Improving the Link Between Pavement Design and Asset Management: Pavement Design Functions, Processes, Inputs, and Outputs

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In 2018-2019, the FHWA conducted a review of its long-standing pavement design policy (23 CFR Part 626). Part of the review involved extensive stakeholder outreach to State Departments of Transportation (DOTs) and industry partners to solicit feedback on the policy and related guidance. Participants at several outreach events commented that clarity was needed regarding how pavement design policies relate to other regulatory requirements such as the State's Transportation Asset Management Plan (TAMP).

The FHWA recognized a need to further understand how project-level pavement design and network-level asset management could be better linked to help DOTs achieve long-lasting, safe, durable, cost-effective pavements. To identify potential strategies for improving the link between pavement design and asset management, FHWA conducted a case study of the New Jersey DOT and reviewed practices at several other State DOTs. Upon completion of this effort, a workshop was held to bring the participating State DOTs together to discuss the identified strategies and assess how they could be adapted for use by other DOTs.

The primary output of the case study is a set of web pages that contain information on the key roles and responsibilities of pavement design, pavement management, and transportation asset management (TAM) units. The website also contains information on potential strategies for establishing links between these units including critical communications and feedback loops that may be helpful in ensuring that the agency's processes and procedures are focused on common goals of maximizing pavement performance while minimizing long-term costs.

The purpose of this document is to provide an overview of pavement design for asset management professionals. This document provides information on pavement design functions, processes, inputs, and outputs. More detailed information on pavement design can be found from numerous other resources that are referenced in this document.</td></tr>
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1. INTRODUCTION

1.1. Purpose

This document provides a brief overview of typical pavement design practices and relates how these practices are relevant to Transportation Asset Management (TAM) and pavement management efforts. Additional information on pavement design can be found at the FHWA Pavement Design & Analysis web page or in the references and additonal sources listed at the end of this document.

1.2. Background

Transportation agencies such as State Departments of Transportation (DOTs) are responsible for operating, maintaining, improving, and expanding the approximately 8.8 million lane-miles of public roads and highways in the United States (USDOT 2020). As with all infrastructure assets, pavements are managed within available budgets and have finite service lives. Managing this expansive network involves continual investments in maintenance, preservation, rehabilitation, and reconstruction.

Pavement service life may be extended through maintenance, preservation, or rehabilitation actions. Many of these actions require the application of new paving materials on top of existing pavement. Some treatments require the structure of the existing pavement to be altered before the new materials are placed. For example, for flexible pavements the structure is commonly altered by removing some of the pavement from the surface by milling. For rigid pavements, a number of repair options can be used to extend service life as well as overlay with portland cement concrete (PCC) or asphalt concrete (AC).

Pavement design is a project-level engineering effort based on detailed engineering and economic considerations meant to optimize pavement type and layer thicknesses to achieve project objectives at the lowest life cycle cost (23 CFR 626.2). The pavement design process also helps to determine the most appropriate strategy thickness and associated design features for a specific pavement. Strategies can vary by pavement type, treatment type, or material. The cost of the pavement work represents a significant portion of overall capital expenditures for State DOTs and other highway owners. A primary objective of pavement design is to ensure that the subject of pavement construction, preservation, rehabilitation, or reconstruction project provides the desired service life in a safe and cost-effective manner.

2. PAVEMENT DESIGN POLICY

FHWA pavement design regulations (23 CFR part 626) provide State DOTs the discretion of choosing a design procedure best suited for their conditions and operating practices. Under this regulation, agencies have established procedures that ensure pavements are “designed to accommodate current and predicted traffic needs in a safe, durable, and cost-effective manner” (23 CFR 626.3). State DOTs’ individual practices support fulfillment of this requirement within their specific engineering, organizational, and financial constraints.

State DOT pavement design policies are developed and disseminated differently. In some agencies, a simple policy memorandum specifies the procedure(s) to be used in the pavement design process, along with basic supporting assumptions or criteria. In other agencies, the policy may take the form of a comprehensive pavement policy or design manual covering all aspects of the design process including:

- Testing and evaluation procedures for the existing pavement.

- Functional and structural design approaches for the new or rehabilitated pavement.
- Pavement strategy selection.
- Pavement preservation strategies.

3. PAVEMENT DESIGN FUNCTIONS

Pavement design is a project-level activity where engineering analyses are utilized to develop a pavement structure with adequate load-carrying capacity and desired performance for the given site conditions. Pavement design is a specialized field that requires specific training and software tools. The functions of pavement designers generally consist of the following, which may be performed internally by DOT staff or design consultants.

- Support project selection and scope development efforts.
- Compile available data and information pertinent to the design of a given project.
- Identify any pavement or geotechnical evaluation/testing activities or special traffic studies needed to properly conduct the pavement design analysis.
- Oversee and/or monitor the pavement or geotechnical evaluation/testing activities and compile the results for use in the design process.
- Identify feasible pavement/treatment alternatives in accordance with agency standards and specifications and conduct preliminary pavement designs for each alternative.
- Perform a strategy selection analysis considering costs and other factors and identify the appropriate pavement/treatment type.
- Conduct the final pavement design (as needed) for the selected pavement/treatment type.
- Prepare the pavement design report and submit it for approval in accordance with the agency approval process.
- Support contract/project delivery efforts (e.g., development of plans, specifications, and estimates) and the efforts of other entities (e.g., pavement management, construction, materials, maintenance, asset management).

The pavement design staff may have several ancillary functions as well. These include:

- Evaluate emerging pavement design methodologies and software programs, pavement and materials technologies, and construction practices.
- Develop and update unit cost and performance data for selected strategies.
- Develop and update pavement-related specifications and construction details.
- Review existing type selection procedures and programs, and identify practical opportunities for improvement.
- Implement new or updated design procedures and develop new or modified design inputs/assumptions.

- Implement revisions to strategy selection procedures as needed.
- Secure updated pavement design software licenses as needed.
- Update the pavement design manual (or pavement design chapter within the roadway design manual) and issue design bulletins as needed between manual updates.
- Train internal staff and/or consultants on the latest pavement design and strategy selection procedures.

4. PAVEMENT DESIGN PROCESSES

Pavement design can be described as a three-stage process.

4.1. Evaluation

During the evaluation stage, all available pertinent information about the project is compiled and all necessary site surveys and testing are performed. Information such as the agency's planned or programmed strategy, the existing pavement and site conditions, the history of the pavement and its performance, and the forecasted traffic provide an initial baseline for pavement design analysis. Important supplemental information is obtained through field activities such as subsurface soils testing, pavement coring, a detailed pavement condition survey, and falling weight deflectometer (FWD) testing. Samples collected in the field may undergo further lab testing as part of geotechnical investigation or materials testing.

Project-specific technical data are only a portion of the information used to conduct a project-level pavement design. The remaining information varies based on the agency's pavement design procedure and strategy selection procedure. This information includes established criteria that govern the design and type selection analyses, as well as supplemental design input data (e.g., lab- or research-derived data, estimates, or assumptions). Examples are provided in Table 1. Selection of performance criteria for pavement design should be coordinated with asset management and transportation performance management (TPM) goals.

The collected information is reviewed to identify feasible pavement/treatment strategies and to develop the required design inputs for each alternative. During this review, there may be opportunities to narrow the number of treatment strategies considered in the design analysis, based on certain factors such as excessive initial cost, past performance issues, or work zone traffic control challenges. Narrowing the number of alternatives reduces the work needed in the remaining stages.

Table 1. Examples of key information in a highway agency's pavement design procedure.

Component	General Design Parameter	Specific Design Parameters for AASHTO Guide Procedure (AASHTO 1993)	Specific Design Parameters for MEPDG Manual of Practice (AASHTO 2020)
Design Analysis	Design Period	Performance Period	Design Life
	Design Reliability	Reliability Level Standard Deviation	Reliability Level (for individual performance measures)
	Performance Measures	Present Serviceability Index (PSI)	International Roughness Index (IRI) Bottom-up and Top-down Fatigue Cracking Total and Hot-Mix Asphalt (HMA)-only Rutting Transverse Thermal Cracking Reflective Cracking Slab Cracking Transverse Joint Faulting
	Performance Criteria	Initial and Terminal PSI	Initial and Terminal IRI Terminal Cracking Terminal Faulting (Jointed Concrete Pacement(JCP)) Terminal Rutting (AC pavement)
	Model Calibration	—	Global or Locally Calibrated Factors
Traffic[1]	Axle Load Spectrum	Load Equivalency Factors	Number of Axles per Truck Axle Configuration
	Truck Loading Variations	—	Hourly Truck Distribution Factors Monthly Truck Adjustment Factors
Subgrade Soil (if project-specific data are not available)	Type	—	AASHTO Classification
	Physical Properties	—	Gradation Atterburg Limits
	Strength/Stiffness Properties	Resilient Modulus (w/ or w/o seasonal adjustments)	Resilient Modulus
Unbound Base/Subbase (if project-specific data are not available)	Type	—	AASHTO Classification or Aggregate Type
	Physical Properties	—	Gradation Atterburg Limits
	Structure	Layer Thickness(es)	Layer Thickness(es) and Orientation
	Strength/Stiffness Properties	Layer Structural Coefficient(s)	Resilient Modulus(i)
	Drainage Properties	Layer Drainage Coefficient(s)	—
Asphalt Concrete	Type/Mix	—	—
	Mix Properties	—	Binder Type Aggregate Type and Gradation Volumetrics (air voids, binder content, etc.)
	Structure	Layer Thickness(es)[2]	Layer Thickness(es)[2]
	Strength/Stiffness Properties	Layer Structural Coefficient(s)	Dynamic Modulus Indirect Tensile Strength Creep Compliance
Portland Cement Concrete	Type/Mix	—	—
	Mix Properties	—	Aggregate Type Cement Content Unit Weight
	Strength/Stiffness Properties	Modulus of Rupture Elastic Modulus	Modulus of Rupture Elastic Modulus
	Slab Properties	Load Transfer Coefficient Drainage Coefficient	Coefficient of Thermal Expansion Load-Transder Efficiency (LTE) Slab Width Slab Length (transverse joint spacing)

[1] Project-specific data are usually available for items such as initial 2-way Average Annual Daily Traffic (AADT), percent trucks, truck growth rate, and vehicle class distribution. Directional and lane distribution percentages may also be available, but often agency-established percentages are used.

[2] For fixed-thickness layers only, not the layer whose thickness is being determined.

4.2. Design Analysis

In the design analysis stage, each of the final pavement/treatment alternatives identified in the evaluation stage are designed in accordance with the agency's pavement design procedures.

While some agencies use proprietary pavement design procedures or have developed their own procedures, many agencies currently use one or both of the following:

- *AASHTO Guide for Design of Pavement Structures* and accompanying AASHTOWare® Design Analysis and Rehabilitation for Windows (DARWin) design software.

- *AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) Manual of Practice* and accompanying AASHTOWare® Pavement ME Design (PMED) software.

The mechanistic-empirical design procedure represents a major advancement in the design process. It incorporates, among other things, pavement responses and behavior under loading, an integrated climatic model, calibrated damage and distress prediction models, improved characterization of traffic and materials, and powerful analysis capabilities. Corresponding to this advancement is an increase in the number of required design inputs, as compared to previous methods, and the need to periodically verify that the performance prediction models are reasonable for local conditions.

Practice Example: Pavement Design Procedures

Several DOTs, like Arizona and Pennsylvania, use both the AASHTOWare® PMED and AASHTO 93 software to account for design uncertainties. Other DOTs customize the standard procedures based on their specific requirements. For example, Texas DOT has developed a Texas ME design software for Hot Mix Asphalt (HMA) and continuously reinforced concrete (CRC) pavements. Washington State DOT (WSDOT) uses standard design tables based on AASHTO 93, MEPDG, and performance history. Though most DOTs use either the original or customized versions of the standard design procedures, other design methodologies are also used, such as Texas DOT's *FPS 21*

Washington State DOT Pavement Design

Pavement designs for WSDOT are conducted in agency-designated Regions in a decentralized manner. To maintain accountability and consistency, WSDOT has developed a rigorous process that is documented in the *Washington State Department of Transportation Pavement Policy* (WSDOT 2018). This policy uses a catalog approach for pavement design and material selection to make the design easier for the end user. The WSDOT Pavement Policy is based on the 1993 AASHTO Guide for Design of Pavement Structures and the AASHTO Mechanistic-Empirical Pavement Design Guide version 1.0, as well as Washington State DOT's experience and historical data.

According to the policy, initial pavement designs are developed by the regional office that is responsible for designing the project. The initial design is then reviewed by the Central Office. More complex pavement designs are typically conducted in the Central Office due to staffing limitations in the Regions. Engineering judgment is applied to make sure that input values are reasonable and to determine if project-specific unique strategies need to be considered.

4.3. Strategy Selection

In the third and final stage, the resulting design for each strategy is analyzed. Depending on the agency and the number of strategies being considered, the selection process may be as simple as selecting the only strategy considered or as elaborate as conducting a detailed LCCA and performing a strategy scoring analysis. Examples of parameters used to support strategy selection are provided in Table 2.

Several DOTs have developed their own strategy selection and economic analysis procedures and tools for use in the pavement design process. Instrumental to the development of these procedures and tools have been the FHWA's *Interim Bulletin on Life-Cycle Cost Analysis in Pavement Design* (Walls and Smith 1998) and accompanying RealCost LCCA spreadsheet program and the NCHRP *Guide for Pavement Type Selection* (Hallin et al. 2011).

Table 2. Examples of key information in an agency's strategy selection procedure (adapted from Walls and Smith 1998 and Hallin et al. 2011).

Component	General Parameter	Specific Parameters
LCCA	LCCA Analysis	Analysis period Discount rate Cost factors to be considered
	Life-cycle Models	Expected types, sequence, timings, and performance lives of future treatments for each alternative
	Agency/Direct Costs	Unit costs of individual pay items for initial and future treatments for each alternative Maintenance of traffic costs for each alternative Design and/or construction engineering costs
	User/Indirect Costs	Work zone details and assumptions for initial and future treatments for each alternative Vehicle operating costs (idling cost rates and added time and added cost rates) Travel time delay costs (value of time and other details)
Type Selection	Selection Factors	Selection factors to be considered
	Factor Weightings	Level of importance weightings assigned to selected factors

Considerations in the LCCA Processes of Pennsylvania DOT, WSDOT, and Iowa DOT

Pennsylvania DOT

For reconstruction and rehabilitation projects greater than 30,000 square yards, the Pennsylvania DOT performs a LCCA to determine the lowest cost alternative. Both agency and user costs are considered in the selection process similar to the process outlined in the FHWA's *Interim Bulletin on Life-Cycle Cost Analysis in Pavement Design* (Walls and Smith 1998). Factors to consider other than cost include pavement performance history and adjacent pavements.

Washington State DOT

For reconstruction and large-scale projects, WSDOT uses a probabilistic LCCA including user costs in their pavement type determination process as outlined in the WSDOT Pavement Policy. The WSDOT approach follows the principles of the FHWA's *Interim Bulletin on Life-Cycle Cost Analysis in Pavement Design* (Walls and Smith 1998) and uses FHWA's LCCA analysis software, RealCost, as the computational tool. WSDOT's approach is unique in that it compares alternatives based on equivalent uniform annual costs (EUAC) rather than present worth (PW). For preservation projects, alternatives are selected based on historical lane-mile costs.

Iowa DOT

The Iowa DOT made a recent update to their LCCA process that includes user benefits from smoother pavement over time in the calculation to determine pavement type and rehabilitation strategies. The pavement smoothness benefit is calculated as (in/mi)*years and is based on the projected smoothness over the analysis period using the IRI, as forecasted by their dTIMS software and performance curves.

5. PAVEMENT DESIGN INPUTS

Pavement design inputs consist of the preliminary scoping information for a given project and the project-specific technical data required to perform a design analysis and strategy selection. The scoping information includes general project data (e.g., location, limits, traffic, geometrics, existing pavement type, and condition) and the recommendations and criteria for what should be done (e.g., scope of work including pavement/treatment type, construction cost, construction timing).

Project-specific technical data include details about the history, conditions, and characteristics of the project such as the existing subgrade soil(s) and pavement structure(s), the current and expected future traffic, and the prevailing climate and site conditions. Table 3 shows the technical data needed depending on the type of pavement/treatment being designed and evaluated as well as the pavement design procedure and strategy selection procedure being used.

Table 3. Example pavement design data obtained from testing and evaluation (adapted from AASHTO 1993 and AASHTO 2020).

Data Type	Details
Pavement History (construction logs and maintenance records)	Original construction (pavement type/structure and year)
	Rehabilitation/preservation treatments (types/thicknesses and years)
	Maintenance (types and years)
Subsurface Conditions (geotechnical investigation and/or soils maps)	Subgrade soil types and properties
	Water table levels
Existing Pavement Surface Conditions (manual or automated distress survey, profile testing, and friction testing)	Distresses (cracking, patching, potholes/spalls, raveling, etc.)
	Wheel path rutting
	Transverse joint faulting
	Roughness
	Friction
	Patching needs (locations, dimensions, and quantities based on distress types and severity levels)
Existing Pavement Structural Capacity (destructive and non-destructive testing)	FWD deflection data, backcalculated material layer moduli, joint load transfer efficiency data
	Dynamic cone penetrometer (DCP) penetration data for unbound material layers
Existing Pavement Material Layer Thicknesses and Conditions and Layer Interface Conditions (destructive and non-destructive testing)	Coring
	Ground penetrating radar (GPR)
Traffic (traffic records and forecasts, special traffic studies)	Average annual daily traffic (AADT)
	Average annual daily truck traffic (AADTT) or percent trucks
	Traffic growth rate
	Vehicle class distribution
	Axle load distribution
	Truck directional and lane distributions
	Calculated equivalent single axle loads (ESALs)
	Operational speed
Climate (weather station data, climatic data)	Precipitation
	Temperature
	Freeze-thaw days or cycles
	Other (relative humidity, cloud cover, wind speed)
Site Conditions (field survey)	Drainage (surface and roadside)
	Geometrics (lanes, shoulders, medians, intersections, etc.)
	Safety (surface polishing, edge drop-offs or buildups, safety feature conditions)
	Topography/terrain
Safety (crash records)	Crash locations and numbers
	Crash rates
Costs	Pay item unit costs for materials and construction activities

New Jersey DOT Pavement Design Inputs

The New Jersey DOT has a rigorous pavement evaluation process that provides a wealth of data for pavement design. When projects are selected for pavement reconstruction, rehabilitation, or resurfacing, the New Jersey DOT prepares a Pavement Evaluation Report containing:

- DCP test results, which provide estimated layer thickness and elastic moduli for unbound layers.
- Core data, which provide pavement layer thickness, visual condition assessment, and can be forwarded for material testing if desired.
- Layer thicknesses and material types from pavement history.
- Materials information from material databases and testing.
- FWD test results, which provide estimated pavement layer elastic moduli from backcalculation of the surface deflections.
- Subgrade information based on visual evaluation (transitioning to collecting and testing undisturbed samples).
- Traffic data, including detailed future traffic loading from traffic database (TRADAS).

The pavement designer also has access to a database of New Jersey's soil properties located spatially across the state. For asphalt materials, a materials catalog was developed by Rutgers University by testing new asphalt mixtures for their engineering properties.

The Pavement Evaluation Report, the soil property database, and materials catalogue provide the designer the information necessary to assign existing and new layer properties and projected traffic loadings for use in the 1993 AASHTO Guide for Design of Pavement Structures and the AASHTO MEPDG Manual of Practice pavement design process.

6. PAVEMENT DESIGN OUTPUTS

The key output of the pavement design process is the final approved design for the selected pavement/treatment type. The final design typically includes details on the proposed pavement structure or treatment, such as material type and thickness of each pavement layer. The approved design report typically includes all the project-specific technical information compiled for the project, as well as a listing of the inputs and assumptions that were used in the design process. It may also contain relevant design outputs such as predicted performance curves, an assessment of treatment needs at the conclusion of the design life, life-cycle cost calculations, and type selection analysis results. The information in the approved pavement design report may be used by units within the agency including roadway design, pavement management, asset management, construction, and materials.

7. THE LINK BETWEEN ASSET MANAGEMENT AND PAVEMENT DESIGN

Pavement design is a project-level activity used to develop a cost-effective engineering solution within project scope, budget, and other constraints for a given site condition. In contrast, asset management is a strategic and systematic process that supports management of asset conditions throughout the entire asset life cycle – new construction, maintenance, preservation, rehabilitation, and reconstruction (23 CFR 515.5).

Despite the differences between the two processes, both asset management and pavement design influence each other. Asset management investment strategies influence project prioritization and selection. Pavement design ensures pavement construction, preservation, rehabilitation, and reconstruction projects provide the expected long-term performance in a cost-effective manner. Linking these two processes supports achievement of an agency's pavement objectives by making sure project-level decision makers are aware of the strategic implications of their decisions. It also helps ensure that strategies are developed with an understanding of how pavements are designed and are likely to perform.

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