Asphalt Pavement

UCPRC Project Manager: Mohamad Elkashef (to August 15, 2021) and John Harvey

Research Needs

The degree of blending between recycled asphalt pavement (RAP), RAP/recycled asphalt shingles (RAS), and virgin binders could be significant, particularly for mixes using highly aged RAP and RAS, typical of inland valley scenarios. Incomplete blending could alter the properties of the mix because of less available binder and partial activation of the stiff RAP and/or RAS binder. Plant-produced mixes subjected to silo storage undergo additional blending and aging leading to increased stiffness, improved rutting, and reduced cracking and fatigue resistance. This incomplete and additional blending needs to be better understood for consideration in mix design procedures and performance-related testing. The impact of long-term aging on the performance of high RAP and RAP/RAS mixes with different rejuvenators needs to be fully investigated using various aging protocols.

Objective/Goals

This study is a continuation of PPRC Project 4.64 (Continued Development of Guidelines for Determining Binder Replacement in High RAP/RAS Content Mixes). The objective of this project is to develop guidelines for determining binder replacement rates in high RAP/RAS content mixes without the need for binder extraction and performance-related tests for use in routine mix design and construction quality control/quality assurance.

Deliverables

Task 1: Updated literature review to include recently completed research

- PowerPoint presentation on updated literature review

Task 2: **Testing of high RAP and RAP/RAS mixes to determine their performance properties**

- PowerPoint presentation on high RAP and RAP/RAS testing findings

Task 3: **Testing of extracted and recovered RAP, RAP/RAS, and RAP/RAS/virgin binder blends to assess the effectiveness of different rejuvenators**

- PowerPoint presentation on RAP, RAP/RAS, and RAP/RAS/virgin binder blend testing findings

Task 4: **Complete investigation into the use of fine aggregate matrix (FAM) mix testing to assess the fatigue performance of mixes and to predict binder properties**

- PowerPoint presentation on FAM mix testing findings

Task 5: **Investigation of long-term aging effects of high RAP and RAP/RAS mixes using different laboratory-aging protocols**

- PowerPoint presentation on high RAP and RAP/RAS mix test findings

Task 6: **Monitoring of field performance of high RAP and RAP/RAS mixes and use results to evaluate laboratory-aging protocols**

- PowerPoint presentation on monitoring of field performance of RAP and RAP/RAS mixes

Task 7: **Preparation of research report with recommendations for use of RAP and RAP/RAS as binder replacement, and, if applicable, recommendations for accelerated wheel load testing**

- Report documenting research findings
- Recommendations for accelerated pavement testing of select RAP and RAP/RAS mixes, if justified

Summary of Progress FY 2020-2021

Periodic updates have been made, including review of the literature and discussions with other researchers working in this area. Considerable progress has been made on the testing of high RAP and RAP/RAS mixes, and this testing will continue. Binders are being extracted from selected mixes to understand the contribution of binders to mix performance. A draft report has been completed showing the efficacy of using FAM in place of mix testing, and the preliminary recommendation is to continue progress with this promising test. Partial results have been collected on long-term aging, particularly a study that looked at mix properties for four high RAP mixes with zero hours of aging in the storage silo at the asphalt plant compared to 5 to 16 hours of silo time. The results showed significant differences, which varied depending on the mix. The mixes had different RAP sources and RAP contents, and some included rejuvenating agents. These and other results indicate that the overall mix properties are affected by aging of the virgin binder, diffusion of the aged RAP binder with the virgin binder, and aging of the rejuvenating agents. Plans have been developed for monitoring of a RAP and RAS pilot on El Dorado State Route 49.

Sustainability

Environmental Life Cycle Analysis (LCA) Updates and Applications

DRISI Project ID: 3820 | **UCPRC Project Number:** 4.80
Caltrans Technical Lead: Deepak Maskey, Office of Concrete Pavement
UCPRC Project Manager: Ali Butt

Research Needs

This project will expand, improve, and update the capabilities of Caltrans to address current and future issues required to meet the California Global Warming Solutions Act of 2006 (AB 32) greenhouse gas emission targets and category pollutant regulations and to conduct more informed decision-making with respect to environmental, energy, and resource use impacts using life cycle analysis (LCA). A triennial update of existing life cycle inventory (LCI) databases using updated data from the government and other sources is needed. Industry-submitted environmental product declarations (EPDs) need further study for their potential use in LCA tools and for procurement as Caltrans receives them in its EPD implementation pilot project. Additional and improved data and algorithms for LCA for the range of design, construction, maintenance, and rehabilitation strategies used in California—including technology changes such as new materials production, construction equipment, and pavement structures—need to be developed. The ability to perform LCA at the conceptual design stage of project development and to consider roadway structures, such as culverts, drainage, standard highway bridge materials, construction, maintenance, and end-of-life, in addition to pavement, is needed. Updated and new LCIs need to be sent for external critical review of assumptions, data, models, and results. LCA procedures for considering uncertainty of data and models for application in California need to be improved.

Objective/Goals

This study is a continuation of PPRC Project 4.66 (Environmental Life Cycle Assessment Updates and Applications). The objective of this project is to continue updating and applying environmental LCA procedures for improving the sustainability of roadway operations in California.

Deliverables

Task 1: **Updating of LCA with new material inventories**

- Improved LCA capabilities in terms of data, models, and procedures
- Technical memorandum on LCI of newly inventoried materials
- Technical memorandum on evaluation of data from Caltrans EPD program

Task 2: **Development and finalizing of models to be implemented in *eLCAP* and in simplified form in *PaveM***

- Technical memorandum on use stage models (roughness, structural response, speed effects, electric vehicles)
- Technical memorandum on other life cycle stage models (construction work zone, materials and construction, end-of-life)

Task 3: **Critical review of inventories and models**

- Completed critical review
- Updated technical memoranda from Task 2

Task 4: **Information and data for implementation of models in tools**

- Information and data ready for updates in *eLCAP*
- Information and data ready for updates in *PaveM*

Summary of Progress FY 2020-2021

The life cycle models and data for the material and construction stages and transportation from 2019 and 2020 have been updated. Modeling of Caltrans construction practices and California equipment emissions data was also updated. The LCI report was updated and submitted to the contracted critical review panel of three international experts. The review panel comments were received in June 2020, and the inventories are being updated based on the reviewer comments. A detailed literature review on the effect of pavements on electric vehicles and their batteries was also performed. Some of the reports from the previous contract were also completed and submitted to Caltrans, including the pavement structural response empirical modeling report, the Caltrans EPD pilot project study report, and the construction work zone modeling report. Updating of the life cycle models and data will continue so that they can be implemented in the Caltrans pavement LCA tool (*eLCAP*).

Implementation of Environmental Life Cycle Assessment (LCA) Data and Models for Project-Level Use in the eLCAP Software

DRISI Project ID: 3821 | **UCPRC Project Number:** 3.55

Caltrans Technical Lead: Deepak Maskey, Office of Concrete Pavement

UCPRC Project Manager: Ali Butt and Jon Lea (to June 29, 2021)

Research Needs

Caltrans personnel—working on project delivery from conceptual design through complete design; evaluation and improvement of specifications, guidance, and policy development; and reporting of emissions—do not currently have a comprehensive project-level tool for full-system life cycle assessment. There are existing spreadsheets and consultant reports for elements of the design stage, such as particular materials and construction. These tools have been intermittently updated, and some do not have documentation that permits the analyst to understand important assumptions, calculations, and data sources. Furthermore, in many cases the data used in these tools have not been reviewed and adjusted where necessary to match local conditions.

Objective/Goals

This study is a continuation of PPRC Project 3.46 (Environmental Life Cycle Assessment Pavement: Tool for Project-Level Use). The objective of this project is to continue the development of a web-based online life cycle assessment (LCA) pavement tool that uses energy and material datasets specific to California and follows the construction practices of Caltrans. It will use other updates developed by the UCPRC for Caltrans in the previous contract projects (Project 4.66: Environmental Life Cycle Assessment Updates and Applications; Project 4.73: Fast Model Energy Consumption Structural Response) and the companion project in the current contract (Project 4.80: Environmental LCA Updates and Applications). The tool will be consistent with the Federal Highway Administration (FHWA) Pavement Life Cycle Assessment Framework and the work of federal agencies (including FHWA) in the Federal Commons initiative.

The data and procedures in *eLCAP* will be updated for use at the conceptual-level design and project-level design stages. User interfaces based on user feedback will also be updated along with documentation for the tool. The compatibility of greenhouse gas emissions and other calculations in *PaveM* will be updated in *eLCAP.* The work will include an outside critical review of the tool itself (the inventories and models will be subject to a formal outside critical review as part of Project 4.80).

Deliverables

Task 1: **Updating of *eLCAP* with updated and new models at every pavement life cycle stage**

- Implementation of updates
- Updated inventory libraries
- Documentation of all the updates in *eLCAP*

Task 2: **Implementation of conceptual design-level module for roadway analysis**

- Incorporation of roadway elements and ability to use them at early stages of design in *eLCAP*
- Documentation with capability for analysis of policy, conceptual designs, and final designs

Task 3: **Updated user interface and system requirements**

- User and system requirement document
- Set of use cases
- User interface, report, and graph mockup documents

Task 4: **Implementation, including UCPRC and Caltrans unit testing and review**

- Online help system
- Results of UCPRC testing
- Results of Caltrans testing
- Results of regression testing

Task 5: **Critical review**

- Identification of willing outside reviewers
- Documentation of the critical review comments and responses
- Updated *eLCAP* project documentation
- Final online web help system
- Review of *eLCAP* (version 2.0)

Task 6: **Updated software, software documentation, and help system**

- Updated software
- Software documentation
- Online help system embedded in the software

Summary of Progress FY 2020-2021

The *eLCAP* software was updated with models and data for materials, construction, and the use stage developed in 2019 and 2020. Updates were also made to the user interface. Extensive testing was done by the UCPRC with Caltrans through a case study. A critical review panel of three international experts was identified and contracted. The *eLCAP* user manual report was prepared for the software and data quality method. As of June 2021, the critical review panel comments had been received and the software and *eLCAP* documentation were being updated in response. Caltrans is expected to begin piloting the software in September 2021, and work on other tasks to update the entire system will proceed during FY 2021-2022 based on a planned list of improvements and feedback from the pilot. Training will also be developed.

Multi-Criteria Decision Support for Prioritization of Strategies to Reduce Environmental Impacts

DRISI Project ID: 3822 | **UCPRC Project Number:** 3.56

Caltrans Technical Lead: Kuo-Wei Lee, Office of Concrete Pavement, and Tom Pyle, Office of Asphalt Pavement

UCPRC Project Managers: Ali Butt and John Harvey

Research Needs

Caltrans roadway decision makers need to quantify changes they are making to reduce greenhouse gas (GHG) emissions. They also need to prioritize proposed changes in practices and policies to reduce GHG emissions and other environmental impacts, considering both cost and reduction in environmental impact, to arrive at the most cost-effective use of limited resources. In the prioritization framework, consideration can also be given to social indicators and the equity of impacts. The multi-criteria decision analysis framework developed in the previous project for Caltrans that considers reduction in life cycle GHG emissions and life cycle cost needs to be updated and improved by considering other existing and current work. The system boundaries for the updated framework need to be updated to consider additional environmental impacts and the possible inclusion of social indicators and the equity of environmental impacts from implementation of GHG mitigation strategies. The analysis will be applied to approaches for reducing GHG emissions and other environmental impacts identified by Caltrans.

Objective/Goals

This study is a continuation of PPRC Project 4.72 (Life Cycle Assessment of Alternate Strategies for GHG Reduction). The objective of this project is to include other environmental impacts in the supply curve method, identify potential social indicators and equity considerations, and investigate other multi-criteria decision analysis frameworks—life cycle assessment and life cycle cost analysis—that can be used by Caltrans in its decision-making process.

Deliverables

Task 1: Literature review of existing multi-criteria decision analysis (MCDA) frameworks

- Summary literature survey of MCDA, including a critique of the previously developed supply curve framework, additional strategies and more details for those identified in the Caltrans study, and inclusion of social indicators and equity in LCA at the state, regional, and neighborhood levels

Task 2: **Expansion of the system boundaries of the supply curve method to include other impacts**

- Technical memorandum including literature survey and updated supply curve framework

Task 3: **Case studies to demonstrate the enhanced framework and other MCDA methods**

- Technical memorandum on evaluation of several strategies as case studies using the updated supply curve and relevant MCDA methods

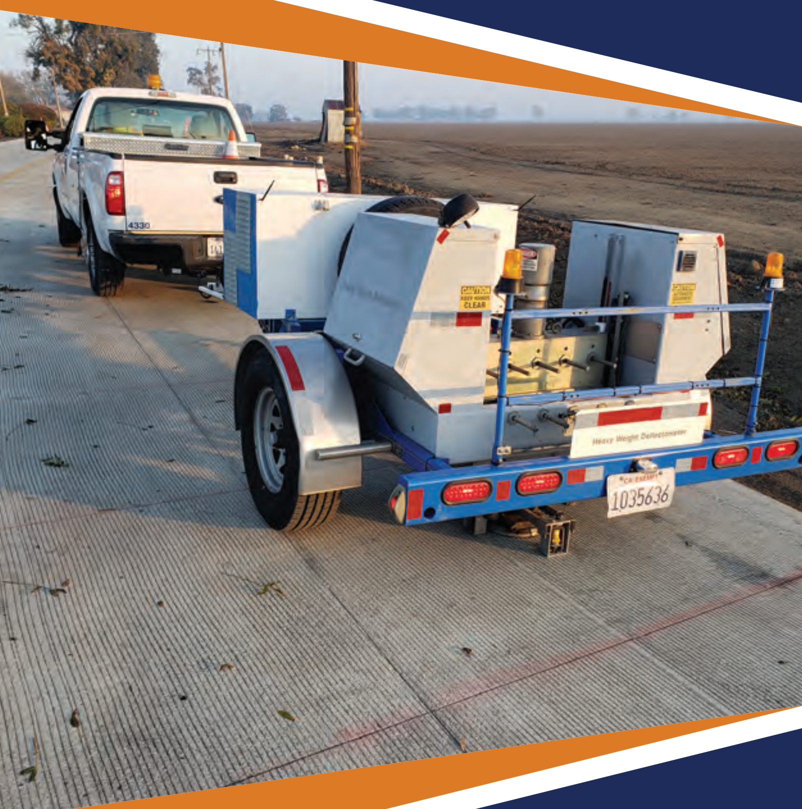
Task 4: **Preparation of white paper and policy brief**

- White paper
- Policy brief

Summary of Progress FY 2020-2021

A literature review was performed to identify the multi-criteria decision support methods that are currently being used. A work plan for this project was developed mainly focusing on the needs of the Caltrans Office of Planning. Although this project was funded by Caltrans, the UCPRC has not been able to get a Caltrans technical lead for this project. Therefore, the project is currently on hold. The principal investigator is currently in contact with personnel from Caltrans, and the UCPRC might be able to change the scope of this project and begin work in FY 2021-2022.

Pavement Management System



Tri-Annual Performance Model Update

DRISI Project ID: 3814 | **UCPRC Project Number:** 3.57
Caltrans Technical Lead: Robert Hogan, Office of Pavement Management
UCPRC Project Manager: Jeremy Lea

Research Needs

By 2023 Caltrans will have collected four additional years of automated pavement condition survey (APCS) data, which are not included in the current performance models. Additional possibilities to improve processing of the old data need to be explored. *PaveM* will replace the built-in model framework with a custom script-based implementation to enable the direct use of the statistical models in *PaveM*. New models will be needed for any new treatments and included in the new implementation framework. Currently, continuously reinforced concrete; full-depth recycling; partial-depth recycling; and crack, seat, and overlay treatments have models that need improvements.

Study Objective/Goal

This study is a continuation of PPRC Project 4.68 (Improved Smoothness and Distress Models for *PaveM*). The objective of this project is to develop updated performance models and any improvements in *PaveM* needed to use them.

Deliverables

Task 1: Continued performance model database development
- Updated performance modeling database

Task 2: Continued and enhanced empirical model development
- New empirical performance models

Task 3: Delivery and integration of new performance models into *PaveM*
- Performance models implemented and validated in *PaveM*

Task 4: Development of alternative models as needed
- Implementation of alternative models in *PaveM* as needed

Task 5: Reporting of model results
- A final report detailing the empirical models developed, along with updates to the relevant *PaveM* documentation sections

Summary of Progress FY 2020-2021

Most of the work on this project has focused on Task 1 (updating the performance modeling database). During FY 2020-2021, the 2016 and 2019 data segment level APCS data were imported, work began on importing the 2021 transportation system network data for a 2021 linear referencing system update, the data extraction was revised to not average data when overlaps occur, and columns were added to capture pavement features not currently captured in the as-builts (particularly widened concrete lanes). Some as-built data were also updated. Data extractions were also performed for continuously reinforced concrete pavement (for NCE) and for the widened lane jointed plain concrete pavement projects. A work plan was developed and approved, and work continues on documentation of the *PaveM* engineering configuration.

Continued Calibration of Mechanistic-Empirical Design Models with Pavement Management System Data

DRISI Project ID: 3764 | **UCPRC Project Number:** 3.58

Caltrans Technical Lead: Raghubar Shrestha, Office of Asphalt Pavement, and Kuo-Wei Lee, Office of Concrete Pavement

UCPRC Project Managers: Jeremy Lea and Rongzong Wu

Research Needs

Pavement performance data are collected for Caltrans on a yearly basis. The newly available data should be used to update calibrations in both *CalME* and *Pavement ME*. An extensive amount of data is generated through various Caltrans activities. These data need to be organized and integrated to provide additional data for periodic mechanistic-empirical (ME) calibration. Detailed field testing and performance data are needed for jointed plain concrete pavement (JPCP) projects with current design features at midlife to supplement pavement management system data. The calibrations for *CalME* and *Pavement ME* need to be updated using the newly available data.

Objectives/Goals

The objective of this project is to establish an efficient and repeatable procedure for updating field calibration of ME design methods.

Deliverables

Task 1: Updated calibration data

- Technical memorandum with results of field testing and laboratory testing of field-sampled materials, comparisons with *Pavement ME,* and recent calibration assumptions and results
- Updated calibration database

Task 2: Updated *CalME* calibration

- Technical memorandum on updated *CalME* calibration

Task 3: Updated Pavement ME calibration

- Technical memorandum on updated *Pavement ME* calibration

Task 4: Integration of network-level ME data management

- Technical memorandum on how to integrate various data at the network level for ME calibration

Task 5: **Preparation of project documentation**

- Quarterly presentation to Caltrans regarding research progress
- Technical memoranda listed in Task 2, 3, and 4

Summary of Progress FY 2020-2021

A work plan for this project was developed and approved. The calibration data for in-place recycling and the *CalME* calibration for these treatments have been updated. A report on the *CalME* calibration has been completed. An outside review panel has been assembled and completed the review of *CalME*, and comments are being addressed. A plan for follow-up data collection (including field sampling) on the existing long life sections (both asphalt and concrete) has been developed, and field work is starting. The calibration of *Pavement ME* has been refined based on the new widened lane JPCP data, and the recommendations have been updated.

Improved Traffic Models for PaveM and Mechanistic-Empirical Design

DRISI Project ID: 3765 | **UCPRC Project Number:** 4.81
Caltrans Technical Lead: Robert Hogan, Office of Pavement Management
UCPRC Project Managers: Jeremy Lea and Changmo Kim

Research Needs

The traffic calculation models in *PaveM* need to be updated based on changes and updates to the road networks made over time in California. The traffic information calculated from the updated process needs validation to ensure its accuracy across the statewide network, especially for the segments where changes in geometry or post-mile have occurred and for routes with limited traffic information. The traffic information models in *PaveM* are accessed by pavement design and life cycle cost analysis and life cycle assessment software.

Objective/Goals

The objective of this project is to update the traffic calculation models in *PaveM* to improve the accuracy of traffic information for road segments.

Deliverables

Task 1: **Improvement of current traffic models**
- Summary notes of literature review
- Summary notes of traffic models
- Updated version of network-level traffic information
- Presentation materials

Task 2: **Development of lane-based traffic information for heavy vehicles**
- Lane-based traffic information database, including lane distribution factors, truck information, and weigh-in-motion (WIM) spectra per lane
- Summary notes and presentation materials

Task 3: **Calculation of the traffic index for *PaveM***
- Traffic index data file
- Summary notes and presentation materials of traffic index estimates

Task 4: **Implementation of WIM spectra in *CalME* and *Pavement ME***
- Functional traffic information (monthly and hourly distribution tables) of WIM spectra for *CalME* and *Pavement ME*
- Summary notes and presentation materials of WIM spectra files

Task 5: **Collection of traffic data for model verification on roads with no sensors**

- Traffic data files and summary notes
- Presentation materials on the verification results

Task 6: **Preparation of study report**

- Technical memorandum

Summary of Progress FY 2020-2021

Current traffic models and collected literature have been reviewed, and a framework for updating current traffic models was developed. The existing traffic database structure in *PaveM* was reviewed. Traffic information (WIM) was collected, traffic parameters were identified, and lane-based traffic patterns for heavy vehicles were analyzed. The new WIM spectra developed in the previous contract were implemented in the *CalME* and *PavementME* software.

Potential for Advanced Image Evaluation in Automated Pavement Condition Surveys (APCS)

DRISI Project ID: 3766 | **UCPRC Project Number:** 4.82
Caltrans Technical Lead: Imad Basheer, Office of Pavement Management
UCPRC Project Manager: Jeremy Lea

Research Needs

New technologies are available that use image analysis to discover features of the pavement from automated pavement condition surveys (APCS) images and data that would be useful for performance prediction and treatment selection. These technologies are best evaluated by testing their readiness on problems such as drainage evaluation and flagging of replaced concrete slabs. This investigation will involve the development of extensive "training" datasets where these features have been manually flagged.

Objective/Goals

The objective of this project is to propose improvements to APCS data collection to facilitate advanced image analysis and a possible pilot implementation.

Deliverables

Task 1: **Capacity development at the UCPRC, including background and establishment of a knowledge and computing environment suitable for training deep learning neural network models**

- A functional machine-learning environment accessible to UCPRC researchers, with training materials about how it can be used

Task 2: **Library of tagged images, using various right-of-way and pavement surface images from different vendors**

- Database of tagged images tied to the performance modeling database

Task 3: **Model for flagging recently replaced slabs on jointed plain concrete pavements and patches on asphalt**

- A trained deep learning agent capable of predicting if a slab observed in an image has been recently replaced
- A trained deep learning agent capable of identifying recently patched areas of the pavement surface

Task 4: **Model for categorizing the drainage conditions and other roadside features at various locations**

- A trained deep learning agent capable of predicting, from the right-of-way image, the state of the drainage at a particular location

Task 5: **Georgia Tech subcontract**

- Advice to the UCPRC on state-of-the-art automated pavement condition survey machine-learning technology advances and planned future developments being funded by the Federal Highway Administration
- Assistance in development of two case studies on finding replaced concrete slabs, identifying drainage features, and classifying their condition

Task 6: **Final report and possible pilot implementation**

- Technical memorandum on and recommendations for future uses of advanced image analysis in automated pavement condition surveys

Summary of Progress FY 2020-2021

A work plan was developed for this project, and the subcontract with Georgia Tech was executed. Meetings have been held to begin work with the subcontractor, but misunderstandings with the subcontractor about work plan expectations and what was agreed to in the contract have taken some time to resolve. A new work plan has been prepared, and it is currently being approved. Some work has been done to begin the data capture needed for the training of the deep learning algorithms.

Updates and Improvements to RealCost-CA

DRISI Project ID: 3815 | **UCPRC Project Number:** 3.59
Caltrans Technical Lead: Leonardo Mahserelli, Office of Concrete Pavement
UCPRC Project Manager: Changmo Kim

Research Needs

Variability and uncertainty of agency and user cost estimates and treatment lives of pavement materials are the key areas of life cycle cost analysis (LCCA) and decision support. Variability and uncertainty in LCCA need to be investigated, and methods of considering them in decision support need to be developed. Caltrans has implemented new pavement materials and treatments and their LCCA procedures, and maintenance and rehabilitation schedules need to be developed and included in the LCCA procedures manual and *RealCost-CA.*

The LCCA procedures manual needs to be continuously updated as new materials and treatments are developed so that designers can consider them along with current materials and treatments when comparing alternatives. An operation manager's manual needs to be developed with detailed procedures for updating default variables such as material unit prices, construction price indices, and other time-sensitive variables. The manual should also describe use of the software and management of input and output files by users. Traffic congestion in construction work zones (CWZs) during reconstruction and rehabilitation causes additional delay and associated road user costs, particularly on urban highways but also on rural routes. Consideration of construction-related delay is a part of Caltrans and Federal Highway Administration LCCA procedures. Better procedures are needed for estimating project-based road user costs from CWZ congestion on future maintenance and repair treatments.

Objective/Goals

This study is a continuation of PPRC Project 3.44 (Update Life-Cycle Cost Analysis Manual and RealCost Version 3.0). The objective of this project is to continue updating the Caltrans *Life-Cycle Cost Analysis Procedures Manual* and *RealCost 3.0CA.*

Deliverables

Task 1: **Consideration of variability and uncertainty for cost and treatment lives**
- Summary notes and presentation file

Task 2: **Procedures for estimating maintenance and repair schedules for new treatments**
- Engineering configuration for maintenance and repair schedules for new treatments
- Updated maintenance and repair sequence selection function in *RealCost-CA*

Task 3: **Operation manager's manual for *RealCost-CA***
- Online operation manager's manual for *RealCost-CA*
- Summary notes and presentation file

Task 4: **Implementation of CWZ studies into *RealCost-CA***
- Engineering configuration for CWZ calculation and an updated *RealCost-CA* version reflecting new CWZ calculation methods

Task 5: **Preparation of project documentation**
- Technical memorandum

Summary of Progress FY 2020-2021

The maintenance and rehabilitation schedules for both asphalt and concrete pavements were updated through mechanistic-empirical approaches (*CalME* and *PavementME*) for Caltrans' latest pavement design methods. The maintenance costs—including preventive treatment, capital maintenance, and rehabilitation—were calculated from the latest construction cost data and updated in the *Life-Cycle Cost Analysis Procedures Manual*. Studies on consideration of variability and uncertainty for cost and treatment lives, maintenance and repair schedules for new treatments, and implementation of CWZ traffic delay models are included in this task. A framework for an operations manual was designed, and development of an interface for the operation manual was started. *RealCost 3.0CA* was completely debugged.

Support Tasks

Develop and Manage Partnered Pavement Research Program

DRISI Project ID: 3823 | **UCPRC Project Number:** 2.01

Overview

Provide management and administration of the overall PPRC contract, and work to establish partnerships with organizations outside of Caltrans to improve Caltrans pavements.

Summary of Progress FY 2020-2021

The UCPRC provided contract and financial administration for projects and worked with industry and other government agencies to support Caltrans-sponsored research.

Provide Advice to State Government on Pavement Technology

DRISI Project ID: 3829 | **UCPRC Project Number:** 2.02

Overview

Perform conceptual and feasibility studies (small projects at a cost of less than $10,000), answer questions, and provide information, as requested by Caltrans.

Summary of Progress FY 2020-2021

The UCPRC's advice has primarily involved supporting Caltrans with requests for information, background briefings, and input for decision-making not tied to PPRC projects.

Provide Support for Pavement Management System (PaveM) Operations

DRISI Project ID: 3832 | **UCPRC Project Number:** 2.03

Overview

Provide continued support for implementation of pavement and asset management within Caltrans, including updates and enhancements to *PaveM*, support for the "pavement portal" applications, and other tasks as directed by Caltrans. Specific tasks include the restructuring and improvement of project information within *PaveM*; annual updating of linear referencing system (LRS), traffic data, and other data; application of the segmenting processes; and documentation of existing engineering configuration, software, and processes.

Summary of Progress FY 2020-2021

Work on this task is as needed by Caltrans. In FY 2020-2021, this work has involved assistance to Caltrans with debugging issues in *PaveM*, discussions around the transition to the new 2019 LRS and models, meetings and planning for the software upgrade to *PaveM*, and various updates to the UCPRC information technology infrastructure that supports the PaveM Portal applications. This support work also included responding to questions from Caltrans about the various *PaveM* support tools (*PCR*, *H-Chart*, *iGPR*, *iGPR-Core*, *PaveM Portal*, *RP-List*) and making changes to them, updating the various files (Highway Log, Project History, Automated Pavement Condition Surveys, and Previous Year Actuals) that are exported out of *PaveM* for use in the UCPRC *PaveM* tools, and fixing bugs and resolving issues related to the server, as necessary.

The programmer/engineer who developed the PaveM Portal applications retired in June 2021, and a new programmer was hired at the end of the fiscal year to assume this role. This personnel change has involved recruitment efforts and transitioning of the tools, including moving the revision tracking from an internal SubVersion server to GiHub, where the code can be shared with Caltrans.

Provide Support for CalME, PavementME, and CalBack

DRISI Project ID: 3831 | **UCPRC Project Number:** 2.04

Overview

Provide support and training for use of *CalME, PavementME*, and *CalBack* to Caltrans users and other users as identified by Caltrans. Update the interface and internal operations of *CalME, PavementME,* and *CalBack* as requested by Caltrans.

Summary of Progress FY 2020-2021

The UCPRC provided extensive support for rewriting of the Caltrans *Highway Design Manual* to reflect updated practice using mechanistic-empirical design and performance-related specifications. A site investigation guide for asphalt- and concrete-surfaced pavement was developed and submitted for review. An update was made to the *CalME* software based on input from the districts and other users.

Provide Support for eLCAP and RealCost-CA

DRISI Project ID: 3779 | **UCPRC Project Number:** 2.05

Overview

Provide support and training for use of *eLCAP* and *RealCost-CA* to Caltrans users and other users as identified by Caltrans. Update the interface and internal operations of *eLCAP* and *RealCost-CA* as requested by Caltrans.

Summary of Progress FY 2020-2021

The UCPRC provided support to Caltrans to answer questions from the districts and headquarters regarding life cycle cost analysis and to update the current *RealCost-CA* software. Support for *eLCAP* primarily consisted of helping Caltrans perform life cycle assessment case studies with the cement industry and supporting District 11 with a case study.

Maintain Laboratory Testing AASHTO Re:source Certification

DRISI Project ID: 3828 | **UCPRC Project Number:** 2.06

Overview

Calibrate laboratory equipment as needed for AASHTO and Caltrans quality assurance specifications to complete Caltrans projects, and pay for certification costs.

Summary of Progress FY 2020-2021

Funds for this support task were used for management of the UCPRC laboratories, including annual and biannual equipment calibrations and all aspects of maintaining Caltrans and AASHTO accreditations. Additionally, improvements to laboratory safety, occupational health, ergonomics, material and specimen flows, and general and management procedures continued. Changes to sustain operations during the COVID-19 pandemic were also implemented. Laboratory consumables (e.g., personal protective equipment, small tools, sample storage, cleaning materials) were also covered under this task.

Maintain Laboratory and Field-Testing Equipment Capability

DRISI Project ID: 3826 | **UCPRC Project Number:** 2.07

Overview

Maintain and/or replace laboratory and field equipment to complete Caltrans projects.

Summary of Progress FY 2020-2021

Funds for this support task were used to maintain and/or replace laboratory and field equipment to complete Caltrans projects. Equipment purchases included a double-bladed saw for cutting asphalt specimens, two dumpsters for disposing of tested specimens, a saw for cutting small specimens, totes for storing purified hydraulic oil, and an environmental chamber for curing recycled material specimens.

Maintain Heavy Vehicle Simulator Equipment

DRISI Project ID: 3827 | **UCPRC Project Number:** 2.08

Overview

Maintain, replace, and calibrate equipment used for accelerated pavement testing with the Heavy Vehicle Simulator (HVS) machines to complete Caltrans projects.

Summary of Progress FY 2020-2021

Funds for this task were used to maintain, replace, and calibrate equipment used for accelerated pavement testing with the HVS machines to complete Caltrans projects. Both machines are overdue for comprehensive hydraulic system overhauls, and this work was initiated. Unfortunately, COVID-19 shutdowns have significantly delayed delivery of critical parts for the overhaul process. Work on both machines included replacement of all hydraulic hoses, overhaul of the hydraulic pumps, and replacement of drive chains and sprockets. Work on HVS-2 included overhaul of the gearbox and replacement of the carriage control unit. A cooling system for the environmental chamber on HVS-3 was installed.

Operate Falling Weight Deflectometer and Profiler Calibration Centers

DRISI Project ID: 3825 | **UCPRC Project Number:** 2.09

Overview

Maintain space, equipment, and certifications for calibration of Caltrans and contractor profiler equipment to support Caltrans smoothness specifications. Maintain space, equipment, and certifications for operation as a Federal Highway Administration falling weight deflectometer (FWD) calibration center.

Summary of Progress FY 2020-2021

The FWD calibration slab was rehabilitated and recalibrated, and three FWDs were calibrated. Profiler calibrations were undertaken on 19 days, during which 37 Caltrans, 69 industry, and 4 UCPRC operators were certified, and 12 Caltrans and 25 industry vehicles and a UCPRC vehicle were certified.

Upgrade/Maintain Research Support Space

DRISI Project ID: 3824 | **UCPRC Project Number**: 2.10

Overview

Update, augment, and rehabilitate research support space in Davis and Richmond as needed to perform research for Caltrans.

Summary of Progress FY 2020-2021

Work included installation and certification of air conditioning and dust extraction systems in the four laboratories on the west side of the Davis building, installation of a certified fume hood for binder extraction, and construction of a new saw cutting and coring room. Compressed air systems were also refurbished to accommodate the additional equipment.

Provide Support to Division of Aeronautics

DRISI Project ID: 3780 | **UCPRC Project Number:** 2.11

Overview

Provide research, development, and implementation support for improved technologies and practices for airfields as requested by the Caltrans Division of Aeronautics. Coordinate activities with research sponsored by the Federal Aviation Administration.

Summary of Progress FY 2020-2021

A meeting was held with the Division of Aeronautics to identify needs, and a detailed work plan was prepared. Personnel changes at the division have delayed approval of the work plan and the start of work.

Conduct Advanced Pavement Research for Long-Term Future Needs

DRISI Project ID: 3830 | **UCPRC Project Number**: 2.12

Overview

Perform conceptual, research, and development studies for long-term future Caltrans and California transportation needs not directly tied to Caltrans line functions at the direction of DRISI.

Summary of Progress FY 2020-2021

Extensive laboratory and field-testing support was given to a pilot project for partial-depth recycling using recycled plastic. Work was also performed on a study of urban metabolism (circular economy) considering materials for hardscape and the water cycle in urban areas.

Appendix A:
UCPRC Publications
FY 2020-2021

Development of Performance-Based Specifications for Asphalt Rubber Binder: Interim Report on Phase 1 and Phase 2 Testing

Report Number: UCPRC-RR-2017-01

Publication Date: September 2020

Authors: David Jones, Hashim Raza Rizvi, Yanlong Liang, Jeffrey Buscheck, Mohammad Zia Alavi, and Bernhard Hofko

Principal Investigator: John Harvey

Caltrans Technical Lead: Guadalupe Magana

Project: 4.50/4.63 (DRISI Task 2671/3186): Performance-Related Specifications for Rubberized Asphalt Binder

Download: escholarship.org/uc/item/4mq5p6sd

Need for Research

In the United States, the Superpave Asphalt Binder Performance Grading system proposed by the Strategic Highway Research Program is the most common method used to characterize the performance-related properties of unmodified and polymer-modified asphalt binders. Dynamic shear modulus and phase angle are the two main binder properties measured using a dynamic shear rheometer with parallel plate geometry and either a 1 mm or 2 mm gap between the plates. Since these Superpave parameters were developed for binders that do not contain additives or particulates, Caltrans does not use them for asphalt rubber binder specifications. Instead, penetration and viscosity are used as acceptance of quality control. However, these parameters do not necessarily provide a satisfactory link between the measured binder properties and potential performance in the field over a range of operating temperatures.

Research Approach

Current specifications require that crumb rubber particles used to produce asphalt rubber binder in the "wet process" be smaller than 2.36 mm (i.e., 100% passing through the #8 sieve), and typically these particles vary in size between 1 mm and 2 mm. Consequently, when parallel plate geometry is used to test this type of binder, the rubber particle rheology can potentially dominate the results and may not be representative of the modified binder as a whole. To address this problem, a potentially more appropriate dynamic shear rheometer testing protocol using concentric cylinder geometry was investigated in Phase 1 of this study as an alternative means to determine the performance properties of asphalt rubber binders.

Phase 2 of the study continued the investigation into the use of the concentric cylinder geometry and alternate parallel plate geometry with a 3 mm gap. The use of these geometries for intermediate-temperature testing and multiple stress creep recovery testing was also investigated, as well as modified procedures for short-term aging in the rolling thin-film oven, long-term aging in the pressurized aging vessel, and specimen preparation procedures for bending beam rheometer testing. Limited mix testing was also conducted to relate high- and low-temperature mix performance to the performance grades determined for the binders used in the mixes.

Results

The concentric cylinder testing approach to measuring the rheological properties of asphalt rubber binders is considered feasible, and the edge effects and trimming issues associated with parallel plate testing can be eliminated with its use. However, the concentric cylinder method requires a longer testing time and a larger binder sample than the parallel plate test method. Initial findings from performance grading and related mix testing indicate that the incompletely digested rubber particles, which have different sensitivities to temperature and applied stress and strain than the asphalt binder, appear to dominate the test results. This issue will need to be factored into the analysis and interpretation of rheology and mix performance test results. The proposed modifications to the short- and long-term aging procedures and to the bending beam rheometer specimen preparation procedures are considered more aligned with the original intent of the tests and will likely reduce the variability between replicate specimens during testing.

Recommendations

The results from Phase 2 support the continuation of testing. The research should continue to refine the testing procedures on additional field binder sources, assess the repeatability and reproducibility of any proposed test methods, and evaluate the applicability of the results to the actual performance properties of mixes produced with asphalt rubber binders.

Optimizing Rubberized Open-Graded Friction Course (RHMA-O) Mix Designs for Water Quality Benefits: Phase I: Literature Review

Report Number: UCPRC-RR-2019-02

Publication Date: September 2020

Authors: Masoud Kayhanian and John Harvey

Principal Investigator: John Harvey

Caltrans Technical Lead: Simon Bisrat

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Element 2.7: Advice to Caltrans under Caltrans Contract 65A0628

Download: escholarship.org/uc/item/1870m3g9

Need for Research

Historically, rubberized and non-rubberized open-graded friction courses have been placed to provide three benefits: (1) increase traffic safety, (2) reduce urban highway noise, and (3) preserve the surface of the main pavement structural section. However, stringent environmental regulations on stormwater runoff management enacted recently have forced transportation agencies with limited rights-of-way in urban areas to search for creative methods to treat runoff and receive credits for preventing pollution from highways. The considerable research completed over the last 20 years needs to be summarized to help support Caltrans planning, research, and development for continued use of open-graded friction courses to achieve the benefits identified.

Research Approach

This literature review was undertaken to explore ways to optimize current rubberized hot mix asphalt-open graded (RHMA-O) mix designs to provide multifunctional benefits, including water quality treatment.

Results

The literature review shows that permeability measurement is an essential parameter that influences the performance of a wide range of open-graded (both rubberized and non-rubberized) pavements. Further, current Caltrans aggregate gradations contain a larger fraction of fine aggregate sizes, which may also influence the permeability and functional performance of RHMA-O pavements.

Recommendations

This literature review presents an action plan recommending that the next phase of this work include optimizing current Caltrans mix designs and the mix design procedure in the laboratory and undertaking subsequent field investigations.

Alternate Strategies for Reducing Greenhouse Gas Emissions: A Life Cycle Approach Using a Supply Curve

Technical Memorandum Number: UCPRC-WH-2019-01

Publication Date: August 2020

Authors: John Harvey, Ali Butt, Arash Saboori, Mark Lozano, Changmo Kim, and Alissa Kendall

Principal Investigator: John Harvey

Caltrans Technical Lead: Julia Biggar

Project: Partnered Pavement Research Center (PPRC) Project Number 4.72 (DRISI Task 3209): LCA Alternate Strategies for GHG Reduction: Example Strategies

Download: escholarship.org/uc/item/7208x78q

Need for Research

The purpose of this white paper is to provide Caltrans with a methodology that uses life cycle assessments and life cycle cost analyses to create a “supply curve” that ranks the different strategies/actions that can be taken to reduce greenhouse gas (GHG) emissions and lessen any other environmental impacts that affect ecosystems and human health. For Caltrans to implement the proposed methodology, the process must be validated and assessed using currently available strategies. This white paper presents the methodology and demonstrates its initial use in quantifying and ranking several potential strategies.

Research Approach

The approach taken to support the prioritization of strategies for reducing GHG emissions was to develop what are variously called supply curves, marginal abatement curves, or McKinsey curves. Caltrans and the research team discussed six strategic pilot case studies to test the methodology and to measure the results of the strategies. The six strategies were grouped into three categories:

1. Pavement Management Related
    a. Fuel use reductions through pavement network roughness management
    b. Increased use of recycled asphalt pavement (RAP)
2. Renewable Energy Generation Related
    a. Energy harvesting using piezoelectric devices under the pavement surface
    b. Solar and wind energy production on state rights-of-way
3. Caltrans Operations Related
    a. Automation of bridge tolling systems
    b. Alternative fuel technologies for agency vehicle fleet

Results

The results showed that keeping the highest-traffic sections of the highway network smoother results in the largest GHG abatement, given the assumptions made in the analysis. This abatement costs Caltrans, but it has a low abatement unit cost. The most cost-effective strategy was increased use of RAP, but this strategy has a perverse effect in that the lowest-cost rejuvenating agent capable of blending the RAP into the mix well also has a higher GHG impact. Therefore, if this lowest-cost rejuvenator is used, the GHG emissions reduction is very small. However, in both cases, the large cost savings to the contractor of using RAP to replace virgin asphalt binder was assumed to be passed on to Caltrans through the low-bid contracting method.

The most expensive strategy per unit of GHG saved appeared to be changing the Caltrans vehicle fleet to electric cars and biodiesel trucks, regardless of the rate of change considered (all at once or following Department of General Services policy). Automated bridge tolling is always cost-effective, but that cost-effectiveness decreases as vehicles using the bridges become more electrified (a perverse conclusion that often occurs in these types of analyses). The cost-effectiveness of both increasing solar and wind energy from Caltrans rights-of-way and parking lots and of installing piezoelectric energy collection devices under pavements is highly dependent on the price given to Caltrans for the energy delivered, either saving or costing Caltrans per unit of GHG reduced.

Recommendations

Further consideration must also be given to implementation readiness because solar and wind technologies are proven technologies while piezoelectric energy generation devices are in the early stages of development and many questions remain about the efficacy of putting these devices under pavement.

Life Cycle Assessment and Life Cycle Cost Analysis for Six Strategies for GHG Reduction in Caltrans Operations

Technical Memorandum Number: UCPRC-TM-2019-02

Publication Date: September 2020

Authors: John Harvey, Ali Butt, Arash Saboori, Mark Lozano, Changmo Kim, and Alissa Kendall

Principal Investigator: John Harvey

Caltrans Technical Lead: Julia Biggar

Project: Partnered Pavement Research Center (PPRC) Project Number 4.72 (DRISI Task 3209): LCA Alternate Strategies for GHG Reduction: Example Strategies

Download: escholarship.org/uc/item/0mx245rd

Need for Research

California state government has established a series of mandated targets for reducing the greenhouse gas (GHG) emissions that contribute to climate change. The various sources of emissions and economic sectors mean that no single change the state can make will enable it to achieve the ambitious goals set by executive orders and legislation. Instead, many actors within the state's economy—including state agencies such as Caltrans—must make multiple changes to their own internal operations.

The focus of this study and technical memorandum is to examine several strategic options that Caltrans could adopt to lower its GHG emissions from operations of the California state highway network and other transportation assets to help meet the state's GHG reduction goals. Although many GHG reduction strategies appear to be attractive, simple, and effective, most also have limitations, tradeoffs, and unintended consequences that cannot be identified without a preliminary examination of the full system within which they operate and their full life cycle. To achieve the most rapid and cost-effective changes possible, the costs, times to implement, and difficulty of implementation should also be considered when the alternative strategies are prioritized.

Research Approach

This project first developed an emissions reduction "supply curve" framework by using life cycle assessments to evaluate full-system life cycle environmental impacts and life cycle cost analyses to prioritize the alternative GHG reduction strategies based on benefit and cost. This framework was then applied to an example set of strategies and cases of Caltrans operations.

Results

This technical memorandum presented the results of the supply curve framework's development and its application to six strategies for changing several Caltrans operations. The six strategies were (1) pavement roughness and maintenance prioritization, (2) energy harvesting using piezoelectric technology, (3) automation of bridge tolling systems, (4) increased use of recycled asphalt pavement, (5) alternative fuel technologies for the Caltrans vehicle fleet, and (6) solar and wind energy production on state rights-of-way. The memorandum includes the details, assumptions, calculation methods, and results of the development of the GHG reduction supply curve for each strategy.

Recommendations

Although this current study's scope is limited to development of a supply curve for GHG emissions only, there are plans to expand the study's scope to include other environmental impacts and to develop supply curves for those impacts.

Effects of Increased Weights of Alternative Fuel Trucks on Pavement and Bridges

Report Number: UC-ITS-2020-19

Publication Date: November 2020

Authors: John Harvey, Arash Saboori, Marshall Miller, Changmo Kim, Miguel Jaller, Jon Lea, Alissa Kendall, and Ashkan Saboori

Principal Investigator: John Harvey

Download: escholarship.org/uc/item/4z94w3xr

Need for Research

California's truck fleet composition is shifting to include more natural gas vehicles, electric vehicles, and fuel cell vehicles, and it will shift more quickly to meet state greenhouse gas (GHG) emission goals. These alternative fuel trucks (AFTs) may introduce heavier axle loads, which may increase pavement damage and GHG emissions from work to maintain pavements. This project aims to provide conceptual-level estimates of the effects of vehicle fleet changes on road and bridge infrastructure.

Research Approach

Three AFT implementation scenarios were analyzed using typical California state and local pavement structures, and a federal study's results were used to assess the effects on bridges.

Results

This study found that more natural gas, electric, and fuel cell trucks are expected among short-haul and medium-duty vehicles than among long-haul vehicles. However, the estimates predicted that by 2050 alternative fuels would power 25%–70% of long-haul and 40%–95% of short-haul and medium-duty trucks. AFT implementation is expected to be focused on the 11 counties with the greatest freight traffic—primarily urban counties along major freight corridors.

Results from the implementation scenarios suggested that introducing heavier AFTs will only result in minimal additional pavement damage, with the extent dependent on the pavement structure and AFT implementation scenario. These estimated results for the effects on pavement were based on the assumption that AFTs will become lighter as they are implemented.

Recommendations

Although allowing weight increases of up to 2,000 lb is unlikely to cause major issues on more modern bridges, the effects of truck concentrations at those new limits on inadequate bridges needs more careful evaluation. The study's most aggressive market penetration scenario for AFT yielded an approximate net reduction in annual well-to-wheel truck propulsion emissions of 1,200–2,700 kT per year of CO_2-e by 2030 and 6,300–34,000 kT by 2050 compared to current truck technologies. Negligible effects on GHG emissions from pavement maintenance and rehabilitation resulted from AFT implementation.

Heavier Alternative Fuel Trucks Are Not Expected to Cause Significant Additional Pavement Damage

Publication Date: November 2020

Authors: John Harvey, Arash Saboori, Marshall Miller, Changmo Kim, Miguel Jaller, Jon Lea, Alissa Kendall, and Ashkan Saboori

Project: UC ITS Project ID: UC-ITS-2020-19

Download: escholarship.org/uc/item/2p76t1g4

Need for Research

Medium- and heavy-duty trucks on California's roads are shifting from conventional gasoline and diesel propulsion systems to alternative fuel (natural gas, electric, fuel cell) propulsion technologies, spurred by the state's greenhouse gas (GHG) reduction goals. While these alternative fuel trucks (AFTs) produce fewer emissions, they are also currently heavier than their conventional counterparts. Heavier loads can cause more damage to pavements and bridges, triggering concerns that clean truck technologies could actually increase GHG emissions by necessitating either construction of stronger pavements or more maintenance to keep pavements functional. California Assembly Bill 2061 (2018) allows a 2,000 lb gross vehicle weight limit increase for near-zero-emission vehicles and zero-emission vehicles to enable these trucks to carry the same loads as their conventional counterparts. The law also asked the University of California Institute of Transportation Studies to evaluate the new law's implications for GHG emissions and transportation infrastructure damage.

Research Approach

This analysis considered three adoption scenarios of AFTs in two timeframes, 2030 and 2050. Based on these scenarios, life cycle assessment and life cycle cost analysis were used to evaluate how heavier trucks might affect pavement and bridge deterioration, GHG emissions, and state and local government pavement costs. The study did not evaluate the safety implications of increasing allowable gross vehicle weights.

Results

The findings indicated that introducing heavier AFTs, as allowed by AB 2061, is expected to result in only minimal additional damage to local and state government-owned pavements. Although natural gas vehicle technology cannot become lighter, it is not expected to have significant market penetration. In addition, the cost of additional pavement damage from AFTs will be negligible.

Projected GHG emissions reductions from AFT adoption will far outweigh emissions from additional road maintenance. The research also showed that ability to model the effects of heavier AFTs on bridges is very limited.

Recommendations

As California transitions to AFTs, monitoring changes in pavement and bridge damage will be important. Refining the results of the current research will require improvements in data collection and models for implementation of AFTs, alternative fuel vehicle axle and vehicle weight changes, GHG emissions related to truck manufacture and use, the effects of road roughness on AFT energy use, and bridge deterioration.

Guide for Partial- and Full-Depth Pavement Recycling in California

Guideline Number: UCPRC-GL-2020-01

Publication Date: December 2020

Authors: David Jones, Stephanus Louw, and John Harvey

Principal Investigator: John Harvey

Caltrans Technical Lead: Allen King

Project: Partnered Pavement Research Center (PPRC) Contract Strategic Plan Elements 4.59, 4.65, 4.69, and 4.70 (DRISI Tasks 2707, 3194, 3195, and 3196): Improved Guidance and Specifications for In-Place Recycling

Download: escholarship.org/uc/item/54z679x4

Need for Research

This document provides guidance to practitioners on project investigation, recycling strategy selection, pavement structural design, environmental life cycle and life cycle cost assessment, mix design, and construction of in-place pavement recycling projects on flexible pavements in California.

Research Approach

This research included a desktop study; a preliminary site investigation; a detailed site investigation; and a decision-making process to select the most appropriate maintenance, rehabilitation, or reconstruction strategy.

Recommendations

The main changes and updates to the 2017 version of the guide (UCPRC-GL-2017-04) include:

- Updates to terminology used for in-place recycling
- Updates to the project investigation chapter, including alignment with the new Caltrans site investigation guide
- Updates throughout the guide to include cold central plant recycling
- Inclusion of mechanistic-empirical design procedures (*CalME*) in the design chapter
- Updates to the mix design chapter to align with the new California Test Method for mix design for partial-depth recycling
- Inclusion of a provisional laboratory procedure for mix designs for full-depth recycling with cement
- Updates to the construction chapter to align with recent specification changes

Updates to CalME and Calibration of Cracking Models

Report Number: UCPRC-RR-2021-01

Publication Date: March 2021

Authors: Rongzong Wu, John Harvey, Jeremy Lea, Angel Mateos, Shuo Yang, and Noe Hernandez

Principal Investigator: John Harvey

Caltrans Technical Lead: Raghubar Shrestha

Project: Partnered Pavement Research Center Strategic Plan Element (PPRC SPE) 2.9 (DRISI Task 3215): CalME Support

Download: escholarship.org/uc/item/460234g0

Need for Research

The conventional approach to calibrating a mechanistic-empirical (ME) method, which has been used since calibration of the Shell Method and Asphalt Institute Method in the 1970s and early 1980s, has limitations. First, it requires expensive and time-consuming sampling and testing of materials properties for each section, resulting in a small number of sections being available for calibration. Second, it ignores the fact that a design-bid-build (low-bid) designer does not know the performance-related properties of the materials the contractor will bring to the job, resulting in a blurred understanding of the sources of variability and their consideration in the design reliability approach. A new calibration approach is needed to calibrate *CalME* (version 3.0) while addressing these limitations, and a new approach is needed to account for reliability in ME designs.

Research Approach

The new calibration approach developed by the UCPRC to calibrate *CalME* (version 3.0) aims to improve calibration and the reliability approach used in ME design by: (1) using all the good-quality distress performance data and as-built data in the Caltrans pavement management system databases collected since 1978 and quality checked over the last 10 years, (2) using median properties to match median performance and using the variability of observed median performance to determine between-project variability, after using *CalME* to account for the effects of climate, pavement cross section, and traffic, and (3) backcalculating within-project variability by matching the shape of observed performance time history.

Results

The following enhancements and additions are all included in the revised program. First, the old software's fatigue cracking transfer functions for hot mix asphalt on aggregate base, cement-stabilized bases, and portland cement concrete were recalibrated using a new approach for the calibration of ME pavement design methods. Second, the updated program also includes new damage models and transfer functions for in-place recycling materials, including full-depth recycling with foamed asphalt plus cement and cement stabilization, and partial-depth recycling with emulsified asphalt and foamed asphalt plus cement. Third, the program now has been given the ability to model partial-depth recycling using cold central plant recycled materials. Fourth, new damage models have been introduced for cement-stabilized bases and cement-stabilized and lime-stabilized subgrade materials to correct problems with the models in *CalME* (version 2.0). Fifth, minimum aggregate base thicknesses were developed based on calculations of permanent deformation under construction traffic. Lastly, simplified methods were developed for estimating subgrade stiffnesses (resilient modulus) based on dynamic cone penetrometer tests, California bearing ratio tests, and R-value tests.

Recommendations

The recommendations are that *CalME* (version 3.0) be implemented for pavement design, the calibration be updated with new data approximately every three to five years, Caltrans traffic databases be checked before they are used again for recalibration, and use of the recently updated Caltrans Data Interchange for Materials Engineering (DIME) database of as-built data be considered for future calibrations.

Pavement ME Sensitivity Analysis (Version 2.5.3)

Report Number: UCPRC-RR-2019-02

Publication Date: May 2021

Authors: Ashkan Saboori, John Harvey, Jeremy Lea, Rongzong Wu, and Angel Mateos

Principal Investigator: John Harvey

Caltrans Technical Lead: Dulce Rufino Feldman

Project: Partnered Pavement Research Center Strategic Plan Element (PPRC SPE) 3.49 (DRISI Task 3199): Implement Concrete ME Design Tools

Download: escholarship.org/uc/item/6bv7d7t6

Need for Research

The *Mechanistic-Empirical Pavement Design Guide (MEPDG)* is a comprehensive tool first developed in 2002 by the American Association of State Highway and Transportation Officials (AASHTO) to analyze and design both flexible and rigid pavements. The models in the *MEPDG* are implemented in software called *Pavement ME,* a program calibrated using long-term pavement performance sections from throughout the United States, including some from California. The *MEPDG* recommends that nationally calibrated models be validated using local data and, if necessary, recalibrated.

Research Approach

The first step in recalibrating *Pavement ME* was to perform a sensitivity analysis to identify the most important variables and to look for results that do not match expected performance.

Results

This report presents the results of a sensitivity analysis showing the effects of design input variables controlled by the designer and those not known to the designer. The sensitivity analysis showed that the overall jointed plain concrete pavements performance prediction by *Pavement ME* is reasonable. The distresses predicted by *Pavement ME* did not show any unexpected trends for any of the variables considered in this sensitivity analysis.

Recommendations

The next steps are to complete the calibration using California pavement management system data and then develop the design tool with the calibrated *Pavement ME* coefficients.

tBeam—A Fast Model to Estimate Energy Consumption Due to Pavement Structural Response: Theoretical and Validation Manual

Report Number: UCPRC-RP-2021-01

Publication Date: June 2021

Authors: Shmuel L. Weissman and James M. Kelly

Principal Investigator: John Harvey

Caltrans Technical Lead: Deepak Maskey

Project: Partnered Pavement Research Center (PPRC) Contract Strategic Plan Element 4.73: Fast Model Energy Consumption Structural Response

Download: escholarship.org/uc/item/3bz9c13f

Need for Research

One of the most important contributors to the environmental impacts from use of highways is the energy exerted by vehicles, particularly routes that carry higher volumes of traffic. Part of this energy is consumed by response of the vehicle's tires and suspension to pavement surface roughness and macrotexture. Another part of the energy consumed is by energy dissipation due to the structural response of the pavement itself under the moving load. This document is the theoretical and validation manual for *tBeam*, standalone software for the analysis of energy dissipation in pavements under moving vehicles. *tBeam* was developed as part of the improvement of modeling capabilities for environmental life cycle assessment of pavements being conducted by the UCPRC for Caltrans.

Research Approach

The energy consumed due to structural response is controlled by the structural properties of the pavement, which are dependent on the time of day, the season, and the condition (damage) of the pavement. The energy dissipation also depends on the speed and weight of each moving wheel load. As a result, estimating the lifetime energy dissipated in a pavement structure requires multiple analyses considering the thousands of permutations of these variables for a given segment of the highway network. Therefore, models for pavement-vehicle energy dissipation must balance two opposing needs: (1) a reasonably accurate estimate of the dissipated energy and (2) high numerical efficiency.

For numerical efficiency, the *tBeam* software employs a one-dimensional finite-element based solution of a wheel traveling at a constant velocity on a viscoelastic beam-foundation system. A further reduction of numerical effort is obtained by formulating the model relative to a moving coordinate system attached to the wheel. The one-dimensional solution is, by nature, an approximation to the three-dimensional world. This approximation can be improved by incorporating a "correction factor," which is based on comparisons with pavement simulations accounting for the double curvature observed in loaded pavements. In this report, prediction disparity for a single structure is studied.

Results

The results showed a clear trend where the correction factor decreased with rising temperature and increased with higher velocity. This study was insufficient to establish a law for the correction factor, even for the single case studied. The correction factor ranged from about 1.25 at low temperature and high velocity to about 0.6 for high temperature and low velocity. The first part of this report presented the underlying theory for *tBeam* and implementation details. The second part presented closed form solutions for specialized pavement-foundation systems. The third component of the report presented some of the validation simulations undertaken to demonstrate the performance of *tBeam*, including comparisons with closed form solutions provided in the report and recommendations for further development of *tBeam*.

Recommendations

The following are recommendations for future research:

- A relation between the *tBeam* predicted energy dissipation and the predicted energy dissipation when accounting for the three-dimensional nature of the pavement system could be determined.
- Application of the load as a uniformly distributed pressure over a specified contact area can be easily changed to account for non-uniform distribution.
- A deformable wheel can replace the rigid wheel model employed by *tBeam*. This enhancement will result in a more realistic prediction of the contact area. Unfortunately, it will add to the numerical cost of the analysis. Therefore, such an enhancement would primarily benefit pavement research.
- *tBeam* can be enhanced to better account for the three-dimensional response of pavements. This enhancement would employ a formulation based on the shear deformable Reissner-Mindlin plate theory. To maintain efficiency, it would be formulated relative to a moving coordinate system. This tool would benefit both pavement research and sustainability analysis.

tBeam—A Fast Model to Estimate Energy Consumption Due to Pavement Structural Response User Manual

Report Number: UCPRC-RP-2021-01

Publication Date: June 2021

Authors: Shmuel L. Weissman

Principal Investigator: John Harvey

Caltrans Technical Lead: Deepak Maskey

Project: Partnered Pavement Research Center (PPRC) Contract Strategic Plan Element 4.73: Fast Model Energy Consumption Structural Response

Download: escholarship.org/uc/item/1pr693v3

Need for Research

This document constitutes the user manual for *tBeam*, standalone software for the analysis of energy dissipation in pavements under moving vehicles. *tBeam* was developed as part of the improvement of modeling capabilities for environmental life cycle assessment of pavements being conducted by the UCRPC for Caltrans.

Research Approach

tBeam is finite-element based, employing multilayered three-node Timoshenko beam elements resting on a viscoelastic Winkler foundation. It provides an approximation of the deflection bowl of pavements and the energy dissipated in pavement structures when subjected to loads moving at constant velocities.

Results

tBeam supports two loading options: (1) a uniform pressure (per unit length) applied to a segment at the center of the beam and (2) a rolling rigid wheel. To achieve numerical efficiency, the load-beam-foundation system is represented relative to a moving coordinate system attached to the moving load. The higher efficiency is made possible because, in this framework, an observer attached to the moving coordinate system perceives a “static” state (i.e., independent of time).

Recommendations

The standalone *tBeam* software serves two purposes. First, it provides developers of pavement life cycle assessment tools a "guide" as to how to integrate *tBeam* technology into their programs. To this end, the "main" of *tBeam* can be used as a "guide" for integrating *tBeam* capabilities within the life cycle assessment tool. Second, *tBeam* capabilities are relevant to pavement research in general. Thus, it could represent a useful addition to the toolset for pavement viscoelastic mechanics.

Appendix B: Pavement Research Roadmaps and Funding Plan

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Pavement Research Roadmap

ME Design of Asphalt

VISION: Develop and use a design procedure that provides the most accurate prediction of asphalt pavement performance possible within a reasonable time and cost

CONCEPT

SCOPE: Mechanistic-empirical approaches and tools for asphalt surfaced pavement evaluation, design and analysis

CAL/APT (1999) Fatigue cracking and rutting in classical ME framework; used on LA-710 long Life

3.1/4.1 Framework for *CalME*
- Incremental-recursive design
- Calibration framework with laboratory, APT, test track, field and PMS data
- Spatial variability

2011-2017

Integration framework for databases between CalME, PaveM, LCCA, LCA

Mechanistic surface characteristics prediction

Interaction between distresses

New approach for models for climate effects on pavement response

Improved response models

Project level TSD for site investigation for use on big rehab projects

Alternatives to TSD: Find moisture issues, delamination, anomolies tied to GPR

RESEARCH

Initial *CalME* development v1.0
2003

Goal 6 Initial *CalME* reflective cracking approach
2005

R21 Rutting mechanism validation
2008-2011

4.1 Framework for *CalME*
- Develop climate databases, traffic/WIM databases
- Initial set of models: rutting, fatigue, crushing, aging, IRI., reflective cracking, etc.

2011-2014

3.31 Models
- Initial thixotrophy evaluation (rest periods), simplified temperature model, aging model, block cracking, improved reflective cracking model

2014-2017

3.32 Comparison of lab & field produced mix properties
2014-2017

3.36 Initial in-place recycling models
2014-2017

3.38/3.41 Improve ME Models
- Rest period determination
- Aging model (3.38 as well)
- Models for FDR-C and FDR-FA
- Improved PDR models
- Characterization of constructed pavements
- Traffic reflective cracking model, updated strain calculation

2017-2020

4.51: tBeam: structural energy model
2017-2020

2.9 Within-project and between-project variability concept
2017-2020

Improved material models
- RAP/RAS (4.76, 4.79)
- IPR (4.78, 3.52)
- RHMA-G (4.75)

2020-2023

3.52 Update ME models
- Effects of wander on rutting
- Effects of moisture on unbound layers
- New WIM categories

2020-2023

Modeling, testing, and validation of interlayer base and overlay reflective cracking performance
MED-D 2020-2023

Improved fatigue and top-down cracking models

Integration of empirical-mechanistic surface degradation models in *CalME* for complete analysis for LCA, LCCA
- IRI, noise, skid resistance, permeability, age-related cracking, fuel consumption

Continued improvement on between- and within-project variability considerations
- RAP, material (construction, mix design, binder, rubber)

Bonding and delamination model or consideration

DEVELOPMENT

4.1 *LEAP* response model 2011-2014

***CalME* v2.0** 2011

***CalBack* backcalculation tool v1.0**
2011

Initial HVS alibration 2005-2011
- Goal 1: Asphalt-Treated Permeable Base
- Goal 3: Asphalt rubber and tire types
- Goal 5: Wet condition ATPB
- Goal 6: Reflective cracking
- Goal 9: New rubberized overlays
- Field data: US-101, StanTec
- External data: WesTrack, CEDEX, NCAT Florida sections, MnRoad

3.18/3.30/3.38 Standard material testing
- Building Standard Materials Library

2011-2020

3.31/3.32/3.37 Test methods
- Sine vs Haversine for fatigue testing
- RSST to RLT conversion

2014-2020

2.9/3.36 *CalME* v3.0 web-based
- Software
- Training
- Site inv. Guide, HDM, CT 357

2017-2020

3.41/3.49 Integrate asphalt & PCC pavement design methods & tools
2017-2020

3.41 Field calibration with Caltrans APCS data 2017-2020

3.51/4.78 Standard material testing
- Inverted pavements with CCPR and CSS/LSS
- CTB, LCB, PG+X, COA

2020-2023

3.52 Integration between *CalME* & other operations (Design, *DiME*, *PaveM*) 2020-2023

3.52 Update *CalBack* and make it web-based 2020-2023

2.04 Operations support for *CalME* & *CalBack* 2020-2023

3.51/4.79 Improved asphalt aging calibration 2020-2023

Additional APT calibration
- R21 composite pavement
- FDR (4.36), wet FDR (4.59)
- WMA, RWMA (4.18)
- OGFC (3.21)
- Any new HVS test data
- FAA NAPTF

Top-down cracking model

Integrate improvements in PRS for asphalt & concrete into *CalME*

tBeam: calibration of structural energy model against 3-D models

Soils characterization for recycled pavement design: durability, stiffness and shear strength

AB specification for recycled material

IMPLEMENTATION

Pilot and AC long life projects
- I-710 AC long life (1999)
- Pilot use of *CalME* for design (3.15, 2011-14)
- TEH-5, SIS-5, SOL-80 AC Long Life (2011-14)

3.33/3.37 *CalME* for SAC-5 long life
2014-2021

3.52 New models as completed
2020-2023

3.41/2.04 *CalME* v3.0 continued roll out & training 2020-2023

Integrated databases & definitions
- *PavementME*, design methods, LCCA, & LCA

Integrate LCA and LCCA calculations into pavement design tools

Implement tBeam: structural energy model in *CalME*

Implement improved asphalt aging model

CCPIC *CalME* for non-Caltrans users

FOR MORE INFORMATION

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu

For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past / Current / Proposed / Future

This roadmap has interactions with the Asphalt PRS, LCA, LCCA, RAS/RAP, Rubberized Asphalt, In-Place Recycling, ME Concrete and PMS roadmaps

Pavement Research Roadmap
ME Design of Asphalt
version date December 9, 2020

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Pavement Research Roadmap

ME Design Concrete

VISION: To develop and use a design procedure that provides the most accurate prediction of concrete pavement performance possible within a reasonable time & cost

CONCEPT

SCOPE: Mechanistic-empirical approaches and tools for concrete surfaced pavement evaluation, design and analysis

Concepts developed by others, including design thickness *PavementME*, *BCOA-ME* (Univ. Pitt.), *MinnPave*, ACPA *StreetPave*, *OptiPave* (Chile), and *HiperPav*

RESEARCH

4.1 Support for development of *EverFE* 2.24 by University of Maine
1998-2005

4.2 Concrete Pavement Study
- Evaluate existing design methods prior to MEPDG and comparison with California performance
- LLPRS Rigid & HiperPav v1 & v2
- Review strengths & other properties of California-specific high early strength mixes for use in ME design

1998-2005

4.8 Evaluate dowel bars and DBR, including alternative dowels
1998-2005

ME Design Concrete, Asphalt, Paver Permeable Pavement (CT DEA)
2010 [3,4]

3.41 Concrete Studies
- Develop understanding of concrete-asphalt and other base types bonding
- Hygrothermal response of concrete slabs, incl. impact of dry weather

2017-2020

3.49/4.74 Evaluate California design and construction effects on JPCP performance
2017-2020

4.58b New models for COA faulting and cracking
2014-2017

3.53 Concrete stress-release mechanisms (creep/relaxation, microcracking, and others)
2020-2023

MED-O 2020-2023 proposal Base design and base-slab interface systems for concrete pavements

Advanced instrumentation techniques for concrete pavements

New methods of calculating fast, accurate concrete responses

Implement new materials in existing ME design procedures (fiber-reinforced concrete, LWA, geo-polymers, etc.)

Develop new pavement designs for low-volume traffic using thinner concrete slabs (based on shorter joint spacing, CCPR, plate dowels, etc.)

DEVELOPMENT

4.1 Concrete Studies
- Evaluate & calibrate MEPDG V0.8
- Collect construction CTE data
- Initial ME Caltrans JPCP designs

1998-2005

ME permeable paver pavement design and HVS validation (ICPI)
2014 [4]

4.17 HVS evaluation of precast concrete pavements
2011-2017

4.67 Develop thin BCOA catalog
2017-2020

2.7 Integrated databases for ME design, PMS, LCA, LCCA[1,2,3]
Pavement ME traffic spectra tool
2017-2020

3.53 Evaluate past long life concrete pavements and support for implementation of new ones
2020-2023

4.81 Improved traffic models for *PaveM* and ME design[1,2,3,6]
2020-2023

Evaluate field performance of precast concrete pavements

Incorporate new PRS tests into ME design

Library of concrete properties for use in Pavement ME, tied to DIME

Web-based version of FE model for concrete pavement structural response

4.2 Evaluated JPCP designs with APT at Palmdale
1998-2005

4.58B Evaluated thin COA designs & identified gaps in knowledge
2014-2017

3.39 Monitor YOL- 113 COA pilot
2017-2020

3.49 Implement ME design tools
- Calibrate *PavementME*, Improve reliability approach, develop catalogue for JPCP, longitudinal cracking model

2017-2020

4.68 Feedback to ME design from *PaveM*
2017-2020

3.54 Develop concrete-asphalt bonding ME model and test
2020-2023

3.53 Develop CRCP catalog with *Pavement ME*
2020-2023

3.54 Monitor thin COA pilots
2020-2023

3.58 Continued calibration of ME design models with PMS data
2020-2023

Integrate improvements in PRS into ME dsign

Updated designs for unbonded concrete overlays of concrete pavements

IMPLEMENTATION

Train Caltrans on ME Design

Training on ME design for local government for more than concrete

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FOR MORE INFORMATION

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past; Current; Proposed; Future

Linked Roadmaps:
1-Pavement Management System
2-Life Cycle Assessment
3-Life Cycle Cost Analysis
4-New Concepts For Materials & Structures
5-Concrete PRS 6-ME Asphalt

Pavement Research Roadmap
ME Design Concrete
version date December 3, 2020

Caltrans

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Pavement Research Roadmap

In Place and Cold Central Plant Recycling

VISION: Reduce life cycle cost, environmental impacts, road user impacts, conserve resources through appropriate use of in-place and cold plant recycling

CONCEPT

SCOPE: All strategies for in-place and cold central plant recycling of asphalt pavements

UCPRC/South Africa workshop on FDR-FA
2000

COL-20, SIE-89, SLO/VEN-33 pilot projects
2001-2005

Initial work by Caltrans on CIR, HIR
2008 onwards

RESEARCH

4.12 Ph 1: FDR-FA
- Pilot study monitoring
- Lab mix design testing
- Lab performance testing
- APT SIE-89
- Construction monitoring
- Preliminary gravel factor

2005-2008

FHWA/Illinois LCA Software for FDR and CIR
2014-2017

4.36/4.59/4.69 Ph 2: FDR
- Pilot long-term monitoring
- APT with FDR-N, FA, AE & C
- Lab ME performance testing
- ME model development
- Guidance document

2014-2020

4.52/4.65 Ph 2: FDR-C Crack Mitigation
- Pilot study monitoring
- Test road
- Lab testing

2014-2020

4.70/4.78 Ph 3: IPR
- Pilot study monitoring
- APT track with CCPR
- Lab mix design testing
- Lab ME performance testing
- ME model development[1]
- Revised guidance

2017-2023

4.78 Ph 4: IPR
- Adding supplemental fines in PDR and CCPR mixes and use of excess mineral fines from quarries
- Fabrics and RHMA in IPR
- CCPR – Inverted pavement concept for improved structural capacity
- Role of tack coats in FDR (top), CIR (top and bottom), and CCPR (all layers)
- Stockpiling CCPR mixes
- Lab compaction methods and MDD determination
- Deep lift FDR-C
- PRS framework for IPR[2]
- 9-62 QC/QA refinement

2020-2023

CCPR – New materials using reclaimed asphalt, concrete & other materials

Recycling for rapid repair of natural disasters

In-place rubblization and recycling of concrete

Use of micromillings

Fibers (multiple sources) and other cementitious products in FDR-C

DEVELOPMENT

5.1 *PaveM* FDR/CIR performance models
2014-2017

4.37/4.54/4.66 LCA Inventory
2014-2020

3.44 LCCA Timelines
2014-2020

Literature update and LCA/ LCCA for HIR

PRS framework for IPR materials[2]

Collection of field data to support ME implementation

IMPLEMENTATION

4.12 Initial Guidance for FDR-FA + Specification
2008

3.46/4.69 Include LCA for FDR, PDR in *eLCAP*
2015-2020

4.36/4.59/4.69 Guidance for In-Place Recycling + Specifications, Mix Design Procedures, and *CalME* Models
2015-2020

3.44/4.69/4.78 Update *RealCost*[3] and *eLCAP*[4] software for FDR/PDR/CCPR
2017-2023

4.69/4.70/4.78 Training for Caltrans, local government & industry
2017-2023

4.78 9-62 QC/QA implementation
2020-2023

CCPIC In-place recycling guidance for local government

FOR MORE INFORMATION
For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past; Current; Proposed; Future

Linked Roadmaps:
[1] Asphalt ME design (*CalME*)
[2] Asphalt performance related specifications
[3] LCCA
[4] LCA

Pavement Research Roadmap
In-Place Recycling
version date November 24, 2020

Performance Related Specifications for Concrete Including Construction QA/QC

Pavement Research Roadmap

VISION Widespread use of appropriate tests and specifications for QC/QA of materials that measure and influence the critical properties affecting pavement performance; integrate with materials and pavement design procedures

CONCEPT

SCOPE Performance related tests and specifications for use with concrete pavement of all types

- AASHTO PP84 Performance engineered concrete pavement mixtures
- FHWA Turner Fairbanks effort on PRS
- Important concepts: formation factor, hygro-volume change, freeze-thaw durability, and degree of saturation
- FHWA pooled fund study to advance PRS for concrete
- FHWA project on advancing concrete pavement technology solutions 2017-2023

RESEARCH

- 4.2 Concrete Pavement Studies
  - Use of maturity for high-early strength concrete pavement
  - Relationship between different strength test results
  - Interaction between shrinkage, thermal contraction, and stress
  - 1998-2005
- 4.58B/3.39/3.41 Change of CTE with moisture conditions 2014-2020
- MED-O 2020-2023 proposal: Base design, including PRS, and base-slab interface systems for concrete pavements
- PRS-L 2020-2023 proposal: Durability of fiber reinforced rapid strength concrete with different cement types and light weight aggregates
- Develop PRS tests and specs for fiber-reincorced concrete
- PRS for curing materials and approaches for concrete pavement
- PRS for concrete pavement abrasion under chain and stud wear
- PRS approaches for rapid strength concrete
- Develop non-destructive PRS tests and specs for early opening time projects, including resistivity and embedded sensors

DEVELOPMENT

- 4.74 Recommendations to reduce early age and premature cracking of lane and slab replacements 2017-2020
- 3.53 Test to measure CTE-moisture dependency 2020-2023
- Develop PRS for bases of concrete pavements
- Implement maturity in fast-track paving
- Evaluate PRS for bond breakers and interlayers in concrete pavement
- Evaluate PRS for curing materials and approaches
- Evaluate benefit/costs of tests and specifications and use of AASHTO/ASTM vs CTM
- Optimize PRS in concrete mix design considering cost and time
- Evaluate PRS for joint sealants for concrete pavement
- Check dowel corrosion performance & PRS for dowels & rebars
- Validate future ASR tests and solutions, including consideration of natural pozzolans
- Develop PRS for use by cities and counties
- PRS for alternative supplementary cementitious materials: Nano-cellolotics, biomass, other new SCM for concrete pavement
- PRS for routine projects with different levels of reliability of materials, and new simplified tests

IMPLEMENTATION

- Training in PRS in concrete where there are gaps
- Training for local government on PRS
- Continue operation of Caltrans CTE website

FOR MORE INFORMATION

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu

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Project Key: Past; Current; Proposed; Future

Linked Roadmaps: New Concepts for Materials & Structures; ME Design Concrete

Pavement Research Roadmap
Performance Related Specifications for Concrete Including Construction QA/QC
version date December 04, 2020

Pavement Research Roadmap

Performance Related Specifications for Asphalt Superpave and QC/QA

Vision: Widespread use of appropriate tests and specifications for QC/QA of materials that measure and influence the critical properties affecting pavement performance; integrate with materials and pavement design procedures

CONCEPT

Scope: Performance related tests & specifications for use with ashpalt pavement

- **Asphalt-Aggregate Mix Analysis System (AAMAS) NCHRP**
- **SHRP A-003A**
- **AC Long Life Specifications Caltrans, TRB symposium**
- **New Construction Quality Database by Caltrans METS**

RESEARCH

- **3.28 Effects of smoothness on GHG**
- **West Track pay factors**
- **Goal 1 Caltrans pay factor report**
- **Goal 1 Compaction, PRS tests, pre-*CalME* design method**
- **Long life asphalt specs for LA-710 mix design, structural design** 1999
- **Updates to LLAC PRS specs TEH-5, SIS-5, SOL-80 and design with *CalME*** 2014-2016
- **3.18 Phase 2 review of potential PRS tests for Caltrans SuperPave mix design** 2011-14
- **3.25 PRS for open graded materials, including rubberized** 2011-2014
- **4.42 Evaluation of previous repairs on smoothness** 2011-2014
- **3.40 Review of simple cracking tests and RLT as PRS tests for Caltrans Superpave mix design** 2017-2020
- **3.51 Use of image analysis in cracking tests to look at strain fields** 2020-2023
- **4.77 PRS for asphalt rubber binders**
  - Refine and implement new AR binder specs
  - Alternative rubber types
  - Review of PGM use

  2020-2023

DEVELOPMENT

- ***CalME* v.1.0, v.2.0, and v.3.0** 2003, 2011, and 2020
- **3.30 Mix design guidance for contractors to meet PRS specs** 2014-2017
- **3.32 HWTT round robin** 2014-2017
- **3.33 Updates to LLAC approaches and extension to other mixes** 2014-2017
- **4.46/4.51a/NCST Initial use of FAM compared to mix tests** 2014-2017
- **3.18, 4.51, 4.64 Relationship between binder, FAM, mix properties, aging & test methods** 2011-2020
- **3.31 Updated AASHTO & ASTM tests for 4-point beam** 2014-2017
- **3.37 PRS development**
  - Simplified PRS procedures
  - Monitoring of previous LLAC projects
  - Pilot projects for using SCB and RLT (SAC-5)

  2017-2020
- **3.37, 3.40, 3.41 Performance related testing in Superpave**
  - Plant & lab aging effects, conditioning, compaction
  - Testing: SCB vs 4PB & RSST vs RLT

  2017-2020
- **4.76 RAP/RAS in RHMA for use in interlayers, Rich Bottom layers, and base for PCC**
  - Framework for PRS for these applications

  2020-2023
- **4.78/4.79 Performance related specifications for non-HMA Components**
  - Updated IPR, CCPR guidance, specifications
  - Updated RAP/RAS tests, guidance, specifications

  2020-2023
- **3.51 Regional and new materials in standard materials library**
  - Continued development of binder, FAM, & mix tests and correlations
  - Caltrans standard addendum for R30
  - Updates to LP3, high RAP procedure

  2020-2023
- **3.52 *CalME* and integration of PRS into routine practice**
  - Simplified categorization of HMA for PRS
  - Simplified tests used in PRS for CalME input

  2020-2023
- **PRS for geogrids, interlayer materials. Lab tests, PRS; APT verification if needed**
- **Low temperature crack tests for PRS for binder in addition to rheological properties**
- **PRS for tack coats.**

IMPLEMENTATION

- **Pilot and AC long life projects**
  - I-710 AC Long Life (1999); TEH-5, SIS-5, SOL-80 (2011-14)
  - SAC-5 (2017-2020)
- **Cost/benefit analysis, LCA of extension of PRS state-wide** Determination of improvements, identification of project types where PRS does not have high benefit/cost
- ***PaveM* follow up on PRS projects**
- **CCPIC PRS for local government** Where beneficial, adaptation for local government constraints
- **3.52 *CalME* and integration of PRS into routine practice**
  - Roadmap and support for Caltrans, industry to do testing, analysis
  - Training, new tests, integration of new materials, implementation of classification framework

  2020-2023

For more information

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu

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Project Key: Past (solid line); Current (shaded box); Proposed (dashed line); Future (dashed line)

Most of the projects in this roadmap also appear in ME Design, Rubberized Asphalt, RAP/RAS, Smoothness and other roadmaps

Pavement Research Roadmap
Asphalt PRS & QC QA
version date December 07, 2020

Surface Treatments and Noise, GnG and OGFC

Pavement Research Roadmap

VISION: Optimize the use of surface treatments that preserve the structure; provide a safe and quiet surface texture; and minimize impacts to operations, the environment and life cycle costs.

CONCEPT

SCOPE: Treatments and textures that Improve surface performance And prolong structure life

- Surface treatment research and development by others; noise measurement technology developed by Donovan; surface treatment design methodologies by others; rolling resistance research by others
- Evaluate GnG (aka NGCS) surface texture
- 2.7 Open graded mixes and stormwater quality literature review 2017 - 2020

RESEARCH

- 4.16/4.19/4.27/4.29 Asphalt overlay noise studies, roughness, cracking and skid 2005-2011
- 4.22/4.29 Existing concrete bridge and pavement surface noise, skid, roughness studies 2008-2011
- 4.20/4.29 New open-graded small stone mixes/ Lab method to estimate OG Noise 2008-2011
- 3.21 Measure noise, skid, roughness on new concrete surfaces (GnG, CRC), GnG pilot monitoring 2011-2014
- 3.21/3.25 APT on OG small stone mixes & improved OG mix design methods 2011-2014
- 4.48/CARB Urban heat island LCA 2017-2020
- 4.62[1] PG+X rubberized binder specifications for surface treatments 2017-2020
- 4.66 Texture and rolling resistance
  - New models for surface texture on fuel economy

  2017-2020
- 3.52[2] Integration of empirical-mechanistic surface degradation models in CalME for LCA, LCCA
  - IRI and Surface Non-Load Related Cracking Model

  2020-2023
- Project 4.80[3] Electric vehicle & rolling resistance
  - Better models for effects of surface texture on fuel economy

  2020-2023
- Autonomous vehicles implications for maintenance treatments
- Recyclable surface treatments for asphalt pavement that can be rolled on like carpet fast construction and quality control
- Thin bonded pavers on asphalt for intersections
- Use of excess quarry fines in thin cemented surface treatments (pavers, slurries)
- Alternative binders in surface treatments
- Reclaimed asphalt/micro-millings use in chip and slurry seals, and microsurfacings.
- Improve chain resistance under trucks of concrete and asphalt surfaces

DEVELOPMENT

- 3.35/3.42 Continued monitoring for noise and roughness of new concrete surfaces (GnG and CRC) 2014-2020
- Guidance of surface treatments versus rehab selection for local government using LCCA (CCPIC) 2019
- Chip seal noise (mainline)
  - Selection and design of chip seals to decrease or increase (shoulders) noise or increase skid resistance
- Bicycle ride quality[4]
  - Follow up on implementation of bicycle ride quality research
- Implement improved open graded mix design including stormwater quality

IMPLEMENTATION

- 3.57[1,3] Implement updated LCA, LCCA results for surface treatments in *PaveM* performance models update 2020-2023
- Guide for chip seal design, construction, timing and functionality (noise, bicycle and skid)
- Develop specification, pilot studies of small-stone RHMA-O, LCA
- Final monitoring and IRI models for GnG and CRC surfaces
- Evaluate specification, pilot and cost studies of grind and groove surfaces

FOR MORE INFORMATION

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu

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Project Key: Past (solid); Current (shaded); Proposed (dashed); Future (dashed)

Linked Roadmaps:
[1] Asphalt rubber
[2] Asphalt ME design (*CalME*)
[3] LCA
[4] Smoothness

Pavement Research Roadmap
Surface Treatments and Noise, GnG and OGFC
version date December 4, 2020

Caltrans | UCPRC UNIVERSITY of CALIFORNIA | PAVEMENT RESEARCH CENTER Davis • Berkeley

Pavement Research Roadmap

Multi-Functional Pavements for Climate Resilience, Urban Environments, and Active Transportation

VISION Use best available climate change information in tactical and strategic transportation infrastructure decision-making. Use pavement and street systems to help reduce environmental impacts and create economically and socially vibrant public places that promote personal mobility, healthy choices and safe communities.

CONCEPT

SCOPE Climate resilience for transportation infrastructure, strategy, development, communication and implementation in California and interaction of pavement design and street design on active transportation (non-motorized).

- Intergovernmental Panel on Climate Change updates
- US Global Climate Change Research Program
- Climate adaptation strategy (Nat Res Agency) 2009
- California climate scoping plan (CARB) 2013
- Nat Res Agency: Safeguarding California Reducing Climate Risk 2014, 2017
- IC Net northeastern US climate modeler and infrastructure managers network (NSF) 2012
- CalAdapt climate change research, UC Berkeley, California Energy Commission
- Literature and concepts developed by others using the Complete Streets (CS) study and other literature that are not covered in CS[1] 2018
- California legislation and policy directives regarding climate resilience
- Nat Assoc of City Trans Officials activities
- Complete Streets America activities
- NCST Urban Metabolism (UM) LCA framework considering permeability and water cycle[1] 2018
- NCST Road Map for Permeable Pavement Research 2017
- Coastal and ocean climate action team (COCAT) impacts on coastal resources (Caltrans)
- ICNet northeastern US climatologist/ infrastructure managers network (NSF) 2012-2017
- Climate change incidents affecting freight
- West Coast ICNet building on other groups in California (through CCPIC)

RESEARCH

- 4.47/4.57 Surface treatments for bicycle ride quality[5] 2014-2020
- NCST LCA framework for CS incl social perf indicators, equity[1] 2018
- UM-LCA Case studies[1] (BlueSkies)
- NCST Case studies: LCA of Complete Streets[1] 2020-2021
- NCST APCS of Complete Streets[1] 2020-2021
- ICNet Gobal climate/infrastructure education/practice/research (NSF) 2019-2022
- Identify scope of potential climate change impacts on transportation infrastructure
- NCST Expand LCA framework for Complete Streets to non-motorized oriented street design
- Identify stakeholders roles and responsibilities
- Improve design & selection of surfaces for Active Transportation
- NCST Guidance and tools for CS LCA[1]
- Inventory best available data and tools for climate change
- LCC approach for CS[2]
- Pavement performance models for Active Transportation
- NCST Models for quantifying consequences of changes in street design on miles traveled, congestion, and motorized-vehicle emissions
- NCST Further improvements of indicators (social, environmental, health, safety, economic, equity)
- New pavement types with reduced environmental impact, faster construction, improved performance, and lower LCC[2]
- Incorporate improved models for CS & related street design strategies
- Identify existing levels of climate change information quality and usefulness, and levels of use in decision making

DEVELOPMENT

- ME design of concrete, asphalt & paver permeable pavement for CT DEA 2010 [3,4]
- ME permeable paver pavement design and HVS validation (ICPI) 2014
- Design and maintenance guidance to reduce costs, improve performance and reduce environmental impacts of active transportation routes
- Optimization of complete streets based on LCA and LCCA[2]
- Simplified on-line CS LCCA tool for local government[2]
- Support for State and Local Scoping for Plans: Climate change and location mapping Infrastructure
- NCST Guidance and tools for CS LCA[2]
- NCST Selection & design guidance & tools for CS for rural & urban functions & contexts
- LCCA of cool pavement[2]
- Simple tests for lab & field for texture, albedo (thermal comfort), durability, friction.

IMPLEMENTATION

- Support and facilitate state & local government implementation & communication with climate change modelers
- Training for selection & design of Complete Streets & nonvehicle oriented streets
- Guidance on assessing vulnerability & asset criticality & cost
- Guidance on incorporating climate change & cost data into design & asset management operation[2]

FOR MORE INFORMATION

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu

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Project Key: Past; Current; Proposed; Future

Linked Roadmaps: [1] Roadway LCA; [2] LCCA; [3] ME Design Concrete; [4] ME Design Asphalt; [5] Smoothness

Pavement Research Roadmap
Multi-Functional Pavements for Climate Resilience, Urban Environments, and Active Transportation
version date December 09, 2020

Life Cycle Cost Analysis (LCCA)

Pavement Research Roadmap

UNIVERSITY of CALIFORNIA | PAVEMENT RESEARCH CENTER, Davis • Berkeley

VISION Develop and use a comprehensive, web-based, LCCA system that considers variability and maintains competency across all users

SCOPE Life cycle cost analysis data, procedure, and software for state and local governments

CONCEPT

- FHWA LCCA guidelines, Walls & Smith — 1998
- Caltrans LCCA procedure manual (version 1.0) — 2003
- Caltrans LCCA procedure manual (version 2.5) — 2013
- Caltrans Transportation Asset Management Plan (TAMP) — 2017

RESEARCH

- DEA 2.4.9 — Extension of LCCA frameworks to permeable pavement — 2011-2014
- 5.15 — Analysis of pavement portion cost of long life rehab projects — 2005-2008
- 3.25 — Evaluation of LCC of preservation vs rehabilitation only — 2014-2017
- 3.26/4.37 — Development of framework for optimizing IRI and benefit cost for greenhouse gas reduction and implement in PMS — 2014-2020
- 3.20 — LCCA for composite pavement — 2014-2017
- 2.8 — Network-level road user cost models for life cycle planning — 2017-2020
- Consideration of variability and uncertainty for cost and treatment lives
- Network-level LCCA approach and simulation based on future budget constraints for long-term planning
- LCC approach for CS[2]
- New pavement types with reduced environmental impact, faster construction, improved performance, & lower LCC[2]

DEVELOPMENT

- Development of Caltrans specific software, *RealCost* ver. 2.0 — 2005-2008
- Development of traffic delay calculator, ver. 2.0 (also used in *CA4PRS*) — 2014-2017
- 5.10/3.44 — M&R sequence updates from performance models and decision trees — 2017-2020
- 2.8 — Network-level road user cost models for life cycle planning — 2017-202
- 3.44 — Improvement of unit cost updating procedures — 2017-2020
- 3.56[1] — Multi-criteria decision support for prioritization of strategies to reduce environmental impacts — 2020-2023
- CCPIC 2020 Simplified spreadsheet local government LCCA tool
- Development of procedure for estimating M&R schedule for new treatments
- Integration of common traffic and cost data with *CalME*, *Pavement ME*, *PaveM*, *eLCAP*, and *RealCost*
- Optimization of complete streets based on LCA and LCCA[2]
- LCCA of cool pavement[2]

IMPLEMENTATION

- 3.44 — Web-based *RealCost* ver. 3.0 — 2017-2020
- 4.72 — LCA & LCCA decision support (Supply Curve)[3] — 2017-2020
- 3.48 — Life-cycle cost optimized decision trees for *PaveM*[1] — 2017-2020
- 4.82 — Updates and Improvements to *RealCost-CA* — 2020-2023
  - Develop an on-line LCCA report tool
  - Create operation manager's manual for LCCA
- 3.56 — Integration of LCCA results into simpler sustainability evaluation[3] — 2020-2023
- Ongoing updates of new materials LCCA to *RealCost*
- Update CWZ & RUC studies into *RealCost*
- Continue integration of pavement planning, design & construction in LCCA & LCA databases & models[3]
- Convert CCPIC LCCA tool to online
- Guidance on incorporating climate change & cost data into design & asset management operations[2]

FOR MORE INFORMATION

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu

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Project Key: Current; Proposed; Future; Past

Linked Roadmaps: 1 Pavement Management Systems (PMS); 2 Multi-Functional Pavements for Climate Resilience; 3 Roadway LCA

Pavement Research Roadmap
Life Cycle Cost Analysis
version date December 04, 2020

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Pavement Research Roadmap

Roadway Life Cycle Assessment

VISION: To be able to quantitatively assess the social, economic and environmental impacts of transportation infrastructure

CONCEPT

SCOPE: Systems for quantifying social, economic and environmental impacts for the project identification and delivery process including asset management, conceptual design, design, and construction

ISO and other standards:
ISO 14000 series, ISO 21930, EN15804

Other related documents:
PAS2050, FHWA Ped and bike perf measures guidebook, impact analysis methods (Traci, Impact+, CML, etc.), ILCD documents, UN env. program docs, UN/ SETAC initiative docs, corporate sustainability reporting docs

4.28 UCPRC LCA guidelines 2010

FHWA LCA guidelines 2016

FAA airfield LCA guidelines 2016-2018

FHWA reference sustainability docs. 2015

Pavement LCA symposia:
- 2010 Davis, 2012 Nantes, 2014 Davis, 2017 Illinois, 2020 Davis

NCST complete streets LCA and initial equitable social indicators[1] 2018

NCST urban metabolism LCA framework[1] 2018

RESEARCH

4.28/4.66 Life cycle inventories 2014-2020

Traffic smoothness study and cool pavement LCA 2014-2017

4.37 Smoothness and optimization approach 2017-2020

4.49/4.53 Vehicle pavement structural response 2014-2020

4.54 Expansion and critical review of LCIs 2014-2017

4.54/4.66 Construction work zone (CWZ) analysis 2014-2020

4.48/4.54 Cool pavement framework development, data collection and case studies using cool pavement LCA software 2014-2020

4.72 LCA alternative strategies to reduce GHGs 2017-2020

3.55 LCA at the planning stages 2020-2023

4.54/4.66/4.55 Framework for truck lane selection, recycling and design life 2014-2023

4.80 LCA updates and applications
- LCA of capital equipment
- LCA of roadway structures
- Improve & expand ability to consider uncertainty & sensitivity
- Expansion and critical review of updated LCIs
- LCIs for new materials (biomass, plastic, additives[3,11]

2020-2023

UM-LCA case studies[1] **(Blueskies)**

Develop new social and equity indicators

Spatially explicit impact calculation and relevant indicators

Integration of approaches and methods for consequential LCA:
- Improved mode choice models, economic models, behavior models.

Impacts of roughness on vehicle life, maintenance of vehicles, freight damage[2,3]

Allocation and open-loop recycling approaches

DEVELOPMENT

FHWA *LCA Pave* tool development 2016-2020

FHWA-University of Illinois LCA software for in-place recycling[9,11] 2017-2020

FAA Airfield LCA Case studies 2018

4.54/3.46 *eLCAP* software conceptual and project levels (v1.0) 2014-2020

4.61/4.66 PG+X rubber asphalt LCA[4] 2017-2020

4.58b/4.66 BCOA LCA[5] 2017-2020

3.47 Policy recommendations and support Caltrans for use of EPDs[6] 2017-2020

4.73 Fast model for Pavement Vehicle Interaction (PVI) 2017-2020

4.69/4.70/4.66 LCA of in-place recycling (FDR, PDR, CCPR)[9,11] 2017-2020

LCA software for heat island LBNL/CARB

3.56 Multi-Criteria Decision Support for Prioritization of Strategies to Reduce Environmental Impacts 2020-2023 [8]

NCST Complete streets LCA framework, tool and analysis[1] 2017-2021

3.47/4.80 Support Caltrans with EPDs[6] 2017-2023

3.46/3.55 Update *eLCAP (v2.0)* to allow development of data, inventories, indicators, other models inside tool 2017-2023

***eLCAP* software for local govt.** (UC-ITS-SB1) 2020-2023

4.80 Updated regional inventories[3]
- North America LCI data center, EPDs and other data, UCB green concrete LCI, UCPRC street features LCI.

Completed: up to 2017; 2020-2023

3.55/4.80 New use stage models:
- Traffic congestion, pavement alterations for new technology, structure response (tBeam), CWZ

2020-2023

Policy recommendation on green procurement (UCPRC funding) 2020-2023

Active transportation LCA integration in planning[2]

Evaluation of construction quality impacts

Evaluation of policies on recycling[9]

FAA Airfield LCA software

IMPLEMENTATION

3.47 Caltrans EPD implementation pilot program and AB269 and advice to pavement industries about PCRs and EPDs[6] 2017-2020

4.55 PMS implementation[7] (initial & updates) 2014

4.72 High level B/C across all transportation strategy alternatives[2,3,8] 2017-2020

Continue integration of pavement planning, design & construction in LCCA & LCA databases & models[8,10]

***eLCAP* case studies and training material updates**

3.56 Integration of LCA results into simpler sustainability evaluation 2020-2023

Continue updating *PaveM*[7]

Standardization of PCRs (one PRC initiative)

Communication tool for progress toward goals based on LCA

Inclusion of consequential LCA in eLCAP

Potential monetization of impacts

FOR MORE INFORMATION
For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
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Project Key: —— Past; —— Current; – – – Proposed; – – – Future

1 Multi-Functional Pavements for Climate Resilience
2 New Technologies and Integrative Frameworks
3 New Concepts For Materials and Structures
4 Rubberized Asphalt
5 ME Design Concrete
6 EPDs
7 PMS
8 Life Cycle Cost Analysis
9 In Place Recycling
10 Design of Asphalt
11 RAP/RAS

Pavement Research Roadmap
Roadway Life Cycle Assessment
version date December 04, 2020

Pavement Research Roadmap

Rubberized Asphalt

VISION Maximize use of waste tire rubber in asphalt in all applications where it makes life cycle, engineering, economical and environmental sense

CONCEPT

SCOPE Utilize waste tire rubber in asphalt pavements

- **ADOT, Industry and Caltrans developments** — 1980 onwards
- **Caltrans Ravendale, Firebaugh and other overlay test sections** — 1990's
- **Asphalt rubber work by other universities, DOTs and industry. RHMA-O on OAK runway** — 2000 onwards

RESEARCH

- **Goal 3** Half thickness RHMA overlay validation — 1995-2000
- **4.9** Moisture study/method spec problems — 2005-2008
- **4.10** MB Road. Half thickness comparison of MB overlays with RHMA and HMA — 2000-2008
- **4.18/CalRecycle** RWMA performance and emissions — 2008-2011
- **4.16/4.19/4.27/4.29** RHMA-G and RHMA-O performance — 2008-2011
- **3.30/3.32** RHMA aging comparison between lab and plant mixes — 2008-2011
- **4.61/4.62** PG+X lab tests and LCCA/LCA — 2014-2020
- **4.45/4.50/4.63 Ph 1-3** PG-AR procedure and specification development — 2014-2020
- **4.77 Ph 4** PG-AR procedure and specification development — 2020-2023
  - Thickness limits
  - Other methods of adding rubber
  - Rubber in dense-graded mixes
  - Base binder selection of AR
- **4.75** RHMA-G Layer Thickness Limits — 2020-2023
- **4.63/4.79/CalR[1]** RAP in RHMA and RRAP in HMA (including APT) — 2014-2023
- **4.26/4.37/4.54/4.72/3.56** LCA of RHMA + updated LCIs — 2014-2023
- **4.76[1]** RAP in RHMA for PCC base, interlayer, and rich bottom layer — 2020-2023
- Use of recycled plastic in conjunction with rubber (future)
- Use of RHMA-O in permeable pavements (future)
- Use of RHMA-G and RHMA-O for airfields (future)
- "Roll-up Road" chip seal for maintenance and preservation (future)

DEVELOPMENT

- **3.25/4.20** New RHMA-O small stone mixes — 2014-2017
- **3.18/3.32** RHMA Superpave mix design — 2014-2017
- **4.63/4.77/CalR** Test method to determine rubber content in binder & mix — 2020-2023
- **4.77** Ongoing support of PG-AR implementation and validate PG-AR specs in pilot studies — 2020-2023
- **4.76/4.79** Validate RAP in RHMA mixes in pilot studies — 2020-2023
- **4.77/4.78** Validate RHMA-G in other layers, with and without RAP
- Validate PG+X mixes in pilot studies (future)
- Validate small stone RHMA-O mixes in pilot studies[2] (future)

IMPLEMENTATION

- ***CalME*** Inclusion of RHMA in models and data — 2008-2020
- **4.63/4.77** Test methods and specifications for PG-AR — 2017-2023
- **2.11** RHMA guidance for airfields (Caltrans and FAA) — 2020-2023
- **CCPIC** RHMA guidance for local government (future)

FOR MORE INFORMATION

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu

For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past; Current; Proposed; Future

Linked Roadmaps: 1 RAP and RAS; 2 New Concepts for Materials

Pavement Research Roadmap
Rubberized Asphalt
version date November 20, 2020

Pavement Research Roadmap

Recycled Asphalt Pavement (RAP) and Recycled Asphalt Shingles (RAS)

VISION: Optimize the use of reclaimed asphalt in new asphalt mixes for cost, environmental impacts, and performance over multiple lifecycles

CONCEPT

SCOPE: Use of reclaimed asphalt in pavement applications

RAP/RAS research by other universities, DOTs and industry (List main studies on high RAP/RAS)

RESEARCH

4.46 Prelim study on RAP/RAS Properties
- Prelim testing on FAM mixes
- Initial investigation of RAP/RAS binders

2011-2014

NCST Study of RAP/RAS binder blends with virgin binder
- Develop FAM mix testing procedure
- Explore use of FAM as an alternative to extraction

2011-2014

4.51A/FAA Ph1
- FAM test instead of extraction
- Blending chart validation
- Effect of RAP in PM mixes

2011-2014

CalRecycle RAP in RHMA and RRAP in HMA

2011-2014

4.72[1] LCCA/LCA for use of RAP in HMA and RHMA

2017-2020

CalRecycle RAP in RHMA-G and RHMA-O
- Prelim Investigation on use of coarse-graded RAP

2017-2020

4.64/3.40 Ph2
- Use of FAM testing to predict binder properties
- Initial study of high RAP mixes including effect of silo storage
- QC/QA tests for cracking

2017-2020

4.76[2] RAP in RHMA for PCC base, interlayer, and rich bottom layer
- Evaluate properties of RAP in RHMA-G
- Conduct ME design

2020-2023

4.79 Guidance, Tests, and Specification of high RAP/RAS
- Effect of rejuvenators
- Long-term lab- and field-aging of RAP mixes
- Simplified tests for QC/QA testing of RAP mixes

2020-2023

Validation of high RAP mixes with APT and field monitoring

Assess multiple RAP-use cycles

Develop new materials with high RAP and rubber

Use of RAP with non-petroleum based binders

Impact of future changes in the oil refining industry on use of RAP

LCA of RAP mixes including updating inventory of rejuvenating additives

DEVELOPMENT

3.18/3.30/4.20 High RAP mixes in long life design

2011-2014

4.54[2] LCA of optimal transport distance for recycled materials

2014-2017

FAA Airfield LCA RAP case study

2014-2017

4.79/4.64/3.40 FAM test to evaluate binder + cracking tests for mix design and QC/QA

2017-2023

IMPLEMENTATION

Guidance for effective use of RAP/RAS, including *CalME* models

2020-2023

Suggested specification language updates for RAP/RAS mixes

2020-2023

FOR MORE INFORMATION

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Project Key: Past / Current / Proposed / Future

Linked Roadmaps: 1 LCA; 2 Rubberized Asphalt

Pavement Research Roadmap
Recycled Asphalt Pavement (RAP) & Recycled Asphalt Shingles (RAS)
version date December 04, 2020

Caltrans | UCPRC UNIVERSITY of CALIFORNIA | PAVEMENT RESEARCH CENTER Davis • Berkeley | Pavement Research Roadmap

Smoothness

VISION Standardize practice of the best methods for cost efficiently providing smooth pavements to maximize fuel economy, user comfort and pavement life, and minimize freight damage

CONCEPT

SCOPE Measurement, analysis and use of information for pavement smoothness

- Development of IRI by World Bank, AASHTO and ASTM specifications, smoothness programs in other states
- Effect of smoothness on variability of pavement life and interactions with pavement thickness
- Identify needed new profile metrics for uses other than car ride quality bicycle profile metric, megatexture, freight damage related metrics
- Create and complete research, development and implementation program for pavement transitions

RESEARCH

- **3.24** Investigate IRI calibration center and process for Caltrans (2011-2014)
- **4.42** Smoothness of asphalt overlays and repairs under old profiler graph specification (2014-2017)
- **4.47/4.57** Identify bicycle ride quality parameters; Chip and slurry seal specifications selection guidance (2014-2017)
- **3.44** Consider influence of smoothness on effective Functional life for LCCA (2017-2020)
- **4.66/4.80** Identify and then update optimal smoothness levels for different context and goals for greenhouse gas emissions (2017-2023)
  - Extend to all treatments, update optimized IRI tables
- Develop alternative profile metrics to better explain fuel economy and freight damage
  - Analyze at small subsections using 4.53 data, 7 Replicates
- Calibration of smoothness disincentives based on life cycle cost analysis, for different contexts and goals
- Wander pattern weighted roughness matrices using 3D tomography data
  - Remove wander of operator
  - 3D profile/full wheelpath IRI gives indication of variability of IRI measurement due to vehicle wander
- Bicycle Ride Quality[1]
  - Follow up evaluation on bicycle ride quality research implementation

DEVELOPMENT

- **4.42/2.7** Asphalt overlay smoothness under new IRI spec (2014-2017)
- **3.35** Evaluation of new IRI construction specification on concrete surfaces (postponed) (2017-2020)
- **4.47/4.57** Recommend maintenance treatments for bicycle ride quality (2014-2017)
- **3.24/3.45** Support setup & operation of smoothness certification program (2011-2017)
- Personal device applications to allow users to access lane based road smoothness data and determine route based on roughness related costs and comfort
- Low cost bumper mounted response ($1,000) type roughness meters for use by maintenance forces and local governments to estimate IRI, flag maintenance location; establish calibration centers for devices
- Software to analyze and report low cost roughness meter data
- Measure and document effectiveness of various construction practices for concrete and asphalt (asphalt overlays done in 4.42), including concrete slab replacement

IMPLEMENTATION

- **2.3** Ongoing operation of IRI calibration center & process for Caltrans & contractors projects & mix designs
- Support implementation of smoothness specification modifications
- Demonstration of construction technologies to improve smoothness IRI behind pavers larger technology rodeo or pilot project[2]
- Support implementation of low cost bumper mounted response meters for maintenance problem location and local government IRI measurement
- Operate low cost roughness meter calibration center
- Implement optimized smoothness disincentives
- Make available personal device application for smoothness data for road users
- Implement new profile metrics in pavement management

FOR MORE INFORMATION

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu

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Project Key: Past; Current; Proposed; Future

Linked Roadmaps: [1] Multi-functional pavement; [2] New materials and structures

Pavement Research Roadmap
Smoothness
version date December 04, 2020

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Pavement Research Roadmap

Pavement Management Systems (PMS)

VISION Proactively manage networks to maximize efficiency within budgetary and policy constraints with regards to performance, cost and environmental impact

CONCEPT

SCOPE Pavement management systems and practices for Caltrans and local government

- **UCPRC evaluation of existing Caltrans PCS/PMS** 1999 - 2003
- **PMS and Division of Pavement roadmap** 2003-2004
- **3.3 As-built & GPR pilot study** 2003-2004
- **3.3 Support budget change proposal (BCP)** 2005-2007
- **3.3 1st APCS manual and vendor rodeo** 2009-2010
- **3.41[1,2] Framework for PMS data for ME calibration** 2017-2020
- **NSF study in advanced civil infrastructure management using big data approach** (future)

RESEARCH

- **3.2.5 Initial performance modeling with WS-DOT data** 2006-2008
- **3.2.5 Preservation efficiency LCCA PCS models survivor** 2009
- **3.9 As-built database, GPR study and coring state network** 2010-2012
- **3.9 Initial performance modeling with PCS data** 2011
- **3.9 Traffic database development and integration** 2009-2011
- **4.60 Traffic Speed Deflectometer (TSD) initial evaluation for PMS** 2015-2017
- **3.9/3.28 1st generation engineering configuration**
  - Segmentation
  - Distress definition
  - Data aggregation
  - Performance models
  - Decision trees
  - Benefit equations

  2010-13
- **3.28/5.04 Grouping segment into realistic projects** 2014-2017
- **3.43 Decision support for inclusion of TSD data in *PaveM*** 2017-2020
- **3.48 Life-cycle cost optimized decision trees** 2017-2020
- **4.68[1,2] Develop historical condition database for performance models and ME calibration** 2017-2020
- **4.81 Verification methods for traffic information** 2020-2023 (current)
- **4.82 Advanced image evaluation of APCS data** 2020-2023 (current)
- **Optimized decision trees for local government (using PCI)** (current)
- **Improved data collection and PMS approaches for local government** (future)

DEVELOPMENT

- **3.9 GPR and core visualization tool & core database (*iGPR*)** 2012-2014
- **3.28 Location reference system quality review and recommendation** 2012-14
- **5.A "H-bar" pavement treatment history and forward projection visualization tool** 2015
- **5.A Support as-built updates** 2014-17
- **5.A Include models and decision for new treatment as developing** 2014-2017
- **5.01/5.02/5.03 Performance model updates with PCS and APCS data** 2015-17
- **5.08 Traffic database updates** 2016-17
- **4.55 GHG calculation update** 2017
- **4.68 Performance Model Updates** 2017-2020
- **3.58[1,2] Calibration of ME design methods with statewide PMS data** 2020-2023 (current)
- **4.81[1,2] Improved traffic models for *PaveM* and ME design** 2020-2023 (current)
- **2.03 Decision trees and performance models for CRCP** 2020-2023 (current)

IMPLEMENTATION

- **3.9 APCS contractor selection** 2010
- **3.9 QA of GPR and first APCS contracts** 2011-12
- **5.A/5.07 2014 LRS update and integration of MAP21 NHS** 2015
- **5.A PMS and asset management integration** 2017
- **2.10 PMS Support**
  - PMS training and assistance
  - Traffic updating
  - As-Built updating & QA
  - LRS updating & QA
  - PaveM portal, H-Bar, RP-List
  - Other improvements

  2017-2020
- **3.57[1,2] Tri-annual update for *PaveM* performance models and GHG equations** 2020-2023 (current)
- **2.03 Continued *PaveM* support, including integration with DIME. Restructure *PaveM* project information** 2020-2023 (current)
- **PMS for ramps, connectors, parking lots** (future)
- **Implementation support and training for local government on PMS principles and best practices** (future)

FOR MORE INFORMATION

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Project Key: Past / Current / Proposed / Future

Linked Roadmaps: [1] ME Design of Asphalt; [2] ME Design of Concrete

Pavement Research Roadmap PMS version date December 4, 2020

New Concepts for Materials and Structures

Pavement Research Roadmap

VISION: To quickly and cost efficiently evaluate new technologies and comprehensively develop those that are promising

CONCEPT

SCOPE: All new materials, structures, construction methods, and quality improvement technologies for pavement

Past UCPRC new materials and structures projects:

- RHMA-G overlays
- Asphalt drainable layers
- Rapid strength concrete
- BCOA
- FDR
- Grind and groove
- Widened JPC lanes
- GPR
- Dowel bar retrofit
- WMA
- Permeable pavement
- Small-stone open graded mixes

2.8 Biomass for transportation materials
Forest and ag biomass applications
2017-2020

2.8 Urban metabolism[1]
2017-2020

ITS SB1 2020 Response to AB2061 project
EV, NGV, fuel cell vehicles effects on roadway

New structures for urban pavements
Low impact (cost & environment), ability to repair utilities

REC-G 2020-2023 proposal
Conceptual review of roller compacted concrete applications on State highways

Conceptual review of grinding slurry waste

Conceptual review of deicing pavement

RESEARCH

Rice ash for concrete (Rice Research Board)[1,3]
Materials, LCA, economics, improved materials
2018, 2019, 2020

4.76 RAP/RAS in RHMA for use in interlayers, rich bottom layers, and base for PCC[2]
2020-2023

4.80 Environmental LCA updates and applications[1]
LCI of concrete and asphalt biomass materials, other new additives
2020-2023

SUS-E 2020-2023 proposal
Alternative supplementary cementitious materials
Nano-cellolotics, biomass, other new SCM for concrete pavement

REC-F 2020-2023 proposal
Recycled plastic in asphalt pavements

MED-D 2020-2023 proposal
Modeling, testing, and validation of interlayer base and overlay reflective cracking performance

PRS-K 2020-2023 proposal
Microsphere technology as alternative to conventional air-entraining admixtures

Effects of pavement conditions on battery electric and fuel cell vehicle durability and performance

Review of early CRCP performance, crack spacing, edge deflections and other early predictions of performance

Cool pavement technologies for human thermal comfort in urban areas

Review of bonded wearing course performance

DEVELOPMENT

Recommendation in RHMA literature review for DEA 2020
Pilot UCPRC open-graded mix design procedure

REC-G 2020-2023 proposal
Guidance for the use of recycled materials in new PCC, RCC, LCB, and base/subbase layers.

CCR-A 2020-2023 proposal
Permeable pavement validation

Permeable pavement roadmap from 2017 workshop
10 pathways to fill the gaps for full consideration of permeable pavement for stormwater, flood control, transportation and place making

Proposal with Oregon State University to U.S. Endowment for Forestry and Communities 2020
Pilot projects for nano-cellolotics for concrete pavement

IMPLEMENTATION

3.21/3.35/3.42 Monitoring of grind and groove pilot projects
2011-2020

2.10 Add CRC decision trees to PMS (*PaveM*)
2020-2023

CRC repair guidance

FOR MORE INFORMATION

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Project Key: Past / Current / Proposed / Future

Linked Roadmaps: [1] LCA, [2] RAP/RAS, [3] ME Design Concrete

Pavement Research Roadmap
New Concepts for Materials and Structures
version date December 04, 2020

New Technologies and Integrated Frameworks

Pavement Research Roadmap

UCPRC — University of California Pavement Research Center, Davis • Berkeley

Caltrans

VISION Perform conceptual evaluation and research on new technologies and integrated frameworks and, if feasible, move them to their own new roadmap

CONCEPT	ASSESMENT		RESEARCH		DEVELOPMENT & IMPLEMENTATION

SCOPE Continue to look for new technologies and approaches and assess, integrate, develop, and move them forward

CONCEPT	ASSESMENT		RESEARCH		DEVELOPMENT & IMPLEMENTATION
Advanced integrated infrastructure for autonomous and alternative fuel vehicles ASCE T&DI initiative on civil infrastructure; Pavement sensor work at universities Wireless, distributed, vehicle-powered	Placing V2V, V2I, I2I communication items in the pavement; Piezo resistive materials for powering embedded instrumentation	Effects of pavement conditions on battery electric and fuel cell vehicle durability and performance	CITRIS/UCPRC 2019 Fiber optic sensors to locate vehicles and communicate via V2I	Damage sensors for asset management	Technologies and projects from this roadmap will be used to create new roadmaps as and when the technology is sufficiently mature to support development and implementation
Advanced integrated infrastructure for active transportation; NCST UCPRC/Georgia Tech[1] Roadmap for new technologies for assessing active transportation infrastructure condition 2020	Photo-sensitive self-lighting crosswalks		2.2/3.41 Digital image correlation for seeing strain field in cracking tests 2017-2020	New technologies for assessing active transportation infrastructure using automated PCS data	
"Big data" and machine learning approaches for pavements[2]	3.43 Traffic speed deflectometer assessment 2017-2020; 4.82 Potential for advanced image evaluation in APCS 2020-2023; PMS-D 2017-2020 proposal Develop low-cost IRI measurement and localized roughness identification procedure	Predicting materials properties & mix design guidance using all performance related testing & AI; AI incorporated into ME design	2.9/3.49[2,5,6] Improved processes for calibrating ME design with large data sets 2017-2020; 3.57[2,3] Tri-annual performance model update 2020-2023	Integration of intelligent construction approaches to collect large scale construction QC data in PMS and design; Approaches to use large scale construction QC data being collected in DIME in PMS and design	
Integration of ME design, LCCA, LCA, and PMS			4.81[2,4,5] Improved traffic models for *PaveM* and ME Design 2020-2023	Integrate data collection, probabilistic analysis & reliability based decision support for ME design, LCA, LCCA, asset management	
4.72[3,4] LCA alternative strategies for GHG reduction 2017-2020	3.56[3,4] Multi-criteria decision support for prioritization of strategies to reduce environmental impacts 2020-2023		Impacts of energy harvesting on pavement		

FOR MORE INFORMATION

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Project Key: Past; Current; Proposed; Future

Linked Roadmaps: [1] Active Transportation, [2] PMS; [3] LCA, [4] LCCA; [5] ME Design Asphalt; [6] ME Design Concrete

Pavement Research Roadmap
New Technologies & Integrated Frameworks
version date December 04, 2020

UCPRC Contract #65A0788

Funding Plan 2020-23

DRISI Proj ID	PPRC Contract	DRISI Task ID	UCPRC SPE	PROJECT TITLE	Task Funding Total	FY19/20	FY20/21	FY21/22	FY22/23	FY23/24 Jul - Sep
P1239				**Mechanistic-Empirical Design**						
	MED-A	3809	3.51	CalME materials library for flexible pavement	$ 1,773,541.41	99,700.15	1,646,341.26	27,500.00	-	-
	MED-B	3810	3.52	Further Improvement for CalME and Integration with PRS Into Routine Practice	$ 933,480.11	82,517.50	663,549.41	-	187,413.20	-
	MED-E	3760	4.75	RHMA-G Layer Thickness Limits	$ 1,006,725.98	423,423.73	583,302.25	-	-	-
	MED-F	3761	4.76A	RAP/RAS in RHMA for use in Interlayers, Rich Bottom Layers, and Base for PCC (AC)	$ 892,834.65	163,641.32	670,874.46	-	-	58,318.87
	MED-F	3977	4.76B	RAP/RAS in RHMA for use in Interlayers, Rich Bottom Layers, and Base for PCC (PCC)	$ 446,417.33	23,836.98	246,687.55	-	146,733.37	29,159.43
	MED-K	3811	3.53	Updated Rigid Pavement Design Catalog for JPCP and CRCP Using the Latest Version of AASHTOWare Pavement ME Design Software	$ 291,287.17		291,287.17	-	-	-
	MED-Q	3812	3.54	Monitoring Performance of Thin BCOA projects	$ 352,607.50		89,212.00	90,612.45	128,991.20	43,791.85
				MED	**$ 5,696,894.15**	**$ 793,119.68**	**$ 4,191,254.10**	**$ 118,112.45**	**$ 463,137.77**	**$ 131,270.15**
P1240				**Performance Related Specifications**						
	PRS-A	3816	4.77	AR Binder Specs	$ 797,677.50	100,000.00	504,174.80	-	193,502.70	-
	PRS-J	3768	4.83	Test to Measure CTE-Moisture Dependency	$ 224,884.00			79,647.00	145,237.00	
				PRS	**$ 1,022,561.50**	**$ 100,000.00**	**$ 504,174.80**	**$ 79,647.00**	**$ 338,739.70**	**$ -**
P1241				**Recycling**						
	REC-A	3817	4.78	Updated Guidance and Specifications for In-Place Recycling	$ 1,903,677.41	285,625.10	1,618,052.31	-	-	-
	REC-D	3819	4.79	Guidance, Tests and Specifications for High RAP/RAS in HMA and RHMA Mixes	$ 952,817.60	100,000.00	852,817.60	-	-	-
				REC	**$ 2,856,495.01**	**$ 385,625.10**	**$ 2,470,869.91**	**$ -**	**$ -**	**$ -**
P1242				**Sustainability**						
	SUS-A	3820	4.80	Environmental LCA Updates and Applications	$ 1,183,623.51	87,834.50	880,767.01	97,650.00	117,372.00	-
	SUS-B	3821	3.55	Implementation of Environmental LCA Data and Models for Project-Level Use in eLCAP	$ 655,584.09	122,566.49	284,728.87	-	207,085.23	41,203.50
	SUS-E	3775	4.84	Alternative Supplementary Cementitious Materials	$ 347,515.00			87,695.00	259,820.00	
	SUS-H	3822	3.56	Multi-Criteria Decision Support for Prioritization of Strategies to Reduce Environmental Impacts	$ 618,160.31	125,021.10	468,118.11	-	-	25,021.10
				SUS	**$ 2,804,882.91**	**$ 335,422.09**	**$ 1,633,613.99**	**$ 185,345.00**	**$ 584,277.23**	**$ 66,224.60**
P1245				**Pavement Management System**						
	PMS-B	3814	3.57	Tri-Annual Performance Model Update	$ 122,417.10		11,612.90	25,829.70	63,272.30	21,702.20
	PMS-D	3764	3.58	Continued Calibration of ME design Models with PMS Data	$ 396,075.01		53,145.50	85,969.46	225,869.25	31,090.80
	PMS-E	3765	4.81	Improved Traffic Models for PaveM and ME Design	$ 352,366.30		44,514.69	144,764.10	163,087.51	-
	PMS-G	3766	4.82	Potential for Advanced Image Evaluation in APCS	$ 506,970.14		36,128.89	142,045.94	255,198.41	73,596.90
	PMS-H	3815	3.59	Updates and Improvements to RealCost-CA	$ 224,627.00		61,178.00	71,562.40	74,358.70	17,527.90
				PMS	**$ 1,602,455.55**	**$ -**	**$ 206,579.98**	**$ 470,171.60**	**$ 781,786.17**	**$ 143,917.80**

RESEARCH SUPPORT

DRISI Proj ID	PPRC Contract	DRISI Task ID	UCPRC SPE	PROJECT TITLE	Task Funding Total	FY19/20	FY20/21	FY21/22	FY22/23	FY23/24 Jul - Sep
P1259				**Research Services**						
	2.01	3823	2.01	Manage PPRC	$ 294,413.00	24,413.00	270,000.00	-	-	-
	2.02	3829	2.02	Advice to Caltrans	$ 544,264.50		147,121.72	166,270.00	185,645.78	45,227.00
	2.03	3832	2.03	Support & Training for PaveM Operations	$ 694,012.80		157,732.49	212,165.20	266,890.41	57,224.70
	2.04	3831	2.04	CalME support	$ 628,023.50		144,621.48	191,991.80	239,628.62	51,781.60
	2.05	3779	2.05	eLCAP and RealCost support	$ 547,397.50		57,357.29	167,349.00	277,577.31	45,113.90
	2.06	3828	2.06	Laboratory Management and AMRL Accreditation	$ 384,000.00		384,000.00	-	-	-
	2.07	3826	2.07	Laboratory and Field Testing Equipment	$ 900,000.00	500,000.00		200,000.00	200,000.00	-
	2.08	3827	2.08	HVS Maintenance and Equipment Refurbishment	$ 300,000.00		300,000.00	-	-	-
	2.09	3825	2.09	Calibration Centers	$ 355,777.50		79,564.86	103,902.50	128,377.94	43,932.20
	2.10	3824	2.10	Maintain Laboratory Space	$ 519,174.00	79,174.00	440,000.00	-	-	-
	2.11	3780	2.11	Advice to Div Aeronautics	$ 90,000.00		90,000.00			-
	2.12	3830	2.12	Long term research	$ 336,009.70		98,919.60	52,726.00	156,670.20	27,693.90
				2.xx	**$ 5,593,072.50**	**$ 603,587.00**	**$ 2,169,317.44**	**$ 1,094,404.50**	**$ 1,454,790.26**	**$ 270,973.30**

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