Sustainable Pavement Ideas Repository

California Department of Transportation, Division of Maintenance, Pavement Program

A Sustainable Pavement Initiative to Reduce Emissions

This Repository is prepared by the California Department of Transportation, Division of Maintenance, Pavement Program. Any organization that would like to build on this document, or add to it, is welcome to do so.

We also want to recognize the work that San Mateo is doing to reduce greenhouse gas emissions. We took inspiration for our formatting from their own Sustainability Ideas Book.

Thanks are given to the University of California, Davis, Pavement Research Center, and Nichols Consulting Engineers for their assistance and help in this document.

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Introduction

The California Department of Transportation's (Caltrans) Sustainability Pavement Ideas Repository aims to promote sustainability by sharing successful solutions for anyone. The purpose of this resource is to assist decision makers in tackling climate change and other sustainability-related issues- through pavement related activities. The aim is to facilitate the adoption of successful solutions, enabling them to act swiftly and efficiently.

Sustainable pavements are designed to meet the needs of both present and future generations. Engineers take into account environmental, social, and economic factors when making decisions. Asphalt and concrete pavements should meet societal needs while using resources efficiently and preserving the ecosystem. To adopt sustainability best practices, it is essential to understand the pavement life cycle, including materials selection and production, design, construction, use, maintenance and preservation, and end-of-life and recycling.

This Sustainability Pavement Ideas Repository is a continuously evolving resource that reflects the progress and innovations of many bright and dedicated It details Caltrans' current and future actions to address pavement life cycle concerns.

Click here to learn who has contributed to the Sustainability Pavement Ideas Repository.

Factors that Affect Life Cycle Analysis Diagram

★ – **Superstar for Greenhouse Reduction and Sustainability**

- ★ Long Life Pavement Design **(e)**
- Concrete Overlay
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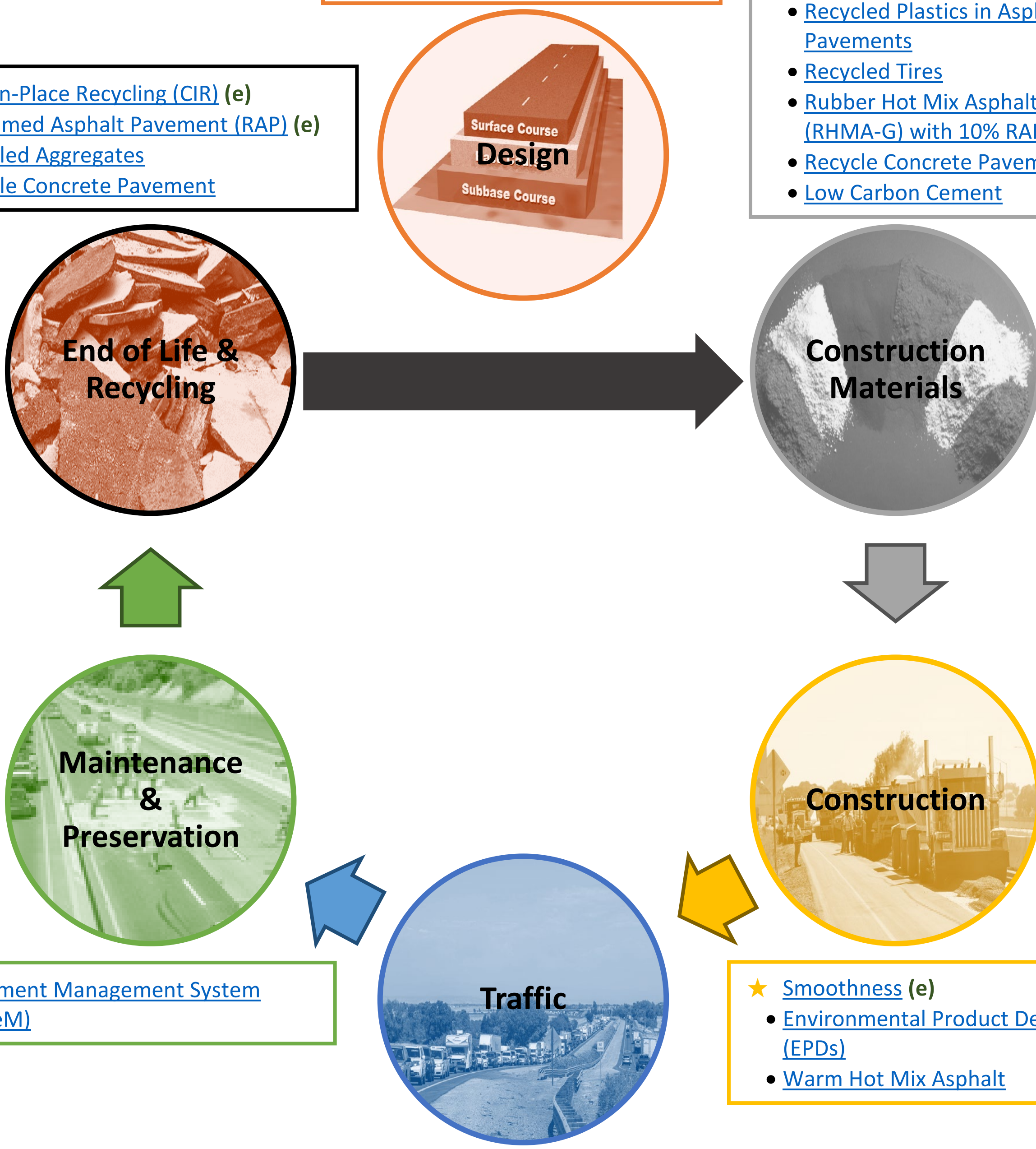
- Cold In-Place Recycling (CIR) **(e)**
- Reclaimed Asphalt Pavement (RAP) **(e)**
- Recycled Aggregates
- Recycle Concrete Pavement



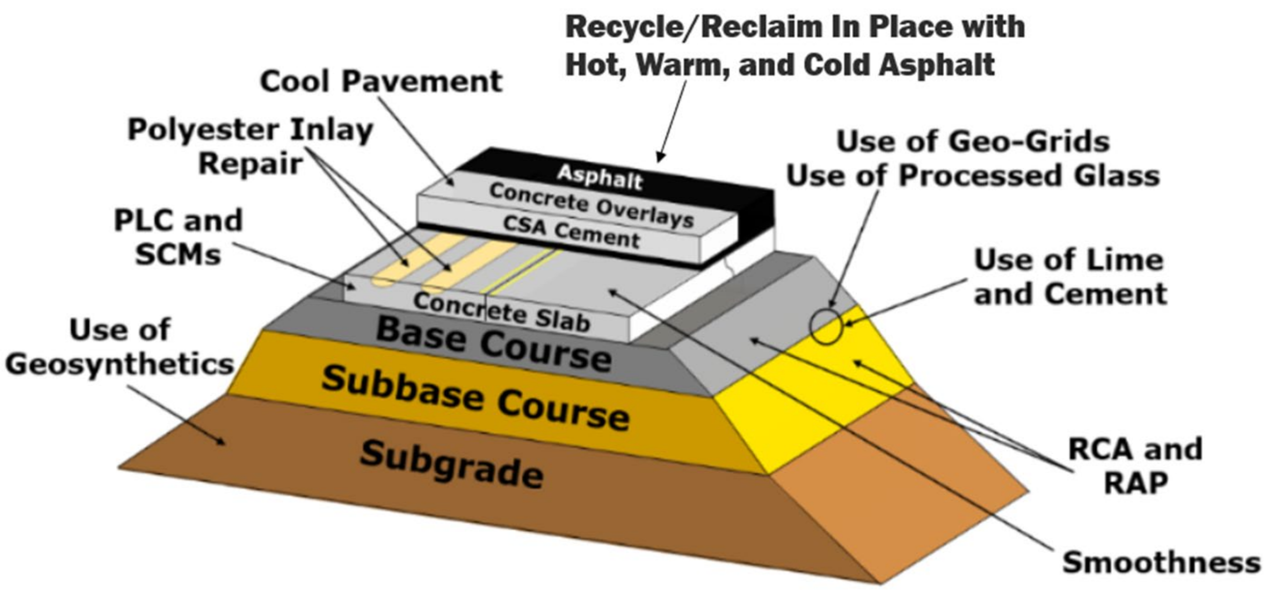
- Pavement Management System (PaveM)

- Reduce Fuel Usage

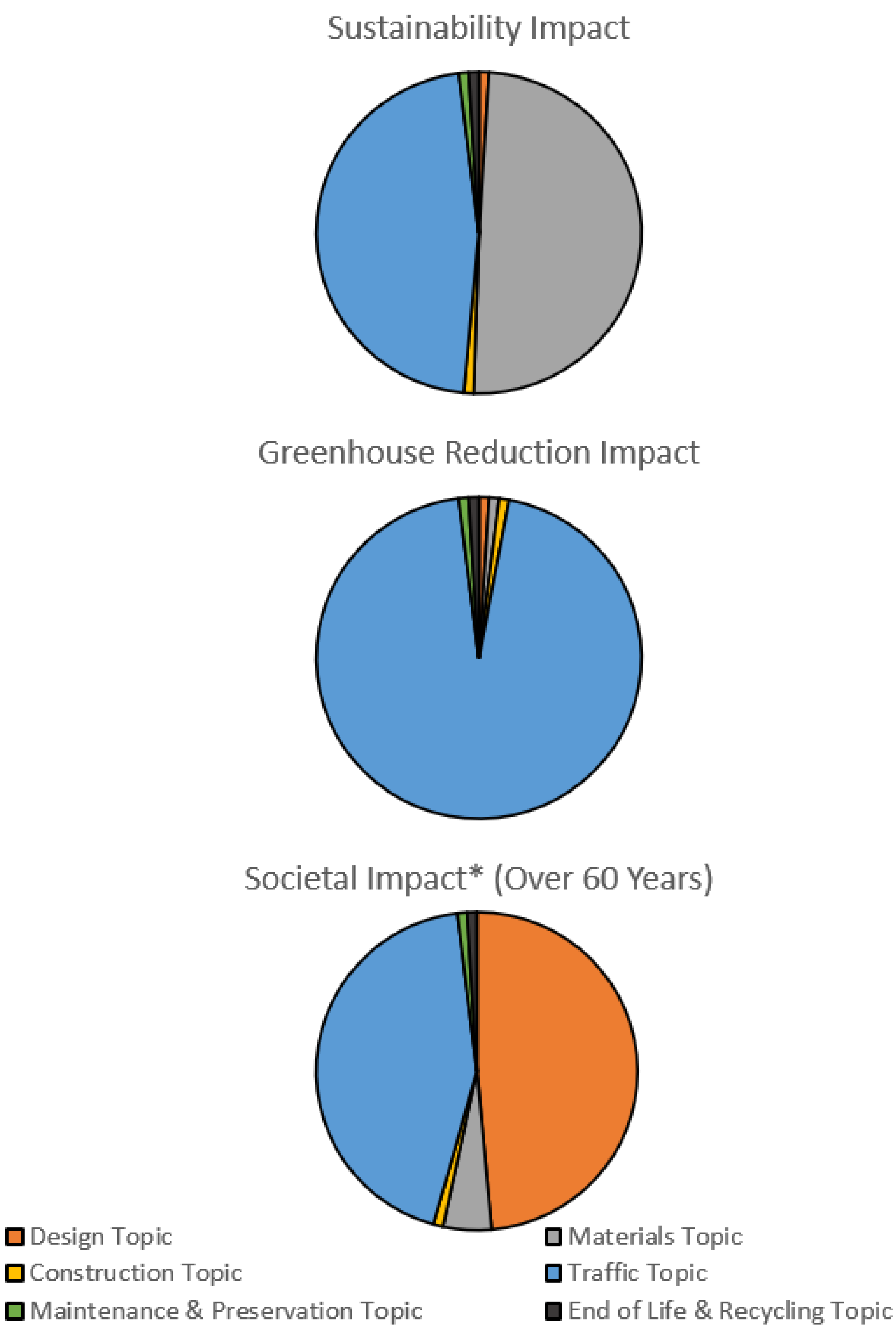
- ★ Smoothness **(e)**
- Environmental Product Declarations (EPDs)
- Warm Hot Mix Asphalt

(e) – SB1 Efficiency

Pavement Structure Diagram



Magnitude Impact Pie Charts



*Societal Impact: the effect on people and communities by pavement. Example – Short Design Life Strategies require constant lane closure and repair.

Design

Long-Life Pavement Design

The Impact

It is believed that the longest-lasting pavement is the most sustainable pavement. Long-life pavement design can be accomplished as a policy objective for high volume roadways in which the target pavement design life ranges from 40 to 60 years. Long-life design can be considered for both asphalt and concrete pavements, and it can be utilized in new, rehabilitation, and reconstruction pavement projects.

The use of long-life pavement can be regarded as an opportunity for reducing life-cycle costs, environmental burdens, and social impacts as compared to a standard, 20-year pavement design. In other words, a long-life pavement design can significantly impact materials usage, improve pavement condition (thus, improving user delays and fuel efficiency), and eliminate maintenance and construction activities over the pavement lifespan.

Description

Highway pavements were historically designed and constructed to provide 20 years of service life. The use of long-life pavement design with 40 to 60 years of design life has shown promising potential to minimize maintenance and rehabilitation costs and reduce public user delays due to road closures, particularly on high-volume roads, and will produce savings for many years after construction. In addition, shorter and fewer road closures reduce risks to both public and construction workers.

Long-life pavement can be achieved by increasing the pavement structural thickness and/or by increasing the material stiffness and durability, along with quality materials/mixture production and construction. As such, long-life design results in an initial cost and possibly initial environmental impact increases, but the overall life-cycle costs and environmental impacts over the life cycle are expected to be less.

Where It's Been Implemented

While Caltrans has been investigating the design and construction of longer-life pavements for several years, the Caltrans Highway Design Manual was revised in 2021 to mandate longer-life pavement for virtually all new pavement construction and rehabilitation projects. An Interstate 5 rehabilitation project in Sacramento is benefitting from advances in pavement design and innovative materials. Caltrans, in collaboration with the University of California Pavement Research Center (UCPRC), utilized the long-life design approach for the FixSac-5 project in which a new road surface with a 60-year pavement life and $37 million in savings over its anticipated lifespan is projected.

Key Factors for Success

Long-life pavement design requires a profound understanding of design and construction factors that affect both short-term and long-term pavement performance. Long-life pavement can be achieved through robust pavement design, use of durable materials, ensured quality during production and construction, and timely maintenance. The design requires typically about 10% thicker pavement and thus 10% additional cost for the pavement. The direct cost savings are produced by the lessening of preservation or rehabilitation over the longer life of the pavement.

Key Obstacles

- Understanding how to design for a longer life
- A good Life Cycle Cost Analysis
- A good Environmental Life Cycle Analysis

References and Resources

100 Year Pavement Design Guidelines

Concrete Overlay

Eliminate the removal of existing pavement and reduce the use of new materials, thus preserving the environment.

The Impact

Concrete overlays are a more sustainable alternative than concrete inlays in terms of life-cycle cost and environmental impact since the latter alternative requires remove and replace. The need for structural rehabilitation of existing pavements is much higher than the need for new construction. The use of overlays can have a significant impact on the Caltrans network.

Description

Concrete overlays are the construction of a concrete pavement Jointed Plain Concrete Pavement (JPCP) or Continuously Reinforced Concrete Pavements (CRCP) on top of the existing pavement, which can be concrete or asphalt. Since they are placed on top of existing pavements, they take advantage of the structural contribution of the existing pavement while reducing or even eliminating disposal of existing materials. In addition, we also save on the placement of new materials since we do not need a new base.

Where It's Been Implemented

In 2021, Caltrans partnered with FHWA on their Targeted Overlay Pavement Solutions (TOPS) initiative under their Every-Day Counts (EDC) program to promote the use of overlays for their cost-savings and sustainability benefits. Caltrans has been using concrete overlays as a strategy since the 1980s when some sections were built on I-80. In the last five years, Concrete Overlays over Asphalt (COA) were used on SR-113 in District 3 and SR-247 in District 8, which are secondary routes where the truck traffic volume is much lower, so the concrete structural section can be thinner and therefore the concrete panels must be short. This type of pavement is called Short Jointed Plain Concrete Pavement (SJPCP). Caltrans has also built CRCP on top of existing JPCP, which is known as a Concrete Overlay over Concrete (COC). With FHWA assistance through TOPS, we will be providing training on concrete overlays.

Key Factors for Success

Training is a key factor for the success because concrete overlay must be a tool in the toolboxes of Caltrans designers. As a result, Caltrans designers need to learn about their benefits, performance, limitations, and changes required on our current specifications and plans when selecting concrete overlay as a strategy. Existing cost and environmental analysis tools must be used in conjunction with engineering judgment to decide on the use of concrete overlays.

Key Obstacles

The lack of knowledge can be overcome with training. Concrete overlays require tapering to the grade of an existing undercrossing or overcrossing, this can be evaluated during the project selection phase of the technical team. It must be emphasized that concrete overlays cannot be used everywhere due to their effect on changing the grade and limiting clearance.

References and Resources

Feldman, Dulce Rufino; Mateos, Angel; Stuart, Charles; Yost, Deborah; Garcia, Reimond, Harline, Joe and Workinch, Addisu, 2022. “Caltrans Concrete Overlays,” Final Report to FHWA EDC-6 on Target Overlay Pavement Solutions (TOPS), California Department of Transportation.

Fick, Gary; Gross, Jerod; Snyder, Mark B.; Harrington, Dale; Roesler, Jeffery, and Cackler, Tom, 2021. “Guide to Concrete Overlays,” Fourth Edition, National Concrete Pavement Technology Center.

Polyester Concrete Inlay

Mitigate chain wear damage on concrete pavements

The Impact

Caltrans continues to battle tire chain wear damage on corridors subjected to high truck volumes and heavy snowfall, as is common in the Sierra Mountain passes on the I-80 corridor. Truck chain wear often causes rapid pavement deterioration with severe ruts on concrete pavements along the wheel path, which impairs driver safety and calls frequent lane closures for repair work.

Description

For polyester polymer concrete (PPC) inlay, grind out the damaged concrete pavement surface along the wheel paths with a width of three feet and a depth of 1–1.5 inches. PPC, a mixture of polyester binder and dry aggregate, is then placed on the ground wheel path. The service life of PPC inlay is expected to be about five years and varies depending on the intensities of snowfall and corresponding chain controls over the winter seasons. When PPC inlay reaches the end of its service life, it can be replaced with new inlay without compromising the structural condition of the existing pavement. Contrary to other available alternatives, such as full-width grinding and overlay or full-depth replacement, PPC inlay could be a more cost-effective and sustainable strategy for mitigating chain wear damage.

Where It's Been Implemented

Since 2017, Caltrans has placed PPC inlays to mitigate truck chain wear damage on I-80 (mountain areas). With over five years of field performance evaluation, PPC inlay along the wheel paths can be used as an effective measure for mitigating truck chain wear damage.

Key Factors for Success

Educate field engineers and inspectors on materials handling and quality assurance in constructing PPC inlay. Use of quality material is also critical for achieving desired performance of PPC inlay.

Key Obstacles

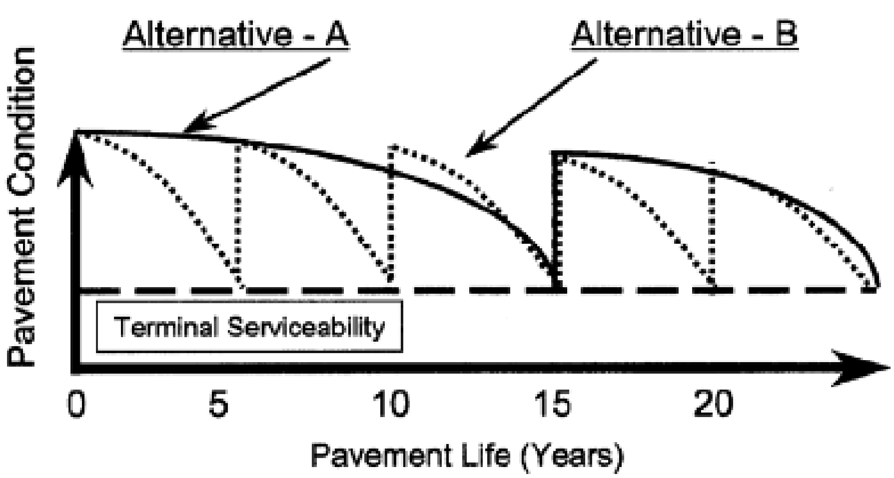
In general, the regional maintenance and construction engineers are satisfied with PPC inlays. There's a concern about the potential need for frequent replacement of the inlays. It would be necessary to conduct a close review of the cost effectiveness of PPC inlays and compare that with other available alternatives.

References and Resources

J. Medina, et al., *Performance Evaluation of Polyester Polymer Concrete (PPC) Inlays on I-80 Nev near Truckee*, Final Report prepared for Caltrans, NCE, November 2022.

Life Cycle Cost Analysis (LCCA)

Analyzes the long-term cost effectiveness of alternative designs for new and existing pavements.



(FHWA, 2002)

The Impact

Caltrans fully considers life-cycle cost impacts when making project-level decisions for pavements. Aside from the Agency cost, the user cost of the public traveling on a highway undergoing construction also has a direct impact on the environment. User costs arise when work zones restrict the normal flow of the facility and increase the travel time of the user by generating queues or speed changes through the work zones. User costs are given serious consideration and can become a significant factor when a large queue occurs for a given alternative, thus increasing the potential for GHG.

Description

LCCA provides decision-makers with the ability to determine the least-cost solution for a transportation investment requirement and is therefore a natural fit within the Asset Management framework. It assists in ensuring that pavement alternatives are analyzed objectively and consistently statewide, regardless of who engineers, builds, or funds the project. It evaluates all major investment decisions to increase the effectiveness of those decisions. The goal is to achieve and sustain a desired state of good repair over the life cycle of the pavement asset at the minimum practicable cost.

Where It's Been Implemented

The first version that was used by Caltrans was RealCost 2.2CA starting in 2007. On July 6, 2012, President Barack Obama signed into law P.L. 112-141, the Moving Ahead for Progress in the 21st Century Act (MAP-21). MAP-21 provides transportation funds and transforms the framework for investments to guide the growth and development of the country’s vital transportation infrastructure. It ensures that investments in federal-aid funds are directed to support progress toward achieving performance targets established in an asset management plan. In 2013, Caltrans developed a newer version of RealCost Version 2.5CA, which is a modified version of FHWA RealCost Version 2.5 and includes many improved features.

Key Factors for Success

The study of costs over a long period of time, gives useful insight into which pavement alternative is the most cost-effective. The result of LCCA is a comparison of pavement alternatives. Engineers should be mindful of the “garbage in, garbage out” mentality. How well RealCost models a project is determined by how well the engineer can match the project conditions with the program’s data input.

Key Obstacles

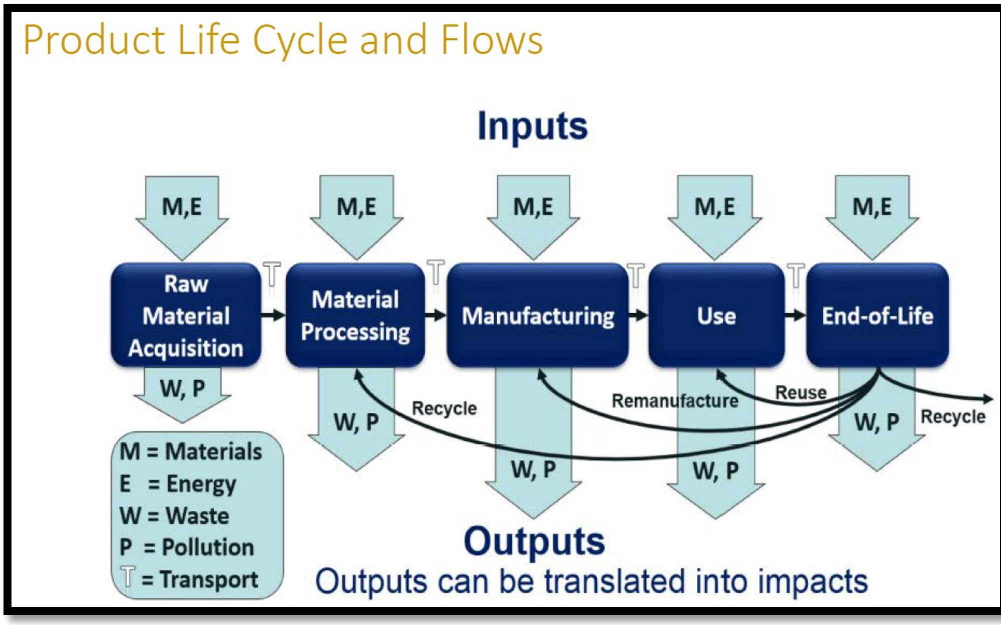
LCCA is not a means to predict the future, its calculations are based on today’s prices and historical average costs for similar projects. Market factors and other events could have a dramatic impact on the actual long-term costs, but not in the comparison. The results of the analysis don't reveal any information about the merits or benefits of a single project, just how the long-term costs of one pavement alternative compare to another. Sound engineering judgment is required when comparing results.

References and Resources

Life-Cycle Cost Analysis Primer", U.S. Department of Transportation, Federal Highway Administration, Office of Asset Management, August 2002.

Life Cycle Assessment (LCA)

Analyze long-term environmental impact of pavement practices.



The Impact

Pavement life cycle assessment (LCA) tool eLCAP could be used to capture all pavement activities and evaluate the complete GHG emission or environmental impacts of pavement practices to determine which pavement practices save GHG emissions during a specified time (long-term or design life). Reducing GHG emissions is necessary to achieve Caltrans' Lead Climate Action goal. All activities associated with pavement construction, preservation, and use phases produce GHG. Some pavement practices could be associated with less GHG emission but may need repeated pavement preservation activities during a specified duration, while others could be associated with more GHG emission but may need less repetitive pavement preservation.

Description

LCA tool eLCAP provides designers and decision-makers the ability to determine green pavement and environmentally sustainable pavement practices. eLCAP utilizes California's based Life Cycle Inventory (LCI) that can quantify its GHG emissions and other environmental impacts of pavement operations. It considers GHG and other impacts in pavement management, conceptual design, design, materials selection, and construction project delivery decisions. Using eLCAP, Caltrans will be able to evaluate the life cycle environmental impacts as part of policy and standards development.

Where It's Been Implemented

Caltrans has developed pavement life cycle assessment (LCA) tool eLCAP and is ready to be implemented. Training has been given to employees in Headquarters and all 12 Districts.

Caltrans is using a spreadsheet based LCA tool from the Federal Highway Administration (FHWA) called the Infrastructure Carbon Estimator (ICE). This can obtain an estimate for GHG production at an earlier stage in project development than what environmental Life Cycle Assessment for Pavements (eLCAP) operates for planning and early conceptual project evaluation. ICE functions at the corridor or higher level with very little input by the user.

Key Factors for Success

Need to develop pavement environmentally sustainable policy or guidelines for pavement practice. The existing LCI needs to be updated with current data, including replacing proprietary data, so eLCAP could be given access to the public. As improvement of equipment and construction practices are continuous, LCI needs to get continuous updating. In addition, existing eLCAP needs to include environmental impacts from lane closures and pavement structural responses. Implementation of eLCAP, with life cycle cost analysis (LCCA) on project decision making, will promote sustainable pavement practice.

Key Obstacles

Caltrans is focused on materials and the construction phase for saving GHG emissions and encourages to use recycled materials in pavements. There is no policy on long-term sustainable pavement practice and use of LCA to include the user phase to determine GHG emissions. Designers and decision-makers need to know the results of the current decisions made to then be able to make future decisions.

References and Resources

eLCAP: A Web Application for Environmental Life Cycle Assessment for Pavements", UCPRC

Towards Sustainable Pavement Systems: A Reference Document", U.S. Department of Transportation, Federal Highway Administration, Office of Preconstruction, Construction and Pavements.

Construction Materials

Use of Supplementary Cementitious Materials (SCMs)

Make concrete more sustainable and durable.

The Impact

Traditional supplementary cementitious materials (SCMs) like fly ash and ground granulated blast furnace slag (GGBFS) are widely used in Caltrans projects for their sustainability and durability. However, supply is limited, and demand for SCMs to reduce GHG emissions increases. The concrete industry is now prioritizing finding new sources of SCMs to meet these demands.

Description

The most common SCMs in California is fly ash, a waste product of coal combustion in electric power plants, and GGBFS, a co-product of the production of iron-based alloys. These resources are diminishing and they are mostly imported from other states or other countries. Research projects are exploring alternative pozzolanic materials like agricultural and forest biomass, natural pozzolans, cellulose nanomaterials, harvested fly ash, and waste glass to improve concrete sustainability and durability. The researchers are also looking into any other alternative sources that could contribute to steady supply of high-quality SCMs for use on Caltrans projects.

Where It's Been Implemented

Traditional SCMs currently accepted in the standard specifications include AASHTO M295 Class F fly ash, Class N natural pozzolans and metakaolin, AASHTO M302 Grade 100 or 120 GGBFS, and AASHTO M307 silica fume. Caltrans is currently conducting research projects to explore alternative sources of SCMs and the feasibility of using them to replace traditional SCMs in concrete production without losing the benefits in reducing GHG emissions and improving concrete durability.

Key Factors for Success

It is critical to obtain continued support and collaboration from stakeholders, including Caltrans functional units and industry. It is also critical to maintain a steady supply of material while keeping the consistency of product quality.

Key Obstacles

It will be necessary to secure steady, commercial level production of alternative SCMs. There may be resistance to the initial cost for developing production plant.

References and Resources

Reclaimed Asphalt Pavement (RAP)

Reduce pavement waste and use of new material by using existing asphalt binder and aggregates in RAP.

The Impact

The most common recycled material used in HMA mixtures is Reclaimed Asphalt Pavement (RAP). The advantages of using RAP are:

- Reuses paving oil and reduces Greenhouse Gas (GHG) generation in the production of paving oil
- Recycles aggregates which are especially important as aggregate supplies are becoming stretched.
- Reduces GHG generation for mining, processing, and trucking aggregate

Description

The High RAP Non-Standard Special Provision (nSSP) allows increasing the maximum allowable RAP percentage in HMA from 25 to 40 percent. Since the traditional Superpave mix design cannot completely account for the increase in RAP content, other mix design tools are being evaluated in this nSSP:

- A new binder test (Delta T_C) has been added to determine the behavior of the virgin binder and extracted binder from the High RAP.

- Contractors are allowed to use a performance-graded asphalt binder grade with upper and lower temperature classifications reduced up to 12°C from the specified grade (2 grades softer binder) and recycling agents.
- Additional tests needed to be performed during mix design and production. A few tests were required by the nSSP, and a few of them were for research purposes, such as IDEAL CT, I-FIT, Repeated Load Triaxial Test, and Bending Beam Fatigue.
- The mix design method has been improved by using Balance Mix Design (BMD) concepts to adjust the binder content and meet the nSSP criteria.

Where It's Been Implemented

Caltrans standard specifications (2018) allow up to 25 percent RAP in HMA mix by aggregate weight. Caltrans is evaluating 40 percent RAP (binder replacement) pilot projects to increase Caltrans RAP usage.

Key Factors for Success

Data collection and analysis are critical for the improvement of the nSSP. The improved nSSP should allow the Contractor to design and produce a good-performing HMA with up to 40 percent RAP.

Key Obstacles

HMA mix containing High RAP could be stiff, brittle, and susceptible to raveling and early cracking due to heavily aged binder in RAP. Agencies should consider Contractor's need to use new tools, such as a softer virgin binder and/or rejuvenator, to soften these high RAP mixes. Conversely, Caltrans also need to have a test that can accurately evaluate the early cracking potential of these high RAP mixes.

References and Resources

CalRecycle: Asphalt Pavement Recycling

Recycled Asphalt Shingles (RAS)

Reduce pavement waste and use of new material by using existing asphalt binder and fines in RAS.

From Roofs to the Roads

The Impact

Using Recycled Asphalt Shingles (RAS) in Hot Mix Asphalt (HMA) creates a cycle of reusing materials that optimizes the use of natural resources. While several factors influence the use of RAS in asphalt pavements, the two primary factors are economic savings and environmental benefits. RAS could be a useful alternative to virgin materials because it reduces the use of virgin aggregate and/or virgin asphalt binder required in the production of HMA.

Using RAS in HMA may conserve energy, lowers transportation costs required to obtain quality virgin materials, and preserves resources. Additionally, it decreases the amount of construction debris placed into landfills and does not deplete nonrenewable natural resources such as virgin aggregate and asphalt binder. Ultimately, recycling asphalt creates a cycle that optimizes the use of natural resources and sustains the asphalt pavement industry.

Description

The HMA-RAS nSSP allows the use of RAS in HMA for a maximum of three percent RAS by weight of total aggregate and a maximum of 15 percent by Binder Replacement (BR). New performance tests have been added to the Caltrans Standard Specifications to ensure the quality of the HMA-RAS mix during mix design and production, as listed below:

- A new binder test (Delta T_C) has been added to determine the behavior of the virgin binder and extracted binder from the HMA-RAS.
- Contractors are allowed to use a performance-graded asphalt binder grade with upper and lower temperature classifications reduced up to 12°C from the specified grade (2 grades softer binder) and recycling agents.
- Additional tests needed to be performed during mix design and production. A few tests were required by the non-Standard Special Provision (nSSP), and a few of them were for research purposes, such as IDEAL CT, I-FIT, Repeated Load Triaxial Test, and Bending Beam Fatigue.
- The mix design method has been improved by using Balance Mix Design (BMD) concepts to be able to adjust the binder content and meet the nSSP criteria.

Where It's Been Implemented

A nSSP has been developed for using RAS in HMA. A RAS pilot project in HMA was built on State Route 49 in El Dorado County (EA 03-2G1004) in November 2021. Four mixes were included in short test sections: (1) a control mix with no RAS or recycled asphalt pavement (RAP), (2) a typically used mix with 10 percent RAP that was also used for construction of the rest of the overall project, (3) a mix with three percent RAS, and (4) a mix with 10 percent RAP and three percent RAS.

A technical report has been drafted on the project performance and test results by the University of California Pavement Research Center (UCPRC) for Caltrans. This pilot project will be monitored to find and address any possible issues in the future. Also, data collection and analysis will be performed to adjust the nSSP and test methods as needed. The working group is working to find more pilot projects for nSSP improvement and data evaluation and analysis purposes.

Key Factors for Success

Data collection and analysis are critical for improvements to the nSSP. Pilot project monitoring helps to ensure the short-term and long-term performances of the HMA-RAS. Life Cycle Cost Analysis (LCCA) for HMA-RAS will also provide very useful information regarding the feasibility of using recycled shingles in HMA.

Key Obstacles

As asphalt ages and is exposed to heat and sunlight, it loses flexibility and the ability to melt and becomes flowable. RAS binders are very stiff as the roofing shingles have been exposed to extreme temperatures for perhaps decades. HMA mixtures containing RAS may be prone to cracking, aging, and raveling, which will reduce their service life. Shingles may contain 25 to 35 percent "extremely aged" asphalt binder. However, binder mobilization from RAS to HMA could be varied depending on the temperature, silo time, use of recycling agents, and types of shingles (post-consumer or manufacturer waste). Assuming complete RAS mobilization of the binder will lead to inaccurate (lower) Optimum Binder Content and poor mix performance. As a result, the mix properties need to be changed to properly account for the RAS.

References and Resources

CalRecycle: Asphalt Roofing Shingles Recycling

Recycled Aggregates

Use recycled aggregates replacing virgin aggregates to manufacture pavement materials.

The Impact

California is facing depletion of virgin aggregates, and consequently, costs are increasing. Often, Industry has difficulties getting virgin aggregates for the construction of pavements and other structures. Virgin aggregates are mined, processed, and transported for use in pavements and have a direct impact on the environment. Each activity before the virgin aggregates is delivered produces greenhouse gases (GHG). The use of recycled aggregates will reduce the use of virgin aggregates and consequently save GHG emissions and conserve natural resources.

Description

Recycled aggregates are manufactured by processing old asphalt, concrete, lean concrete base, and cement treated base. The recycled aggregates could be used alone or combined with virgin aggregates but need to be clean and comply to the material requirements as specified. Recycled aggregates do not require mining and long hauling and will produce relatively less GHG.

Where It's Been Implemented

Caltrans has developed standard specifications and included use of recycled aggregates in bound and unbound bases, and in minor concrete. Almost all pavement bases and subbase are built with recycled aggregates throughout California, including city and county roads.

Key Factors for Success

Promote use of recycled concrete aggregates (RCA) to manufacture concrete for individual slab replacement and bottom lift of two-lift concrete pavement. Develop guidelines for using high RAP in asphalt pavements and RCA in concrete pavements, including incentives for using recycled aggregates.

Key Obstacles

Caltrans does not have design guidelines to use high RAP in asphalt pavement and use of RCA in concrete pavements. Use of RCA in two-lift concrete pavement is promising but construction is relatively expensive.

References and Resources

Sections 23 through 30, 90-2, Caltrans Standard Specifications.

Recycled Plastics in Asphalt Pavements

Reduce plastic waste, and greenhouse gas emissions, conserve asphalt binder, improve service life and sustainability

The Impact

Plastic waste poses a significant global issue, with no end in sight despite efforts to reduce and recycle plastics. We must make more efforts to prevent waste plastic from ending up in landfills. Utilizing waste plastic in asphalt roads is one of these efforts.

Description

Two processes can achieve the addition of waste plastic; in the first process, the waste plastic is converted to pellets after a thorough cleaning and is added to the binder like an asphalt polymer modifier up to 10 percent by binder weight. Such a process can be called a wet process. Preliminary lab tests on the modified binder indicate that the waste plastic acts as a stiffening agent by increasing the stiffness of the binder. The over binder property modification is a function of the type of waste plastic (LDPE, HDPE, PET, PVC, PP, PS, etc.).

In the second process, cleaned waste plastic is introduced into the hot plant with heated aggregate, where the waste plastic melts and coats the aggregate facilitating stronger bonding of asphalt over aggregate, improving the over properties of the resulting mix. Some plastic polymers may improve both deformation and cracking resistance of base binders. Caltrans is evaluating through extensive literature reviews and comprehensive laboratory testing, as this can meet Caltrans' goals of sustainability and environmental stewardship.

Where It's Been Implemented

Since 2020, Caltrans has been evaluating various technologies to incorporate waste plastics into our highways after carefully researching the processes and technologies. Caltrans successfully placed a pilot project that established the proof of concept, but the first pilot did not work well due to adverse environmental conditions and material issues. Another pilot project paved last year has been successful. The pilot section is performing quite well after being exposed to the recent flurry of storms.

Key Factors for Success

Careful vetting and evaluation of various waste plastic additive products and the HMA incorporation technologies through comprehensive laboratory testing and comparative performance analysis, along with LCCA implication, are keys to success.

Key Obstacles

Lack of literature, research studies, and long-term field performance data, limited literature about the usage methodologies, etc., are some of the challenges.

References and Resources

National Asphalt Pavement Association: Plastics in Asphalt

Recycled Tires (Coming Soon)

The Impact

Description

Where It's Been Implemented

Key Factors for Success

Key Obstacles

References and Resources

Rubber Hot Mix Asphalt Gap Grade (RHMA-G) with 10 Percent RAP

Reduce tires in landfill by incorporating into asphalt pavements.

The Impact

The default surface mix in Caltrans is RHMA-G mix, and Caltrans placed approximately 3.5 million tons of RHMA-G in 2020. The ability to include RAP in RHMA-G represents a great opportunity for Caltrans to increase RAP usage. Allowing 10 percent RAP in RHMA-G will potentially enable Caltrans to consume an additional 0.35 million tons of RAP each year.

Description

The 10 percent RAP in RHMA-G nSSP allows the use of 10 percent RAP by weight of aggregate blend in RHMA-G mixes. The minimum asphalt rubber binder content remained unchanged at 7.5 percent. Pilot projects have three percent and four percent air voids to accommodate the additional RAP binder in the RHMA-G mix.

Where It's Been Implemented

In 2022, Caltrans through the Pavement and Materials Partnering Committee (PMPC), drafted the 10 percent RAP in RHMA-G nSSP, and several pilot projects are being built for evaluation. If the pilot projects have equal or better performance, the 10 percent RAP in RHMA-G specification will be designated as standard specifications allowing it to be used statewide.

Key Factors for Success

10 percent RAP in RHMA-G has equal or better performance when compared to RHMA-G.

Key Obstacles

Neglect or fail to invest in the design of a good 10 percent RHMA-G mix. The asphalt plant is not willing to adjust to produce a consistent and good 10 percent RHMA-G mix.

References and Resources

Caltrans Crumb Rubber Usage News Article

Recycle Concrete Pavement

In-place recycling deteriorating concrete pavement and use in base.

The Impact

Caltrans has many concrete pavement sections over 40 years old, exceeding design life and need frequent maintenance and lane closure, as the pavement condition is deteriorating rapidly. In some cases, it requires major rehabilitation or reconstruction. Current practice of concrete pavement rehabilitation or reconstruction is to remove and replace with a new concrete pavement. This removed concrete is often transported for reprocessing or dumped at a landfill. The in-place recycling of old concrete pavements and use in base could reduce waste, trucking, and conserve natural resources.

Description

The recycling or rubblization of existing deteriorating concrete pavements is performed with aggressive techniques to reduce concrete slabs to aggregates typically to less than 12 inches to eliminate slab action of the concrete pavements. This rubblized concrete pavements is used as a base for asphalt concrete or concrete overlay. The deteriorating concrete pavement is completely utilized in the pavement structural section reducing or eliminating the requirement of virgin aggregates and hauling distance.

Where it's been implemented

Caltrans has not implemented in-place recycling or rubblization of deteriorating concrete pavement and used it as a base. Other DOTs e.g.., Illinois, Michigan, and Wisconsin have practiced rubblization of concrete pavement and used in base. California has historically only used a crack seat and overlay strategy, however this rubblization strategy is most effective if there is D-Cracking or Alkali Silica Reactivity present.

Key Factors for Success

Develop design and construction guidelines for in-place recycling or rubblization of existing deteriorating concrete pavements and overlaying with asphalt or concrete pavements. Include in Caltrans pavement design tools or design table and train District design engineers and material engineers to use concrete pavement rubblization techniques.

Key Obstacles

Caltrans does not have design guidelines to use in-place recycling or rubblization of concrete pavements and overlay with asphalt or concrete. The concrete pavement rubblization is a new practice for Caltrans and requires encouragement through training, incentives, and/or piloting.

References and Resources

Rehabilitation of concrete pavements utilizing rubblization and crack and seat methods", Iowa State University.

Guidance, Parameters, and Recommendations for Rubblized Pavements", Wisconsin Highway Research Program

Rubblizing Portland Cement Concrete Pavement", Michigan Department of Transportation.

Low Carbon Cement

Reduce GHG emissions in cement and concrete production.

The Impact

Production of Portland cement generates a significant amount of GHG emissions, mainly in the process of making cement clinkers. Use of low carbon cement, such as Portland Limestone Cement (PLC) and other types of blended cement, reduces GHG emissions in cement manufacturing by using less amount of cement clinkers in the cement manufacturing process.

Description

American Society for Testing and Materials (ASTM) C150/ American Association of State Highway and Transportation Officials (AASHTO) M85 permits ordinary Portland cement (OPC) to contain up to five percent of limestone inter-ground with clinker at finish grinding, while ASTM C595/AASHTO M240 allows Type IL blended cement, aka PLC, to contain up to 15 percent of inter-ground limestone. PLC is known to help reducing GHG emissions in cement and concrete production by up to 10 percent as it uses less amounts of clinker, the production of which accounts for more than 90 percent of the CO2 emissions in cement manufacturing. After three years of laboratory investigation on the properties of PLC and its concrete mixtures with California specific materials, Caltrans decided to allow the use of PLC in Caltrans concrete projects in the same way of using OPC.

Where it's been implemented

Caltrans revised the Standard Specifications in 2021 to allow the use of PLC (Type IL) and ternary blended cement (Type IT) in addition to the existing list of allowable blended cement such as Portland blast-furnace slag cement (Type IS) and Portland pozzolan cement (Type IP) for concrete production in Caltrans projects. Moderate sulfate resistance (MS) or higher is required in all types of blended cement, and they can be used in the same way of using conventional Portland Type II/V cement.

Key Factors for Success

It is recommended to conduct short- and long-term field performance evaluation for concrete pavements and structures built with PLC. It is critical to obtain coordinated collaboration and support from all stakeholders including districts and industry.

Key Obstacles

There is potential resistance to adopt the new practice of using PLC over traditional OPC, partly because of a misconception on the performance of PLC concrete. It would be necessary to provide engineers and practitioners with proper education on the properties and performance of PLC concrete.

References and Resources

J. Weiss, et al., *Impact of the use of Portland-Limestone Cement on Concrete Performance as Plain or Reinforced Material*, Final Report prepared for Caltrans, Oregon State University, June 2021.

Construction

Smoothness

Smoother pavements improve driver safety, fuel efficiency, ride quality, vehicle wear and tear, and pavement durability.

The Impact

Smoothness is perhaps the top three single largest most impactful attributes to make a pavement sustainable. First, A smooth pavement will stop vehicles from bouncing down the road will naturally reduce the impacts to the pavement and causse less stress and thus a longer life. Second, and perhaps more important, a smooth pavement will require less energy for vehicles to travel over them. Smooth pavement can reduce the GHG emissions of every vehicle to travel over them by 3-10 percent.

Smoothness is a measure of the level of comfort experienced by the traveling public while riding over a pavement surface. Ride quality is crucial for the traveling public, with smoothness being a key performance indicator in pavement maintenance and rehabilitation. This reduces fuel and vehicle costs, extends service life, and enhances motorist safety and satisfaction.

The fuel efficiency of vehicles on our roads improves with a smoother pavement. Due to more "bumps in the road," more energy is required to move a vehicle over a rough surface than a smooth one. This extra energy, of using additional fuel, results in extra GHG into our environment. In addition, smooth pavements last longer than rough pavements (smoothness is a key design factor).

Description

All projects will be managed by tenth-mile segments, and the smoothness data will be collected using Inertial Profilers (IP). IP will provide a simulation of the longitudinal lane profile, including International Roughness Index (IRI) and Mean Roughness Index (MRI). Smoothness in Asphalt Pavement is managed by the HMA thickness and the initial existing pavement roughness. Thicker pavements and paving in more lifts will provide better opportunities for the contractors for smoothness. Also, pre-paving corrections or leveling courses can increase the chance for smoother pavement. Caltrans will pay in full for smoothness that is very near the specification and pay a bonus for extra smooth pavement. Conversely, Caltrans will charge a disincentive for pavement that is rough. Extremely rough pavement will be corrected or removed and replaced.

The concrete pavement smoothness specification is in Section 40-1.01D(8)(c)(iii). Pavement smoothness acceptance and verification is based on results of the inertial profiler testing. A specific Target Smoothness Table is provided, depending on the project type (new alignment, widening, lane replacement) and the pavement type (CRCP or JPCP). Based on the mean IRI (or MRI), Contractors can either receive pay adjustments, be required to perform corrective action, or do nothing. There is no additional payment for corrective action.

Where it's been implemented

In 2018, Caltrans introduced a new mandated nSSP for smoothness using Inertial Profiler (IP) for paving projects. Since then, the nSSP has been used on thousands of lane miles in California's state highway system. Over time, modifications and improvements have been made based on smoothness data analysis from hundreds of projects. The HMA smoothness nSSP has become standard and published in the 2022 Caltrans Standard Specifications.

In February of 2019, the Caltrans Pavement Program, under the Division of Maintenance, implemented a non-standard special provision (nSSP) for concrete pavement smoothness using incentives and disincentives using the international roughness index (IRI). After a few years of using the nSSP on constructed projects, input from industry, contractors, and Districts, this new concrete pavement smoothness specification was included into Section 40 (Concrete Pavement) of the 2018 Revised Standard Specifications in April 2022.

Key Factors for Success

New technologies and equipment on the inertial profilers can provide better data in terms of smoothness. It is also important to educate engineers on how to use the IP data during the design and how to enforce the specifications during and after the construction of the pavements.

Constructing concrete pavements under the requirements and tolerances provided in the Standard Specifications will result in longer lasting, smoother, and more sustainable concrete pavements.

Key Obstacles

Smoothness enforcement in urban areas may be challenging due to inertial profilers' speed limits and construction complications, including manholes, railroad crossings, and sharp curves.

Meeting the requirements in the Standard Specifications is the responsibility of everyone on the project team (Designers, geotechnical engineers, Project Managers, Resident Engineers, Contractors, etc.). Every project requires sound engineering decisions and good communication throughout the entire project delivery process.

References and Resources

Caltrans Pavement Smoothness Webpage

Caltrans, 2022. "Standard Specifications."

Caltrans, 2018. "Guidelines for Concrete Pavement Smoothness Requirements."

Environmental Product Declarations (EPDs)

ENVIRONMENTAL IMPACTS Declared Products: Description:Exterior 4000 PSI Compressive strength: 4000 PSI at 28 days Declared Unit: 1 m^3 of concrete	
Global Warming Potential (kg CO -eq)	318
Ozone Depletion Potential (kg CFC-11-eq)	7.15E-6
Acidification Potential (kg SO -eq)	0.95
Eutrophication Potential (kg N-eq)	0.24
Photochemical Ozone Creation Potential (kg O -eq)	20.7
Abiotic Depletion, non-fossil (kg Sb-eq)	5.82E-5
Abiotic Depletion, fossil (MJ)	658
Total Waste Disposed (kg)	94.2
Consumption of Freshwater (m^3)	2.40
Product Components: natural aggregate (ASTM C33), Portland cement (ASTM C150), fly ash (ASTM C618), batch water (ASTM C1602), admixture (ASTM C494), admixture (ASTM C260)	

A sample of EPD for a concrete mix (Source: FHWA)

An Environmental Product Declaration for Asphalt Mixtures		
PRODUCT DESCRIPTION Gradation Type: dense Mix Design Method: superpave Nominal Maximum Aggregate Size: 12.5 mm Performance Grade of Asphalt Binder: PG 58-28 This mix producer categorizes this product as a Hot Mix Asphalt (HMA) asphalt mixture. This asphalt mixture was produced within a temperature range of 150 to 161°C		
IMPACT CATEGORY	POTENTIAL IMPACT PER METRIC TONNE ASPHALT MIXTURE (PER TON ASPHALT MIXTURE)	
Global warming potential (GWP-100)	*71.05 (64.46) kg CO2 Equiv.*	
Ozone depletion potential (ODP)	*9.92e-08 (9.00e-08) kg CFC-11 Equiv.*	
Eutrophication potential (EP)	*1.24e-02 (1.13e-02) kg N Equiv.*	
Acidification potential (AP)	*1.72e-01 (1.56e-01) kg SO2 Equiv.*	
Photochemical ozone creation potential (POCP)	*4.51 (4.09) kg O3 Equiv.*	
DECLARED UNIT: The declared unit is 1 metric tonne (1 short ton) of an asphalt mixture		
PRODUCT INGREDIENTS		
Component	*Material*	*Weight %*
Aggregate	*Natural Stone*	*15*
Aggregate	*Natural Stone*	*21*
Aggregate	*Natural Stone*	*13*
Aggregate	*Natural Stone*	*14*
Aggregate	*Natural Stone*	*8*
RAP	*Reclaimed Asphalt Pavement*	*24*
Binder	*Unmodified*	*4*

A sample of EPD for an asphalt mixture (Source: FHWA)

The Impact

An environmental product declaration (EPD), also called Type III Environmental Declaration, is a transparent, objective, and verified report that communicates what a product is made of and how it impacts the environment (e.g., resource use, energy, emissions). The scope for developing an EPD is referred to as a product category rule (PCR) that provides guidance and defines the requirements for EPDs for a certain product category.

EPDs allow comparisons of the environmental impacts of materials (if they fit into the same PCR) that help agencies make informed decisions on selecting products with less environmental impact. For both agency and industry, EPDs can be used as a tool to track and communicate efforts being made toward sustainability goals and environmental stewardship. Agencies can encourage industry to move toward environmental efficiency by providing incentives to develop and use EPDs. Similar to LCCA, they can be regarded as a tool to evaluate the environmental impacts of various pavement design alternatives and to establish policies and specifications.

Description

Similar to the "nutrition facts" label seen on a food product, EPDs are product labels for manufacturing or production of construction materials (e.g., asphalt, cement, asphalt mixtures, concrete mixtures, or steel reinforcement) that can be used to communicate environmental impacts and quantify greenhouse gas (GHG) emissions. EPDs are developed by industry and they are compliant with the ISO 14025 standard. They are developed based on independently verified life cycle assessment (LCA) procedures and the industry consensus methodology described in the PCR. Most EPDs currently include a "cradle-to-gate" LCA that only includes raw materials extraction, transportation of raw materials to the production facility, manufacturing/production of materials at the facility, and transportation of the product to the plant gate (i.e., before it is transported to the construction site).

Where it's been implemented

The Buy Clean California Act (Assembly Bill 262) originally signed into law on October 15, 2017 mandates collection of EPDs for eligible materials (carbon steel rebar, structural steel, flat glass, and mineral wool board insulation). Through the implementation of the BCCA, California became the first US state to ask for EPDs for these construction materials. Beginning in 2019, Caltrans initiated a pilot study requiring EPDs for hot mix asphalt, aggregates, and concrete in addition to the materials specified by BCCA.

The purpose of the Caltrans EPD Implementation Project is to collect EPDs for materials incorporated into construction projects in order to quantify the GWP emissions in the manufacturing of those materials for our transportation system. In 2023, a joint Caltrans-Industry special working group of the Pavement and

Materials Partnering Committee (PMPC) was formed. Their objective is to develop and implement specifications for collecting EPDs for concrete and asphalt mixes. In addition, Caltrans has participation in the Federal Highway Administration (FHWA) Climate Challenge in 2023. This pilot program supports the development of EPDs in the asphalt and concrete industries by reimbursing some of the costs it takes to develop EPDs on mixtures used on Caltrans projects.

Key Factors for Success

During the policy and specification development for collection of EPDs and establishing benchmarks, it is important to engage material suppliers, contractors, and other external stakeholders for input regarding the viability of proposals. This effort enhances transparency, accountability, collaboration, communication, and empowerment.

To establish a successful program with consistent and quality EPD data, guidance on how to interpret PCRs to produce EPDs as well as training on how to review EPDs are required for both manufacturers and agencies. The process for developing EPDS must be transparent to be confidently used for reporting and decision-making. Systems for storing data from EPDs should include data quality checks, system consistency, and certification.

Key Obstacles

As noted earlier, cradle-to-gate EPD only represents one stage in the life cycle of a pavement which is material production. Requiring materials with lower environmental impacts may impose tradeoffs in long-term performance and subsequent life-cycle phases. As such, relying only on EPDs and environmental performance without taking long-term performance can be detrimental to the big picture of true sustainability.

References and Resources

Caltrans Environmental Product Declaration (EPD) Webpage

Lessons Learned from Caltrans Pilot Program for Implementation of EPDs

Warm Mix Asphalt

Potential to reduce emissions associated with asphalt production and placement

The Impact

Warm Mix Asphalt (WMA) is a combination of mechanical and chemical technologies that produce hot mix asphalt at temperatures below 325°F, achieving equal pavement performance. Lower temperatures can help reduce natural gas consumption, reduce emissions, and smoke, during asphalt production.

Description

Hot mix asphalt production requires high temperatures exceeding 325°F to fully coat pavement aggregate, ensuring optimal performance and a tight, uniform, long-lasting mat. This results in a compacted, uniform pavement, preventing air from entering and extending its life.

WMA technologies use mechanical or chemical means to facilitate the coating of the aggregate without the need for higher production temperatures. Depending on the technology used, the production temperature may be reduced to 10°F to 50°F lower. Some WMA technology also allows improved pavement compaction resulting in a long-lasting mat. Such mix produced at normal production temperature can be hauled over a longer distance and/or placed in a colder paving environment without compromising the long-term pavement performance.

Where It's Been Implemented

In 2006, Caltrans began its evaluation of WMA on state highways. WMA has been used in most of the Caltrans districts, evaluated by the University of California, Davis Pavement Research Center (UCPRC). WMA is allowed at the Contractor's option in Section 39, "Asphalt Concrete," of the Caltrans Standard Specifications.

Key Factors for Success

Caltrans Standard Specifications, Section 39, "Asphalt Concrete," allows the use of WMA at the Contractor's option. Certain districts regularly specify WMA due to challenges with low temperature paving or long hauling distances between the asphalt plant and the project location. Since it is already a tool in the toolbox, Caltrans needs to decide the best way to use WMA to reduce potential emissions.

Key Obstacles

The contracting community and Caltrans need to further discuss the best ways to use WMA as a greenhouse gas emissions tool. There is a risk in lowering production temperatures as it may affect long term performance of asphalt pavement.

References and Resources

FHWA Warm Mix Asphalt FAQ

Traffic

Reduce Fuel Usage (Coming Soon)

The Impact

Description

Where it's been implemented

Key Factors for Success

Key Obstacles

References and Resources

Maintenance And Preservation

Pavement Management System (PaveM)

Focusing on developing right treatments at right times to plan and deliver pavement projects more effectively.

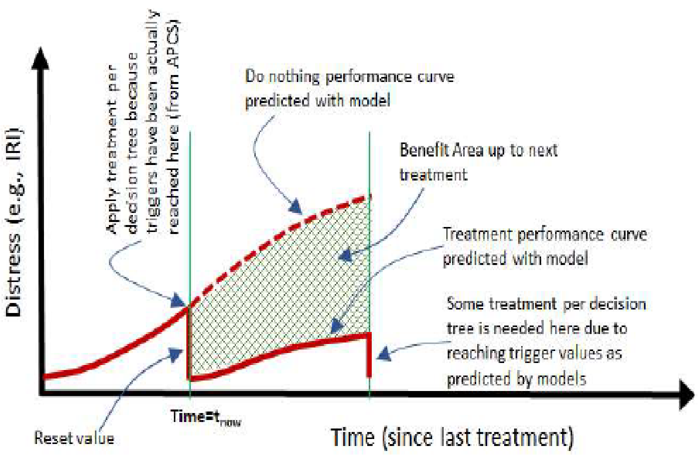
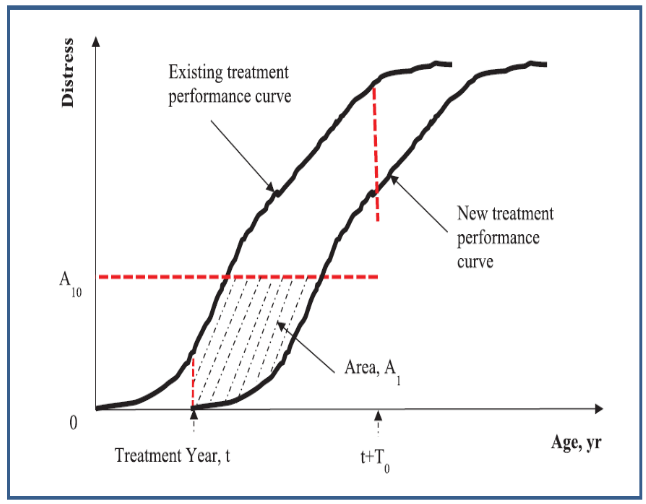


Figure 2-2. Schematic of performance Benefit Area using IRI improvement



The Impact

A fundamental goal of pavement management is to extend service life by treating distress with the right strategy at the right time to efficiently meet performance targets. PaveM incorporates asset management data and leverages economic analyses, including LCCA and Benefit-Cost Analysis (BCA) to apply basic cost and performance data to screen many potential project alternatives. Selecting the proper pavement performance-based objective functions can lead to future projects that minimize GHG emissions, while maintaining near optimal repair cost. Additionally, the reduced fuel consumption could result in substantial user cost savings.

Description

PaveM utilizes pavement performance data to efficiently recommend pavement investments. The system's approach maximizes the return on investment of every pavement dollar, extends pavement life by treating distresses at the right time, and achieves targeted performance goals. PaveM Tools were designed to aid

Caltrans pavement staff in identifying hot spots for needs, focusing on developing right treatments at right times to plan and deliver pavement projects more effectively. Current pavement condition is one of the most critical inputs for PaveM, it is collected through the Automated Pavement Condition Survey (APCS) contract. APCS also provides video images for the entire network. The Automated Pavement Condition Report (APCR) shows current and future pavement condition for any specified project range. It also calculates the State Highway Operation and Protection Program (SHOPP), Rehab effectiveness of the specified projects range.

Where it's been implemented

As the steward of the State Highway System (SHS), Caltrans is responsible for maintaining over 50,000 lane-miles of pavement along more than 255 state and interstate highways. PaveM is Caltrans' state-of-the-art Pavement Management System. Caltrans conducts an APCS to collect pavement data at highway speeds for all lanes along the SHS. The first APCS data was collected in 2015 and 2016.

Key Factors for Success

Pavement condition data shall be as accurate and precise as possible. Caltrans accomplish this by following the Federal Highway Administration's requirement defined in 23 Code of Federal Regulations (CFR) Part 490.319(c), by developing a Data Quality Management Plan (DQMP) that addresses all areas of the pavement condition data collection, quality control, and acceptance processes.

Key Obstacles

Providing data in a in a timely manner and report the results to Caltrans by the Contractor.

References and Resources

Implementing a pavement management system: The Caltrans experience by Tom Pyle and Zhongren Wang, 6 February 2019

End of Life And Recycling

Cold In-Place Recycling (CIR)

Reduce pavement waste and use of new material by recycling existing pavement and base in situ.

The Impact

In conventional asphalt pavement rehabilitation methods, old asphalt is milled, reprocessed, and reused as recycled asphalt pavement (RAP) for new roads. Cold in-place recycling (CIR) addresses some of the issues by reusing existing pavement, further reducing material to landfill and trucking for construction. CIR strategies include Full Depth Recycling (FDR) and Partial Depth Recycling (PDR). The decision whether to use FDR or PDR strategy is primarily based on the origin of the distresses, and whether the goal of Capital Preventive Maintenance (CAPM) or rehabilitation is simply to restore structural capacity or make structural improvements and/or alignment changes.

Description

FDR is a rehabilitation process which involves pulverizing the existing asphalt pavement and parts of the granular base in place to depths of up to 12 inches, either mixing with a small quantity of foamed asphalt as binding agent (FDR-FA) or cement (FDR-C), grading, and compacting, and overlaying with a new Hot Mix Asphalt (HMA) surface layer. FDR-FA is typically used when the existing pavement contains good quality material with marginal fines after pulverization. If there is significant poor-quality material and fines, then FDR-C should be considered.

PDR is a preventative maintenance or rehabilitation process which involves pulverizing part of the existing asphalt, between 3 to 6 inches, mixing with a small quantity of recycling agent (foamed asphalt or emulsion), grading, and compacting, and overlaying with a new HMA surface layer. The key difference between PDR and other CIR strategies is that a thin layer of existing HMA remains underneath the PDR.

CIR use has increased as sustainability efforts have heightened, and virgin material has increased in costs through economic factors and material supply. The existing pavement layers or upper portion are recycled instead of being hauled away, resulting in decreased removal, and hauling of the existing material to landfills. After mixing and compacting the recycled material, the result is a homogeneous base layer to support a new surface layer. Rubberized Hot Mix Asphalt (RHMA) can be used for the new surface layer which is sustainable. From recent bid analysis, FDR has been shown to be 20 to 30 percent less expensive than traditional removal and replacement methods. PDR has been shown to be up to 20 percent less expensive than an equivalent mill and fill method.

Where it's been implemented

Since 2001, Caltrans has paved several thousands of lane miles of FDR and PDR throughout the California state highway system. Local agencies such as cities and counties also implement CIR on their routes.

Key Factors for Success

As with other pavement rehabilitation strategies, adequate site investigation, proper structural design, life cycle cost analysis, and best construction practices are key to successful CIR projects.

Key Obstacles

As in traditional roadway paving projects, traffic and site conditions determine where CIR strategies can be done. Lack of experience and resistance to the initial costs of paving CIR must be met with education on the necessity and benefits of CIR. Any pavement draining issues must be addressed prior to CIR activities. Also, utilities should be located so the contractor can work around them or can be considered for relocation or adjustment if utilities would be in the way of operations.

References and Resources

Caltrans Guide for Partial and Full Depth Pavement Recycling in California

Caltrans Cold In-Place Recycling Webpage

Reclaimed Asphalt Pavement (RAP)

Please refer to Construction Materials Section - Reclaimed Asphalt Pavement.

Recycle Concrete Pavement

Please refer to Construction Materials Section – Recycle Concrete Pavement.

Recycled Aggregates

Please refer to Construction Materials Section – Recycled Aggregates.

Contributors

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