Sustainability in Practice 102

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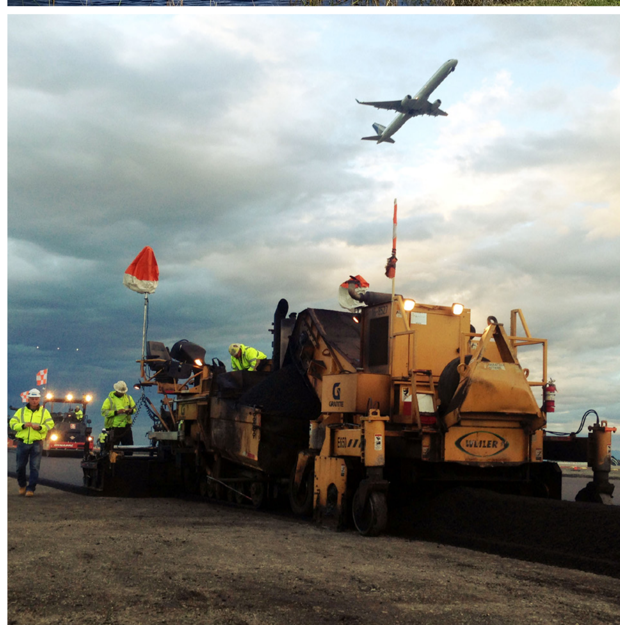
Sustainable Asphalt Pavements: A Practical Guide

Sustainability Specifics



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NAPA Members are dedicated to providing the highest quality asphalt paving materials and pavements, and to increasing the knowledge of quality asphalt pavement design, construction, maintenance, and rehabilitation. NAPA also strongly supports the development and dissemination of research, engineering and educational information that meets America's needs in transportation, recreational, and environmental pavements.

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Sustainability in Practice Series 102

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Sustainable Asphalt Pavements: A Practical Guide

Sustainability Specifics

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Sustainable Asphalt Pavements: A Practical Guide

This is the second of four publications in the NAPA Sustainable Asphalt Pavements: A Practical Guide series meant to provide a practical guide to sustainability. That means a focus on what a NAPA member business or asphalt project can do now to address sustainability within the confines of good business practice. The four publications in this series are meant to work together and are organized as follows:

1. **SIP 101: Sustainability Overview**. A practical definition of sustainability and the elements of and reasons for a business approach to sustainability.
2. **SIP 102: Sustainability Specifics**. Specific sustainability actions that can be taken in corporate/organizational strategy, project delivery, mix design, materials production, construction activities, and pavement design.
3. **SIP 103: Procuring & Evaluating Sustainability.** How sustainability is included in public project procurement, and how sustainability efforts are evaluated within the industry.
4. **SIP 104: How to Develop a Sustainability Program**. Important components of a company sustainability program including goals, best practices, implementation, and reporting.

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SIP 102: Sustainability Specifics

"Sustainability" refers to the idea of meeting human needs while maintaining a healthy planet over the long term. A simple way to think of this is to: (1) go above and beyond the standard/minimum or (2) show innovation in meeting standards/minimums. If you believe there is business value in sustainability (the first document in this series, *SIP 101: Sustainability Overview*, addresses why we think there is), then the next step is to put belief into action.

This document describes specific sustainable practices at the corporate/organizational, project delivery, and project levels that can be implemented using today's technology and know-how. Put another way, this document is a catalogue of sustainable practices. Think of it like an "idea book" for home remodeling, or, if you're into it, a Pinterest page for sustainability. Use it as a source of inspiration to guide you in identifying sustainable practices you want to put into action or to help you recognize ones you may already be doing. Each sustainable practice is detailed with enough information to define it, reasons it might be a good idea to consider, and a key resource or two that more fully explains the concept.

As with any idea book, not all these sustainable practices will be appropriate for every company or every project. We are relying on your expertise and knowledge to determine which ideas work best for your situation and how they might best be practiced.

This document organizes sustainable practices into the following main categories:

1. **Corporate/Organizational.** Sustainable practices at the corporate or organization level.
2. **Project Delivery.** Sustainable practices that can be required, incentivized, or included in project procurement and contracting.
3. **Materials Production.** Sustainability ideas that can be accomplished in materials production. These are often ideas that are not required by a project, but make good business sense to do anyway, so long as they are allowed.
4. **Construction.** Sustainability ideas for pavement construction. Many are ideas for project requirements that improve quality or provide greater flexibility to the contractor to be efficient. Many are also items not covered by contractor requirements that make good business sense to do.
5. **Pavement Design.** Pavement designs with sustainability implications. Design methods are not addressed in detail.

For each sustainable practice in this document you will see:

- **Summary.** A brief overview of the idea and why it might be worthwhile to pursue.
- **Motivation.** The potential motivations for using the sustainable practice. This is limited to three categories:
    - *Goodwill.* Friendly, helpful, or cooperative practices generally done by organizations as part of their community involvement efforts.

- *Project requirement.* Practices required by a project that likely represent an expense for the contractor that must be reimbursed by the owner. These are generally sustainable practices where the contractor incurs expense (for example, building an open-graded friction course), but does not directly get the benefits (reduced splash and spray, better friction, lower tire–pavement noise).
- *Business opportunity.* Practices that can result in increased revenue or market share, reduced expenses, increased employee productivity, or reduced risks. Often, these items are not required by contract, but may be done by contractors so long as they are allowed.

- **Reference.** One or more key references that best describes the practice and its benefits.

"Cost" is often not addressed because it is highly dependent upon a project or company's context, it can be difficult to directly quantify, it has never been quantified, or the associated benefits are poorly quantified.

1. Corporate/Organizational

Sustainability starts at the corporate and management level. As with most things in a business, strong support from management is essential to success. In other words, a company or organization must really want to do it and support it through its values, beliefs, principles, and actions. This section addresses organizational actions in support of sustainability, but does not address general values, beliefs, and principles, which are covered in a lot of general writing on sustainability. Specifically, this section overviews corporate/organizational sustainability in two broad categories: general goodwill and management, policies, and programs.

1.1 General Goodwill

As goodwill (or charity), sustainability is essentially a donation for the greater good. Much corporate goodwill in the asphalt industry focuses on community involvement: being a generous, caring, and contributing member of the community. NAPA's Community Involvement Award annually recognizes outstanding programs in community relations. Integral to this award and company goodwill in general are (1) help to multiple groups and/or focus areas and (2) employee participation. In general, goodwill often involves:

- **Charitable donations, fundraising, volunteering, and leadership.** For example, matching employee donations with equal company donations, providing staffing and financial support to charitable events, purchasing school supplies for those in need, veteran support, scholarship programs, blood drives, serving on non-profit boards.
- **Local community events.** For example, running open houses, sponsoring community events (barbeques, celebrations, carnivals).

- **Materials/expertise for community projects.** For example, donating materials and construction expertise for a community pathway or sport court, fixing/upgrading non-profit equipment and space, and assisting Habitat for Humanity with materials and labor.
- **Education/mentoring programs.** For example, participating in school career days, internship programs, donating hours for elementary school tutoring, donating hours to local Boys & Girls Clubs.

Goodwill is integral to community relations both personally and professionally. The choice of how to express this goodwill is up to each individual and the company for which they work. While goodwill may create a positive image for the company and can increase employee morale, it seems that the choice of engaging in goodwill is genuine: the main reason for doing it is the positive impact it has on the community.

Impacts on Sustainability:

- Workers
- Neighbors & Stakeholders
- Pollution
- Local Ecosystem & Habitat
- Economic Development/Employment

1.2 Management, Policies, and Programs

Meaningful management, policies, and programs are what give definition to an organization's commitment to sustainability. By themselves, they do little to ensure successful sustainability efforts; however, they provide the high-level direction and commitment needed to focus an organization's efforts.

Impacts on Sustainability:

- Workers
- Pollution
- Local Ecosystem & Habitat
- Consumption
- Climate
- Project Budget
- Maintenance & Operations
- Economic Development/Employment

1.2.1 Include Sustainability in Organizational Mission

At the highest level, sustainability ought to be included in an organization's mission if it is to be taken seriously by the organization. Many organizations have aspects of sustainability mentioned in their mission, vision, and values, but have not yet incorporated "sustainability" as a specific term.

Motivation

- Business Opportunity
- Project Requirement

The following pages include examples of how sustainability shows up in organizational vision, mission, and value statements on the websites, annual reports, and other materials of four organizations associated with the asphalt pavement industry: Washington State Department of Transportation, construction and building materials company CRH PLC, construction and construction materials company Granite Construction Inc., and civil infrastructure project company Salini Impregilo S.p.A.

Washington State Department of Transportation (WSDOT)

CRH PLC

CRH Annual Report and Form 20-F I 2017

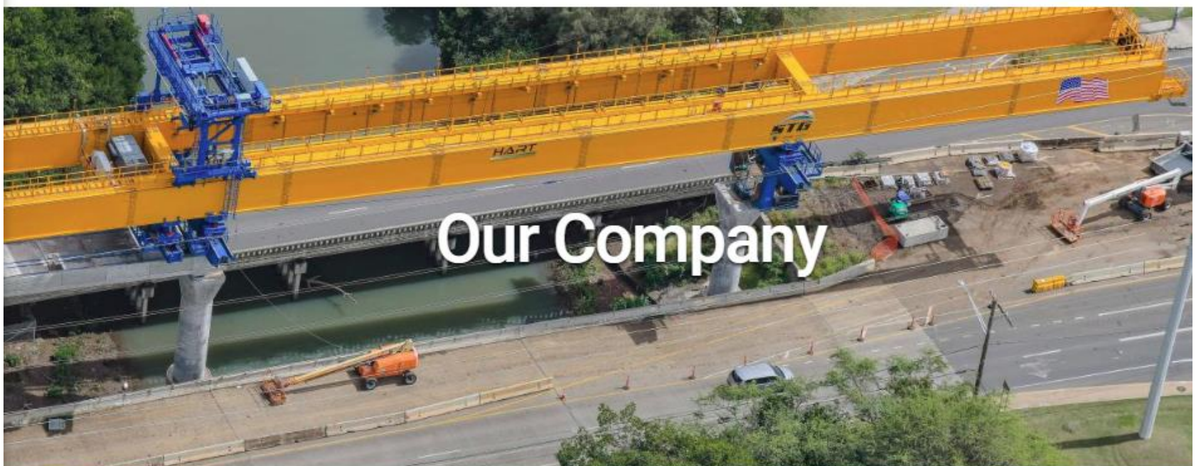
Sustainability

Achieving long-term success through sustainability

We believe that a strong sustainability performance is fundamental to achieving our vision of becoming the leading building materials business in the world. As part of our strategy to maximise long-term value and deliver superior returns, we embed sustainability principles in all areas of our business. As we deliver on our strategy, we have a unique opportunity to contribute to some of the key sustainable development challenges facing society.

Granite Construction Inc.

GRANITE™

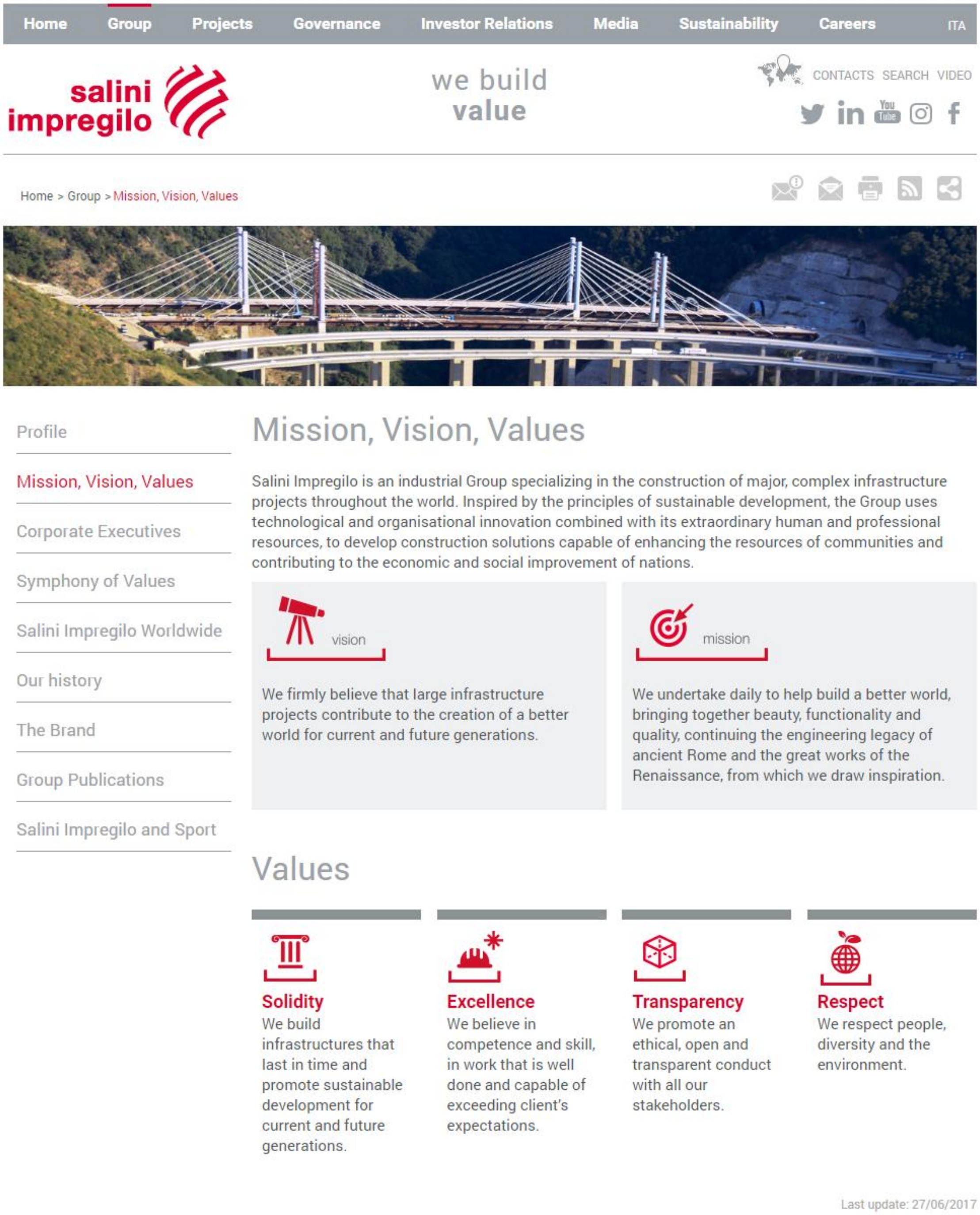


Sustainability

The work we do today will have an impact on countless future generations—and we don't take the responsibility lightly. We follow a comprehensive approach to sustainability, one that reduces our environmental impact and fosters positive community interactions in all aspects of our business. It is our instinct to constantly seek out new solutions and to create meaningful and sustained change today, tomorrow and for years to come.

Read More >

Salini Impregilo S.p.A.



1.2.2 Corporate Sustainability Reporting

The Global Reporting Initiative (GRI) describes a sustainability report (a.k.a. a Corporate Social Responsibility — CSR — report) as "… a report published by a company or organization about the economic, environmental, and social impacts caused by its everyday activities. A sustainability report also presents the organization's values and governance model and demonstrates the link between its strategy and its commitment to a sustainable global economy." This sort of report also serves as a focal point in the management of sustainability efforts and a tool for communicating sustainability performance and impacts. The Governance & Accountability Institute reports that in 2017 82% of S&P 500 companies did some form of sustainability reporting; however, the GRI (2008) states that sustainability reporting is not as well established in the construction sector.

The most popular standards for sustainability reporting are from the GRI, the Sustainability Accounting Standards Board (SASB), and the International Integrated Reporting Council (IIRC). GRI, at about 80% of the market, is the dominant sustainability standards resource across all industries and continents.

Motivation

- Business Opportunity
- Project Requirement

Reference

GRI (2008). A Snapshot of Sustainability Reporting in the Construction and Real Estate Sector. Global Reporting Initiative, Amsterdam, Netherlands.

Global Reporting Initiative. www.globalreporting.org

International Integrated Reporting Council. integratedreporting.org

Sustainability Accounting Standards Board. www.sasb.org

1.2.3 Greenhouse Gas Reporting

Independent of CSR reporting, tracking greenhouse gas (GHG) emissions can be a proactive way of managing environmental risk and energy use. GHG reporting should be done to a commonly accepted standard, such as that described by The Climate Registry or CDP (the Carbon Disclosure Project). These organizations offer toolkits and step-by-step processes for GHG reporting. NAPA also offers a free GHG calculator for asphalt plants that uses emission factors from The Climate Registry.

Motivation

- Goodwill
- Business Opportunity

Reference

CDP Worldwide. www.cdp.net/en

NAPA GHG Calculator. www.asphaltpavement.org/GHGC

The Climate Registry. www.theclimateregistry.org

1.2.4 Management Systems

Actively manage efforts that affect sustainability. Quality, safety, and environmental-management systems have been in existence for decades and provide a systematic way to define, measure, improve, and document these important considerations. The International Organization for Standardization (ISO) provides standards for these types of management systems and a certification process. Sustainability management systems are a new concept with little formal guidance.

Motivation

- Business Opportunity
- Project Requirement

Reference

ISO 9001 Quality Management Systems

ISO 14001 Environmental Management Systems

ISO 45001 Occupational Health and Safety Management Systems

BS OHSAS 18001 Occupational Health and Safety Assessment Series

1.2.5 Employee Assistance and Rewards

Employee assistance and reward programs contribute to their well-being. Some practices include:

- Employee development, retention, and education programs.
- Targeted hiring for minority contractor employees near a job.
- Hiring low-risk formerly incarcerated people and supporting pre-training.
- Healthy living programs (exercise, produce buying, etc.).
- Employee assistance programs, such as suicide prevention programs.
- Share bonuses.

Motivation

- Business Opportunity
- Project Requirement

Reference

Construction Industry Alliance for Suicide Prevention. pages.cfma.org/alliance-interest

1.2.6 Recycling Program

Recycling of reclaimed asphalt pavement (RAP), lead–acid batteries, used oil, and spent solvents is very common in the asphalt industry. But some companies overlook more common office materials, such as cardboard, paper, bottles & cans, food waste (composting), and common dry-cell batteries. An office recycling program can help reduce waste disposal costs, reduce GHG emissions, and establish sustainability as a core part of corporate culture.

Motivation

- Business Opportunity

Reference

EPA (2018). *Managing and Reducing Wastes: A Guide for Commercial Buildings*. U.S. Environmental Protection Agency, Washington, D.C. www.epa.gov/smm/managing-and-reducing-wastes-guide-commercial-buildings

1.2.7 Establish a Wildlife Conservation Area

Commercial and industrial facilities can designate a portion of their property to benefit wildlife. This can be as extensive as a woodland reserve, which can also help screen the facility from neighboring properties, or as small as pollinator gardens outside an office. Programs managed by the Wildlife Habitat Council, the National Wildlife Federation, the Audubon Society, and similar organizations can certify wildlife conservation areas. For example, Preferred Materials Inc.'s Winter Springs, Florida, Asphalt Plant earned a 2013 Wildlife at Work certification (re-certified in 2015) from the Wildlife Habitat Council for its 8-acre wildlife habitat site, where they restored approximately 2.5 acres of the property to a wildflower meadow and pollinator gardens.

Motivation

- Goodwill

Reference

National Audubon Society. www.audubon.org

National Wildlife Federation. www.nwf.org

North American Butterfly Association. nababutterfly.com

Wildlife Habitat Council. www.wildlifehc.org

1.2.8 Recognize Sustainability Efforts

Recognition for sustainability efforts can range from individual appreciation for a single act to certification of an organization or project by an independent third party. Several sustainability rating systems offer independent third-party certification for projects, and the NAPA awards program specifically honors key sustainability values: quality, safety, community involvement, and ecology. NAPA's Diamond Achievement Sustainable self-certification provides a framework for assessing and documenting sustainable activities at asphalt plants.

Motivation

- Business Opportunity
- Project Requirement

Reference

Envision v3. www.sustainableinfrastructure.org

Green Globes v1.5. www.thegbi.org/green-globes-certification

Greenroads Rating System v2. www.greenroads.org

INVEST v1.3. www.sustainablehighways.org

LEED v4. new.usgbc.org/leed

NAPA Diamond Commendation Program. www.asphaltpavement.org/diamond

NAPA Operational Excellence Awards Program. www.asphaltpavement.org/awards

2. Project Delivery

"Project delivery" refers to procurement, contracting, and delivery methods used for a project. For the purposes of this document, project delivery is limited to practices directly related to paving projects and contractors. More general project delivery sustainable practices, such as public private partnerships (PPPs or P3s) used for project financing and the use of alternative contracting, are not addressed.

2.1 Procurement

"Procurement" is the purchasing process for projects. Sustainability can be a project component that is directly assessed during procurement, or provisions can be made to accept alternate designs to improve performance and save money. Document three in this series, *SIP 103: Procuring & Evaluating Sustainability*, goes into greater detail about sustainability and the project procurement process.

Impacts on Sustainability

- Neighbors & Stakeholders
- Users
- Pollution
- Local Ecosystem & Habitat
- Consumption
- Climate
- Project Budget
- Maintenance & Operations

2.1.1 Include Sustainability in Best-Value Procurement

Best-value procurement is a procurement process where factors beyond initial price are considered in contractor selection. These factors can include schedule, financial requirements, contractor past experience/performance, safety record, key personnel, small business participation, subcontractors, management plan, quality management, design alternates, technical proposal, and environmental considerations. They rarely include sustainability as a defined evaluation criterion. While "environmental considerations" is close, it usually refers to methods of meeting environmental regulatory requirements only. If defined well (see work in NCHRP Project 10-91A), sustainability could be included as a separate evaluation category in a best-value procurement process and, therefore, become part of the project selection criteria.

Motivation

- Project Requirement

Reference

Molenaar, K.R., N. Sobin, & E.I. Antillón (2010). A Synthesis of Best-Value Procurement Practices for Sustainable Design-Build Projects in the Public Sector. *Journal of Green Building*, Vol. 5, No. 4, pp. 148–157. doi:10.3992/jgb.5.4.148

Scott III, S., K.R. Molenaar, D.D. Gransberg, & N.C. Smith (2006). *NCHRP Report 561: Best-Value Procurement Methods for Highway Construction Projects*. Transportation Research Board of the National Academies, Washington, D.C.

2.1.2 Alternative Technical Concepts (ATCs)

A request by a project proposer (contractor, design–build team, etc.) to modify a contract requirement. Typically, an ATC must be of equal or better value than the original contract requirement, and it is often done to reduce project price or complexity to the benefit of the proposer (competitive advantage during bidding or money savings during construction) and owner (money savings). ATCs are most frequently used in design–build project delivery, but have also been successfully used in design–bid–build project delivery. Key ATC issues are: (1) confidentiality of the proposed ATCs (protecting them from public disclosure), (2) design liability arising from ATCs, (3) minimizing protest risk from a non-traditional procurement feature, and (4) who owns ATCs submitted by non-winning bidders. The key sustainability feature in ATCs is getting contractor involvement in a project's design.

Motivation

- Business Opportunity
- Project Requirement

Reference

Gransberg, D.D., M.C. Loulakis, & G.M. Gad (2014). *NCHRP Synthesis 455: Alternative Technical Concepts for Contract Delivery Methods*. Transportation Research Board of the National Academies, Washington, D.C.

2.1.3 Alternate Design/Alternate Bid (AD/AB)

AD/AB is a method where alternative pavement designs (nearly always asphalt and concrete) can be bid for the same project. Sometimes, a life-cycle adjustment factor is applied to the bid based on predicted future maintenance and rehabilitation costs. A construction schedule bidding component (for example, A+B bidding) is also sometimes considered to account for different construction times. The general sentiment is that AD/AB may increase competition and provide cost savings (Gransberg et al., 2017). However, to ensure best value, it is critical that alternative pavement designs be functionally equivalent and that inputs for a life-cycle adjustment factor (if used) be based on high-quality, performance-based data.

Motivation

- Project Requirement

Reference

Epps, J.A., & D.E. Newcomb (2015). *Considerations and Case Studies in Rapid Highway Construction Using Asphalt Pavements*. Texas A&M Transportation Institute, Texas A&M University, College Station, Texas.

Gransberg, D.D., A. Buss, I. Karaca, & M.C. Loulakis (2017). *NCHRP Synthesis 499: Alternate Design/Alternate Bid Process for Pavement-Type Selection*. Transportation Research Board of the National Academies, Washington, D.C.

2.2 Contracting

"Contracting" refers to the written agreement to design/build a project. Certain provisions can be made in the contract that improve a contractor's flexibility in employing resources, increase productivity and safety on the job, elevate sustainability to a managed element of the contract, reduce work zone user delays, and make environmental impacts more transparent.

Impacts on Sustainability

- Workers
- Neighbors & Stakeholders
- Users
- Pollution
- Consumption
- Climate
- Project Budget
- Maintenance & Operations
- Economic Development/Employment

2.2.1 Productivity

Practices that improve productivity can have a significant effect on project sustainability, particularly in terms of reducing the length and timing of road closures, which helps minimize user delay and other traffic impacts.

2.2.1.1 Flexible Start Time

A contract provision that allow the contractor to choose the construction start date within given limits. For instance, the Florida DOT normally requires a contractor to begin work within 15 days of receiving notice to proceed (NTP), but with a flexible start that date may be extended (usually up to 100 days). A flexible start date can allow the contractor to more efficiently use workforce, equipment, and subcontractors across a variety of projects. Owner requirements to coordinate multiple projects and other factors may limit flexible start options.

Motivation

- Business Opportunity
- Project Requirement

Reference

Caltrans (2018). Section 3-803B. *Construction Manual*. California Department of Transportation, Sacramento, California.

WSDOT (2018). Flexible Start Date. Washington State Department of Transportation, Olympia, Washington. www.wsdot.wa.gov/Projects/delivery/alternative/FlexibleStart.htm

2.2.1.2 Full-Road Closure

Using full-road closures for roadway work zones can result in positive public sentiment, better productivity, improved safety, reduced project duration and, in some cases, cost savings (FHWA, 2003). Longer individual closures (either partial or full), but fewer overall closures may achieve similar results in some circumstances. The Rapid Road Rehabilitation (R3) suite of scoping tools (formerly CA4PRS) can be used to quickly estimate productivity and traffic impacts for multiple closure scenarios.

Motivation

- Business Opportunity
- Project Requirement

Reference

Caltrans (2018). Construction Analysis for Pavement Rehabilitation Strategies: Caltrans “Rapid Rehab” Software. California Department of Transportation, Sacramento, California. www.dot.ca.gov/newtech/roadway/ca4prs/

FHWA (2003). Full Road Closure for Work Zone Operations: A Cross-Cutting Study (FHWA-OP-04-009). Federal Highway Administration, Washington, D.C.

2.2.2 Sustainability Measurement and Tracking

Most state DOTs have language that refers (either directly or indirectly) to sustainability as a value. Sustainability becomes a manageable practice once it is consistently measured. Absent formal tracking or accountability, sustainability for a project or organization becomes something between (1) a low-priority task and (2) a series of carefully selected, unverifiable stories. Document three in this series, *SIP 103: Procuring & Evaluating Sustainability*, goes into greater detail about measuring sustainability efforts.

2.2.2.1 Rating Systems

Sustainability rating systems can (1) identify appropriate sustainable practices, (2) provide independent third-party verification of sustainability efforts, (3) measure and manage sustainability efforts, and (4) communicate sustainability efforts to project stakeholders.

Usually, it is beneficial to have staff trained and accredited by a rating system before using it. Often this can be worth points within the rating system. Rating systems typically used in the U.S. are: Envision, Greenroads, and INVEST, as well as LEED and Green Globes (both building rating systems). The following table lists prominent U.S. rating systems, and how they address asphalt pavements.

	Envision v2	Greenroads v2	Green Globes v1.5 for NC	INVEST v1.3 PD only	LEED v4 BD+C NC
Type of Rating System	Infrastructure	Road	Building	Road	Building
Third-Party Certification Available	Yes	Yes	Yes	No	Yes
Total Points Available	809	130	1,000	171	110
Total Pavement-Related Points	247	63	31	61	19
Fraction of Points for Pavements	31%	48%	3%	36%	17%

Motivation

- Business Opportunity
- Project Requirement

Reference

Envision v3. www.sustainableinfrastructure.org

Green Globes v1.5 for NC. www.thegbi.org/green-globes-certification

Greenroads v2. www.greenroads.org

INVEST v1.3. www.sustainablehighways.org

LEED v4 BD+C NC. new.usgbc.org/leed

NAPA (2018). *Asphalt Pavements and LEED v4: Credits and Opportunities* (SIP 001). National Asphalt Pavement Association, Lanham, Maryland.

2.2.2.2 Sustainability Management Plan

A written plan to manage quality. As of this publication, sustainability management plans are uncommon in the road industry, but may emerge as a reasonable way to consolidate and document contractor sustainability requirements, efforts, and results. Essential elements of a sustainability management plan are:

1. Designated contractor representative responsibility for sustainability.
2. Statement of major sustainability goals of the project (in terms of aspects of sustainability that are a priority).
3. Description of project sustainability features. These should address the goals in #2 and should be clearly identified to the project team.

4. Procedure to follow when a sustainability feature (identified in #3) is changed or eliminated. This may include permission from project management, written documentation, or something simpler, such as an information-only process.
5. Short set of metrics by which the project can be judged for sustainability efforts. These should be directly related to #2 and #3.
6. Monthly reports/submittals from the contractor that report metrics from #4, any sustainable practices addressed in the previous month (for example, 2,500 tons of open-graded friction course placed) and provide explanations for any sustainable practices removed via change order or not accomplished.
7. Final report/submittal that summarizes the contractor's sustainability performance on the project and provides final results from the #4 metrics.

Motivation

- Project Requirement

2.2.3 Reduce User Delay

User delay can be a major contributor to overall project financial impact, especially in congested urban areas where the cost of work zone user delays can easily exceed the contract price of the work. Reducing user delay by accelerating construction can be incentivized in contracting. The major impacts of doing this are (topics from Fick et al., 2010):

- **Cost.** Accelerated construction generally costs more. Contractors typically spend more to achieve an incentive. Therefore, achieving the incentive is important to the profitability of the project.
- **Contract time measurement.** If payment is linked to faster completion, contract time measurement and adjustments for excusable delays have added importance.
- **Staffing.** Accelerated construction generally requires more working hours per day/week which contributes to mental and physical fatigue.
- **Quality.** Incentives for construction speed may compromise quality if time must be sacrificed for quality.
- **Safety.** While safety standards are not compromised for construction speed, fatigued staff could be compromised.

LaMondia et al. (2018) highlights ways to calculate a total work zone impact cost, which includes user delay costs, crash mitigation costs, and local business impact costs. Quantification of these kinds of impacts can be used as supporting evidence for accelerated construction or A+B bidding or incentives/disincentives to reduce construction time.

Accelerated construction is typically measured against a baseline determined by the owner, so faster contractor construction may be a result of an owner-offered incentive, or it may reflect a conservative baseline set by the owner. This section addresses A+B bidding and incentives/disincentives, but there are many other similar methods for the owner to communicate to the contractor that they are willing to pay a premium for accelerated construction.

Reference

Fick, G., E.T. Cackler, S. Trost, & L. Vanzler (2010). *NCHRP Report 652: Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts*. Transportation Research Board of the National Academies, Washington, D.C.

LaMondia, J., M. Fisher, R. Turochy, & W. Zech (2018). *Calculating Road User, Crash Mitigation and Local Business Impact Costs Generated by Pavement Rehabilitation, Maintenance and Other Roadway Reconstruction Projects*. Auburn University, Auburn, Alabama.

2.2.3.1 A+B Bidding

A bidding method that places a cost on the duration of a project or portion of a project. An A+B bid contains the contract price (item A) as well as a time to complete the contract. This time is converted to a monetary value (item B) and the overall bid is evaluated as the total cost of the contract plus the time cost (A+B). This method places value on project duration (which impacts roadway user costs) and often results in (1) shorter project durations than estimated by the owner and (2) somewhat higher costs than those associated with a standard schedule (Minchin Jr. & Chini, 2016). A+B bidding has a greater impact when user delay is a major cost, such as in urban areas or major freight corridors, and works best with an associated incentive/disincentive clause based on actual construction duration vs. the contractor's promised duration in the bid.

Motivation

- Business Opportunity
- Project Requirement

Reference

Anderson, S.D., & J.S. Russell (2001). *NCHRP Report 451: Guidelines for Warranty, Multi-Parameter, and Best Value Contracting*. TRB, National Research Council, Washington, D.C.

Epps, J.A., & D.E. Newcomb (2015). *Considerations and Case Studies in Rapid Highway Construction Using Asphalt Pavements*. Texas A&M Transportation Institute, Texas A&M University, College Station, Texas.

Minchin Jr., R.E., & A.R. Chini (2016). *Alternative Contracting Research: Final Report* (FDOT Contract Number BDV31-977-40). Florida Department of Transportation, Tallahassee, Florida.

WSDOT (2018). A+B Bidding. Washington State Department of Transportation, Olympia, Washington. www.wsdot.wa.gov/Projects/delivery/alternative/

2.3.3.2 Lane/Ramp Rentals or Charges

A bidding method where charges for closing a lane or ramp are established by the owner and deducted from contractor revenues. Either the contractor is paid for an estimated lane rental amount and then actual lane rental is deducted from revenues, or lane/ramp rental/charges can be included as a contract pay item.

Motivation

- Business Opportunity
- Project Requirement

Reference

Anderson, S.D., & J.S. Russell (2001). *NCHRP Report 451: Guidelines for Warranty, Multi-Parameter, and Best Value Contracting*. TRB, National Research Council, Washington, D.C.

Fick, G., E.T. Cackler, S. Trost, & L. Vanzler (2010). *NCHRP Report 652: Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts*. Transportation Research Board of the National Academies, Washington, D.C.

Minchin, R.E., & A.R. Chini (2016). *Alternative Contracting Research*. FDOT Contract Number BDV31-977-40. FDOT, Tallahassee, Florida.

2.2.3.3 Incentives and Disincentives to Reduce Construction Time

Contractual incentives and disincentives (I/D) are commonly used to encourage early project completion and minimize user delay cost. Standard practice usually involves (1) incentives to finish early and (2) disincentives (penalties or liquidated damages) for finishing late.

Motivation

- Business Opportunity
- Project Requirement

Reference

Fick, G., E.T. Cackler, S. Trost, & L. Vanzler. (2010). *NCHRP Report 652: Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts*. Transportation Research Board of the National Academies, Washington, D.C.

LaMondia, J., M. Fisher, R. Turochy, & W. Zech (2018). *Calculating Road User, Crash Mitigation and Local Business Impact Costs Generated by Pavement Rehabilitation, Maintenance and Other Roadway Reconstruction Projects*. Auburn University, Auburn, Alabama.

2.2.4 Environmental Product Declarations (EPDs)

A concise, verified eco-label for a product (for example, an asphalt mixture) that quantifies its key environmental impacts, an EPD is a declared life cycle assessment (LCA) that follows a standard process, called a product category rule (PCR). The NAPA Emerald Eco-Label EPD tool provides asphalt mixture producers a way to quantify their environmental impacts with a verified EPD. While EPDs are relatively new to the paving industry, their use is likely to increase as rating systems award points for their use and owners investigate ways to use them. As of 2019, the industry is still working through EPD issues and best uses. Some have started to use the

Emerald Eco-Label Tool to evaluate and optimize the environmental impacts of raw material supply chains and plant operations.

Motivation

- Business Opportunity
- Project Requirement

Reference

Harvey, J.T., J. Meijer, & A. Kendall (2014). *TechBrief: Life Cycle Assessment of Pavements* (FHWA-HIF-15-001). Federal Highway Administration Washington, D.C.

Harvey, J.T., J. Meijer, H. Ozer, I.L. Al-Qadi, A. Saboori, & A. Kendall (2016). *Pavement Life Cycle Assessment Framework* (FHWA-HIF-16-014). Federal Highway Administration, Washington, D.C.

NAPA Emerald Eco-Label EPD tool. www.asphaltepd.org

2.2.5 Anti-Idling Specifications and Policies

Many states have regulations that limit engine idling (a 2006 EPA accounting lists 30 states and D.C.) and many construction contracts have similar limits; however, the federal government does not. Typical maximum allowed idle times are 15 minutes or less. Equipment idling uses fuel and emits pollution while the equipment is not engaged in productive work. It also accelerates engine wear and shortens warranty coverage. In operations involving queuing (for example, asphalt mix delivery trucks) short allowable idle times can actually increase fuel use and emissions because of the delays and reduced production associated with stopping and starting equipment (Abbasian-Hoseini et al., 2016). In these cases, it is better to exempt queuing and similar tasks (for example, trucks waiting to offload asphalt mix) from anti-idling specifications. Companies located in regions without mandatory anti-idling regulations can develop and implement their own anti-idling policies.

Motivation

- Business Opportunity
- Project Requirement

Reference

Abbasian-Hosseini, S.A., M.L. Leming & M. Liu (2016). Effects of Idle Time Restrictions on Excess Pollution from Construction Equipment. *Journal of Management in Engineering*, Vol. 32, No. 2. doi:10.1061/(ASCE)ME.1943-5479.0000408

EPA (2006). *Compilation of State, County, and Local Anti-Idling Regulations* (EPA420-B-06-004). U.S. Environmental Protection Agency, Washington, D.C.

Jackson, T. (2014). Creating an Anti-Idling Policy. *Equipment World*, Vol. 26. No. 4, pp. 51–52. www.equipmentworld.com/how-to-save-money-protect-equipment-by-creating-an-anti-idling-policy-at-your-construction-company/

3. Materials Production

"Materials Production" refers to raw materials, processes, and equipment associated with the production of asphalt mixtures. For the purposes of this document, materials production is limited to aggregates, recycled materials, and hot- and warm-mix asphalt, as these are the materials most paving contractors produce. Similar to other construction materials, energy consumption and emissions are important considerations in asphalt mixture production. Asphalt pavements have been successfully recycled back into new asphalt pavements since the 1970s. This requires careful mix design and quality control to assure good mix performance. Both conventional and specialty asphalt mixtures can be produced to offer many sustainable benefits. Several of the items described in this section reduce environmental impacts as measured by EPDs.

3.1 Energy and Emissions

In the future, asphalt plants are expected to continue a long-term trajectory of becoming more fuel-efficient while producing less emissions. Today energy and emissions are key considerations in material production at asphalt plants. Using RAP, managing moisture in aggregates and RAP, and plant management with a focus on energy consumption are all important sustainability considerations.

Impacts on Sustainability

- Neighbors & Stakeholders
- Consumption
- Climate
- Budget
- Worker Safety
- Maintenance & Operations

3.1.1 Aggregate Moisture

Reducing the moisture content of the aggregates and RAP fed into a hot plant is an effective means of reducing production costs and increasing the production rate for materials with relatively high moisture, like washed fine aggregates and RAP. It takes about 24,000 Btus to remove 1% moisture from 1 ton of aggregate. Methods available for reducing moisture include grading and paving under stockpile areas, covering stockpiles, and taking material from stockpiles 2 to 3 feet above the bottom of the pile where moisture collects. For every 1% reduction in moisture content, drying cost is reduced by slightly more than 10%, and the plant production rate can be increased by over 10%. If aggregate/RAP blend moisture is reduced by 2% at a plant with a drying cost of $2.50/ton, the cost savings is $50,000 per 100,000 tons of production. Also, increasing productivity at the plant can often increase productivity at the jobsite during periods of peak production.

3.1.1.1 Grading, Paving Under, and Covering Stockpiles

Grading with a slope of about 4% under a stockpile of aggregate or RAP will promote drainage away from the face of the stockpile from which material is being fed to the plant. Paving will accelerate the rate of drainage, reduce standing water, and prevent it from wicking up into the stockpile. With graded and paved stockpile areas, maintenance and equipment operating costs will be reduced also. Subgrade compaction before paving is critical to success as any subsidence (due to the weight of stockpiles or otherwise) could cause water pooling in localized low points beneath stockpiles. With a 2% reduction in moisture at a typical asphalt plant producing 300,000 tons annually, the cost savings from using drier aggregates could amount to about $150,000, depending on the fuel cost. If it costs $50,000 to grade and pave a stockpile area, this cost would be recovered within a fraction of a year.

Covering stockpiles is more costly; it takes about three years to recover the cost of the investment. Therefore, covering is normally only done for RAP and fine aggregates that are not free draining, especially in locations where rain is common. Examples of covers include open metal or pole buildings, simple trusses, and fabric-roof structures. It is important for air be able to move in the stockpile area. Covering stockpiles directly with plastic tarps is not effective for this reason.

Motivation

- Business Opportunity

Reference

Simmons Jr., G.H. (n.d.). *Stockpiles* (Technical Paper T-129). Astec Inc., Chattanooga, Tennessee.

Young, T.J. (2007). *Energy Conservation in Hot-Mix Asphalt Production* (QIP-126). National Asphalt Pavement Association, Lanham, Maryland.

3.1.1.2 Real-Time Aggregate Moisture Measurement

In most stockpiles and environments, aggregate moisture content is variable to some degree. Asphalt plant controls compensate for moisture on aggregates when supplying asphalt binder in the drum. This requires the plant operator to input a representative moisture content for the material going over the weighbridge on the collector belt feeding the dryer. For a mixture with a target asphalt content of 5%, if there is a difference of 0.5% between the actual moisture content and the moisture content in the plant controls, then the asphalt content of the produced mixture will be either 0.2% low or high. If too high, the mix production cost is unnecessarily increased and if too low the durability of the mix could be compromised. At the same time, variability in aggregate moisture content will result in variability in asphalt content test results, potentially reducing the mix pay factor. A reliable real-time aggregate moisture measurement system will allow for more frequent and timely adjustments to asphalt plant control settings and reduced risk for both the asphalt producer and mix customer. The equipment is relatively new, so information for determining the time to recover the initial investment cost is not available.

Motivation

- Business Opportunity
- Project Requirement

Reference

Dep, L., C. Thao, S. Glidden, & D. Porter (2019). A System for Real-Time Measurement of Moisture in Aggregate Mixes During Asphalt Production. In *Asphalt Paving Technology 2018: Journal of the Association of Asphalt Paving Technologists*, Vol. 87, pp. 348–359.

3.1.2 Plant Management

There are several business opportunities associated with efficient plant management. It's important to recognize that many investments in plant management that reduce energy consumption will be recovered in one to two years, after which annual savings continue at no cost. Details of nine energy-reducing hot plant production alternatives with details on investment and recovery can be found in NAPA publication QIP-126, *Energy Conservation in Hot-Mix Asphalt Production*. Additional brief examples can be found in NAPA publication QIP-127, *101 Ideas to Reduce Costs and Enhance Revenue*.

3.1.2.1 Maintain the Baghouse

Emissions of particulate matter (PM) from an asphalt plant are controlled primarily by the baghouse. Baghouse efficiency can be monitored regularly using a black light leak test or EPA Method 5 testing. Air permits typically require one or both of these tests on a periodic basis, but increasing the frequency can help ensure the baghouse is performing as designed, as well as prevent small problems from becoming enforcement issues.

Motivation

- Business Opportunity
- Project Requirement

Reference

Astec (2004). *Baghouse Black Light Test* (Service Information Letter #018). Astec Inc., Chattanooga, Tennessee. www.astecinc.com/images/file/service/018-Blacklight.pdf

Mansfield, C. (2016). How to Properly Maintain the Baghouse. *Asphalt Contractor*, Vol. 30, No. 2, p. 62. www.forconstructionpros.com/asphalt/article/12152096/how-to-properly-maintain-the-baghouse

EPA (2017). *Method 5 — Determination of Particulate Matter Emissions from Stationary Sources*. U.S. Environmental Protection Agency, Washington, D.C.

3.1.2.2 Insulate Plant Components

Insulation of plant components, such as tanks, dryer drums, silos, and piping, will reduce heat loss to the environment and thereby reduce production cost. Something as simple as putting 1½ inches of insulation on 3-inch asphalt pipe with typical flanges and hot-oil jumper lines can reduce costs over $10,000 per 100 feet of pipe per year. Additional sustainable benefits include reductions in energy needed for production, conservation of natural resources, reduction of GHG emissions, and safer worker exposure conditions.

Motivation

- Business Opportunity

Reference

Hansen, K.R., & R. Sandberg (2008). *101 Ideas to Reduce Costs and Enhance Revenue* (QIP-127). National Asphalt Pavement Association, Lanham, Maryland.

May, J., T. Wilkey, M. Swanson, J. Daub, G. Farrow, J. Clayton, D. Clum, M. Moon, B. Eley, & F. Eley (2003). *Heating and Storing Asphalt at HMA Plants* (Technical Paper T-140). Heatec Inc., an Astec Industries Company, Chattanooga, Tennessee.

Young, T.J. (2007). *Energy Conservation in Hot-Mix Asphalt Production* (QIP-126). National Asphalt Pavement Association, Lanham, Maryland.

3.1.2.3 Use Alternative Fuels

Asphalt plants can efficiently operate on multiple fuel types. Traditionally, natural gas, fuel oils, liquid propane (LP), and coal have been used. Key considerations when evaluating alternative fuels are emissions, fuel cost, capital equipment cost, maintenance cost, and availability. Emissions have to be considered first as federal, state, and local regulations will define allowable levels. In urban areas, clean fuels (natural gas, LP) coupled with low-emission burners may be required. However, some renewable energy sources, such as biodiesel, biomass, wind energy, and solar energy are becoming available. In many locations No. 4 to No. 6 fuel oils and recycled fuel oils are economically available. It is possible to burn these fuels with most burners today via a manifold change and/or tuning. Burning them may require additional equipment, such as a fuel tank, in-line heater, and filter. Because the fuel cost is lower, recovery of the equipment investment can often be realized in six to 12 months. Cost comparisons for burning different fuel sources need to be done based on heating value of the fuels (Btu/gal, Btu/therm, etc.). NAPA publication QIP-126, *Energy Conservation in Hot-Mix Asphalt Production*, contains a simple table for making these comparisons.

Motivation

- Business Opportunity

Reference

Swansen, M.S. (2017). *Traditional & Alternative Energy for Hot Mix and Warm Mix Asphalt Plants* (Technical Paper T-147). Astec Inc., Chattanooga, Tennessee.

Young, T.J. (2007). *Energy Conservation in Hot-Mix Asphalt Production* (QIP-126). National Asphalt Pavement Association, Lanham, Maryland.

3.1.2.4 Fix Air Leaks

Air leaks will negatively impact production rates at an asphalt plant, increasing required fuel consumption to maintain the same production rate. They will commonly occur at the breeching on the drum, recycle collar, and ductwork, especially where angles exist in the ductwork. A dollar invested in air-leak repairs will return 2 to 3 dollars in savings. The repair costs are typically low, so the return on investment is not huge, but the return on investment accumulates with every ton produced.

Motivation

- Business Opportunity

Reference

Hansen, K.R., & R. Sandberg (2008). *101 Ideas to Reduce Costs and Enhance Revenue* (QIP-127). National Asphalt Pavement Association, Lanham, Maryland.

3.1.2.5 Conduct an Energy Audit

An energy audit allows you to assess the efficiency of fuel use and electricity. Energy audits are typically conducted by a third party who specializes in industrial electrical and energy efficiency. The U.S. Department of Energy's *Guide to Energy Audits* provides detailed information that can assist companies in developing contracts for third-party energy audits. A directory of third-party energy professionals who hold credentials as Certified Energy Auditors and Certified Energy Managers is available in the Association of Energy Engineers (AEE) *Certified Professionals Directory*. Small- and medium-sized companies that meet certain criteria can utilize Industrial Assessment Centers (IACs), which provide no-cost energy audits.

Motivation

- Business Opportunity

Reference

AEE *Certified Professionals Directory*. portal.aeecenter.org/custom/cpdirectory/index.cfm

Baechler, M., C. Strecker, & J. Shafer (2011). *A Guide to Energy Audits*. Building Technologies Program, U.S. Department of Energy, Washington, D.C. www.pnnl.gov/main/publications/external/technical_reports/PNNL-20956.pdf

Energy Star. www.energystar.gov/buildings/facility-owners-and-managers/industrial-plants

U.S. Department of Energy Industrial Assessment Centers. www.energy.gov/eere/amo/industrial-assessment-centers-iacs

3.1.2.6 Utilize Renewable Energy

Installation of solar panels, wind turbines, or other renewable energy solutions can reduce energy costs and your company's greenhouse gas footprint. If this is not feasible for a specific plant site, most electric utilities allow a customer to purchase renewable energy through pre-defined programs. Facilities can also purchase renewable energy certificates (RECs) regardless of who their electric supplier is.

Motivation

- Business Opportunity
- Goodwill

Reference

U.S. EPA Green Power Partnership. www.epa.gov/greenpower/renewable-energy-certificates-recs

3.1.2.7 Tune the Burner

Efficient combustion of the burner requires an optimum air/fuel ratio, which can only be achieved through routine tuning of the burner. Untuned burners can also increase gaseous emissions, cause blue smoke in the stack, coat the baghouse with hydrocarbons, and even create a fire hazard. Asphalt plant and burner manufacturers have tuning guides, and specialists can be brought in to help as well.

Motivation

- Business Opportunity

Reference

Young, T.J. (2007). *Energy Conservation in Hot-Mix Asphalt Production* (QIP-126). National Asphalt Pavement Association, Lanham, Maryland.

3.1.2.8 Monitor Fuel Consumption

Monitoring fuel consumption can help identify issues with aggregate moisture, burner tuning, veiling efficiency, air leaks, and other production issues. The simplest method is to compare your monthly fuel bill to the plant's production to determine the average amount of energy it takes to produce one ton of asphalt. Some producers have installed real-time fuel monitors that integrate with the plant's control system, allowing the plant operator to find the most efficient plant configuration and production rate. Monitoring fuel consumption of other equipment, such as hot oil heaters and on-site power generation equipment, can yield similar results.

Motivation

- Business Opportunity

Reference

Young, T.J. (2007). *Energy Conservation in Hot-Mix Asphalt Production* (QIP-126). NAPA, Lanham, MD.

3.1.2.9 Optimize Veiling Efficiency

Efficient operation of a dryer depends on proper veiling of the aggregates. When the flights wear down with age, or recycled content changes, veiling efficiency can be impacted. Improper veiling is often identified by high stack exit gas temperatures in the dryer. Routine maintenance of the flights and reconfiguring the flights can help optimize veiling efficiency and reduce fuel consumption.

Motivation

- Business Opportunity

Reference

Young, T.J. (2007). *Energy Conservation in Hot-Mix Asphalt Production* (QIP-126). NAPA, Lanham, MD.

3.1.2.10 Re-Use Waste Heat

The waste heat emitted though the stack of a hot oil heater can be captured using a heat exchanger, reducing the amount of fuel and cost needed to keep asphalt tanks and piping hot.

Motivation

- Business Opportunity

Reference

Young, T.J. (2007). *Energy Conservation in Hot-Mix Asphalt Production* (QIP-126). National Asphalt Pavement Association, Lanham, Maryland.

3.1.2.11 Install Variable-Frequency Drives (VFDs) on Large Motors

Energy can be conserved by installing VFDs on large motors, like burner fans, exhaust fans, and slat conveyor motors. A VFD simply changes a fixed-speed motor to a variable-speed motor through a frequency change that reduces energy consumption. A classic example is using a VFD to slow a baghouse motor instead of using a damper to reduce flow at constant motor speed. The investment in a VFD will be recovered within about two years for a typical asphalt plant, and even sooner with utility company rebates and reductions in demand charges. Noise level is also reduced with the installation of the VFD and elimination of the damper, too.

Motivation

- Business Opportunity

Reference

Hansen, K.R., & R. Sandberg (2008). *101 Ideas to Reduce Costs and Enhance Revenue* (QIP-127). National Asphalt Pavement Association, Lanham, Maryland.

Young, T.J. (2007). *Energy Conservation in Hot-Mix Asphalt Production* (QIP-126). National Asphalt Pavement Association, Lanham, Maryland.

3.1.2.12 Produce Warm-Mix Asphalt (WMA)

Warm-mix asphalt technologies allow asphalt pavement mixtures to be produced at significantly lower temperatures than HMA, offering several sustainable benefits, as well as improved constructability and worker conditions. An NCHRP study (West et al. 2014) found that the performance of WMA and HMA is virtually identical and indicated that little or no rutting, no evidence of moisture damage, and very little indication of transverse or longitudinal cracking was observed on a series of field projects. Energy consumption, asphalt plant and paver emissions, and worker exposure to fumes were extensively measured on three multiple WMA technology projects and found to be lower than with HMA due to the reduced WMA production and paving temperatures. There are tools available, such as the NAPA Greenhouse Gas Calculator, to determine reductions in energy consumption and GHG when producing WMA.

Motivation

- Business Opportunity
- Project Requirement

Reference

NAPA Greenhouse Gas Calculator. www.asphaltpavement.org/ghgc

Prowell, B.D., G. Hurley, & B. Frank (2012). *Warm-Mix Asphalt: Best Practices, Third Edition* (QIP-125). National Asphalt Pavement Association, Lanham, Maryland.

West, R.C., C. Rodezno, G. Julian, B.D. Prowell, B. Frank, L.V. Osborn, & T. Kriech (2014). *NCHRP Report 779: Field Performance of Warm Mix Asphalt Technologies*. Transportation Research Board of the National Academies, Washington, D.C.

3.1.2.13 Manage Trucking Operations

One of the most common complaints from neighbors is the impact of trucking operations from a nearby asphalt plant. Sometimes, trucking can be avoided by siting an asphalt plant in a location where raw materials can be delivered by rail or barge. If this is not possible, other options are available, such as creating designated haul routes to avoid sensitive or congested roads or neighborhoods, enforcing speed limits through the use of GPS systems on fleet vehicles, establishing off-street areas for waiting/queuing of trucks, and establishing policies that do not allow early arrival of trucks prior to the facility gates opening. Traffic studies can evaluate potential impacts of truck traffic and offer recommended mitigation measures.

Motivation

- Goodwill

Reference

McRae, J., L. Bloomberg, & D. Muldoon (2006). *Best Practices for Traffic Impact Studies*. Oregon Department of Transportation, Salem, Oregon. www.oregon.gov/ODOT/Programs/ResearchDocuments/BestPracticesforTraffic.pdf

3.1.2.14 Use Locally Available Aggregates

Many agencies have aggregate quality requirements that are the same for use in all asphalt pavement mixtures, regardless of mix type, location in the pavement structure, and anticipated traffic loading. However, for lower volume roads and for base and intermediate courses good performance can be achieved using aggregates with less stringent quality requirements that can sometimes be satisfied with local aggregate sources. Shorter aggregate transport distances can save money, as well as reduce fuel use and associated greenhouse gas emissions.

Motivation

- Business Opportunity

3.1.2.15 Minimize Light Pollution

Improperly designed outdoor lighting can impact wildlife, such as migratory birds, waste energy, and obscure visibility of the natural night sky. Installation of dark sky-friendly lighting can help reduce the impacts of outdoor lighting without compromising illumination of a facility. This can reduce a plant's potential impact on endangered species and help with community relations.

Motivation

- Goodwill

Reference

International Dark Sky Association. darksky.org

3.1.2.16 Reduce Noise

Noise associated with an asphalt plant can distract workers and contribute to hearing loss. For plants located near residential or commercial areas, noise can be a major concern by neighbors. Noise surveys conducted by a qualified acoustician can ensure regulatory compliance with local noise ordinances and provide specific recommendations to reduce noise pollution.

Motivation

- Goodwill

Reference

Knauer, H., & S. Pedersen (2006). *Construction Noise Handbook* (FHWA-HEP-06-015). John A. Volpe National Transportation Systems Center Acoustics Facility, U.S. Department of Transportation, Cambridge, Massachusetts. www.fhwa.dot.gov/environment/noise/construction_noise/handbook/

NAPA (1977). *Noise in and Around Asphalt Plants* (IS-75). National Asphalt Pavement Association, Lanham, Maryland.

3.1.2.17 Minimize Odor

Asphalt plants are sometimes like airports. At the time they are built, they are located well away from residential development, but over time changes in population and development patterns occur and new residential developments become close neighbors. Asphalt plants emit odors that some neighbors do not appreciate. In extreme cases, residents can get frustrated with this and go to the local press with their complaints, tarnishing the asphalt plant owner's reputation, or even file legal action, which is costly to resolve. There are odor-capture systems available for tanks, as well as natural odor neutralizing agents that do not rely on harsh chemicals or masking fragrances. An odor-mitigation strategy using these types of tools can improve worker conditions and relationships with residential neighbors to preserve or rebuild goodwill and acceptance by the local community.

Motivation

- Business Opportunity
- Goodwill

Reference

Haupert, L., & R. Mulford (2016). Laurel Asphalt Paves the Way for Reducing Odors and Keeping Neighbors Happy. *Asphalt Contractor*, Vol. 30, No. 7, pp. 70–73. www.forconstructionpros.com/asphalt/article/12196593/laurel-asphalt-paves-the-way-for-reducing-odors-and-keeping-neighbors-happy

3.2 Materials Quality

Good pavement performance is directly related to the quality of the asphalt mix. Asphalt producers can impact mix quality through both mix design and production quality control processes.

Impacts on Sustainability

- Consumption
- Climate
- Budget
- Maintenance & Operations

3.2.1 Mix Design

Getting good mix performance starts with the selection of raw materials and optimization of recycled materials in the mix design process. The industry has been responsibly focusing on mix durability since the Great Recession that started in the late-2000s. Increased asphalt binder cost at that time sparked rapid increased use of recycled materials, which led to some durability challenges. The outcomes have been material standards and laboratory tests to help ensure good mix quality.

3.2.1.1 Balanced Mix Design Process

The FHWA Expert Task Group on Mixtures and Construction defined balanced mix design (BMD) as “asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure.” The BMD process incorporates mechanical tests to determine the rutting- and cracking-resistance of a mix so that the mix is “balanced” to optimize both rutting and cracking performance. Most agencies are successfully using the Hamburg Wheel Tracking test to evaluate rutting and moisture sensitivity along with a cracking test(s) that is most appropriate for the geographic conditions. BMD evaluates final mix properties rather than individual raw materials, allowing for optimization of recycled materials and assurance of good mix performance for producers.

Motivation

- Business Opportunity
- Project Requirement

Reference

NCHRP Project 09-58 (2019). *The Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios.* Final report due for publication by third quarter 2019. apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3645

NCHRP Project 20-07/Task 406 (2018). *Development of a Framework for Balanced Asphalt Mixture Design.* Report currently under review. apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4324

3.2.1.2 Optimize Mix Design to Increase RAP and RAS

A 2013 NCHRP project evaluated the field performance of many high RAP mixtures in comparison to low RAP or virgin mixes. It illustrated that equal performance can be achieved with responsible use of RAP. The ongoing NCHRP Project 09-58 has evaluated both high RAP and reclaimed asphalt shingles (RAS) mixtures, focusing on asphalt binder, rejuvenators, and blended binder properties. This work is also indicating that with proper virgin binder and rejuvenator selection, good mix performance can be achieved with high RAP, though the required rejuvenator doses are up to 10%, as opposed to the 3% commonly used. The project also illustrates that RAS can be used responsibly in low doses when the mix design is engineered properly and produced and constructed with best practices.

Motivation

- Business Opportunity

Reference

West, R., J.R. Willis, & M. Marasteanu (2013). *NCHRP Report 752: Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content*. Transportation Research Board of the National Academies, Washington, D.C.

3.2.2 Materials Quality Control

Effective quality control (QC) processes in the production/processing of aggregates, recycled materials, and asphalt mix are essential to good mix quality.

3.2.2.1 RAP Materials QC

In addition to routine aggregate and mix quality control, RAP QC is of particular importance today to manage risk and optimize consistency, quality, and payment bonus. Close inspection of materials to be recycled is critical. Inbound RAP can be contaminated with undesirable materials that can only be caught through rigorous inspection. Contaminants can include glass (for example, from the allowance of recycled glass in previous mixtures), porcelain tile, geotextiles from milling operations, and other construction materials like aggregate base and PCC. In addition, undesirable materials — like mix made with highly absorptive aggregates or sulfur-extended asphalt — need to be identified and managed. Once inbound RAP is free of contaminants, RAP quality can be improved through blending, crushing, fractionating, and QC testing. Some successful operations separate plant waste (from mix changes on the fly), millings, and contaminated RAP for processing and stockpiling to maximize RAP use and quality. There is cost associated with managing multiple RAP stockpiles, but this cost can be recovered by improving the consistency of RAP, which can allow for increased RAP use.

Motivation

- Business Opportunity

Reference

West, R.C. (2015). *Best Practices for RAP and RAS Management* (QIP-129). National Asphalt Pavement Association, Lanham, Maryland.

3.2.2.2 QC Department Resources and Operations

Asphalt mixture design and production have become much more complex since the 1950s. Today, highly qualified QC department staff are needed to understand the specifications, design requirements, mechanical and conventional test methods, as well as to analyze the related results for success. This means that engineers and well-trained technicians are becoming the norm in successful QC operations. There are national, regional, and state materials technician qualification or certification programs that assure competency and consistency, similar to the professional engineer requirements for QC managers that allow the asphalt producer to confidently rely on in-house QC. Similarly, the AASHTO Accreditation Program (AAP) formally audits and recognizes the competency of testing laboratories performing construction materials tests. AAP is the largest and most widely accepted accrediting body in the construction materials industry. There are also relatively inexpensive QC database software packages available that can help reduce testing time and calculation errors. More importantly, such software can send real-time notifications of results to operations staff immediately upon completion of tests, as well as automatically generate and distribute specification test results and trend analyses. Engineering licensure, technician certification, laboratory accreditation and use of database software provide for confidence, credibility, efficiency, and effectiveness in QC. The investment is worth it.

Motivation

- Business Opportunity

Reference

AASHTO Accreditation Program. www.aashtoresource.org/aap/overview

3.2.3 Recycle/Reuse

The asphalt industry is a proud leader in recycling with nearly all end-of-life asphalt being diverted from landfills and back to beneficial use in new pavements.

3.2.3.1 RAP and RAS in Asphalt Mixtures

Reductions of more than 20% in greenhouse gas production and over 45% in energy consumption have been reported by using RAP and RAS in asphalt mixture production. Mix quality can be maintained with proper design, especially when optimized for the layer where the mix will be used in a pavement structure. Today most asphalt plants have the necessary hardware to use RAP, although increasing the percentage used could lead to additional costs for processing (fractionation); additional hardware, such as a second RAP cold-feed bin; and/or using recycling agents or grade bumping to softer asphalt binders. Published RAP cost savings range significantly because many variables impact the actual cost at a given location and RAP percentage used. Cost savings estimates of 6% at 15% RAP, 10–20% at 25% RAP, and 29–40% at 50% RAP have been published. Estimates of $2.50/ton at 15% RAP and $4–$5/ton at 25% RAP have also been published. Every situation is unique and should be closely evaluated.

Motivation

- Business Opportunity

Reference

Newcomb, D.E., E.R. Brown, & J.A. Epps (2007). *Designing HMA Mixtures with High RAP Content: A Practical Guide* (QIP-124). National Asphalt Pavement Association, Lanham, Maryland.

West, R.C. (2015). *Best Practices for RAP and RAS Management* (QIP-129). National Asphalt Pavement Association, Lanham, Maryland.

3.2.3.2 In-Place Recycling

In some cases, particularly in rural areas far from aggregate and asphalt production facilities, in-place recycling can be a viable, sustainable use for end-of-life asphalt pavements. Hot in-place, cold in-place, cold-central plant, and full-depth reclamation have all been successfully employed to recycle asphalt mixture sustainably.

Motivation

- Project Requirement

Reference

ARRA (2015). *Basic Asphalt Recycling Manual, Second Edition* (FHWA-HIF-14-001). Asphalt Recycling & Reclaiming Association, Annapolis, Maryland.

3.2.3.3 Other Recycled Materials: The Three Es

Other waste materials and industrial byproducts, including recycled tire rubber, blast furnace and steel slag, fly ash, and recycled cellulose fiber have also been successfully used in asphalt pavement mixtures. However, to ensure true sustainability, it is important that any new material added to an asphalt pavement mixture deliver engineering, environmental, and economic benefits and performance. This is referred to as “The Three Es.” Although public interest and policy goals may be served by adding new waste materials to pavements, without proper evaluation, testing, and mix design, it is impossible to ensure that road owners and the public will receive the same or improved performance and pavement life as with virgin materials or proven technologies.

3.2.4 Specialty Mixes

Several types of asphalt mixtures can be produced and used to provide good performance and unique benefits for specific applications and locations in a pavement structure. The NAPA–FHWA publication IS-128, *HMA Pavement Mix Type Selection Guide*, is an excellent tool for identifying the best use of specialty mixes.

3.2.4.1 Porous Asphalt

Porous asphalt pavements are unique in that they are used to construct pavements, but they also serve as stormwater storage and infiltration systems. They are attractive to planners and public works officials wanting storm water management systems that promote infiltration, improve water quality, and ground water recharge while maintaining peak and total water volume of flow at or below pre-development levels. Porous asphalt pavements can be especially cost-effective in situations near water bodies (oceans, lakes, and streams), where drainage structures and filtration systems can be eliminated with the use of porous asphalt pavement.

Motivation

- Project Requirement

Reference

Hansen, K.R. (2008). *Porous Asphalt Pavements for Stormwater Management* (IS-131). National Asphalt Pavement Association, Lanham, Maryland.

Schwartz, C.W., & K.D. Hall (2018). *Structural Design Guidelines for Porous Asphalt Pavements* (IS-141). National Asphalt Pavement Association, Lanham, Maryland.

3.2.4.2 Open-Graded Friction Course (OGFC)

OGFC is an open-graded mix that provides improved surface drainage during rainfall due to its interconnecting air voids structure. Water can drain vertically through OGFC to the underlying dense-graded mix where it drains laterally to a day-lighted edge. OGFC wet weather advantages include reduced hydroplaning, increased surface friction, reduced vehicle splash and spray, enhanced visibility of pavement markings, and reduced nighttime surface glare in wet weather. OGFC also provides reduced tire–pavement noise in dry weather conditions.

Motivation

- Project Requirement

Reference

Kandhal, P.S. (2002). *Design, Construction, and Maintenance of Open-Graded Asphalt Friction Courses* (IS-115). National Asphalt Pavement Association, Lanham, Maryland.

3.2.4.3 Polymer-Modified Asphalt (PMA) in Surface Course Mixes

Polymer-modification of surface courses can improve surface course durability and longevity at acceptable cost. Especially for high-traffic pavements, many DOTs either directly specify polymer-modified mixes or have implemented testing that often requires polymer modification to pass. Von Quintus et al. (2007) found that polymer-modified mixtures significantly improve rutting, fatigue, and fracture performance of asphalt pavements.

Motivation

- Project Requirement

Reference

Von Quintus, H.L., J. Mallela, & M.S. Buncher (2007). Quantification of Effect of Polymer-Modified Asphalt on Flexible Pavement Performance. In *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2001*, pp. 141–154. Transportation Research Board of the National Academies, Washington, D.C. doi:10.3141/2001-16

3.2.4.4 Rubberized Asphalt in Surface Course Mixes

Rubberized asphalt mixes have been used in warm climate states as a high-performance surface course that is highly resistant to reflective cracking. The predominant rubberized asphalt mix type is ½-inch nominal maximum aggregate size (NMAS) gap-graded with high design asphalt binder content (7–8%) containing about 20% ground tire rubber. Recent variations on this include ⅜-inch (9.5 mm) NMAS mixes and dense-graded mixes with about 10% terminal-blended fine tire rubber. The California Department of Transportation, considered a leader in rubberized asphalt use, will place asphalt rubber mix at half the thickness of conventional dense-graded mix due to its superior reflective-cracking resistance. The high cost of the mix is offset by the reduced thickness required.

Motivation

- Project Requirement

Reference

Way, G.B., K.E. Kaloush, & K.P. Biligiri (2011). *Asphalt Rubber Standard Practice Guide, First Edition*. Rubber Pavements Association, Phoenix, Arizona.

3.2.4.5 Stone-Matrix Asphalt (SMA) for Surface Course Mixes

SMA is a high-performance asphalt mix that provides excellent rutting resistance and durability for surface courses in demanding situations. It is primarily used for high-volume interstate and U.S. highway routes. It has also been used for special situations where heavy, slow-moving traffic exists, such as industrial areas, and for studded-tire wear resistance. These gap-graded mixes have a stable stone-on-stone skeleton with a rich mastic composed of asphalt binder, filler, and fibers and/or asphalt modifiers. SMA is a premium mix with higher initial cost that should be offset by improved performance life in heavy-loading situations. Beyond improved durability and fatigue and rutting resistance, SMA has been reported to be more resistant to reflective cracking and to improve wet-weather friction compared to conventional asphalt surfaces.

Motivation

- Project Requirement

Reference

Garcia, J., & K.R. Hansen (2001). *HMA Pavement Mix Type Selection Guide* (IS-128). National Asphalt Pavement Association, Lanham, Maryland.

Hughes, C.S., & P.S. Kandhal (2002). *Designing and Constructing SMA Mixtures — State-of-the-Practice* (QIP-122). National Asphalt Pavement Association, Lanham, Maryland.

4. Construction

"Construction" refers to all processes and equipment associated with the construction of asphalt pavement systems. This includes the initial construction of new pavement systems, as well as subsequent maintenance and rehabilitation efforts. For the purposes of this document, construction activities are limited to actions and equipment within the project limits and materials transported to and from the project site. Production of mixtures is addressed in the Materials Production section.

4.1 Construction Quality

Construction quality influences pavement life, required rework, and the amount and frequency of maintenance and rehabilitation. These items directly influence the use of non-renewable natural resources and contribute to human health and happiness (think about added traffic delay and safety risks due to rework and additional maintenance resulting from poor quality). In many sustainability metrics, the quality of construction is largely ignored, often because it is difficult to find a useful universal metric for quality.

Impacts on Sustainability

- Workers
- Users
- Consumption
- Climate
- Budget
- Maintenance & Operations

4.1.1 Density

Density can be considered the best singular indicator of asphalt pavement construction quality. While many other efforts contribute to construction quality, none have more direct and proven influence on pavement life. State DOTs and other large owners with adequate resources pay close attention to density and often pay bonuses or assess penalties based on density. Smaller owners with fewer resources tend to trust contractor practices with less verification.

4.1.1.1 Higher In-Place Density

A 2017 FHWA demonstration project examined the impact of higher density on asphalt pavement durability. A survey of the literature found that in laboratory testing higher densities (93–94% Rice density compared to typical specification values of 91–92% Rice density) generally result in better fatigue life and less rutting. Field demonstrations in 10 states generally found densities in the 93–95% range are possible using a combination of methods, including multiple rollers, WMA, and reduced gyration levels. The general claim is that a 1% decrease in air voids is estimated to extend service life by 10% (an idea first put forward in 1989 by Linden et al.). As of 2018, demonstration projects attempting to determine the benefits of higher in-place density are ongoing in the U.S.

Motivation

- Project Requirement

Reference

Aschenbrener, T., E.R. Brown, N.H. Tran, & P.B. Blankenship (2017). *Demonstration Project for Enhanced Durability of Asphalt Pavements Through Increased In-Place Pavement Density* (NCAT Report 17-05). National Center for Asphalt Technology at Auburn University, Auburn, Alabama.

Linden, R.N., J.P. Mahoney, & N.C. Jackson (1989). Effect of Compaction on Asphalt Concrete Performance. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1217*, p. 20–28. Transportation Research Board of the National Academies, Washington, D.C.

4.1.1.2 Intelligent Compaction (IC)

IC is usually presented as a way to monitor compaction effort in near real time. IC uses accelerometers on rollers to measure compaction effort and material response to estimate in-place density. GPS is used to locate data and systems often show maps of estimated density in near real time. While the reliability and accuracy of IC asphalt pavement density estimates still needs improvement, the GPS output showing roller location and roller passes can be useful. Additionally, IC can be used in subgrade compaction to identify soft areas, allowing project teams to proactively repair these areas to prevent future maintenance issues.

Motivation

- Project Requirement

Reference

FHWA Intelligent Compaction Website. www.fhwa.dot.gov/pavement/ic/

4.1.1.3 Non-Nuclear Field Density Measurement

The standard for in-place density is a field core tested in the laboratory. However, for quicker density results, the nuclear gauge has been used since the 1970s. While a properly calibrated nuclear gauge can give density readings within minutes, its radioactive source requires licensing, a radiation safety program, gauge safety certification training, gauge security/control, calibration, and proper disposal procedures. Gauges without nuclear sources (or sources small enough to be exempt from controls), usually electromagnetic gauges, can be quicker to use and are subject to fewer rules; however, numerous studies have shown these gauges to have poor correlation with core and nuclear densities, large variability in measurements, and be quite dependent on calibrated and consistent dielectric values. Work to improve and evaluate these gauges is ongoing.

Motivation

- Business Opportunity

Sargand, S.M., S.-S. Kim, & S.P. Farrington (2005). *A Working Review of Available Non-Nuclear Equipment for Determining In-Place Density of Asphalt* (FHWA/OH-2005/18). Ohio Research Institute for Transportation and the Environment, Ohio University, Athens, Ohio.

4.1.1.4 Variable Density Standards Based on NMAS

Research from NCAT and elsewhere shows a relationship between NMAS, density, and permeability. In general, as NMAS increases the density required to achieve an impermeable asphalt pavement increases. For instance, ⅜ and ½-inch NMAS mixtures may become permeable below about 92–93% Rice density, while ¾-inch NMAS mixtures become permeable below about 94.5% Rice density. If an impermeable asphalt pavement is wanted (and it usually is), the required density to achieve this should vary with NMAS.

Motivation

- Project Requirement

Reference

Cooley Jr., L.A., E.R. Brown, & S. Maghsoodloo (2001). *Development of Critical Field Permeability and Pavement Density Values for Coarse-Graded Superpave Pavements* (NCAT Report 01-03). National Center for Asphalt Technology at Auburn University, Auburn, Alabama.

4.1.2 Lift Thickness ≥ 4 × NMAS

NCHRP research from NCAT recommends the minimum paving depth be at least three times NMAS for fine-graded mixes (including Thinlays) and at least four times NMAS for coarse-graded and SMA mixes. This allows enough room for aggregate to rearrange in the mixture from the weight and vibration of the screed and rollers. Thinner lifts cool rapidly making roller placement close to the paver even more important (for instance: a 2-inch lift cools twice as fast as a 2.5-inch lift). At mat thicknesses less than about 1.5 times NMAS, the screed may be supported by the large aggregates in the mixture rather than floating on the mixture as a whole.

Motivation

- Project Requirement

Reference

Brown, E.R., M.R. Hainin, A. Cooley, & G. Hurley (2004). *NCHRP Report 531: Relationship of Air Voids, Lift Thickness, and Permeability in Hot Mix Asphalt Pavements*. Transportation Research Board of the National Academies, Washington, D.C.

NAPA (2002). *Paver Operations for Quality* (IS-125). National Asphalt Pavement Association, Lanham, Maryland.

4.1.3 Longitudinal Joints

Longitudinal joints are a focal point for asphalt pavement quality because low compaction and surface irregularities at the joint can be more common and lead to premature cracking and raveling. Ideally, the joined area between two passes of asphalt mixture should be an integral part of the pavement structure and as durable as any other part of the finished mat. Work at NCAT, subsequently expanded by others, investigated and recommended several best practices, including proper joint overlap, rolling from the hot side 6 inches away from the joint, and using rubberized joint material and notched wedge joints. Other useful techniques are cutting back the cold edge (often done in airfield work) and echelon paving to create a hot joint.

Motivation

- Project Requirement

Reference

Buncher, M.S., & C. Rosenberger (2012). *Best Practices for Constructing and Specifying HMA Longitudinal Joints*. Asphalt Institute, Lexington, Kentucky.

Kandhal, P.S., T.L. Ramirez, & P.M. Ingram (2002). *Evaluation of Eight Longitudinal Joint Construction Techniques for Asphalt Pavements in Pennsylvania* (NCAT Report 02-03). National Center for Asphalt Technology at Auburn University, Auburn, Alabama.

NAPA (2002). *Paver Operations for Quality* (IS-125). National Asphalt Pavement Association, Lanham, Maryland.

4.1.4 Eliminate Segregation

Segregation is a separation of coarse and fine aggregate particles during the production and laydown process. The result is a non-uniform mat that, in places, will not conform to the original job mix formula and will perform poorly. Eliminating segregation requires effort throughout production and laydown, including stockpiling, plant operations, truck loading, paver operations, and material-transfer vehicle use.

Motivation

- Project Requirement

Reference

Brock, J.D., J.G. May, & G. Renegar (2003). *Segregation: Causes and Cures* (Technical Paper T-117). Astec Inc., Chattanooga, Tennessee.

4.1.5 Smoothness

Smoothness is a defining quality characteristic for asphalt pavement. Smoother pavements indicate higher construction quality and reduce vehicle operating costs and emissions, and there is evidence that pavements built to a higher initial level of smoothness are more durable.

4.1.5.1 Construction Practices

Tactics for achieving smoothness include surface preparation (including leveling courses and cold planing), reducing paver stops, uniform mix temperature, grade control for pavers, compaction efforts, and joint construction.

Motivation

- Business Opportunity
- Project Requirement

Reference

Brock, J.D., & J. Hedderich (2007). *Pavement Smoothness* (Technical Paper T-123). Roadtec, an Astec Industries Company, Chattanooga, Tennessee.

4.1.5.2 Use a Smoothness Specification

About three-quarters of state DOT asphalt pavement specifications have smoothness requirements based on International Roughness Index (IRI) measurements and about 90% of those involve incentive/disincentive pay adjustments based on statistical analysis. About half of smoothness is related to the roughness of the underlying layer, and improvements in smoothness per lift are on the order of 40–65% at most. For states that base pay on smoothness, the upper limit for full pay (higher IRI values would result in a penalty) ranges from 43–100 inches/mile. Incentive/disincentive specifications for smoothness should also allow for construction methods to improve smoothness, such as a leveling course and milling of the existing surface.

Motivation

- Project Requirement

Reference

Merritt, D.K., G.K. Chang, & J.L. Rutledge (2015). *Best Practices for Achieving and Measuring Pavement Smoothness, a Synthesis of State-of-Practice* (FHWA/LA.14/550). Louisiana Transportation Research Center, Baton Rouge, Louisiana.

4.1.6 Mat Temperature

Construction-related temperature differentials (sometimes called "thermal segregation") are isolated cooler areas of the mat that may not be adequately compacted using a rolling pattern designed for the majority mat temperature. Thus, they can result in isolated areas of low density that fail prematurely by raveling and cracking. Often, these areas are caused by the top surface of the mix in the dump truck cooling during transit and then passing through the paver and being placed in mat relatively intact.

4.1.6.1 Infrared Monitoring of Mat Temperature

Infrared (IR) equipment can readily detect isolated areas of low temperature as they happen. Infrared temperature measuring devices and thermal imaging cameras can both be used, with more expensive options having better mat coverage, data retention and processing, and visual displays.

Motivation

- Business Opportunity
- Project Requirement

Reference

Fernández Cerdas, S. (2012). *Thermal Segregation: Causes and Effects on In-Place Density and Fatigue Performance of Asphalt Mixtures* (Master's thesis). Auburn University, Auburn, Alabama.

4.1.6.2 Use a Density Differential Specification

Some state DOTs use a specification to identify and correct isolated areas of low density in the mat, usually caused by construction-related temperature differentials that do not get adequately compacted. These isolated spots of low density may not be captured by normal random sampling but can still lead to early pavement failure. Specifications usually require a "thermal profile" (temperature measurements taken along a short distance: 100–500 feet). Areas significantly cooler than the surrounding mat require further investigation with density testing.

Motivation

- Project Requirement

Reference

TxDOT (2015). *Tex-244-F: Test Procedure for Thermal Profile of Hot Mix Asphalt*. Texas Department of Transportation, Austin, Texas.

WSDOT (2017). WSDOT SOP 733: Determination of Pavement Density Differentials Using the Nuclear Density Gauge. *Materials Manual* (M 46-01.30). Washington State Department of Transportation, Olympia, Washington.

4.1.7 Tack Coat

Although flexible asphalt pavements are built in layers, the structural strength of the pavement system owes much to the bond between those layers. A variety of tack coat products are available, and following best practices helps ensure they provide the bond strength the pavement needs for good performance.

4.1.7.1 Pay for Tack Coat Separately

Tack coat can be paid for as a separate item or included as incidental to the bid price of the asphalt material. Tack coat as a separate pay item is done by 66% of U.S. DOTs (33 out of 50) as of 2017. Paying for tack as a separate item best aligns the goals of owner and contractor: the owner can ask for more tack coat, and the contractor can be properly compensated for providing the additional material. Tack coat represents a small job expense (usually less than 0.5% of bid price) but incorrect application and potential failure due to de-bonding is an extreme consequence.

Motivation

- Project Requirement

Reference

Gierhart, D., & D.R. Johnson (2017). *NCHRP Synthesis 516: Tack Coat Specifications, Materials, and Construction Practices*. Transportation Research Board of the National Academies, Washington, D.C.

4.1.7.2 Control Tack Coat Dilution

Often, slow-setting (SS) tack coats are diluted with water to help the tack truck more evenly apply the tack coat emulsion because it is better at metering the higher flow needed to obtain the right residual rate. However, dilution must be closely controlled because an inaccurately determined dilution rate will result in the incorrect residual asphalt application. As of 2017, 48% of state DOTs allow dilution. If dilution is allowed, only do so at the emulsion supplier's terminal, where it is better controlled. It is best to verify the dilution rate before applying tack coat so that a proper residual asphalt rate will result. It may be easiest to disallow dilution, thereby eliminating the issue.

Motivation

- Project Requirement

Reference

Gierhart, D., & D.R. Johnson (2017). *NCHRP Synthesis 516: Tack Coat Specifications, Materials, and Construction Practices*. Transportation Research Board of the National Academies, Washington, D.C.

Mohammad, L.N., M.A. Elseifi, A. Bae, N. Patel, J. Button, & J.A. Scherocman (2012). *NCHRP Report 712: Optimization of Tack Coat for HMA Placement*. Transportation Research Board of the National Academies, Washington, D.C.

4.1.7.3 Use Non-Tracking Tack Coat

Construction machinery that drives on tack coat may pick up the tack with their rubber tires and remove the emulsion material from the intended pavement surface, which can reduce bond strength in the wheel paths. Since the mid-2000s, non-tracking (or *trackless*) tack coats have been available from some manufacturers. Not all owners allow non-tracking tack, but when properly applied, it appears to largely prevent tracking.

Motivation

- Business Opportunity
- Project Requirement

Reference

Mohammad, L.N., M.A. Elseifi, A. Bae, N. Patel, J. Button, & J.A. Scherocman (2012). *NCHRP Report 712: Optimization of Tack Coat for HMA Placement*. Transportation Research Board of the National Academies, Washington, D.C.

4.1.7.4 Tack Coat Best Practices

NAPA publication QIP-128, *Best Practices for Emulsion Tack Coats*, provides best practice guidance on emulsion tack coats, covering storage, handling, sampling, testing, distributors, hand application, surface preparation, residual determination, application rate, break and set, and tack tracking/pick up.

Motivation

- Business Opportunity
- Project Requirement

Reference

Decker, D.S. (2013). *Best Practices for Emulsion Tack Coats* (QIP-128). National Asphalt Pavement Association, Lanham, Maryland.

4.1.8 WMA as a Compaction Aid

A variety of warm-mix asphalt (WMA) additives and processes have been found to aid compaction at normal construction temperatures. In some instances, WMA additives have been specified as compaction aids for particularly stiff mixes (for example, high PG 82 grades, asphalt rubber mixtures, open-graded mixtures requiring hand work).

Motivation

- Business Opportunity
- Project Requirement

Reference

Kristjánsdóttir, Ó. (2006). *Warm Mix Asphalt for Cold Weather Paving* (WA-RD 650.1). Master's thesis, University of Washington, Seattle, Washington.

Prowell, B.D., G. Hurley, & B. Frank (2012). *Warm-Mix Asphalt: Best Practices, Third Edition* (QIP-125). National Asphalt Pavement Association, Lanham, Maryland.

4.1.9 Pay for Asphalt Binder Separately

The asphalt binder in asphalt pavement can be paid for as a separate item or included as incidental to the bid price of the asphalt pavement. Paying for asphalt binder as a separate item best aligns the goals of owner and contractor: the owner can ask for more asphalt binder and the contractor can provide it and be properly compensated for the additional material.

Motivation

- Project Requirement

4.1.10 Use a Warranty

Some U.S. owners and many international ones have extensive experience with pavement warranties. Stated reasons for their use are (1) improved quality and (2) reduced owner oversight during construction. While either may happen, neither is a necessary result of a pavement warranty. Essentially, a warranty is an added upfront expense (warranties are priced and bid accordingly) to hedge against the risk of a costlier expense later. A warranty price can be a differentiator for a contractor who builds a superior quality product that reduces the risk of later repairs.

Motivation

- Project Requirement

Reference

Scott III, S., T. Farragut, M. Syrnick, & S. Anderson (2011). *NCHRP Report 699: Guidelines for the Use of Pavement Warranties on Highway Construction Projects*. Transportation Research Board of the National Academies, Washington, D.C.

4.1.11 Use a Construction Quality Control Plan

A construction quality control plan is intended to document the structure, responsibilities, and procedures to effectively manage construction quality. While plans do not ensure actions, properly developed plans do provide a framework and guidance for good quality control practice.

Motivation

- Business Opportunity
- Project Requirement

Reference

FLH (1998). *Contractor Quality Control Plans: Contractor Guidelines and Example Quality Control Plan*. Federal Lands Highway Office, Federal Highway Administration, Washington, D.C.

Molenaar, K.R., D.D. Gransberg, & D.N. Sillars (2015). *NCHRP Report 808: Guidebook on Alternative Quality Management Systems for Highway Construction*. Transportation Research Board of the National Academies, Washington, D.C.

Rath, T. (2017). *Trans Mountain Expansion Project: Quality Management Plan* (Document #01-13283-GG-0000-RPT-CM-0002). Kinder Morgan Canada Inc., Calgary, Alberta, Canada. apps.neb-one.gc.ca/REGDOCS/File/Download/3179049

4.2 Equipment

Equipment operation influences productivity, fuel use, and the health of workers and neighbors. These items directly influence pollution, resource consumption, and project cost, as well as contribute to human health and happiness (think of the effects of construction noise on workers — hearing loss prevention — as well as its effect on neighbors — annoyance and stress). This section presents several sustainable practices that go beyond improving productivity.

Impacts on Sustainability

- Workers
- Neighbors & Stakeholders
- Pollution
- Consumption
- Climate
- Budget

4.2.1 Tier 4 Engines

By 2015, EPA Tier 4 diesel engines were phased in for non-road equipment. They reduce diesel NO_x and particulate exhaust emissions by 90% compared to engines manufactured prior to implementation of the standard. Existing equipment may continue to operate, but new equipment must meet Tier 4 engine standards. While not yet common in the paving industry, some projects place requirements on the age and emissions performance of the project's equipment fleet. Starting in 2018, large equipment fleets are prohibited from adding any more Tier 2 engine vehicles.

Motivation

- Business Opportunity
- Project Requirement

Reference

EPA (2018). *Regulations for Emissions from Heavy Equipment with Compression-Ignition (Diesel) Engines*. U.S. Environmental Protection Agency, Washington, D.C. www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-heavy-equipment-compression

4.2.2 Alternatives Fuels

Diesel from fossil fuel is the overwhelmingly predominant fuel source for construction equipment. However, price, environmental, and future supply risks may make alternative fuels a viable option. Limited use of biofuel is already allowed, and research continues on other alternative fuels. B20 (20% biodiesel) is usually the maximum recommended for current diesel engines, but some specialty contractors do use B100 (100% biodiesel) even though current costs and reduced power make it less competitive. Other alternative fuels must address refueling logistics and the high energy-density fuel requirements of construction equipment. For example, while natural gas has gained in overall U.S. market share, it has an energy density that is two to five times less than diesel, which limits its use in heavy construction equipment.

Motivation

- Business Opportunity
- Project Requirement

Reference

David, J. (2015). Growing the Demand for Biofuels in Off-Highway Equipment Applications. *Equipment Today*, Vol. 51, No. 4. www.forconstructionpros.com/equipment/fleet-maintenance/article/12056642/growing-the-demand-for-biofuels-in-offhighway-equipment-applications

FPT Industrial. (2015). Fuel for Thought: Diesel Alternatives for the Non-Road Sector. *Sustainable Construction*, Winter 2015. www.forconstructionpros.com/sustainability/article/12122157/fuel-for-thought-diesel-alternatives-for-the-nonroad-sector

4.2.3 Reduce Noise

Hearing loss is the top injury reported by highway construction workers. Additionally, noise is a major complaint by construction site neighbors. Generally, construction site noise is regulated by local ordinances, to which some variations may be allowed. Sustainability generally represents innovation in meeting or exceeding existing regulations. The FHWA's *Construction Noise Handbook* (Knauer & Pedersen, 2006) contains some basic ideas for mitigating construction noise during roadway construction.

Motivation

- Project Requirement

Reference

Knauer, H.S., & S. Pedersen (2006). *Construction Noise Handbook* (FHWA-HEP-06-015). U.S. Department of Transportation, John A. Volpe National Transportation Systems Center Acoustics Facility, Cambridge, Massachusetts.

4.2.4 Automated Grade Control

Hybrid laser-GPS systems are capable of tightly controlling paving and milling grades. This is beneficial especially for projects with variable-depth paving and milling in that it (1) saves the surveying step of marking variable depths on the pavement, and (2) eliminates manual machine control required for variable elevation and cross-slope changes.

Motivation

- Business Opportunity

Reference

Asphalt Contractor (2012). All in a Weekend's Work. Vol. 26, No. 9, www.forconstructionpros.com/asphalt/pavers/article/10785573/automated-grade-control-system-holds-milling-and-paving-grade-during-fasttrack-paving-project

4.3 Work Zone Traffic Delay and Impacts

Work zone traffic delays can have a major impact on the indirect costs of construction, especially in urban areas where traffic volumes are generally higher. Road user costs in work zones include vehicle operating costs, motorist/passenger/freight delay costs, and crash costs. These are real, quantifiable costs, but are generally not tracked as part of the construction cost beyond the cost of traffic management itself. However, for larger urban roadway projects the economic impact can be several times larger than the cost of the project. 23 CFR 630, Subpart J establishes baseline requirements for work zone safety and mobility but stops short of requiring specific practices.

Impacts on Sustainability

- Workers
- Neighbors & Stakeholders
- Users
- Pollution
- Consumption
- Climate
- Project Budget

4.3.1 Reduce/Mitigate Work Zone Traffic Delay

Much has been written about work zone traffic delay, its impacts, and practices for reducing or mitigating those impacts. Anderson & Ullman (2000) categorize these practices into:

1. **Programming and planning.** For example: interagency coordination, traffic management plans, road user cost considerations, safety, public perception
2. **Design.** For example: constructability reviews, materials, prefabrication
3. **Contracting.** For example: lane rental, cost + time (A+B), incentives/disincentives, flexible start times
4. **Construction.** For example: preconstruction planning, construction equipment/techniques, materials, partnering, value engineering

5. **Maintenance.** For example: work restrictions, traffic management and lane control, methods and materials, work planning, public communications.

Motivation

- Project Requirement

Reference

Anderson, S.D., & G.L. Ullman (2000). *NCHRP Synthesis 293: Reducing and Mitigating Impacts of Lane Occupancy During Construction and Maintenance*. TRB, National Research Council, Washington, D.C.

FHWA. (2017). Work Zone Traffic Management, ops.fhwa.dot.gov/wz/traffic_mgmt

4.3.2 Use R3 to Model Construction Plan Productivity and Delay

Rapid Road Rehabilitation (R3, formerly CA4PRS) is an online set of software applications to help quickly analyze schedule, traffic, and cost options for highway projects. It can provide quick analysis using planning-level input values for productivity and closure scenarios.

Motivation

- Business Opportunity
- Project Requirement

Reference

Caltrans (2018). Construction Analysis for Pavement Rehabilitation Strategies: Caltrans “Rapid Rehab” Software. www.dot.ca.gov/newtech/roadway/ca4prs/

4.4 Waste Management

Construction produces waste from unsuitable, temporary, and short-use materials, as well as clearing/grubbing, demolition, and packaging. The EPA estimates 534 million tons of construction and demolition waste were generated in the United States in 2014, which is more than the amount of municipal solid waste (a.k.a. garbage or trash) generated. Road construction waste can be significant: the EPA estimates 14% of construction and demolition waste is asphalt concrete, however nearly all of this is diverted from landfills. Waste directly impacts pollution and the local ecosystem; not recycling/reusing this material increases consumption of virgin materials.

Impacts on Sustainability

- Pollution
- Local Ecosystem & Habitat
- Consumption

4.4.1 Reduce/Eliminate Waste to Landfill and Document

The asphalt pavement industry does well recycling old asphalt pavement. The EPA notes that more C&D debris is generated by roads and bridges (234 million tons) than buildings

(166 million tons), but nearly all (99%) of asphalt pavement C&D debris is diverted from landfills with the intention of reusing it in new asphalt pavements or base layers. Thus, making pavement construction a documented zero-waste activity is a realistic possibility. From a consumer perspective, the "zero waste" idea (sometimes called "closed loop") is that manufacturers should take back their product in a free and convenient way when it reaches the end of its useful life, and then recycle the material in a safe and responsible way. This is asphalt pavement; only the documentation is missing.

Motivation

- Business Opportunity
- Project Requirement

Reference

UL 2799: Zero Waste to Landfill standard. standardscatalog.ul.com/standards/en/standard_2799

Van Dam, T.J., J.T. Harvey, S.T. Muench, K.D. Smith, M.B. Snyder, I.L. Al-Qadi, H. Ozer, J. Meijer, P.V. Ram, J.R. Roesler, & A. Kendal (2015). *Towards Sustainable Pavement Systems: A Reference Document* (FHWA-HIF-15-002). Federal Highway Administration, Washington, D.C. (Chapter 8 covers zero waste/closed loop.)

Williams, B.A., A. Copeland, & T.C. Ross (2018). *Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage: 2017, 8th Annual Survey* (IS-138). National Asphalt Pavement Association, Lanham, Maryland. www.asphaltpavement.org/recycling

4.5 Project Management and Control

Project management and controls often determine the profitability of a project and the owner's satisfaction with the work. This section focuses on tools and equipment available to assist in project management and control; it does not address general management science (for example, what it takes to be a good manager). Tools and equipment are generally able to provide more data from more sources (for example video, audio, QR codes) at a higher quality and in a more timely manner. Such technology can be used to reduce project risk, provide more insight into project issues, better track materials and metrics, and keep the entire project team better informed. Project management and controls impact efficiency, risk and awareness, all of which can result in better decisions and lower costs.

Impacts on Sustainability

- Project Budget

4.5.1 Enhanced Information Technology

Enhanced information technologies (IT) encompass mobile and wearable devices, cloud-based technology, real-time information availability, and multimedia tools. The FHWA and AASHTO promote e-Construction, which is "… the collection, review, approval, and distribution of highway construction contract documents in a paperless environment."

Importantly, the goal of “enhanced IT” is not just making existing processes paperless but enabling better processes that create more value using available data and connectivity.

Motivation

- Business Opportunity
- Project Requirement

Reference

Shah, K., A. Mitchell, D. Lee, & J. Mallela (2017). *Addressing Challenges and Return on Investment (ROI) for Paperless Project Delivery (e-Construction)* (FHWA-HIF-17-028). Federal Highway Administration, McLean, Virginia.

Yamaura, J., G. White, S. Katara, K. Willoughby, R. Garcia, & M. Beer (2015). *Project Inspection Using Mobile Technology — Phase II* (WA-RD 840.2). Washington State Department of Transportation, Olympia, Washington.

4.5.2 Geospatial Technologies

Geospatial technologies can be used to gather, store, process, and display geographic or spatially referenced information. Systems that use the Global Positioning System (GPS), geographic information systems (GIS), light detection and ranging (LIDAR), and even barcoding and radio frequency identification (RFID) are considered geospatial technologies. These technologies can all assist with locating and tracking pavement construction materials, progress, and data. For example, LIDAR can be used for machine control (paver, milling machine), as-built documentation, quality control, and materials quantity tracking.

Motivation

- Business Opportunity
- Project Requirement

Reference

Olsen, M.J., G.V. Roe, C. Glennie, F. Persi, M. Reedy, D. (2013). *NCHRP Report 748: Guidelines for the Use of Mobile LIDAR in Transportation Application*s. Transportation Research Board of the National Academies, Washington, D.C.

Schwartz, C.W., J.S. Khan, G.H. Pfeiffer, & E. Mustafa (2014). *Radio Frequency Identification Applications in Pavements* (FHWA-HRT-14-061). Federal Highway Administration, McLean, Virginia.

4.6 Work Zone Health and Safety

Work zone health and safety has been a point of emphasis by the FHWA, state agencies, and others for quite some time. In 2016 (most recent data at time of publication), there were about 158,000 work zone crashes. Roadway construction worker fatalities have fluctuated between 100 and 145 per year over the past 10 years. Work zone health and safety is highly regulated, with most practices being mandatory rather than optional. This section only addresses optional, non-standard items that may contribute to construction worker health and safety within the work zone. Regulatory requirements (for example, OSHA and MUTCD requirements) are not addressed. In general, work zone health and safety efforts are intended to reduce/eliminate work zone injuries and crashes, which affect worker and user health.

Impacts on Sustainability

- Workers
- Users
- Project Budget

4.6.1 Health and Safety Management Plan

A proactive approach to managing workplace safety and health. OSHA provides general guidance for starting and running a health and safety program (OSHA, 2016).
ISO 45001:2018 Occupational Health and Safety describes minimum standards for occupational health and safety performance and offers certification. Like other standards from ISO (for example ISO 9001 for quality management systems and ISO 14001 for environmental management systems), there is effort and cost associated with certification.

Motivation

- Business Opportunity
- Project Requirement

Reference

ISO 45001:2018 Occupational Health and Safety Management Systems — Requirements with Guidance for Use. www.iso.org/obp/ui/#iso:std:iso:45001:ed-1:v1:en

OSHA (2016). *Recommended Practices for Safety and Health Programs* (OSHA 3885). Occupational Safety & Health Administration, Washington, D.C.

4.6.2 Job Hazard (Safety) Analysis

Job hazard analysis is a technique to analyze a job task and identify hazards to determine the safest way to perform the task. OSHA provides basic guidance on how to perform a job hazard analysis (OSHA, 2002). More detailed guidance also exists (for example, Roughton & Crutchfield, 2015); however, job hazard analysis is generally not required by regulation.

Motivation

- Business Opportunity

Reference

OSHA (2002). *Job Hazard Analysis* (OSHA 3071). Occupational Safety & Health Administration, Washington, D.C.

Roughton, J., & N. Crutchfield (2015). *Job Hazard Analysis: A Guide for Voluntary Compliance and Beyond, Second Edition*. Butterworth-Heinemann, Waltham, Massachusetts.

4.6.3 Work Zone Intrusion Alert Systems

Work zone intrusion alert systems refer to a variety of technologies used to notify workers and drivers of unauthorized vehicles entering work zones. Intrusion alarms are most beneficial for temporary work zones with minimal separation from moving traffic. Sensors can range from pneumatic tubes, to impact sensors placed on traffic control devices, to multiple sensors (video, radar, GPS) working in concert. Alarms are typically audible, with some systems also using visual (flashing lights) and haptic methods (wearable units that vibrate). Research and development of these systems is ongoing and progressing rapidly. Current issues are: (1) quantifying the resulting risk reduction, (2) minimizing false alarms, and (3) ensuring drivers and workers notice and react to warnings.

Motivation

- Business Opportunity
- Project Requirement

Reference

Fyhrie, P.B. (2016). *Work Zone Intrusion Alarms for Highway Workers*. California Department of Transportation. Sacramento, California.

Gambatese, J.A., H.W. Lee, & C.A. Nnaji (2017). *Work Zone Intrusion Alert Technologies: Assessment and Practical Guidance* (SPR 790). Oregon Department of Transportation, Salem, Oregon.

Theiss, L., T. Lindheimer, & G.L. Ullman (2017). *Closed-Course Performance Testing of a Work Zone Intrusion Alarm System*. Presented at the 97th Annual Meeting of the Transportation Research Board, Washington, D.C.

4.6.4 Design for Construction Safety (DfCS)

Design for construction safety (DfCS), also known as prevention through design (PtD) or construction hazard prevention through design (CHPtD), is a process to include worker safety considerations in design and constructability review. Improved construction worker safety is the obvious benefit, while designer liability is the major issue.

Motivation

- Business Opportunity

Reference

Toole, M. (2017) Prevention through Design. designforconstructionsafety.org (Overview of DfCS/PtD and available resources)

5. Pavement Design

5.1 New Pavements

New or reconstructed pavements are those built with an entirely new pavement structure. This document addresses selected new pavement design options, but does not address design methods, processes, and other technical inputs for pavement design.

Impacts on Sustainability

- Users
- Consumption
- Climate
- Project Budget
- Maintenance & Operations

5.1.1 Perpetual Pavement

Perpetual Pavement describes a long-lasting pavement structural design, materials selection, construction, and maintenance concept. The Asphalt Pavement Alliance (APA) annually recognizes long-life pavements that meet the Perpetual Pavement ideal with its Perpetual Pavement Award, the criteria for which includes pavements that are:

- Asphalt pavement
- Pavement age of at least 35 years
- No structural failure
- No rehabilitation that has increased total pavement thickness by more than 4 inches
- Resurfacing intervals of no less than 13 years on average

Essentially, asphalt pavements constructed to a minimum structure are not likely to suffer significant structural damage even when subjected to very high traffic over long periods of time. Minimum structure varies with loading and other factors: high-volume highways may be about 12–15 inches of asphalt pavement constructed in specific layers; low-volume local roads may be about 5–8 inches of asphalt pavement. Newcomb et al. (2010) discusses specifics.

Motivation

- Business Opportunity
- Project Requirement

Reference

Newcomb, D.E., J.R. Willis, & D.H. Timm (2010). *Perpetual Asphalt Pavements: A Synthesis* (IM-40). Asphalt Pavement Alliance, Lanham, Maryland.

5.1.2 Specialty Layers

Most asphalt pavements are designed for and built with dense-graded mixtures. However, certain traffic and environmental situations may make alternative mixtures more appropriate and offer sustainability advantages. Specifically:

- **Porous asphalt pavements.** Pavement structures intentionally designed to be permeable so they can serve a stormwater management function. A porous asphalt pavement system can be comparable in cost to an equivalent impermeable pavement combined with the necessary traditional stormwater management system. Porous asphalt pavement systems are generally efficient at removing pollutants (with phosphorus being a notable exception). Most porous pavement systems are designed for light automobile traffic in residential and, especially, parking lot applications.

- **Open-graded friction course (OGFC).** Pavement surfaces constructed of an open-graded (15–25% air voids) asphalt mixture, and typically paved in a thin lift (often ¾–2 inches thick). The main benefits are (1) improved safety due to reduced splash/spray and reduced risk of hydroplaning, (2) improved skid resistance, and (3) potential reduction in tire–pavement noise.

- **Stone-matrix asphalt (SMA).** Gap-graded mixture with strict aggregate specifications, modified asphalt binder, and mineral fillers. SMAs generally cost more than dense-graded mixtures and involve special construction considerations. There is substantial evidence that properly constructed SMA pavements outperform dense-graded equivalents. The Washington State DOT estimated that an SMA pavement must last about 2.5 years longer than a dense-graded pavement to break even on cost (Wen et al., 2016).

Motivation

- Business Opportunity
- Project Requirement

Reference

Cooley Jr., L.A., J.W. Brumfield, R.B. Mallick, W.S. Mogawer, M. Partl, L. Poulikakos, & G. Hicks (2009). *NCHRP Report 640: Construction and Maintenance Practices for Permeable Friction Courses*. Transportation Research Board of the National Academies, Washington, D.C.

Hansen, K.R. (2008). *Porous Asphalt Pavements for Stormwater Management* (IS-131). National Asphalt Pavement Association, Lanham, Maryland.

Hughes, C.S., & P.S. Kandhal (2002). *Designing and Constructing SMA Mixtures — State-of-the-Practice* (QIP-122). National Asphalt Pavement Association, Lanham, Maryland.

Kandhal, P.S. (2002). *Design, Construction, and Maintenance of Open-Graded Asphalt Friction Courses* (IS-115). National Asphalt Pavement Association, Lanham, Maryland.

Schwartz, C.W., & K.D. Hall (2018). *Structural Design Guidelines for Porous Asphalt Pavements* (IS-140). National Asphalt Pavement Association, Lanham, Maryland.

Wen, H., S.T. Muench, S. Chaney, K. Littleton, & T. Rydholm (2016). *Recommendations for Extending Asphalt Pavement Surface Life within Washington State* (WA-RD 860.1). Washington State Department of Transportation, Olympia, Washington.

5.2 Rehabilitation

Pavement rehabilitation is the act of repairing portions or all of an existing pavement to reset the deterioration process. This differs from maintenance (routine service and repairs done to slow the rate of deterioration) and reconstruction (removing and replacing a pavement with an entirely new structure). This document addresses selected non-traditional rehabilitation guidance and methods but does not address design methods and processes or other technical input for pavement design.

Impacts on Sustainability

- Users
- Consumption
- Climate
- Project Budget
- Maintenance & Operations

5.2.1 Use R23 Guidance

The SHRP 2 R23 project provides guidance on rehabilitating existing high volume (≥10 million ESALs) pavements for long life (at least 30 years). rePave (www.pavementrenewal.org) is the associated online scoping tool that allows users to input existing pavement information and provides viable long-term rehabilitation solutions. The rePave scoping tool and its associated resources are based on an extensive review of in-service pavement performance in the U.S. and internationally.

Motivation

- Business Opportunity
- Project Requirement

Reference

rePave. www.pavementrenewal.org

5.2.2 Crack, Seat, and Overlay

To restore ride quality and serviceability, existing deteriorated concrete pavement is often cracked into smaller slabs then overlaid with asphalt pavement. The smaller slabs are less likely to cause reflective cracking in the asphalt pavement overlay. This method is most successful with thicker (greater than 7 inches) asphalt pavement overlays, no evidence of pumping under existing slabs, good subgrade support, and existing drainage. While it is most often done on unreinforced concrete pavement, it can be adapted to reinforced concrete pavement by first sawing the pavement in the transverse direction every 4–5 feet, deep enough to cut the reinforcing steel.

Motivation

- Business Opportunity
- Project Requirement

Reference

rePave (2013). *Flexible Best Practices: Recommendations for the Design and Construction of Long-Life Flexible Pavement Alternatives Using Existing Pavements*. www.pavementrenewal.org/#resources

5.2.3 Rubblization

Existing deteriorated concrete pavement can be turned into rubble by a fracturing process and then overlaid with asphalt pavement. The rubble is left in place and functions as a high-quality base for the asphalt pavement overlay. Rubblization works best when the existing subgrade provides adequate strength, support, and drainage, and there is no evidence of pumping under existing slabs. Long-term performance of rubblized pavements depend on the rubblization quality (all concrete broken, relatively uniform size distribution of rubblized concrete, bottom half of slab size limit of 6–12 inches), subgrade strength (in combination with overlay thickness), and existing moisture problems eliminated. If viable, crack-and-seat is usually preferred to rubblization as it retains more of the existing pavement stiffness.

Motivation

- Business Opportunity
- Project Requirement

Reference

Decker, D.S. (2006). *Rubblization: Design and Construction Guidelines on Rubblizing and Overlaying PCC Pavements with Hot-Mix Asphalt* (IS-132). National Asphalt Pavement Association, Lanham, Maryland.

rePave (2013). *Flexible Best Practices: Recommendations for the Design and Construction of Long-Life Flexible Pavement Alternatives Using Existing Pavements*. www.pavementrenewal.org/#resources

5.2.4 Thin Overlays

Thin overlays and Thinlays™ are thin surface mixes that are 1.5-inch thick or less and placed on a well-prepared surface for use as part of a pavement preservation/management program. Thin overlays are ideally suited for existing pavements with low to medium levels of surface distress and can provide 10+ years of service on asphalt surfaces and 6–10 years of service on concrete surfaces (Newcomb, 2009). Thin overlays can be used earlier in the deterioration cycle of a pavement to preclude the onset of more severe distresses that might make a thicker structural overlay necessary. By using Thinlays, agencies can extend the life of pavements that are in good to fair condition, decreasing life-cycle costs, improving ride, and decreasing roadway noise (Heitzman et al., 2018).

Motivation

- Business Opportunity
- Project Requirement

Reference

Heitzman, M.A., E.R. Brown, & J. Hickey (2018). *Thinlays for Pavement Preservation* (IS-141). National Asphalt Pavement Association, Lanham, Maryland.

Newcomb, D.E. (2009). *Thin Asphalt Overlays for Pavement Preservation* (IS-135). National Asphalt Pavement Association, Lanham, Maryland.

Watson, D.E., & M.A. Heitzman (2014). *NCHRP Synthesis 464: Thin Asphalt Concrete Overlays*. Transportation Research Board of the National Academies, Washington, D.C.

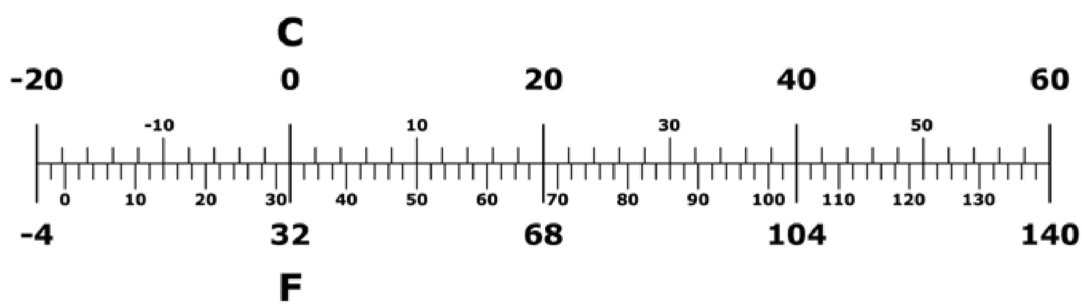
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSION TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	645.2	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L should be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lbs	pounds	0.454	kilograms	kg
T	short tons	0.907	megagrams	Mg
T	short tons	0.907	metric tonnes	t
NOTE: A short ton is equal to 2,000 lbs				
TEMPERATURE (exact)				
°F	Fahrenheit	$\frac{5(F-32)}{9}$	Celsius	°C

APPROXIMATE CONVERSION FROM SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lbs
Mg	megagrams	1.102	short tons	T
t	metric tonnes	1.102	short tons	T
NOTE: A short ton is equal to 2,000 lbs				
TEMPERATURE (exact)				
°C	Celsius	(1.8×C)+32	Fahrenheit	°F



*SI is the symbol for the International System of Units

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