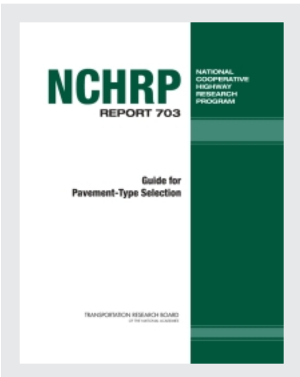

Guide for Pavement-Type Selection

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Transportation Research Board

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 703

Guide for Pavement-Type Selection

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in cooperation with the Federal Highway Administration

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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Mr. Hallin was supported in the research by ARA Research Engineers, Dr. Suri Sadasivam, Mr. Jagannath Mallela, Mr. David Hein, Dr. Michael Darter and Mr. Harold Von Quintus. Ms. Robin Jones served as the technical editor.

The research team gratefully acknowledges the participation and cooperation of state departments of transportation (DOTs) and industry associations who responded to the questionnaire survey on pavement-type selection practices. The team also acknowledges the contributions of Messrs. Jay Goldbaum of Colorado DOT, John P. Donahue of Missouri DOT, Craig White and Paul Ruttan of 407 Express Toll Route (ETR) to the pavement-type selection case studies.

FOREWORD

By Amir N. Hanna
Staff Officer
Transportation Research Board

This report presents a recommended *Guide for Pavement-Type Selection*. The guide includes practical, logical, and transparent processes for conducting systematic evaluations of pavement alternatives and for making decisions on pavement-type selection. These processes can be used for both agency-based and contractor-based type selections and may be applied to different pavement types and structures. These processes are supplemented by examples to illustrate the application of the recommended guide for the commonly encountered scenarios of alternative bidding and design-build of operations and maintenance projects. The material contained in the report will be of immediate interest to state pavement engineers, design consultants, paving contractors, and others involved in project design and pavement-type selection.

The pavement-type selection process traditionally uses life-cycle cost analysis concepts to model the cost of pavement alternatives during a performance period. However, other forms of pavement selection processes have emerged in recent years. For example, some state departments of transportation have opted to the selection of pavement type or other highway materials through the alternate design/alternate bidding procedure that allows the bidding contractors to select the pavement type that will be constructed. However, the effectiveness and equity of these innovative pavement-type selection processes are not well documented and often not considered. Research was needed to identify and evaluate current practices and develop rational processes that consider all relevant factors and provide a realistic means for pavement-type selection. Also, there was a need to incorporate these processes into a *Guide for Pavement-Type Selection* to facilitate use by highway engineers and administrators.

Under NCHRP Project 10-75, "Guide for Pavement-Type Selection," Applied Research Associates, Inc. of Champaign, Illinois, worked with the objective of developing a *Guide for Pavement-Type Selection* that included processes for consideration in making decisions regarding pavement-type selection for agency-based (decision is internal to the highway agency) and contractor-based (selection is made by the contractor using criteria stipulated by the agency) options. To accomplish this objective, the research identified and evaluated traditional and innovative processes for pavement-type selection and incorporated the best practices into a rational *Guide for Pavement-Type Selection*. The processes contained in the guide address the identification of feasible pavement alternatives, the consideration of economic and noneconomic factors, and the selection of preferred alternatives. These processes are supplemented by examples to illustrate the application of the recommended guide for two commonly encountered scenarios of pavement-type selection.

The research agency's final report provides further elaboration on the work performed in this project. This document, titled "Research Report," is not published herein, but it is available on the *NCHRP Report 703* summary webpage at http://www.trb.org/Main/Blurbs/165531.aspx.

C O N T E N T S

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

Guide for Pavement-Type Selection

This proposed guide, prepared as part of NCHRP Project 10-75, "Guide for Pavement-Type Selection," is a recommendation by NCHRP Project 10-75 staff at Applied Research Associates, Inc. This guide has not been approved by NCHRP or any AASHTO committee or formally accepted for adoption by AASHTO.

CHAPTER 1

Introduction

1.1 Background

Pavement-type selection is one of the challenging engineering decisions that highway administrators face today. They must balance issues of both short- and long-term performance with initial and long-term costs, as well as highway user impacts. The traveling public generally does not express strong feelings on the type of pavement constructed, as long as reasonable levels of service, safety, and ride quality are provided.

Pavement-type selection is a management decision process where the choice of engineering factors such as materials and structural performance must be weighed against initial and life-cycle costs. There is a certain level of risk involved in the process because of the variations in both performance and costs. Further, the typical life span of a long-life pavement system may be 30 years or more. Changes in the characteristics of the vehicle traffic over the pavement's service life can have a significant impact on performance and life-cycle costs.

Because of the competitive nature of the pavement industry, controversies and legislative reviews of the pavement-type selection process are not uncommon. Therefore, there is a need for a balanced and transparent process for making pavement-type selections that objectively considers different pavement design strategies representing the best solution on a specific project or roadway.

It is important that the reasons for reaching the decision be fully documented. The pavement type selected for a given project may be disputed at some subsequent time, but if sound reasons are outlined and documented, the matter becomes only a difference of opinion. Thus, the factors that control pavement-type selection should be documented, and the persons involved in the decision-making process should be identified.

1.2 Objective and Scope

This *Guide for Pavement-Type Selection* provides a comprehensive set of procedures that highway agencies can use to develop pavement-type selection policies and processes. Each step is described, and the factors that must be considered are identified. Because of differences in agency decision-making processes, it is expected that each agency will adopt or modify these procedures to meet its specific needs.

1.3 Application

The successful application of the pavement-type selection process requires a multidisciplinary approach within the agency, as well as the involvement of representatives from the paving industry. The process will need to be tailored to address an agency's goals and any applicable state laws. Key features that must be addressed include the following:

1. *Type of Projects Covered by the Procedure*: The pavement-type selection procedure is detailed and requires a rigorous effort to achieve rational results. Therefore, the procedure will yield benefits that outweigh the costs of performing the process only for projects that are significant enough in scope. Each agency needs to develop a policy governing when and how the process will be applied. The following factors should be considered in establishing a policy on selecting projects for inclusion in the pavement-type selection process:
    - Project cost.
    - Project length.
    - Traffic type.
    - Traffic volume.
    - Road system classification.
    - Pavement quantity.
    - Presence of bridge structures.
    - Lane modifications or additions.
    - Ramps.
    - Acceleration/deceleration lanes.
2. *Identification of Alternatives*: Development of a process for identifying pavement alternatives currently used, assessing their performance, and identifying promising new alternatives.

3. *Application of a Life-Cycle Cost Analysis (LCCA) Procedure*: This includes identification of a computational model as well as the gathering of cost and performance data for each alternative to be considered. Guidance and computational procedures for performing LCCA are being improved all the time, and it is important that the agency keep abreast of these developments.
4. *Evaluation of Economic and Noneconomic Factors*: After the LCCA is completed, the feasible alternatives must be evaluated to determine whether they meet the agency's goals. An agency must identify those factors that previously have been used in determining pavement type, as well as newly identified factors, and weigh their importance. This guide describes the types of factors to consider and the development of a screening matrix to evaluate these factors.
5. *Development of Policies for Alternate Bidding*: Alternate bidding provides a competitive method of selecting a pavement alternative when two or more equivalent pavement alternatives are identified for a specific project. Policies will need to be developed as to when alternative bidding is to be used, along with the processes to be followed.
6. *Development of Policies for Alternative Contracting Projects*: The limits and criteria to be used for allowing the bidder to select the type and design of pavements on alternative contracting projects, such as design-build and performance warranty projects, will need to be determined.

1.4 Organization and Use

This guide is organized into seven chapters.

Chapter 1 includes introductory material.

Chapter 2 provides an overview of the pavement-type selection process, including a flow chart outlining the entire process. This guide addresses agency-based selection for traditional design-bid-build and alternate pavement-type bidding projects, as well as contractor-based selection for design-build and warranty projects.

Chapter 3 outlines the steps to identify and evaluate potential pavement alternatives that should be considered in the pavement-type selection process. This chapter also presents a discussion on developing strategies for each alternative to sustain the desired performance level over the pavement's life cycle.

Chapter 4 describes LCCA of pavement alternatives, including establishing an LCCA framework, estimating initial and future costs, computing life-cycle costs, and analyzing and interpreting the results.

Chapter 5 provides detailed guidance on the evaluation of pavement alternatives using economic and noneconomic factors. This chapter also provides guidance on the application of an alternative-preference screening matrix in selecting the preferred pavement type. The application of the screening matrix is illustrated with an example presented in Appendix A.

Chapter 6 presents a discussion on the use of alternate bidding to select between two equivalent pavement alternatives. On these projects, the agency provides the alternatives and specifies them in the bid document, and the contractor must choose one of the agency-provided alternatives. The agency develops the bid adjustment factors based on its own pavement life-cycle model.

Chapter 7 outlines the processes for contractor-based pavement selection on design-build and warranty projects. For these projects, when the contractor is responsible for all or portions of the pavement design and selection processes, the project criteria generally require the contractor to follow processes similar to the one used by the agency for design-bid-build projects. However, the process may be modified if the contractor provides extended warranties or assumes responsibility for operations and maintenance.

Appendix A illustrates the application of an alternative-preference screening matrix for pavement-type selection. Appendixes B and C present examples to illustrate the pavement-type selection process for alternate bidding and design-build operations and maintenance projects, respectively. A summary of the research performed in NCHRP Project 10-75 that led to the development of this *Guide for Pavement-Type Selection* is presented as an attachment to this guide.

CHAPTER 2

Overview of the Pavement-Type Selection Processes

2.1 Overview

For any given project, the selected pavement type is expected to provide the maximum utility value for taxpayers and facility users over a predetermined design and analysis period. The process for selecting pavement type should consider the project requirements as well as the agency's operational policies and public goals. It entails a careful and rational consideration of economic, engineering, and environmental factors.

The pavement-type selection process entails identifying two or more feasible alternatives for a specific project from a broader group of pavement types or design strategies. A pavement life-cycle model is developed for each proposed alternative that constitutes an initial pavement structure and a sequence (type and timing) of probable maintenance and rehabilitation (M&R) activities. Based on the agency and user costs associated with these activities, the competing alternatives are evaluated for their cost-effectiveness. The economic analysis over the entire life cycle of the pavement is performed using a deterministic or probabilistic approach. The alternatives are further evaluated to select a preferred strategy using economic and noneconomic factors that reflect the agency's goals, policies, experience, and project-specific conditions.

A flow chart of the pavement-type selection process is provided in Figure 1. As shown, this process is applicable to both agency-based and contractor-based pavement-type selection.

2.2 Agency Planning and Programming

The pavement-type selection process begins with the agency's determination of the contracting type for the project. A project may be procured through traditional design-bid-build or alternate contracting methods. The agency-based selection process generally is used for design-bid-build projects. Alternate pavement-type bidding may be used on traditional design-bid-build projects. In those cases, the agency identifies equivalent alternatives for the contractor to choose from during bidding.

For design-build projects, the agency may determine the final pavement type for the project, or otherwise may allow the contractor to select the pavement type using the criteria contained in the request for proposals (RFPs). Contractor-based selection typically is used for projects where the contractor undertakes long-term responsibility for operations and maintenance (O&M) or performance warranty. For projects that require contractor-based selection, the agency develops contract provisions for the request for proposals or the bid documents. As discussed in Chapter 3, the inputs from the agency's pavement-type selection committee are incorporated in identifying feasible alternatives and developing contract clauses for both agency-based and contractor-based selection projects.

2.3 Identification of Feasible Pavement Alternatives

The agency-based process begins with identifying potential candidates for a specific project from an approved list of pavement types. However, the agency may consider some candidates inappropriate for the project because of physical constraints, constructability issues, or other reasons. The acceptable alternatives are then considered appropriate (feasible) candidates for further analysis. Additional discussion of feasible pavement alternatives is presented in Chapter 3.

2.4 Development of Life-Cycle Strategies for Pavement Alternatives

For each feasible candidate, the agency identifies the pavement life-cycle strategies required to achieve target performance levels over a chosen analysis period. The strategies include identification of the initial pavement section together

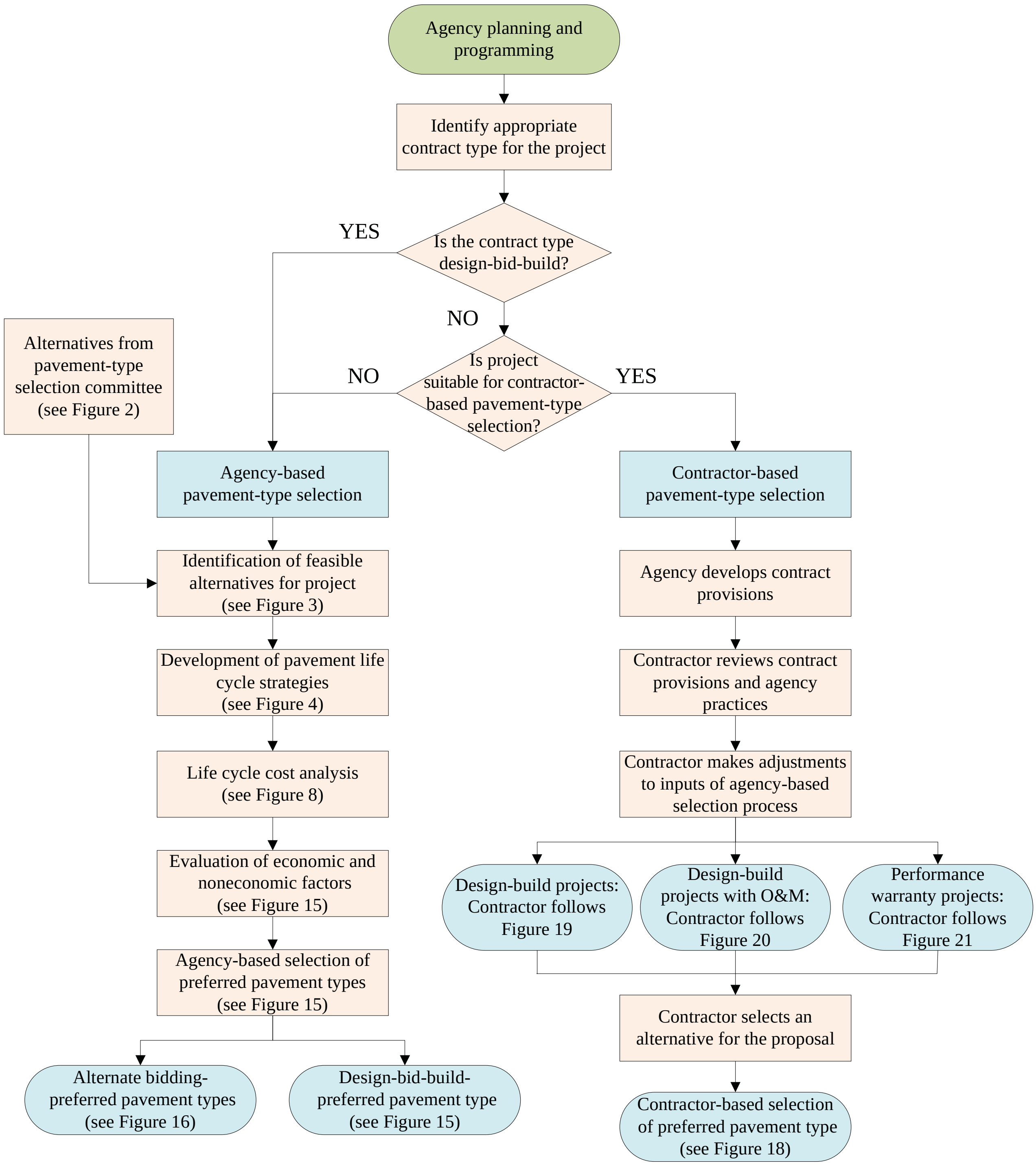

Figure 1. Overview of the pavement-type selection process.

with the timing and type of future maintenance and rehabilitation activities. The pavement life-cycle model is a conceptual representation depicting the proposed strategies on a time scale. Chapter 3 provides details on developing life-cycle strategies for alternatives.

2.5 Life-Cycle Cost Analysis

The direct agency costs for initial construction and future M&R activities of each proposed alternative are estimated and converted into a single discounted life-cycle cost (net present value, NPV). Similarly, the NPV of work zone user costs associated with these activities is estimated for each alternative. The alternatives are then compared for their cost-effectiveness by evaluating the agency costs and user costs independently. A detailed discussion of LCCA is presented in Chapter 4.

2.6 Evaluation of Economic and Noneconomic Factors

Upon completion of the LCCA, the alternatives are evaluated using economic and noneconomic factors that reflect an agency's goals, operational policies, and individual project needs. A list of such factors is provided in Chapter 5. The alternatives that are not feasible from a cost perspective are eliminated from future consideration. All alternatives found to be cost-effective are evaluated using noneconomic factors to determine whether a specific alternative has overriding factors that make it a preferred alternative (or not desirable such that it should be eliminated).

When an alternative meets economic needs and there are no noneconomic risks to outweigh its inclusion, the alternative is considered as qualified for further evaluation. If there are two or more qualified alternatives, they are compared using the alternative-preference screening matrix. Chapter 5 presents a detailed discussion on the steps involved in using a screening matrix, and Appendix A illustrates its application with an example.

2.7 Agency-Based Selection of Most-Preferred Pavement Type

In the final step of the selection process, the agency selects the most-preferred pavement type(s) for the project. If one alternative is considerably more preferred over other alternatives, then the alternative can be selected as the most-preferred alternative for use in traditional design-bid-build projects. If several months have elapsed between the original pavement-type selection and a call for bids, the selection should be reviewed to ensure that conditions have not changed.

If the results of the alternative-preference screening matrix do not indicate a clear preference, all alternatives qualify as candidates for alternate pavement-type bidding. The suitability of the alternate bidding procedure for the project should be evaluated. If suitable, a cost adjustment factor should be determined from the difference in the discounted future costs of the alternatives. If the project is unsuitable for alternate bidding, any of the preferred alternatives can be selected as the final pavement type. Chapter 6 presents a detailed discussion of the alternate pavement-type bidding method.

2.8 Contractor-Based Pavement-Type Selection

Contractor-based type selection takes several forms and is controlled largely by the contract provisions specified in the RFP. The agency typically communicates the project requirements to the contractor using contract provisions. These provisions often are unique to an agency, contract type, and project-specific goals. Therefore, the contractor's involvement is related to project-specific contract obligations, the risks undertaken by the contractor, and the agency's level of control.

In design-build projects (where the contractor assumes no operational responsibilities and provides no long-term warranty), the agency is responsible for risks associated with future performance. In such cases, the agency can stipulate the preferred pavement type(s) or allow the contractor to select a pavement type based on the agency-specified criteria (e.g., design inputs and life-cycle strategies). In either case, the contractor can follow the agency's selection process or any other similar process accepted by the agency.

In projects involving O&M responsibilities and long-term performance warranty, the contractor assumes the risks associated with post-construction for an extended period of time. In such cases, the contractor selection process is stipulated largely by the performance criteria specified in the RFP. Therefore, it is imperative that bidders review the contract provisions, understand agency practices, and evaluate risks before undertaking the selection process. For pavement-type selection, the contractor can follow the overall framework described in this chapter, with the discretion to use customized inputs as deemed necessary. Upon selection, the agency validates the assumptions and criteria used in the contractor-based selection process.

Based on the agency's validation and independent evaluation, the agency may accept (assign a high score to the pavement component of the contractor's proposal), reject (assign a low score), or initiate negotiations for further modifications. Chapter 7 presents a detailed discussion of contractor-based pavement-type selection and the steps involved in various contracting scenarios.

CHAPTER 3

Identification of Pavement Alternatives and Development of Pavement Life-Cycle Strategies

3.1 Overview

This chapter presents a process for identifying feasible pavement-type alternatives for a given project by considering life-cycle strategies required to achieve a desired performance level throughout a specific period. The process begins with identifying potential alternatives to be considered. From this broad group of alternatives, unfeasible options are eliminated by applying project-specific constraints. Strategies (including initial pavement structural design and probable M&R activities) over the life cycle of the pavement are identified for each of the remaining alternatives.

3.2 Pavement-Type Selection Committee

It is suggested that agencies form a pavement-type selection committee that includes representation from pavement design, materials, construction, and maintenance groups. The committee should provide a formal mechanism for seeking input from the paving industry. The purpose of the committee is to identify a broad range of alternatives for consideration in a systematic and unbiased manner. The following are the key responsibilities of the committee:

- Developing and maintaining a list of strategies that should be considered in the pavement-type selection process.
- Addressing sustainability and other nonengineering considerations.
- Making the pavement-type selection on projects where multiple feasible alternatives are identified, with no clear advantage to any of the alternatives.
- Performing periodic reviews of the pavement-type selection process and recommending modifications for improvement.

3.3 Development of Potential Alternatives

The pavement-type selection process should be comprehensive and transparent. Engaging a pavement-type selection committee composed of representatives from the agency, industry, and the research community would ensure that a broad range of input was received on existing as well as innovative techniques. The selection process would provide a set of alternatives that should be considered. It is expected that these alternatives reflect the findings of national and state research studies, regional experience, type and size of projects, and type of traffic the pavement is expected to carry. Figure 2 presents a suggested process for the selection of potential alternatives.

One of the key components of identifying alternatives is determining what does or does not work in the geographic area where the project will be constructed. An agency's pavement management system is a good source of data for making this determination. Pavement management systems usually contain condition data that can be used to determine the performance of the various pavement designs and materials. Where pavements perform better than expected, this input can be fed into the LCCA. Where pavement performance is not as good as expected, an evaluation should be made to determine if the deficiencies can be corrected through design or material modifications. This process also may identify regions or specific traffic conditions where there are differences in performance. However, using these data should not preclude the consideration of designs for which the agency has little or no experience. In those cases, performance estimates can be based on the experiences of other agencies, together with the application of analysis tools such as the American Association of State Highway and Transportation Officials (AASHTO) *Mechanistic-Empirical Pavement Design Guide, Interim Edition: A Manual of Practice* (AASHTO 2008). The sustainability of the various alternatives also must be considered.

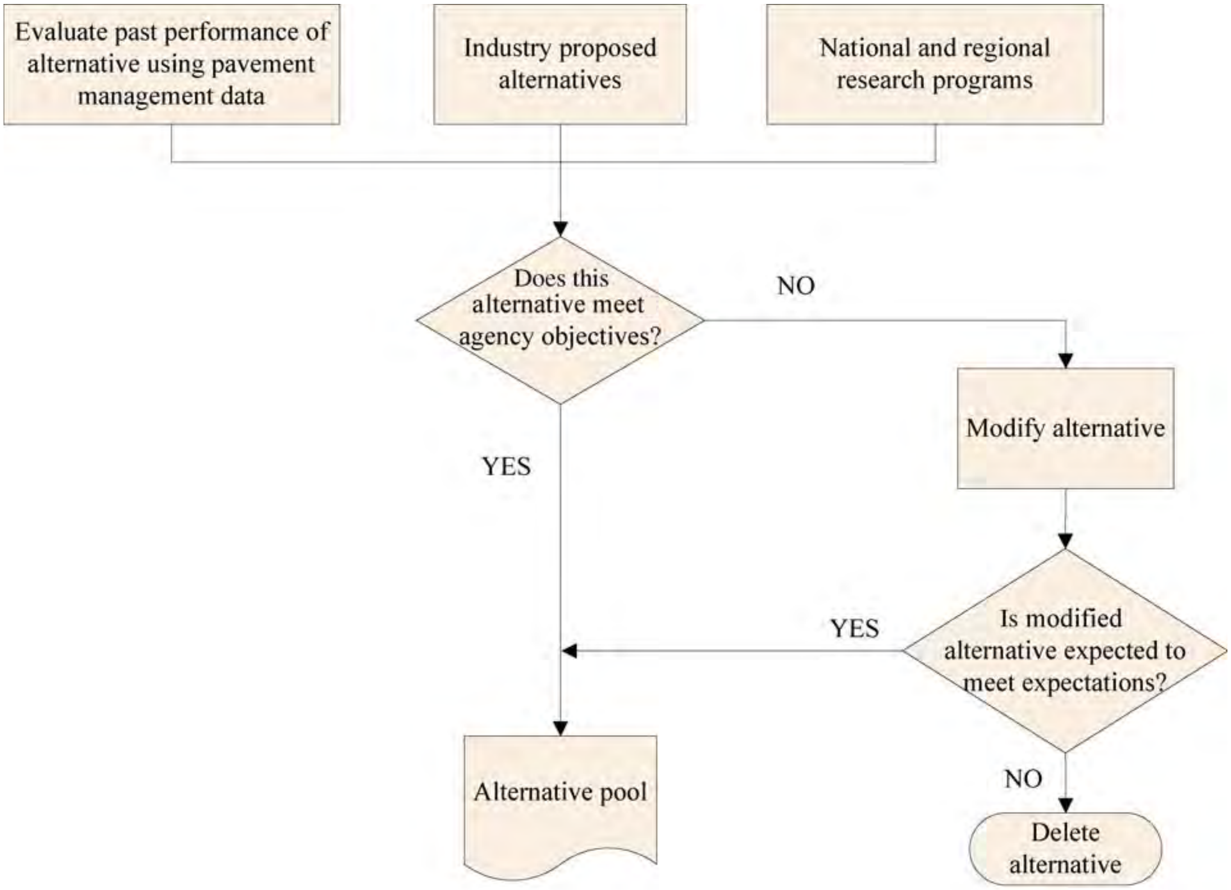

Figure 2. Process for determining alternatives for consideration in pavement-type selection.

It is important that the selection process allows for the consideration of innovative approaches that may be identified by the pavement industry and other sources. The industry associations generally are familiar with the designs and techniques being used under a variety of conditions and the extent of their success. Therefore, the pavement-type selection committee should request input from industry associations. The performance of these innovative approaches needs to be quantified for the LCCA and M&R schedules used in the LCCA process. The third major component of the alternative identification process is a program for monitoring and evaluating the results of ongoing research programs at both the national and regional levels.

3.4 Identification of Alternatives for a Specific Project

Within the broad group of alternatives, certain choices may be inappropriate for a specific project under consideration. The following factors should be considered in evaluating alternatives for a specific project:

- **Functional class.** There are three functional classifications: arterial, collector, and local roads. All highways and roadways are grouped into one of these classes, depending on the character of the traffic (i.e., local or long distance) and the degree of vehicle access permitted. Some pavement-type alternatives may not be appropriate for specific functional classes.
- **Traffic level/composition.** The percentage of commercial traffic and frequency of heavy load applications have a major effect on the alternatives appropriate for a specific project. Agencies may choose to establish minimum structural requirements to ensure adequate performance and service life for minor facilities where traffic is unknown. For heavily trafficked facilities in congested locations, the need to minimize the disruptions and hazards to traffic may dictate the selection of strategies having long initial service lives with little M&R needed, designed at a high level of reliability.
- **Existing pavement condition and historical condition trends.** The condition of the existing pavement and its historical performance, as determined through manual or automated distress surveys and smoothness testing, can impact the identification of alternatives for both reconstruction and rehabilitation projects. Overall condition indicator values; distress types, severities, and amounts; and ride quality measurements help define the structural and functional needs of

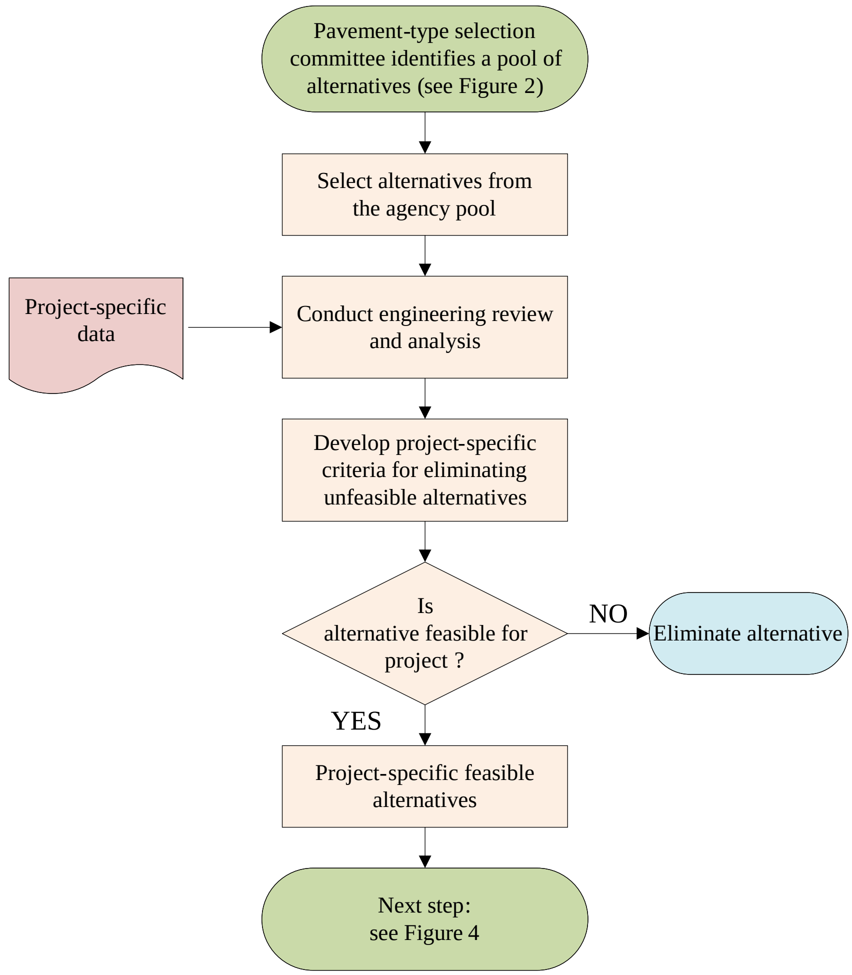

Figure 3. Identification of pavement alternatives for a project.

the pavement. Such needs are better addressed by some alternatives than others, thus helping narrow the list of feasible alternatives.

- **Detailed evaluation of existing pavement properties.** Coring, nondestructive testing, and other on-site evaluations (drainage, friction) provide information on the causes, extent, and variability of pavement distress and the structural and functional capacities of the existing pavement.
- **Roadway peripheral features.** Peripheral features such as guardrails, curbs and gutters, traffic control devices, overhead clearances, and on-grade structures may play important roles in the selection of alternatives. Such features may have special bearing on rehabilitation work where grade changes are limited. For example, in some cases, recycling or reconstruction may be more desirable than an overlay.

In practice, the broadest range of alternatives (including the various forms of recycling) should be considered on each project. However, certain alternatives may not be appropriate for certain classes of roads or under certain traffic conditions. In addition, there may be project features that limit the number of feasible alternatives. Decisions regarding the identification of alternatives at the project level should be documented in the pavement-selection document. This step is presented in Figure 3.

3.5 Development of Pavement Life-Cycle Strategies

For each alternative identified and designed, a life-cycle strategy is developed to sustain the desired functional and structural performance level of the pavement over the chosen analysis period. The life-cycle strategy includes the construction of the original pavement structure, as well as rehabilitation, preventive maintenance, and corrective maintenance activities. Figure 4 presents a flow chart of this step.

Each alternative pavement should be designed for the same conditions of traffic level, reliability, life, and terminal performance thresholds that trigger rehabilitation. However, the required M&R activities, their timing, and associated costs will be different for design alternatives over the life of the pavement. In the long term, these differences result in different cost

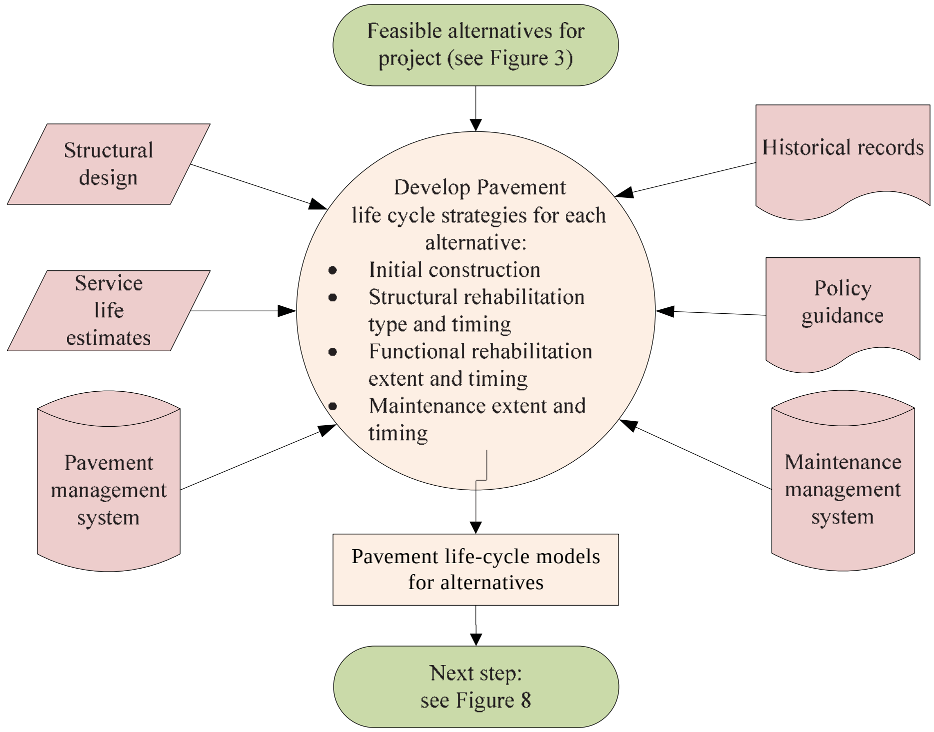

Figure 4. Development of a life-cycle model for pavement alternatives.

streams for alternatives developed with similar design and performance criteria.

Establishing the life-cycle model requires knowledge of the expected service lives of the original or structurally rehabilitated structure and the sequence of expected timing and extent of future M&R treatments, as illustrated in Figure 5. Viable strategies are selected for structural rehabilitation based on the predicted terminal pavement condition in the future. A viable strategy should be feasible from an engineering and economic standpoint, address existing causes of deterioration, and mitigate the recurrence of the same distress over the analysis period.

The selection of life-cycle strategies requires the collection and meticulous evaluation of a large amount of data. Such data pertain to the current project and similar past projects (e.g., in terms of pavement-structure design, costs, performance, traffic characteristics, climate, materials, or subgrade). Historical project data may consist of direct source data or could be manifest as practical-experience information held by the agency, its engineering consultants, paving contractors, or various other project stakeholders. Data should be updated and expanded as necessary to accommodate the continuous evolution of structural design, materials, specifications, and construction practices. As noted earlier, the suggested approach is to use data housed in an agency's pavement management system database.

If sufficient data are unavailable to incorporate new technologies, the past data can be considered along with research findings, specific evaluation and testing results, experience in other states, and modeling tools such as the *Mechanistic–Empirical Pavement Design Guide* (MEPDG) (AASHTO 2008).

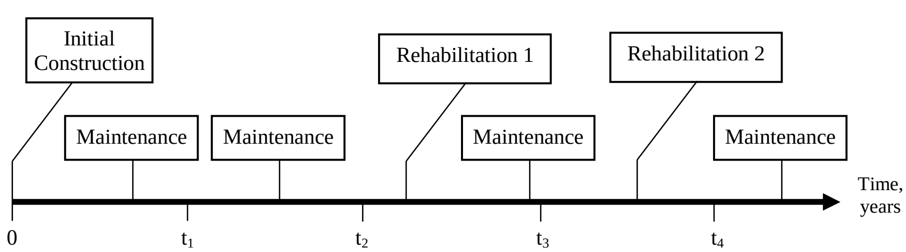

Figure 5. Example pavement life-cycle model.

3.5.1 Service Lives of Initial Pavement and Future Rehabilitation Treatments

The service life of the initial pavement structure before the first major rehabilitation and the service life of future rehabilitation treatments are estimated for each proposed alternative. The service life until rehabilitation depends on factors such as material durability, climate condition, construction quality, and traffic loading and may be shorter or longer than the design life of the pavement (Darter and Hall 1990).

Pavement service life can be estimated using various techniques, ranging from expert modeling using the opinions of experienced engineers to detailed performance-prediction modeling using historical pavement performance data to construct survival curves. The following guidelines are suggested when considering a technique for developing service-life estimates:

- Historical pavement performance data documented in the agency's pavement management system should be the first and foremost source.
- Expert opinions are prone to biases and should be considered only when reliable historical performance data are unavailable or are greatly limited, such as if the pavement or rehabilitation types being considered are substantially different, due to changes in traffic or use of new materials or technologies.
- Experience-based estimates, in conjunction with data trends from other sources, can be used in the absence of reliable and adequate historical performance data.

The following items should be taken into consideration when developing service-life estimates:

- The reliability and accuracy of estimates greatly depend on the data quality and the number of data points available.
- It is important to assess how closely the pavement management sections used in the analysis represent the pavement alternative under consideration. This requires grouping of pavement sections with similar characteristics as a "family" of pavements. A factorial table can be used to construct such pavement families. The grouping factors include, but are not limited to, similarities in structural design, traffic loading, functional class, climate, geographic region, pavement type, design features, design type, subgrade, and materials. For simplicity and clarity, the number of factors should be minimized as much as possible while remaining comprehensive enough to cover the entire range of distinct characteristics.
- If the design, materials, construction specifications, funding, or operating conditions of the pavement alternative are different from those available from pavement management files, the pavement-type selection committee should discuss appropriate adjustments.

The commonly used approaches in pavement management–based estimations are performance trends and survival analyses.

Performance-Trend Analysis

In performance-trend analysis, historical pavement condition data representing a given strategy are compiled and regressed over time. A threshold pavement condition level is then established that indicates the need to restore deteriorating functional and/or structural capacity. On the regression curve, the time at which the pavement reaches the threshold condition level is determined. The estimated time reflects the average age for a rehabilitation need or the estimated service life of the pavement.

Performance-trend analysis is essentially a four-step process:

1. Existing pavement sections with similar structural features, traffic loadings, subgrade type, and functional classes to those of the proposed alternatives are identified. The historical condition data of these sections are extracted from the pavement management system or other sources. Careful attention is given to the "representative" aspect of the selected pavement sections, and the data are screened for any factors that might have an unusual effect on pavement condition (e.g., design or construction issues and traffic loading). Sections that are not representative may warrant removal from the dataset.
2. Time-series performance plots are created using the condition data for each family of pavements. Best-fit linear or nonlinear models relating pavement condition to age are developed. To the extent possible, the time-series plots include separate trends for structural and functional indicators. Some data filtering usually is needed in eliminating the time-series data that reflect any significant improvement in pavement condition due to M&R activities.
3. Acceptable condition thresholds that serve as triggers for any major intervention should be identified. The threshold trigger values depend on factors such as the roadway type (rural or urban), functional class, size of highway network, agency's resources, policies, and programmatic constraints.
4. Service-life estimates are made for each family of pavements based on their condition trends and threshold values. These estimates can be developed using both deterministic and probabilistic analyses.

Figure 6 illustrates the estimation of functional service life for a family of pavements using smoothness data. In this example, a threshold International Roughness Index (IRI) value of 150 in./mi was used. The model trend line intersects the threshold IRI where the estimated service life is about 18 years. Therefore, in this example, the estimated mean for functional life

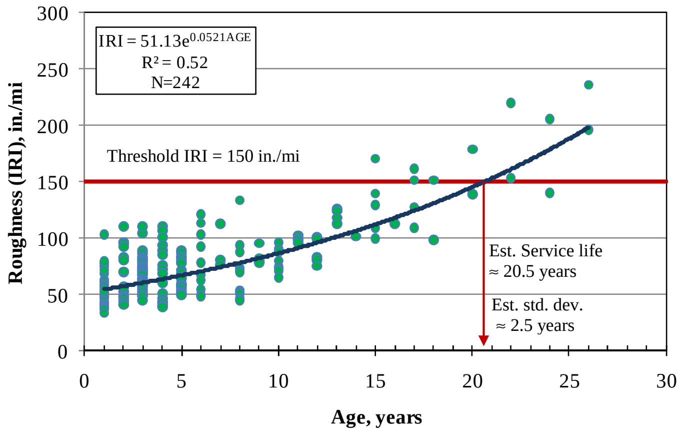

Figure 6. An example of functional life estimation for a family of pavements (N = number of observations).

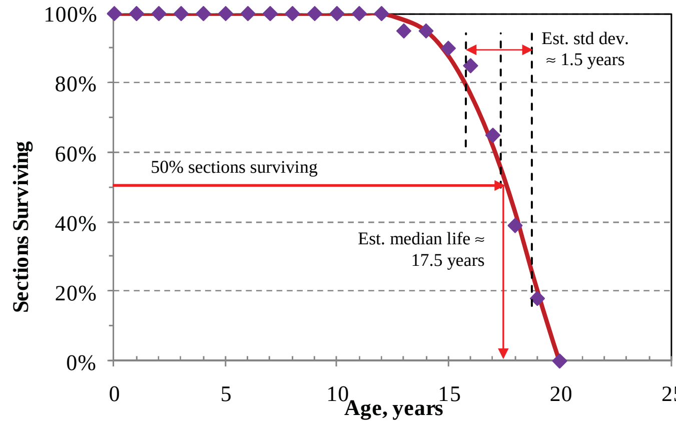

Figure 7. An example of pavement-family survival analysis.

(ride quality) is about 18 years, and the estimated standard deviation is about 2.5 years.

Survival Analysis

The "survival" of a pavement section is defined as the nonoccurrence of failure—or, in other words, the nonoccurrence of major rehabilitation. This technique uses historical construction and rehabilitation data for a family of pavements to construct a survival curve that plots the percent survival as a function of time (or traffic loadings). Using a value of 50 percent pavement sections surviving (or, conversely, 50 percent sections failed), an estimate of the median life (and standard deviation) for a pavement with similar features and loading conditions can be developed. Figure 7 shows an example survival curve developed for a family of pavements. The estimated median service life and the standard deviation are 17.5 and 1.5 years, respectively.

The preferred method of survival analysis is to develop pavement survival curves within each district or region and to confirm those survival relationships periodically over time. Trying to segregate the data into too many groups, however, can result in too few roadway segments for a survival analysis to be representative of the agency's operational policies and procedures. Another drawback to this approach is the inability to account for the benefits or improvements in pavement design, materials, and specifications. This drawback can be overcome by using survival analysis in conjunction with mechanistic-empirical methods to estimate pavement lives. Such a distress-dependent approach can be used to determine the effect of using materials and design features that are not represented adequately in the agency's pavement management system database.

3.5.2 Timing and Extent of M&R Treatments

The timing and extent of future rehabilitation treatments for functional improvement (e.g., thin overlays and diamond grinding), as well as future maintenance treatments (e.g., routine maintenance, preventive maintenance, and minor repairs), should be estimated based on pavement management system and/or history records. The focus of maintenance costs should be on the timing and extent of preventive and major forms of maintenance.

CHAPTER 4

Life-Cycle Cost Analysis

4.1 Overview

LCCA is an integral part of the pavement-type selection process. While pavement-type selection based solely on initial costs allows for more to be accomplished with a specified annual budget, it does not account for long-term costs paid by taxpayers and facility users. Considering the time value of money, the initial and future costs occurring at different points in the life cycle of various alternatives should be compared to determine their cost-effectiveness. In this manner, the LCCA helps to evaluate the overall long-term economic efficiency of competing pavement alternatives and provides an economic basis for optimum strategy selection.

The quality of LCCA results is only as good as the quality of the inputs. Therefore, all available, applicable, and reliable data should be used in quantifying the many LCCA inputs, although experience-based estimates can be used in this effort.

The LCCA procedure involves establishing the LCCA framework, estimating initial and future costs, computing life-cycle costs, and analyzing/interpreting the results. Figure 8 presents a flow chart of this procedure.

4.2 Establish LCCA Framework

This section discusses the fundamental economic indicators required for establishing the LCCA model. Additional information on economic indicators can be obtained from the Federal Highway Administration's (FHWA) most current guidance on LCCA.

4.2.1 Analysis Period

The life-cycle analysis period must be sufficiently long to distinguish any differences in the cost-effectiveness of pavement alternatives and long enough such that each alternative pavement strategy includes at least one future major rehabilitation event. For new/reconstruction projects, an analysis period of at least 40 years is suggested. For rehabilitation projects, an analysis period of at least 30 years is suggested. Longer analysis periods may be warranted for long-life pavement designs, and greater effort must be made to make reliable long-term forecasts.

4.2.2 Discount Rate

The discount rate represents the real value of money over time and is used to convert future costs to present-day costs. It is approximately the difference of the interest and inflation rates. Historically discount rates are in the 3 to 5 percent range. However, it is proposed that the long-term real discount rate values provided in the latest edition of the Office of Management and Budget (OMB) Circular A-94, Appendix C, which is updated annually (currently OMB 2010), should be utilized.

4.2.3 Economic Analysis Technique

The NPV is suggested for pavement-type selection applications. The suggested practice is to use constant or real dollars and a real discount rate in NPV computations.

4.2.4 LCCA Computation Approach

There are two basic approaches for computing life-cycle costs: deterministic and probabilistic.

In deterministic LCCA, a single value is selected for each input parameter (usually the value considered most likely to occur based on historical evidence or professional experience), and the selected values are used to compute a single projected life-cycle cost. No "real world" uncertainties or variations are considered in this approach.

The probabilistic approach takes into account the variability associated with the input parameters in LCCA. In this approach, for a given pavement strategy, sample input values

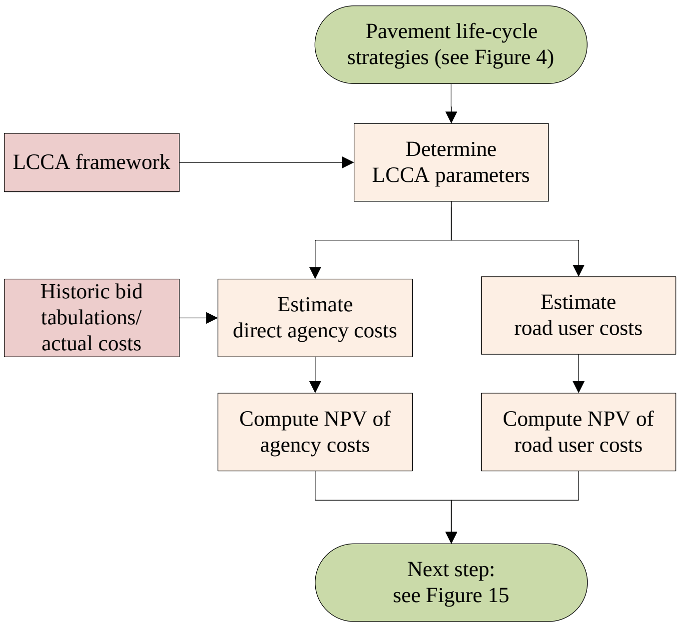

Figure 8. Evaluation of life-cycle costs.

are randomly drawn from the defined frequency distributions, and the selected values are used to compute one forecasted life-cycle cost value. The sampling process is repeated hundreds or even thousands of times, thereby generating a "pseudo-population" of forecasted life-cycle cost values for the pavement strategy. The resulting forecasted costs are analyzed and compared with the forecasted results of competing alternatives to identify the most cost-effective strategy.

It is proposed that the probabilistic LCCA computation approach be used when reliable historical data exist to model one or more of the input parameters (e.g., standard deviations of discount rate, unit costs, pavement service life). These data can be obtained from agency files (variable bid prices, survival analysis of pavement lives to get means and standard deviations and annual discount rates over time). If such data cannot be obtained, a deterministic approach should be used.

4.3 Estimation of Initial and Future Costs

The estimated life-cycle costs are used in the economic analysis to identify the most cost-effective pavement alternative. The life-cycle costs include direct costs incurred by the agency for initial construction and future M&R activities, as well as costs incurred by road users. Only the differential costs of alternatives are considered to evaluate whether substantive differences can be identified among competing alternatives. Guidance on LCCA is evolving; therefore, FHWA's current recommendations on LCCA procedures for estimating life-cycle costs for pavement alternatives should be used.

4.3.1 Direct/Agency Costs

Direct/agency costs include the physical costs of pavement activities (initial construction/rehabilitation costs and future M&R costs), salvage value, and supplemental costs. Routine reactive-type maintenance costs typically are ignored because they generally are not very high and not substantially different between pavement types (Walls and Smith 1998).

Physical Costs of Pavement Activities

Physical cost estimates are developed by combining quantities of construction pay items with their unit costs. It is important to obtain sufficient and reliable unit cost data from available sources, such as historical bid tabulations. Recent highway projects, undertaken within the last 5 to 7 years within the region, are preferred sources for historical cost data. These data often are compiled and summarized on a regular basis for project estimation purposes.

Unit cost estimates can be derived from the unit price data of the lowest bid, three lowest bids, or all bids tendered on similar projects. Each average unit price must be adjusted to the present day to account for the effects of inflation, and consideration should be given to filtering out prices biased by projects that included atypically small or large quantities of a particular pay item. Using inflation-adjusted and quantity-filtered unit price data, the mean cost of each pay item, as well as key variability parameters (standard deviation, range), can be computed for use in the economic analysis. The effect of cost adjustment factors on the final cost of the pavement should be evaluated when bid tabulations are used.

Cost-based estimates can be used in situations where the historical bid-based estimates are not available or defendable. Examples of such situations include projects with unique characteristics, new materials/technologies, geographical influences, market factors, and the volatility of material prices. A combination of cost-based and historical bid-based estimates also can be used. Pavement industry groups can be consulted to help identify appropriate data sources for cost-based estimates. Engineering judgment must be applied wherever necessary.

The time from completion of estimate to bid advertisement should be as short as possible to reflect market prices at the time of construction, while allowing sufficient time for internal review. If necessary, the cost estimates should be updated before bid advertisement.

Salvage Value

Salvage value is the estimated value of a pavement asset at the end of the analysis period. It includes two components:

- **Remaining service life.** The structural life remaining in the pavement at the end of the analysis period.
- **Residual value.** The value of the in-place pavement materials at the end of their service lives less the cost to remove and process the materials for reuse.

Salvage values are used in the economic analysis, as the in-service performance of different alternatives depreciate at different rates. The end of the analysis period very often does not coincide with the end of the alternative's service life. On the other hand, the residual values are different for competing alternatives but not very large; when discounted over the analysis period, the residual values generally have little effect on the NPV.

One method of determining the value of a pavement's remaining life is to determine the depreciated value (at the end of the analysis period) of the costs of initial construction and subsequent M&R. Depreciation is an accounting term used to attribute costs across the life of the asset. Straight-line depreciation is the simplest and most commonly used technique for estimating salvage value at the end of the analysis period.

Depreciation can be applied to both the structural and functional life components of a pavement (see Figure 9). A functional improvement cost relates to those treatments that do not add structural capacity. Typically, this includes preventive and corrective maintenance and improvements to the pavement ride, such as surface treatments, thin overlays, and localized mill-and-fill treatments. In computing the depreciation of functional treatments, the life of the functional treatment cannot exceed the structural life of the pavement.

The structural remaining life of the pavement can be determined by several methods. One method is to compare the design traffic loads to the cumulative traffic to date, with the difference between these values representing the remaining life of the pavement. Another method is to perform structural capacity testing and compare the measured value with structural design limiting criteria to determine the remaining life of the pavement.

Supplemental Costs

Supplemental costs, applicable to anticipated future M&R events, can be grouped into three categories:

- **Administrative costs.** Contract management and administrative overhead costs.
- **Engineering costs.** Design and construction engineering costs, construction supervision costs, and materials testing and analysis costs.
- **Traffic control costs.** Traffic control setup and communications costs.

If these costs are approximately the same for different alternatives, then these costs can be ignored. Because estimating these costs can be difficult and time-consuming, an alternative method to consider is to specify them as a percentage of the total project-level pavement costs.

4.3.2 Indirect/User Costs

Although borne by highway users, the user costs are given serious consideration by agencies, since an agency acts as the proxy for the public. User costs are an aggregation of time delay costs, vehicle operating costs, crash costs, environmental costs, and discomfort costs associated either with work zones or any time during normal (nonrestricted) operating conditions. In many instances, since the absolute value of user costs of the project far exceeds the direct-agency costs, user costs are evaluated independently without combining with the direct costs.

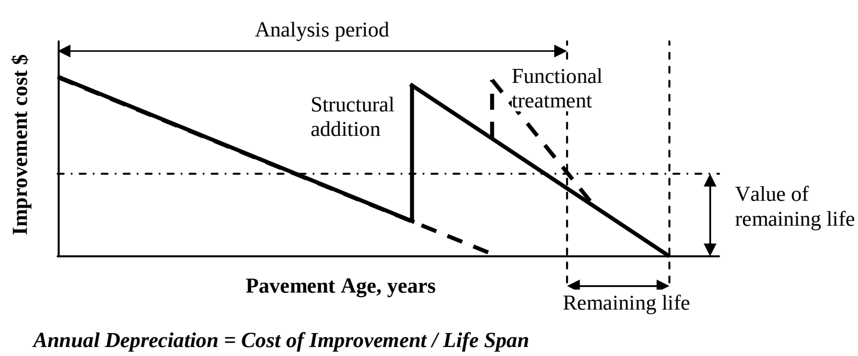

Figure 9. Example of depreciation curves for structural and functional improvements.

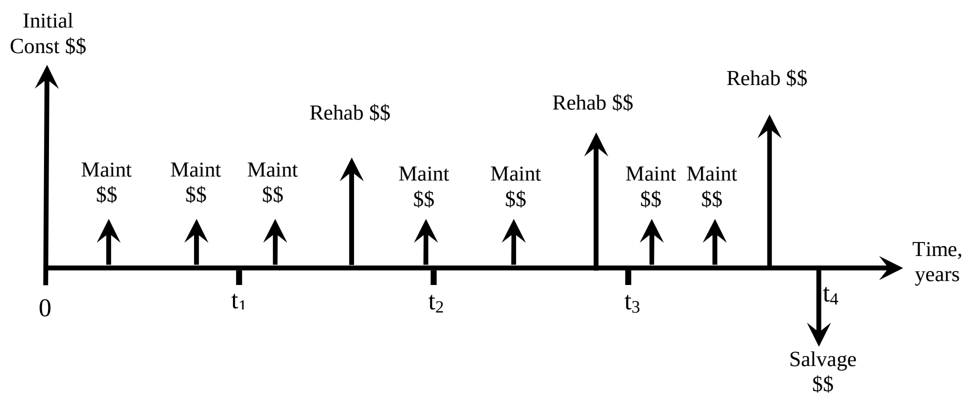

Figure 10. Example expenditure-stream diagram.

For economic analysis, only the differential user costs incurred from the use of one alternative over another are considered. The suggested practice is to consider only the time delay and vehicle operating cost components associated with work zones. These components can be estimated reasonably well and constitute a large portion of the total user costs. Other user cost components are difficult to collect and quantify accurately.

More detailed discussion on user costs can be found in the FHWA's guidance on the LCCA.

4.3.3 Develop Expenditure-Stream Diagrams

Expenditure-stream diagrams are graphical or tabular representations of direct-agency expenditures over time. These diagrams help the designer/analyst visualize the magnitudes and timings of all expenditures projected for the analysis period for each alternative. As illustrated in Figure 10, an expenditure-stream diagram shows the costs and benefits associated with various activities of an alternative's pavement life cycle on a time scale. Costs normally are depicted using upward arrows, and benefits (e.g., salvage value) are depicted using downward arrows.

4.4 Compute Life-Cycle Costs

Once the expenditure-stream diagram for each alternative pavement strategy has been developed, the task of computing projected life-cycle costs is undertaken. This step combines initial and future agency costs that are projected to occur at different points in time on a comparable scale. Considering the time value of money, all future costs are converted to present values using a specified discount rate. The initial costs and all discounted future costs are then summed together to produce the NPV of agency costs. The user costs are not combined with the agency costs but are evaluated separately using the process discussed in Chapter 5.

In deterministic analysis, computing life-cycle costs involves a simple application of NPV. In probabilistic analysis, the NPV is calculated after each iteration to generate an array of forecasted costs. These costs are then analyzed and compared with the forecasted costs of other alternatives to identify the most cost-effective strategy. Probabilistic simulation requires the use of a computerized spreadsheet program equipped with the necessary probabilistic distribution functions, such as FHWA's RealCost (Office of Assett Management 2004), or a stand-alone computer program to perform the simulation.

When performing a probabilistic simulation, it is important to make sure that each iteration represents a scenario that can actually occur. Two modeling errors with the potential to create unreal scenarios are as follows (Walls and Smith 1998):

- **Lack of appropriate predefined relationships between input parameters.** Although each randomly selected value for a given iteration may be legitimate on its own, reality may dictate that certain relationships exist between the input parameters. For example, since higher traffic volume generally is linked with shorter pavement life for a given design cross section, it is important to establish an appropriate sampling correlation between these two inputs. Such a correlation would ensure that, for each iteration, a sample from the high side of the traffic probability distribution is countered with a sample on the low side of the pavement life probability distribution, and vice versa.
- **Lack of fixed limits on input sampling distributions.** For some types of sampling distributions, the limits for sampling are not among the criteria used to define the distribution (e.g., in defining a normal sampling distribution, only the mean and standard deviation are needed). However, it is important to know the minimum and maximum values for sampling so that reasonable values are used in the simulation. Misleading simulation results can be expected, for instance, if the distribution for a cost or pavement service-life parameter allows negative values to be selected.

4.5 Analyze/Interpret Results

Regardless of whether deterministic or probabilistic life-cycle costs are computed, the results must be analyzed and interpreted carefully to evaluate the cost-effectiveness of a pavement strategy. Because the outputs of each computational approach are different, the ways in which they are evaluated and interpreted also are different.

4.5.1 Analysis of Deterministic Life-Cycle Cost Results

In the analysis of deterministic results, the percent difference in life-cycle costs of alternatives is computed. The cost-effectiveness of alternatives is established by comparing the percent difference against some established threshold requirement. Since the agency has to take other financial considerations into account, such as the cost feasibility of alternatives, available funding levels, and the impact on overall system needs, the decision to eliminate or further evaluate an alternative is made after the evaluation of pertinent economic criteria. Chapter 5 discusses the evaluation of alternatives using economic factors.

4.5.2 Analysis of Probabilistic Life-Cycle Cost Results

In the analysis of probabilistic results, the likelihood of an alternative's cost-effectiveness is evaluated with those of other alternatives. This can be accomplished by risk assessment of forecasted NPV distributions.

This approach involves comparing NPV distributions of different alternatives at a specified level of probability. A probability level between 75 and 85 percent will provide reliable estimates. Figure 11 shows the cumulative probability distributions of NPV for two alternative strategies at 50 percent (mean value) and 75 percent probabilities. The figure indicates that Alternative B has a lower NPV than Alternative A at both probability levels.

Suppose that Alternative A had a slightly lower mean NPV ($1.608 million instead of $1.611 million) and a more dispersed distribution, as shown in Figure 12. In such a case, the tails of the frequency distribution curves should be evaluated for any potential cost-associated risks. The distribution curves shown in Figure 12 indicate clear differences in the forecasted NPV at the tails. For Alternative A, there is potential for a cost underrun if the true NPV is low (say, less than $1.45 million). This opportunity for cost savings is called *upside risk*. If, on the other hand, the true NPV is high (say, greater than $1.75 million), there is a potential for a cost overrun associated with Alternative A. This chance for financial loss is called *downside risk*.

In the cumulative distributions shown in Figure 13, it can be seen that there is a 10 percent probability that the NPV of Alternative A will be less than that of Alternative B by as much as $26,000. At the other end of the spectrum, there is a 10 percent probability that Alternative A will exceed the cost of Alternative B by up to $41,000. Although many agencies may find this information insufficient for identifying the most cost-effective strategy, to some risk-averse agencies it may provide enough assurance that the allocated budget is best served by choosing Alternative B. In other words, there is a greater risk of the true cost of Alternative A exceeding the cost of Alternative B.

4.5.3 Reevaluate Strategies

In the final step of the LCCA process, information resulting from the LCCA is reevaluated to determine if any modifications to the alternative strategies are warranted, prior to making a final decision on which alternative to use. Such adjustments may entail changes to the original structure or

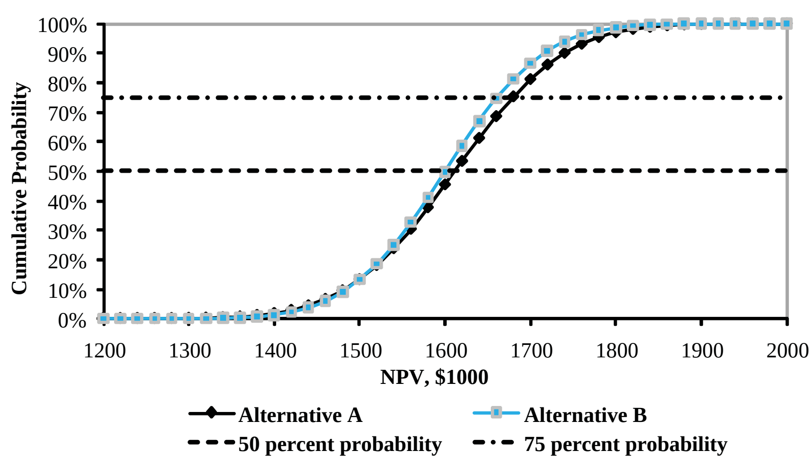

Figure 11. NPV frequency distributions for alternative strategies A and B.

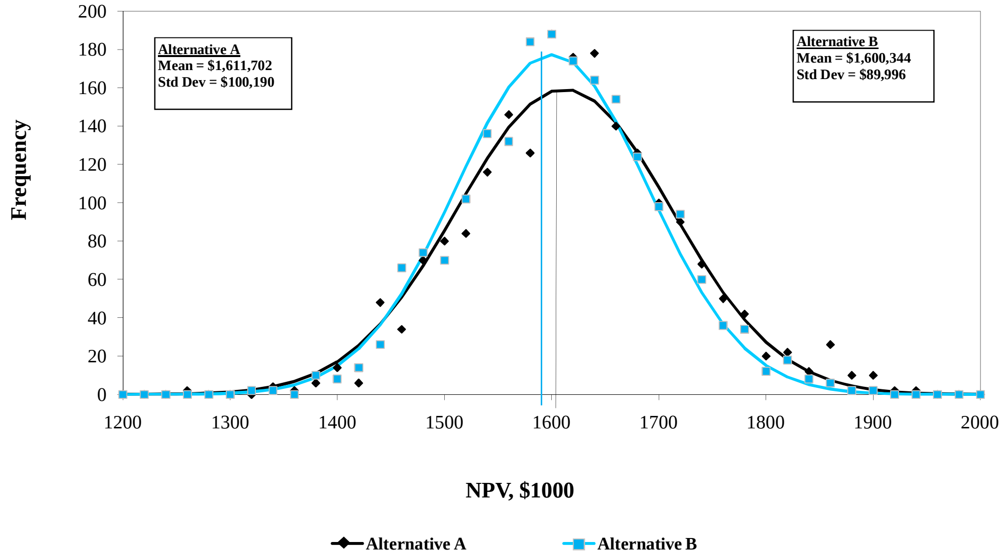

Figure 12. Risk assessment—NPV frequency distributions.

rehabilitation treatment, revisions to the maintenance of traffic plans, reductions in construction periods, or changes in future M&R activities.

Probabilistic sensitivity analysis can provide insight on the refinement of strategies. This technique uses correlation analysis and tornado plots to show the impacts of key input parameters on life-cycle costs. Inputs found to be driving the LCCA results can be scrutinized to determine if actions can be taken to improve cost-effectiveness.

Figure 14 presents an example showing the correlation coefficients of factors influencing the NPV of a pavement alternative. The correlation coefficient is a statistical measure that indicates the strength of the linear association between two variables. A correlation coefficient of +1 indicates that two variables are perfectly related in a positive linear sense, while a value of −1 indicates perfect negative correlation. Values closer to zero indicate poor or no correlation, and other intermediate values indicate partial correlation.

In this example, the NPV of the pavement alternative is positively correlated with cost factors while negatively correlated with the discount factor and pavement service-life estimates. The initial construction cost appears to be the dominating factor influencing NPV, followed by the initial life of the original pavement. In other words, to reduce the NPV of this pavement alternative, a strategy to reduce initial construction cost would be more effective than other possible strategies.

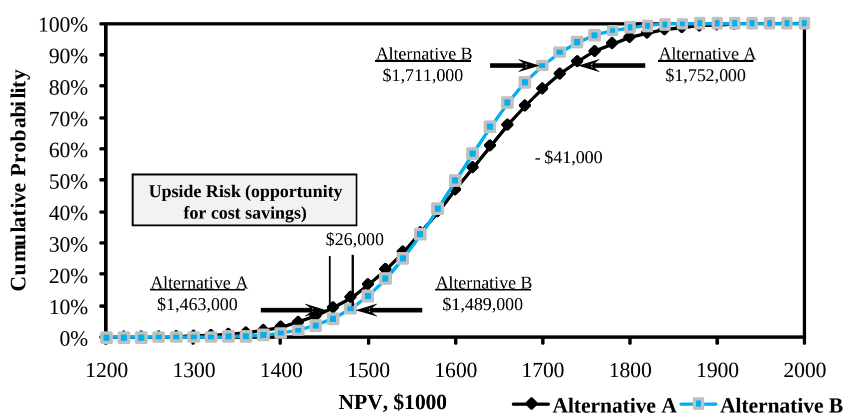

Figure 13. Risk assessment—NPV cumulative distributions.

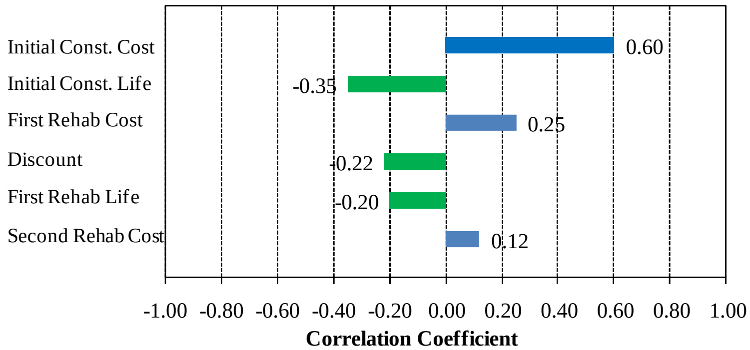

Figure 14. Correlation coefficients of factors affecting the NPV of a particular pavement strategy.

CHAPTER 5

Selection of Preferred Pavement Alternatives

5.1 Overview

Upon completion of the LCCA, the alternatives are evaluated using economic and noneconomic factors to select the preferred pavement type(s). The outcome of this process is a single preferred pavement type for traditional design-bid-build projects and multiple preferred pavement types for alternative bid projects, which are consistent with the agencies financial goals, policy decisions, and experience.

Figure 15 presents a flow chart of the proposed approach for selecting preferred pavement types, and this chapter presents a detailed discussion. The selection process is outlined as follows:

1. The alternatives are evaluated using the economic factors; alternatives that fail to meet the economic criteria are eliminated.
2. The alternatives that meet the economic criteria are evaluated using the noneconomic factors.
   - If an alternative fails to meet the noneconomic criteria, further evaluation may be necessary to ascertain whether the noneconomic factors unduly override its inclusion. If the risks from noneconomic factors outweigh the economic advantages, the alternative is eliminated.
   - If there are no noneconomic factors to override its inclusion, the alternative is selected as a qualified alternative.
3. The alternatives that meet both economic and noneconomic criteria are considered as qualifying alternatives.
   - If there is only a single qualifying alternative, it is selected as the most-preferred alternative.
4. When there are two or more qualified alternatives, then the economic and noneconomic aspects of these alternatives are weighed using an alternative-preference screening matrix to identify the most preferred type. The screening matrix is used to evaluate if there are considerable differences among the alternatives.
   - If there is a clear cut preference among the alternatives, the most advantageous alternative is recommended for selection.
   - Conversely, if the differences between all or some of the alternatives are not significant, then the similar alternatives could be considered for alternate pavement-type bidding.

5.2 Economic Selection Factors

An important step in the selection of the preferred strategy is the consideration of the financial aspects of the project. The agency evaluates the pavement-type alternatives on the basis of these aspects and their importance. The following list describes the economic factors that should be included in the evaluation:

- **Initial costs.** Agencies may set maximum funding levels for individual projects so that the entire system can be maintained at a desired level. Such constraints may result in eliminating some alternatives, particularly those with high initial costs, even if the alternatives are attractive from a life-cycle cost perspective. The evaluation should determine if the first costs of an alternative exceed the available resources or would impact the management of the overall system.
- **Rehabilitation costs.** Certain alternatives may provide a low overall life-cycle cost but require several rehabilitation activities to maintain the desired functional and structural performance level. Such costs may have an impact on the management of the entire system. Frequent interventions also may result in higher work zone user costs and impacts on local business and community. The evaluation should determine if an alternative that requires frequent rehabilitation actions may be suitable for the project.
- **Maintenance costs.** Certain alternatives may require a disproportionate maintenance effort over their lifetime that exceeds the resources available for applying the maintenance. The evaluation should focus on the maintenance actions that an alternative may require to maintain performance levels over its life.

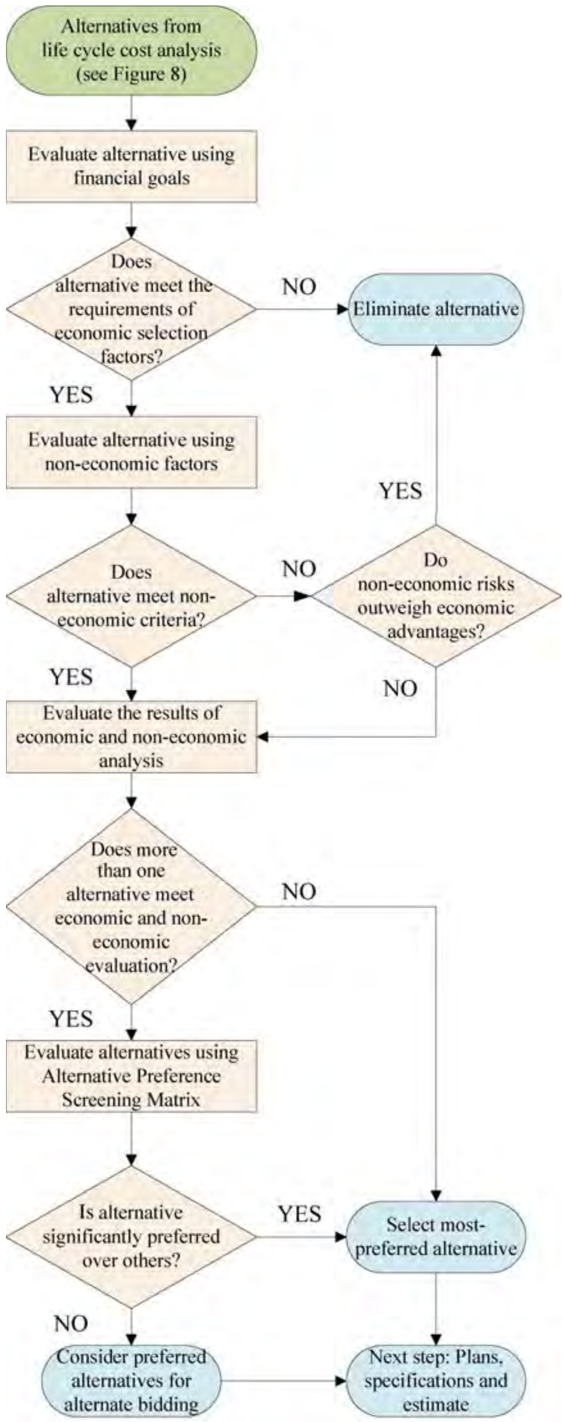

Figure 15. Selection of preferred pavement-type alternative(s).

- **User costs.** Alternatives with high user costs require special evaluation, even if the overall life-cycle cost is low. High user costs indicate the potential for a high degree of user dissatisfaction, or a negative impact on the traveling public. When high user costs are computed, the agency should review the project design and construction sequencing to determine if the impacts to the user can be reduced. In cases where high user costs cannot be reduced, consideration should be given to alternatives with a lesser impact. More information on user costs may become available from FHWA, NCHRP, and state departments of transportation (DOTs) research efforts.
- **Life-cycle costs.** The life-cycle costs indicate the aggregation of estimated initial and future costs normalized to their time value. If the percent difference between the two lowest cost strategies is greater than some established threshold requirement, then the lowest cost strategy is accepted as the most economical one. If, in contrast, the percent difference is less than this threshold requirement, then the life-cycle costs of the two strategies are deemed equivalent, thereby leaving the analyst with the option of reevaluating the strategies or allowing other factors to dictate the strategy selection process. The percent difference threshold value between two competing alternatives will depend on the accuracy of the factors collected by the agency. The percent difference, typically 5 to 20 percent, should be determined and set by the pavement-type selection committee. Where data is available, the impact of the variances of the LCCA input variables on the variance of the NPV should be considered in establishing the percent difference threshold value.

5.3 Noneconomic Selection Factors

In addition to economic factors, numerous noneconomic factors must be considered in making a pavement-type selection for a specific project. The importance of these factors may vary from project to project. The following list describes the factors that should be included in pavement-type selection. This is not an exhaustive list; other factors and project-specific conditions should be considered as necessary.

- **Roadway/lane geometrics.** Lane widths may be fixed by design standards, yet there will be occasions, especially with rehabilitation design, when it is necessary to work with varying widths. Lane widths also play a major role in where wheel loads will be located. Overall, lane width can be important in determining the width and type of shoulder, as well as the type of pavement. Longitudinal grades and the absence or presence of vertical curves can be important pavement design considerations, as they may influence drainage features and even the type and speed of traffic to use the facility. Slower traffic produces larger deformations, stresses, and strains in a pavement structure and requires special materials considerations.
- **Continuity of adjacent pavements.** When filling a gap between two similar pavement types, it may be preferable to continue a similar pavement type to avoid a hopscotch pattern and provide for continuity of maintenance operations and experience.

- **Continuity of adjacent lanes.** Nonuniform sections can result in differential pavement performance and condition across the width of the roadway. Consistent performance across the width of the roadway is preferred. (The preferred uniformity is applicable to driving lanes only and not to existing shoulders that will remain shoulders.)
- **Traffic during construction.** Speed of construction, accommodating traffic during construction, safety to traffic during construction, ease of replacement, anticipated future widening, seasons of the year when construction must be accomplished, and other related factors may have a strong influence on the strategy selections in specific cases. Construction considerations can be especially important for the design of rehabilitation projects. For example, limited overhead clearances may preclude an overlay or limit its thickness such that pavement-type selection is affected. Other geometric factors, such as roadway width, guardrail heights, and cut–fill slopes often impact the design decision.
- **Availability of local materials and experience.** The availability and adaptability of local material may influence the selection of a pavement strategy. Also, the availability of commercially produced mixes and the equipment capabilities of area contractors may influence the selection, particularly on small projects.
- **Conservation of materials/energy.** Selection of a pavement strategy may be influenced by the criticality of materials supply as well as by the energy requirements of materials production. The construction energy requirements associated with various pavement types may be an additional consideration.
- **Local preference.** The issues raised by consideration of municipal or local government preferences and local industries may be outside the control of most highway engineers. However, the highway administrator often must take these preferences into consideration, especially if other factors do not yield a clear pavement-type preference.
- **Stimulation of competition.** Most agencies consider it desirable to encourage improvements in products and methods through continued and healthy competition among the paving industries and materials suppliers. Where alternate pavement designs have comparable initial costs, including the attendant costs of earthwork, drainage facilities, and other appurtenances, and provide comparable service-life or life-cycle cost, the highway agency may elect to take alternate bids to stimulate competition and obtain lower prices.
- **Noise issues.** Noise can have a significant impact on quality of life and is costly to mitigate after the fact. Tire–pavement noise mitigation is particularly important on urban highways. The life of the low-noise surface should be considered, as some deteriorate rapidly. Construction noise also can be an issue, influenced by factors such as the equipment type, traffic rerouting, and day/night operations. So certain alternatives may have noise intensity issues in sensitive settings or may have noise duration issues due to longer periods of construction and/or M&R.
- **Safety considerations.** The particular characteristics of a wearing course surface, the need for delineation through pavement and shoulder contrast, reflectivity under highway lighting, and the maintenance of a nonskid surface as affected by the available materials may influence the pavement strategy selected in specific locations. In the context of nonskid surfaces, it is important to consider the profile and texture durability (i.e., how long the desirable characteristics are going to last). Excessive ruts on the surface often increase the likelihood of safety hazards such as hydroplaning, insufficient friction, and loss of control of the vehicle, especially in wet weather and at high speeds.
- **Subgrade soils.** For new locations or reconstruction, the ability of the foundation to support construction equipment and processes may be an important concern. Sometimes it is necessary to stabilize subgrade soils with cementitious materials to provide a suitable working platform. Such stabilized subgrades often have not been considered as part of the pavement structure. The load-carrying capability of a native soil, which forms the subgrade for the pavement structure, is of paramount importance in pavement performance. Even for small projects, the inherent qualities of such native soils are far from uniform, and they are further subjected to variations by the influence of weather. The characteristics of native soils not only directly affect the pavement structural design but also may, in certain cases, dictate the type of pavement economically justified for a given location. As an example, problem soils that change volume with time require a pavement structure able to conform to seasonal variations in longitudinal and transverse profile. An approach sometimes used is to provide for staged construction to accommodate large expected deformations over time.
- **Experimental features.** In some instances, it is necessary to determine the performance of new materials or design concepts by field testing under actual construction, environmental, or traffic conditions. The incorporation of such experimental features may dictate the strategy selected.
- **Future needs.** Future needs on geometric or capacity changes during the analysis period are evaluated to determine if the use of staged construction is warranted.
- **Maintenance capability.** It is necessary to determine if the maintenance unit responsible for the pavement section has the experience and equipment to maintain all pavement alternatives being considered.
- **Sustainability.** Sustainability in pavements is achieved through practices emphasizing energy efficiency, emissions reduction, and resource conservation. Incorporating these strategies leads to an approach that balances environment conservation, societal needs, and economic development

in existing practices. Sustainable practices include increased use of recycled materials, industrial by-products, and local materials; decreased use of energy-intensive materials and construction processes; improvements in material production and processes; techniques that preserve or increase the longevity of pavements; and eco-friendly design alternatives. Life-cycle assessment (LCA) methods typically are used in evaluating the environmental impact of materials, equipment, and processes used in pavements. The LCA-based environmental impacts can be incorporated qualitatively or quantitatively in the pavement-type selection process.

5.4 Weighing of Economic and Noneconomic Factors Using Alternative-Preference Screening Matrix

The pavement-type selection process should weigh both economic and noneconomic factors to ensure that the agency goals and policies are incorporated in decision making. An alternative-preference screening matrix is suggested for this purpose. The screening matrix is a decision support tool that is designed to help agencies determine whether there are advantages in selecting one alternative over others and whether these alternatives should be evaluated more closely.

The following sections describe how to set up the screening matrix and evaluate the results obtained. Appendix A illustrates the application of the screening matrix and includes an example of its use.

Step 1: Identify and Group Evaluation Factors

The economic and noneconomic factors that have a potential impact on the pavement-type selection process for a given project are identified and grouped. The factors identified in Sections 5.2 and 5.3 are suggested. A suggested grouping structure and sample factors are illustrated in Table 1. The factor groups could include economic factors, construction factors, local factors, maintenance factors, traffic and safety factors, environmental factors, and others. Agencies are expected to modify the contents of Table 1 as necessary to best suit their goals, expectations, and project requirements. The evaluation factors and groups may vary from project to project within an agency.

Table 1. Grouping structure of the alternative-preference screening matrix.

General Version	Example
Group A	Economic factors
Factor A1	Initial costs
Factor A2	Future rehabilitation costs
…	…
Factor An	User costs
Group B	Construction factors
Factor B1	Continuity of adjacent lanes
Factor B2	Traffic during construction
…	…
Factor Bn	Lane geometrics
Group C	Local factors
Factor C1	Availability of local materials
Factor C2	District/local preferences
…	…
Factor Cn	Stimulation of competition
Group D	Other factors
Factor D1	Noise
Factor D2	Subgrade soils
…	...
Factor Dn	Experimental features

Table 2. Group weights of the screening matrix.

General Version		Example	
Group	Weight	Group	Weight
A	W_A%	Economic factors	50%
B	W_B%	Construction factors	25%
C	W_C%	Local factors	10%
D	W_D%	Other factors	15%
	Total score = 100%		Total score = 100%

Note: W = weight.

Step 2: Assign Group and Individual Factor Weights

Next, weights must be assigned to each of the factor groups and each factor within a group to reflect their importance to the pavement-type selection process for a given project. Table 2 and Table 3 illustrate the group and factor weighing scheme, respectively. The factor groups and factors within a group can be assigned equal or unequal weights, but the sum of all group weights and all the factor weights within each group must equal 100 percent.

Step 3: Assign Preference Rating of Individual Factors

To facilitate a comparative evaluation of alternatives, the evaluation factors are assigned with preference

Table 3. Factor weights of the screening matrix.

General Version		Example	
Group A	Weight	Economic Factors	Weight
A1	W_{A1}%	Initial costs	30%
A2	W_{A2}%	Future rehabilitation costs	25%
A3	W_{A3}%	Road-user costs	20%
An	W_{An}%	Future maintenance costs	25%
	Group total = 100%		Group total = 100%

Table 4. Sample rating guidelines for the alternative-preference screening matrix.

Factor	Low	Medium	High
Initial costs	Cost >10%	Cost >5% and <10%	Cost within 5%
Life-cycle costs	Cost >20%	Cost >10% and <20%	Cost within 10%
User costs	User cost >20%	User cost >10% and <20%	User cost within 10%
Future rehabilitation costs	Cost >10%	Cost >5% and <10%	Cost within 5%
Future maintenance costs	Cost >10%	Cost >5% and <10%	Cost within 5%
Roadway/lane geometrics	Significant complexity to accommodate	Moderate complexity to accommodate	Easy to accommodate
Continuity of adjacent pavements	Significant issues	Some significant issues possible	No significant issues
Continuity of adjacent lanes	Significant issues	Some significant issues possible	No significant issues
Availability of local materials and experience	Lack of local experience	Some experience	Commonly used
Traffic during construction	Very difficult to accommodate	Somewhat difficult to accommodate	Easy to accommodate
Noise	Much higher noise likely	Some increased noise possible	No difference in noise generated
Subgrade soils	Significant issues for construction	Some issues possible for construction	No significant issues for construction
District/local preference	No preference	Some preference	Significant preference
Safety considerations	Significant issues related to safety features	Some issues related to safety features	Better safety features
Conservation of materials/energy	Much higher materials/ energy use	Somewhat higher materials/energy use	No significant difference
Stimulation of competition	Very few capable contractors	Some experience	Common experience for each
Maintenance capability	Little to no local experience	Some experience	Common experience for each
Future needs	Very difficult to accommodate	Somewhat difficult to accommodate	Easy to accommodate
Experimental features	Common technology	National but no local experience	New and unproven technology

ratings using predetermined criteria. The purpose of the ratings is to quantify the relative advantages and disadvantages among the alternatives for each evaluation factor. When an alternative offers significant advantages associated with a given evaluation factor, then the alternative is rated with a high preference for that factor.

The rating scheme can be discrete or continuous. While a discrete rating scheme is simple to use, a continuous rating scheme provides more flexibility for users. As with factors, groups, and weights, it is proposed that the agencies develop their own rating guidelines that reflect their goals and expectations. As a first step, each agency should ask decision makers about the factors they currently use in making pavement-type decisions and what additional factors should be considered in the process. Test runs should be made on several older projects to determine if the proposed screening process results in acceptable pavement selections. The pavement-type selection committee can help establish these guidelines for the agency's use.

Table 4 provides sample guidelines on rating individual factors on a discrete scale. For example, the Initial Cost factor is assigned a preference rating of "high" when the initial cost value of an alternative is within a 5 percent difference of the lowest values of all candidates or "low" if the initial cost difference of the alternative exceeds 10 percent of the lowest value.

Step 4: Score Pavement-Type Alternatives

Upon assigning preference ratings, the numerical weighted scores of evaluation factors and groups are calculated for each alternative. Ratings of "low," "medium," and "high," if used, should be converted to numerical scores. Table 5 presents example criteria for converting these ratings to a numerical scale.

Table 5. Example criteria for preference rating.

Preference Rating	Numerical Score
No difference	0%
Low	20%
Medium low	40%
Medium	60%
Medium high	80%
High	100%

Table 6. Example of the calculation of weighing scores for individual factors.

Economic Factors	Individual Factor Weight	Preference Rating	Numerical Rating	Weighted Score
Initial costs	30%	Medium	60%	18.0%
Future rehab costs	25%	High	100%	25.0%
User costs	20%	Low	20%	4.0%
Future maintenance costs	25%	Medium-low	40%	10.0%
Total unweighted score for *Economic Factors*				57%

For a given alternative, the numerical scores of each evaluation factor are multiplied by their corresponding factor weights to calculate the weighted scores of factors. The sum of weighted scores of factors within each group is the unweighted score of that group. The example in Table 6 calculates the weighted score for individual factors within the Economic Factors group and the unweighted score for that group. The weighted group scores are then calculated by multiplying their unweighted score by their corresponding group weights (see Table 7). The sum of weighted group scores is the total score for that alternative; it should not exceed 100 percent.

Step 5: Interpret Results

Based on the final scores of alternatives, the "best possible" pavement-type alternatives are selected.

When the final score of an alternative is higher than that of other candidates, the alternative with the highest score may be much better suited than others. However, when the final scores of multiple alternatives are comparable, any of these alternatives could be selected. Such cases are well suited for alternate bidding. If no alternative appears to be satisfactory, further investigation is needed.

Agencies should determine their own criteria to interpret the screening-matrix results. An agency can develop a threshold value to determine how different the alternatives are. For instance, if the difference in the final scores of two alternatives is more than 10, the alternative with the higher score can be selected as the preferred one.

Recognizing that the project goals and the choice of feasible alternatives are unique to each project, this guide recommends the application of informed judgment and agency experience in the selection process, with or without a threshold criterion in place. The screening matrix provides a systematic framework for practical decision making by setting "musts" and "wants" of an ideal choice for the project, exploring and prioritizing alternatives based on their strengths and weaknesses, and choosing the most-preferred alternative(s).

Table 8 provides a template of the screening matrix. Users can add or eliminate any number of alternatives, groups, and individual factors within a group, as appropriate. Appendix A illustrates the application of the alternative-preference screening matrix.

Table 7. Example of the calculation of weighted group scores.

Group	Group Weight	Unweighted Group Score	Weighted Group Score
Economic factors	50%	57%	28.5%
Construction factors	25%	45%	11.3%
Local factors	10%	25%	2.5%
Other factors	15%	15%	2.3%
Total score of the matrix			44.6%

Table 8. Alternative-preference screening-matrix worksheet.

Factor	Factor Weight	Alternative 1 (Alt1)		Alternative 2 (Alt2)	
		Rating	Weighted Score	Rating	Weighted Score
Group A					
Factor A1	W_{A1}	$R_{A1\text{-}Alt1}$	$W_{A1}*R_{A1\text{-}Alt1}$	$R_{A1\text{-}Alt2}$	$W_{A1} * R_{A1\text{-}Alt2}$
Factor A2	W_{A2}	$R_{A2\text{-}Alt1}$	$W_{A2} *R_{A2\text{-}Alt1}$	$R_{A2\text{-}Alt2}$	$W_{A2} *R_{A2\text{-}Alt2}$
Factor A3	W_{A3}	$R_{A3\text{-}Alt1}$	$W_{A3} *R_{A3\text{-}Alt1}$	$R_{A3\text{-}Alt2}$	$W_{A3} *R_{A3\text{-}Alt2}$
Factor An	W_{AN}	$R_{AN\text{-}Alt1}$	$W_{AN} *R_{AN\text{-}Alt1}$	$R_{AN\text{-}Alt2}$	$W_{An} *R_{AN\text{-}Alt2}$
Group A unweighted total	100%		$\Sigma(W_{Ai}*R_{Ai\text{-}Alt1})$		$\Sigma(W_{Ai} * R_{Ai\text{-}Alt2})$
Group B					
Factor B1	W_{B1}	$R_{B1\text{-}Alt1}$	$W_{B1}*R_{B1\text{-}Alt1}$	$R_{B1\text{-}Alt2}$	$W_{B1}*R_{B1\text{-}Alt2}$
Factor B2	W_{B2}	$R_{B2\text{-}Alt1}$	$W_{B2} *R_{B2\text{-}Alt1}$	$R_{B2\text{-}Alt2}$	$W_{B2} *R_{B2\text{-}Alt2}$
Factor B3	W_{B3}	$R_{B3\text{-}Alt1}$	$W_{B3} *R_{B3\text{-}Alt1}$	$R_{B3\text{-}Alt2}$	$W_{B3} *R_{B3\text{-}Alt2}$
Factor Bn	W_{BN}	$R_{BN\text{-}Alt1}$	$W_{BN} *R_{BN\text{-}Alt1}$	$R_{BN\text{-}Alt2}$	$W_{Bn} *R_{BN\text{-}Alt2}$
Group B unweighted total	100%		$\Sigma(W_{Bi}*R_{Bi\text{-}Alt1})$		$\Sigma(W_{Bi}*R_{Bi\text{-}Alt2})$
Group C					
Factor C1	W_{C1}	$R_{C1\text{-}Alt1}$	$W_{C1}*R_{C1\text{-}Alt1}$	$R_{C1\text{-}Alt2}$	$W_{C1}*R_{C1\text{-}Alt2}$
Factor C2	W_{C2}	$R_{C2\text{-}Alt1}$	$W_{C2} *R_{C2\text{-}Alt1}$	$R_{C2\text{-}Alt2}$	$W_{C2} *R_{C2\text{-}Alt2}$
Factor C3	W_{C3}	$R_{C3\text{-}Alt1}$	$W_{C3} *R_{C3\text{-}Alt1}$	$R_{C3\text{-}Alt2}$	$W_{C3} *R_{C3\text{-}Alt2}$
Factor Cn	W_{CN}	$R_{CN\text{-}Alt1}$	$W_{CN} *R_{CN\text{-}Alt1}$	$R_{CN\text{-}Alt2}$	$W_{Cn}*R_{CN\text{-}Alt2}$
Group C unweighted total	100%		$\Sigma(W_{Ci}*R_{Ci\text{-}Alt1})$		$\Sigma(W_{Ci}*R_{Ci\text{-}Alt2})$
Group D					
Factor D1	W_{D1}	$R_{D1\text{-}Alt1}$	$W_{D1}*R_{D1\text{-}Alt1}$	$R_{D1\text{-}Alt2}$	$W_{D1}*R_{D1\text{-}Alt2}$
Factor D2	W_{D2}	$R_{D2\text{-}Alt1}$	$W_{D2} *R_{D2\text{-}Alt1}$	$R_{D2\text{-}Alt2}$	$W_{D2} *R_{D2\text{-}Alt2}$
Factor D3	W_{D3}	$R_{D3\text{-}Alt1}$	$W_{D3} *R_{D3\text{-}Alt1}$	$R_{D3\text{-}Alt2}$	$W_{D3} *R_{D3\text{-}Alt2}$
Factor Dn	W_{DN}	$R_{DN\text{-}Alt1}$	$W_{DN} *R_{DN\text{-}Alt1}$	$R_{DN\text{-}Alt2}$	$W_{Dn}*R_{DN\text{-}Alt2}$
Group D unweighted total	100%		$\Sigma(W_{Di}*R_{Di\text{-}Alt1})$		$\Sigma(W_{Di}*R_{Di\text{-}Alt2})$
Subtotals	**Group Weights**	**Group Unweighted Total**	**Group Weighted Total**	**Group Unweighted Total**	**Group Weighted Total**
Group A	W_A	$\Sigma(W_{Ai}*R_{Ai\text{-}Alt1})$	$W_A *\Sigma(W_{Ai}*R_{Ai\text{-}Alt1})$	$\Sigma(W_{Ai}*R_{Ai\text{-}Alt2})$	$W_A *\Sigma(W_{Ai}*R_{Ai\text{-}Alt2})$
Group B	W_B	$\Sigma(W_{Bi}*R_{Bi\text{-}Alt1})$	$W_B *\Sigma(W_{Bi}*R_{Bi\text{-}Alt1})$	$\Sigma(W_{Bi}*R_{Bi\text{-}Alt2})$	$W_B *\Sigma(W_{Bi}*R_{Bi\text{-}Alt2})$
Group C	W_C	$\Sigma(W_{Ci}*R_{Ci\text{-}Alt1})$	$W_C *\Sigma(W_{Ci}*R_{Ci\text{-}Alt1})$	$\Sigma(W_{Ci}*R_{Ci\text{-}Alt2})$	$W_C *\Sigma(W_{Ci}*R_{Ci\text{-}Alt2})$
Group D	W_D	$\Sigma(W_{Di}*R_{Di\text{-}Alt1})$	$W_D *\Sigma(W_{Di}*R_{Di\text{-}Alt1})$	$\Sigma(W_{Di}*R_{Di\text{-}Alt2})$	$W_D *\Sigma(W_{Di}*R_{Di\text{-}Alt2})$
Grand total	100%		**Final score- Alt 1**		**Final score- Alt 2**

CHAPTER 6

Alternate Pavement-Type Bidding

6.1 Overview

Alternate pavement-type bidding is a procurement process in which the contractor is permitted to select one of two or more pavement-type alternatives specified by the agency. The agency develops pavement life-cycle strategies, computes life-cycle costs, and identifies preferred pavement types for inclusion in bid documents of a project. The contractor then selects the final pavement type for the project from the alternatives listed in the bid documents. Typically, the agency uses an adjustment factor (C) in bid evaluation to account for the differences in future costs between alternatives.

Best-value alternate differential bidding, a variant of alternate bidding, allows for specifying superior alternatives at an agency-determined price differential along with a baseline configuration. The contract award is based on the lowest responsive bid that includes the sum of the base bid price and differential price. Table 9 illustrates how the lowest responsive bid is selected in alternate bidding and best-value alternate differential procedures.

6.2 Proposed Pavement-Type Selection Process

Because the agency establishes the alternatives for alternate pavement-type bidding, it is suggested that the pavement-type selection follow the agency's process. Additional steps are needed to facilitate successful implementation of the procedure. Active involvement of various stakeholders in the process development will help agencies in developing consensus for best practices and troubleshooting conflicts during implementation (Temple et al. 2004). The agency can follow these steps in developing a pavement-type selection process for alternate bidding projects:

1. *Identify potential pavement-type alternatives.*
   This step involves developing a formalized process for identifying a broad group of alternatives using the approach discussed in Sections 3.2 and 3.3. The pavement-type selection committee identifies a list of alternatives to be considered in the selection process based on experience within the state or a region within the state.
2. *Identify feasible pavement-type alternatives.*
   This step involves developing criteria for identifying feasible alternatives at the project level from the broad group of alternatives, through engineering review and noneconomic selection factors. This approach is discussed in Section 3.4.
3. *Establish suitability criteria of alternate bidding projects.*
   Factors such as the project type, project size and scope, market trends of commodity prices, relative competitiveness of the pavement alternatives, and others influence the suitability of alternate bidding. The agencies should determine their own criteria for executing this procedure in paving projects. Alternate bidding may not be suitable for all types of paving projects but is suitable for the following:
   - <u>No preferred alternative:</u> Alternative bidding is appropriate for projects when there is no clear preference among alternatives. The agency can use a "cutoff" difference based on total costs or the alternate-preference screening matrix to select equivalent alternatives.
   - <u>Periods of commodity price uncertainty:</u> Alternative bidding is suitable when the prevailing commodity prices (at the time of contract letting) may not reflect historical material and construction costs, especially during periods of uncertain price trends in the market. In such instances, agencies can use this procedure to manage some of the risks in market price fluctuations, as the type selection is made at the time of contract letting.
   - <u>Appropriate application:</u> Alternative bidding is more advantageous where the pavement cost items impacted by the alternate bid are likely to influence the final determination of the lowest responsive bidder for the project.
   - <u>Lack of historical price data for pavement alternatives:</u> Alternative bidding can be used when an agency lacks historical price data for certain alternatives.

Table 9. Bid evaluation of alternate bidding contracts.

Alternate Bidding	Best-Value Alternate Differential Bidding
Lower of $\left[\begin{array}{l} \text{low } Alt_1 \text{ bid} + PV(FC\ Alt_1) \\ \text{low } Alt_2 \text{ bid} + PV(FC\ Alt_2) \end{array}\right]$ OR Lower of $\left(\begin{array}{l} \text{low } Alt_1 \text{ bid} \\ \text{low } Alt_2 \text{ bid} + C \\ C = PV(FC\ Alt_2) - PV(FC\ Alt_1) \end{array}\right)$	Lower of $\left(\begin{array}{l} \text{low Baseline bid} \\ \text{low } Alt_1 \text{ bid} + D(Alt_1) \\ \text{low } Alt_2 \text{ bid} + D(Alt_2) \\ \quad \ldots \\ \quad \ldots \\ \text{low } Alt_n \text{ bid} + D(Alt_n) \end{array}\right)$

Note: PV = present value, FC = future costs, C = bid adjustment factor, D = differential bid price.

4. *Develop pavement life-cycle strategies.*
The life-cycle strategy of an alternative consists of assigning an initial structure (whether new or rehabilitated) and probable M&R activities covering the selected analysis period.

The initial structure of the equivalent alternatives should be designed for the same design conditions, such as the traffic level, reliability, and life, and for similar terminal-performance thresholds. In other words, the structural designs should be developed to result in the same magnitude of relative distresses and roughness at the end of the design period.

Realistic sequencing of the timing and extent of M&R activities is vital to the determination of the LCCA adjustment factor. The agency should develop realistic M&R strategies based on the approach described in Section 3.5.

5. *Develop guidelines for conducting LCCA.*
This step is identical to the approach discussed in Chapter 4. Since LCCA plays a vital role in developing equivalent alternatives and bid evaluation, consensus among the stakeholders on a realistic framework is emphasized.

6. *Develop criteria for establishing equivalency of design alternatives.*
Equivalency of pavement-type alternatives is a primary factor in making the decision to use the alternate bidding procedure (Office of Pavement Technology 2008). Equivalent alternatives are designed to perform equally, provide the same level of service, over the same performance period, and have similar life cycle costs (FHWA 1999). Because of the difficulties in developing truly equivalent alternatives, the equivalency is established on the basis of life cycle costs.

Highway agencies typically use a "cutoff" difference ranging up to 20 percent of total costs in selecting equivalent alternatives. The cutoff difference should be established based on the average differences in the bid costs of previous alternate bid contracts. If sufficient data is not available for establishing the cutoff value, local experience with the life-cycle cost differences of alternatives in design-bid-build projects should be taken into consideration. As an alternate approach, the alternative-preference screening matrix discussed in detail in Section 6.3 can be used for identifying equivalent alternatives.

7. *Establish criteria for determining bid adjustment factor.*
While it is feasible to design the initial structure of pavement alternatives for the same conditions using appropriate inputs, the required M&R activities, their timing, and associated costs will be different for equivalent alternatives over the life of the pavement. This results in differences in the future cost streams of the various alternatives. Therefore, to compare the final costs of alternatives on a level basis during bid evaluation, an adjustment factor that reflects the present value of the difference in future costs may be used.

The agencies should predetermine the cost components they wish to include for estimating future costs. For instance, some agencies may include only the direct cost components of future M&R activities, while other agencies may include associated user delay costs. Therefore, to avoid any conflicts, a consensus is required among stakeholders on the approach to be used in determining future costs for a bid adjustment factor.

8. *Use comparable project specifications.*
The agency should ensure that the project specifications do not encourage bias in the contractor's selection of one alternative over another. As outlined in the following list, the contractual provisions should provide comparable opportunity for each alternative.
   - Specifications of material quantities: Agencies should consider approaches that balance materials quantity risk between the pavement-type alternatives. Using different methods to specify/quantify alternatives may result in different levels of materials quantity risk.
   - Commodity price adjustment: The agency should not allow adjustment factors for material prices, as it is difficult to administer equal treatment to various alternate materials.
   - Incentive/disincentive provisions for quality: The agency should identify any potential bias in using a quality-based incentive/disincentive structure for

different pavement types. The use of end-result or performance-related specifications helps to reconcile any inherent biases in these areas. Performance-related specifications also promote contractor innovation and allow for more opportunity for competitive bidding.

The selected alternatives should be comparable and competitive to provide reasonable chances for contractors to win the bid with either of the alternatives. However, it should be recognized that alternatives cannot always be competitive, especially during periods of significant price fluctuation.

9. *Involve industry in developing and reviewing the proposed process.*
There may be concerns and conflicting interests among stakeholders over many aspects of alternate bidding procedures, such as the appropriateness of rehabilitation strategies, LCCA inputs, and other design-life assumptions. Upon drafting the process, the agency should actively involve the stakeholders in reviewing and finalizing the proposed process.
10. *Implement the alternate bidding procedure.*
The agency can evaluate the proposed process through implementation projects. Efforts should be made to identify lessons learned, stakeholder feedback, and impending issues. Based on the evaluation, the agency can further refine the process for use in future projects. Agencies also should develop a mechanism for periodic evaluation and review of the process.

6.3 Selection of Alternatives for Alternate Pavement-Type Bidding

The alternative-preference screening matrix should be used for identifying equivalent pavement types. As discussed in Chapter 4, when an alternative meets the economic criteria and there are no noneconomic risks that outweigh its inclusion, then the pavement type is considered a qualified alternative. When there are two or more qualifying alternatives, their advantages and disadvantages are analyzed using the screening matrix. The alternatives are ranked and assigned numerical scores. Based on the final scores, the screening matrix indicates whether there is a clear preference among the alternatives. When there are no significant differences among them, the alternatives may qualify for alternate bidding. Some level of engineering judgment may be necessary in establishing the equivalency of alternatives. Figure 16 presents a flow chart of this procedure.

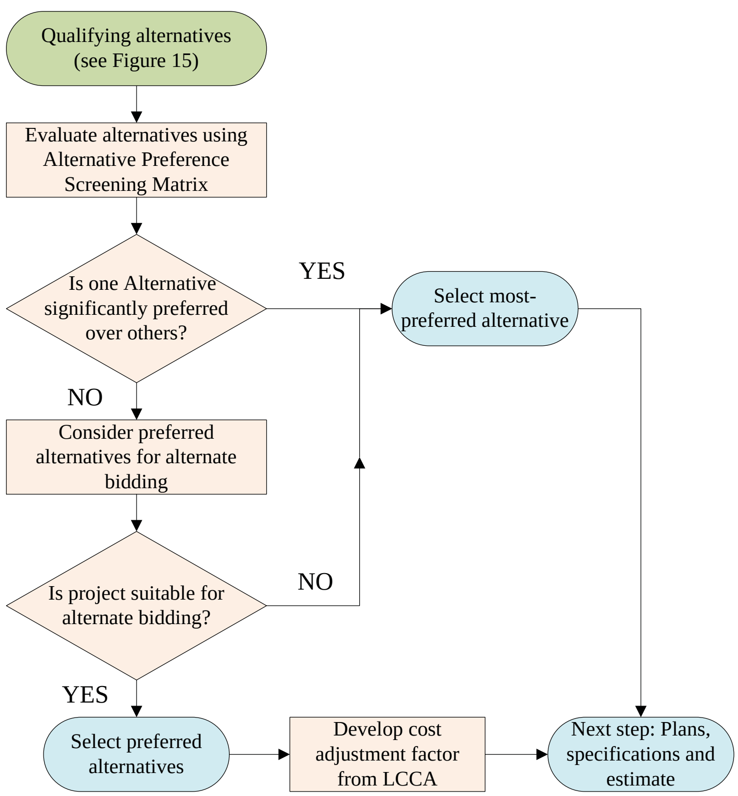

Figure 16. Selection of equivalent pavement-type alternatives for alternate bidding.

CHAPTER 7

Contractor-Based Pavement-Type Selection

7.1 Overview

In traditional design-bid-build contracts, the contractor delivers construction services as defined in the standard plans and specifications issued by the highway agency. The contractor assumes no responsibility for the delivered product except with regard to materials and workmanship quality for a limited time period. The agency has the entire responsibility and risk for design, construction, and post-construction performance of the pavement.

With the inception of alternative contracting methods, highway agencies strive for better "value for money" through specific project objectives relating to construction time, quality, innovation, safety, and costs. Examples include lane rental, interim completion dates, performance warranties, and design-build and design-build–finance-operate contracts.

These initiatives have shifted the roles and responsibilities of agencies, contractors, and designers from traditional paradigms, which have in turn resulted in the shift of risk allocation from agencies to contractors, thus opening up new challenges in program delivery and facility management. The alternative contracting scenarios involving contractor-based pavement-type selection are defined as follows:

- **Design-build.** Contractor is responsible for only design and construction (involves materials and workmanship warranty or other warranty types).
- **Design-build involving O&M.** Contractor is responsible for design, construction, M&R, and operations during the concession period (involves performance thresholds established by the agency).
- **Performance warranty.** Contractor is responsible for design, construction, and M&R over the warranty period with no operational responsibilities (involves performance thresholds established by the agency).

Although these contracting approaches include much more than pavement-type selection, the discussion in this guide focuses on how to deal with the selection process under such scenarios. In alternate contracting, particularly for projects requiring long-term contractor involvement, the contractor (or a concessionaire) bears significantly greater financial risks than in traditional contracts. However, as the long-term owner of the facility, the agency holds the ultimate responsibility toward taxpayers and road users for the performance of the pavement.

Table 10 shows the agency and contractor relationship for different contracting scenarios in order to provide the necessary backdrop for understanding pavement-type selection in such scenarios. These challenges can be managed effectively when risks are understood, their consequences measured, and they are allocated to the party that can best manage them.

7.2 Risk Assessment in Contractor-Based Type Selection

In alternate contracting projects, the agency communicates the project goals, requirements, and deliverables to the contractor through contract provisions in the RFP. The contractor is obligated to provide the product and services specified in the contract provisions with certain technical, cost, time, and quality requirements.

As the selection process proceeds from the preliminary engineering phase to the selection of the final pavement type, three distinct milestones are recognized in this process:

- Advertising for bids—The agency's internal assessments and decisions culminate with the development of contract provisions. The agency then communicates its requirements to the potential contractor.
- Submission of bids—The contractor's internal assessments and the business decisions culminate in the development of bidding strategies and bid submittal (i.e., the contractor proposes a pavement-type alternative for a certain cost value in the submitted bid).

Table 10. Agency and contractor roles in different contracting scenarios.

Process	Design-Bid-Build	Alternate Bidding	Design-Build[1]	Long-Term Performance Warranty[1]	Design-Build with O&M[1]
Identification of pavement alternatives					
Development of potential alternatives at agency level	Agency	Agency	Agency	Agency	Agency
Identification of feasible alternatives at project level	Agency	Agency	Agency & Contractor[2]	Agency & Contractor	Contractor
Development of a life-cycle model for pavement alternatives					
Service life of initial pavement structure (includes pavement design)	Agency	Agency	Agency & Contractor[2]	Contractor	Contractor
Service lives of future rehabilitation treatments	Agency	Agency	Agency	Contractor	Contractor
Timing and extent of M&R treatments	Agency	Agency	Agency	Contractor	Contractor
Estimation of life-cycle costs					
Initial construction	Agency	Agency	Agency & Contractor[2]	Contractor	Contractor
Future M&R	Agency	Agency	Agency	Contractor	Contractor
Salvage	Agency	Agency	Agency	N/A	N/A
Remaining service life at hand back	N/A	N/A	N/A	Contractor	Contractor
Supplementary	Agency	Agency	Agency & Contractor	Agency & Contractor	Agency & Contractor
Work zone costs	Agency	Agency	Agency & Contractor[2]	Agency & Contractor	Agency & Contractor
Traffic operations[4]	Agency	Agency	Agency	Agency	Agency& Contractor
Economic analysis of pavement alternatives					
Develop expenditure-stream diagrams	Agency	Agency	Agency & Contractor[2]	Contractor	Contractor
Establish LCCA framework	Agency	Agency	Agency & Contractor[2]	Contractor	Contractor
Compute life-cycle costs	Agency	Agency	Agency & Contractor[2]	Contractor	Contractor
Analyze/interpret results	Agency	Agency	Agency & Contractor[2]	Contractor	Contractor
Reevaluate strategies	Agency	Agency	Agency & Contractor[2]	Contractor	Contractor
Economic and noneconomic evaluation of pavement alternatives					
Evaluate pavement alternatives using economic factors	Agency	Agency	Agency & Contractor[2]	Contractor	Contractor
Evaluate pavement alternatives using noneconomic factors	Agency	Agency	Agency & Contractor [3]	Agency & Contractor [3]	Agency & Contractor[3]
Weigh noneconomic factors against economic analysis	Agency	Agency	Agency	Agency & Contractor [3]	Agency & Contractor[3]
Final selection of pavement alternative	Agency	Contractor	Agency & Contractor[2]	Contractor	Contractor

[1]Agency may perform the pavement-type selection process independently for validating contractor-based analysis and internal purposes.
[2]Depends on the type of design-build contract.
[3]Contractor may not consider factors relating to environment, road users, and society.
[4]It may be difficult to develop consensus on calculating differential costs during normal traffic operations between pavement types.
N/A = Not applicable

- Evaluation of contractor proposal—Upon receipt of bids, the agency accepts/rejects the contractor's proposal based on its conformance to contract provisions of the project.

Figure 17 presents a flow chart of the steps involved in the contractor-based type-selection process.

7.2.1 Agency Risks

In contractor-based type selection, the agency process begins with the determination of an appropriate contracting method in the preliminary phase of the project. The alternate contracting methods involving contractor-based selection typically include design-build, design-build with O&M, and long-term performance warranty methods. The contracting method largely defines the contractor scope in the project and the associated risks.

The agency then conducts a comprehensive risk assessment in the preliminary engineering phase prior to establishing the contract provisions. Typical agency risks include reduced pavement performance, increased unplanned intervention, cost overruns, time delays, and associated indirect effects such as public dissatisfaction and increased work zone accidents. The agency also can perform an independent evaluation of economic and noneconomic factors to address responsibilities toward to the taxpayers, road users, and the environment. Table 11 lists factors that should be considered in the agency's risk assessment. The process includes identification of risks, categorizing the probability of occurrence, determining the likely impact, and properly allocating risks to the parties that can best manage them.

To leverage these risks, the agency uses contract provisions as control points to define the contractor's obligations. For example, an agency may use performance criteria to leverage risks associated with the "pavement" component of a proposed facility. The agency then specifies performance threshold values and scheduled monitoring to ensure a desired level of service.

Whenever the measured performance fails to meet the requirements, the contractor is obligated to undertake repair and rehabilitation work, and failure to maintain the threshold performance may result in disincentives (Molenaar et al. 2005). On design-build projects, where the contractor has no responsibility for operation or maintenance, it is appropriate for the agency to reduce its risk by stipulating the pavement alternative(s) suitable for use or by specifying the selection criteria for the contractor to follow. In these cases the agency should clearly indicate the procedure and inputs to be used in the pavement design.

In addressing risks, the agency may be inclined to be more stringent in specifying the control points. Such stringent criteria may lead to contractor bids with higher prices than the agency's estimate. In some cases, the contract provisions may not be adequate to cover all the agency risks, which can result in a significant loss to the agency. Therefore, the agency-specified criteria should be robust, realistic, and achievable in order to attract reasonable bid prices from bidders. The agency should establish criteria for evaluating contractor-proposed pavement types and communicate them in the RFP or bid documents. Input from the pavement-type selection committee may be helpful in establishing contract provisions and evaluation criteria pertinent to pavements.

The agency also may use risk-sharing mechanisms such as warranty ceiling or price adjustment clauses for inflation management in order to achieve a balance in risk allocation. These strategies may play a significant role in developing reasonable contract provisions and attracting balanced bids from contractors.

The agency then communicates the project requirements and the evaluation criteria to potential bidders through the RFP or bid documents. The agency should ensure that these requirements are defined precisely in these documents.

7.2.2 Contractor Risks

The contractor's risks generally are associated with the contract provisions of a project and the primary organizational objectives. To put it practically, as a private enterprise, the contractor's primary organizational objectives are to increase the probability of winning the bid, meet the contractual requirements, minimize losses, and maximize profits. The contractor's risks depend on the following factors:

- Construction details (constructability and specifications).
- Location and site conditions (traffic, subgrade, working conditions, etc.).
- Performance and financial elements (initial costs, future needs, anticipated cost inflows, etc.).
- Performance criteria.
- Chances of a successful bid.
- Incentive/disincentive structure.
- Agency's receptiveness to proposed strategies.
- Contractor's experience.
- Contractor's ability to control operations and subcontractors.

The project-specific contractor risks begin with the contract provisions of a project. The contractor's perceived risks increase as the "unknowns" in the proposed project increase. Contractors tend to manage these perceived risks by building financial contingencies into their bid price. Similarly, if the project criteria are unrealistic (e.g., unreasonable quality limits), the contractor perceives higher risk, resulting in a higher proposed price. If the final bid price is too high, it is likely that the contractor will lose the contract.

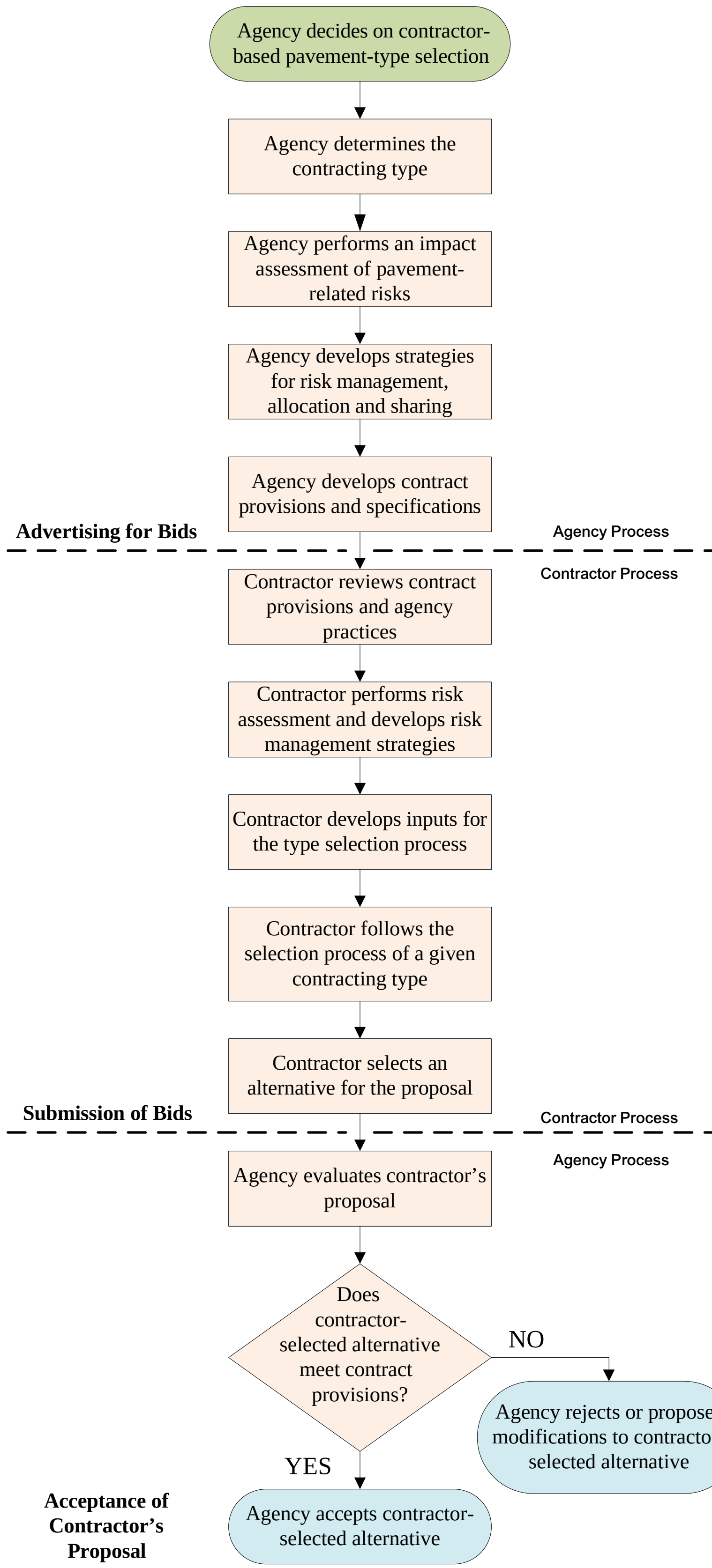

Figure 17. Overview of the contractor-based type-selection process.

Table 11. Factors suggested for risk analysis.

Design-Build	Design-Build with O&M	Performance Warranty
• Initial costs • Supplementary costs • Work zone costs • Noneconomic factors	• Agency's pool of alternatives • Performance criteria • Service life of initial pavement • Service life of structural rehabilitation • Type and timing of maintenance and functional rehabilitation • Initial costs • Commodity price inflation • Supplementary costs • Future maintenance costs • Future costs for rehabilitation • Future operational costs • Work zone costs • Noneconomic factors • Inflation, discount factors, and macroeconomic risks • Projected traffic volume • Projected revenue	• Agency's pool of alternatives • Performance criteria • Service life of initial pavement • Service life of structural rehabilitation • Type and timing of maintenance and functional rehabilitation • Initial costs • Commodity price inflation • Supplementary costs • Future maintenance costs • Future costs for rehabilitation • Future operational costs • Work zone costs • Noneconomic factors • Inflation, discount factors, and macroeconomic risks • Projected traffic volume • Additional costs for warranty requirements (for surety bonds as in additional bid price, $/sq. yd)

Note: In design-build scenarios, where the contractor is not responsible for O&M or long-term performance warranties, the contractor would follow the agency-specified process in developing life-cycle strategies.

The contractor's risk assessment process includes careful reviewing of the project criteria specified in the RFP or bid documents, identifying potential risks, categorizing the probability of occurrence, determining how significant the impact would be if the risk occurred, and developing strategies to mitigate the risks.

7.3 Developing Inputs for Contractor-Based Selection Process

While the overall framework of the agency-based pavement-type selection process is applicable to contractor-based pavement-type selection, contractor-based pavement-type selection also needs to incorporate the impact of increased risks in determining the inputs for the process. These factors can be incorporated in the proposed framework of contractor-based selection under the evaluation of feasible alternatives using economic and noneconomic factors.

When identifying inputs for the selection process, the contractor may find it advantageous to begin by reviewing the agency's pavement-type selection practices, pavement design methodology, and pavement management data. The agency-based pavement-type selection process can provide a solid starting point. The agency-based selection process reflects local practices on inputs such as M&R and future impacts to traffic, and the agency is likely to evaluate contractors' technical proposals based on how well they address local conditions. In some alternate contracting projects, the agency may provide specific guidance in the RFP on pavement-type selection criteria, such as pavement life-cycle strategies and design methodology.

Just as for agency risk assessment, contractors may analyze the factors listed in Table 11 to assess their own risk. The contractor should take a holistic view of the contract provisions, results of risk assessment, and the available risk-sharing mechanisms into consideration in customizing the inputs.

The contractor risk assessment can be utilized in establishing statistical distribution of risk factors to characterize their variability or uncertainty. For example, the inflationary risks of commodity prices may help to set the standard deviation of future costs, while the assessment of incentives/disincentives for measured pavement performance may prompt the contractor to focus more on maintenance strategies and less on rehabilitation.

Statistical characterization of risk factors may be unfeasible if sufficient data are unavailable. In such cases, the contractor can make adjustments based on the results of sensitivity analysis and Monte Carlo simulation. Contractors should make use of probabilistic risk assessment for determining inputs, which is similar to the probabilistic LCCA process.

7.4 Agency's Evaluation of Contractor-Based Selection

The agency evaluates the contractor's proposed pavement type for its conformance to contract provisions of the project, as illustrated in Figure 18. The agency can validate the assumptions and analysis criteria used in the contractor's selection process, as well as whether the contractor's selection meets the overall project goals. Once the contractor submits the preferred pavement type, the agency should check for compliance with its economic and noneconomic goals.

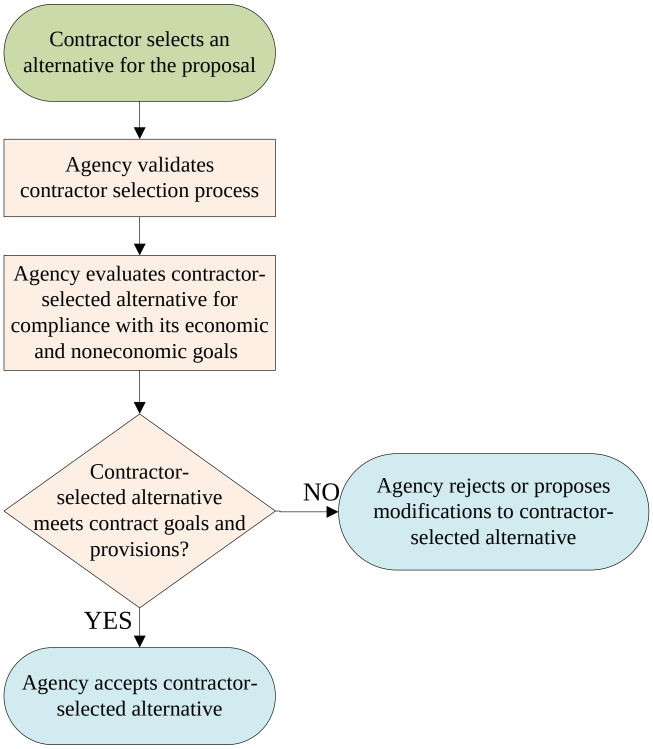

Figure 18. Agency evaluation of contractor pavement type.

The agency can use the following criteria in evaluating the contractor-selected pavement type:

- Cost feasibility and reasonableness of alternatives.
- M&R schedule.
- Structural design.
- Innovative/new practices proposed.
- Quality management.
- Construction time and the impact of work zone to traffic.
- Constructability.

Based on the evaluation, the agency can accept or reject the contractor's proposed pavement type or initiate negotiations for further modifications. When the pavement portion is a relatively small part of the project, scoring on the pavement design will not be a determining factor in the award of the project. In such cases, and where a low bid award is mandated by law, the agency should consider specifying the acceptable pavement designs in the RFP.

7.5 Pavement-Type Selection in Alternate Contracting Projects

7.5.1 Design-Build Projects

In design-build projects, an agency executes a single contract for both design services and construction of a project. The contractor assumes primary responsibility for both design and construction teams and thus contributes to the elimination of the conflicts between them and the acceleration of the construction schedule. Design-build projects are awarded based on either lowest price (with or without adjustments for technical value) or best value for a fixed price.

An agency may define the contractor's role in pavement-type selection in one of the following ways:

- **Agency-specified.** The agency specifies the pavement type in the proposal and specifies either the final thickness of each pavement layer or the minimum thickness (or minimum compacted depth). The contractor is allowed to make necessary design adjustments for certain conditions (e.g., frost protection). In any event, the contractor must follow the agency-specified pavement type and thickness design.
- **Agency-preferred.** The agency specifies the preferred pavement types as well as any pavement types that are not allowed. The contractor must select a pavement type from the choice the agency provides. The agency may ask the contractor to perform thickness design for the selected pavement type in accordance with the standard procedures.
- **Agency-permitted.** The agency allows the contractor to select the pavement type and perform structural design. The agency requires the contractor to provide detailed documentation of the design inputs, a narrative on how the inputs were determined, the design methodology, and the outputs.

Design-build projects usually involve contractor services only in the design and construction phases, typically with a limited warranty period; they usually do not extend to other phases of the pavement life cycle, such as M&R. On projects with a shorter turnover period and limited contractor responsibility, the agency assumes the responsibility for managing future performance risks. Therefore, the agency can stipulate the pavement alternative(s) to be used in a project or specify the criteria, such as the life-cycle strategies, design criteria and inputs for LCCA, to be followed in the selection process. These stipulations help to ensure that the contractor builds a pavement that meets the agency's expectations.

In the agency-specified scenario, the agency performs the pavement-type selection using its own design methodology, life-cycle strategies, and cost criteria. While specifying the final pavement type, the agency is encouraged to allow for incentives for contractor innovation and competition that would result in long-term cost savings. In the agency-preferred and agency-permitted scenarios, contractors follow the agency's process in pavement-type selection. The contractor can follow

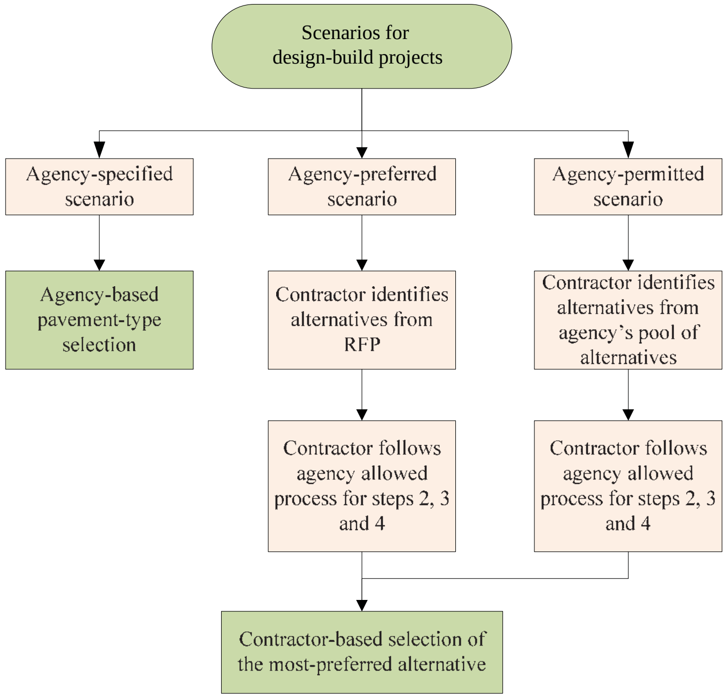

Figure 19. Pavement-type selection for design-build projects.

the process presented in Figure 19. The individual steps of the selection process include:

Step 1. Identifying feasible alternatives from the RFP when restrictive, or the agency's pool of alternatives when permissive (see Figure 3).
Step 2. Following agency-allowed practices or RFP instructions in developing pavement life-cycle strategies for alternatives (see Figure 4).
Step 3. Following agency-allowed practices or RFP instructions in conducting LCCA (see Figure 8) and evaluation using economic and noneconomic factors (see Figure 15).
Step 4. Selecting the most-preferred alternative (see Figure 18).

7.5.2 Design-Build Projects with O&M

These projects involve a greater role for the private sector through public–private partnerships in areas such as project conceptualization, financial planning, project financing, O&M, toll collection, congestion pricing, and design and construction. Design-build projects with O&M typically are larger and more complex than traditional projects.

Variants of design-build projects with O&M include:

- Design-build–operate–maintain.
- Design-build–finance–operate.
- Long-term lease.

Due to the complexity of these projects, there are several risk factors associated with finance, revenue, macroeconomics, and facility management that may have a direct or indirect bearing on the pavement-related costs. These risks may have a "subjective" influence on the contractor's decision making. Assumptions pertaining to the following factors contribute to these risks:

- Traffic volume projections.
- Revenue from tolls.
- Maintenance costs.
- Operational costs.
- Financing costs.
- Commodity prices.
- Inflation and discount rates.

Given the contractor's risks and responsibilities in design-build with O&M, agencies generally allow the contractors to select the preferred pavement type. The contractor can follow the process presented in Figure 20. The individual steps of the selection process can include:

Step 1. Reviewing contract provisions to identify potential risks (see Figure 17 for Steps 1 through 4).
Step 2. Performing risk assessment to develop risk management strategies.
Step 3. Reviewing the agency's pavement-type selection practices, design methodology, and pavement performance data.

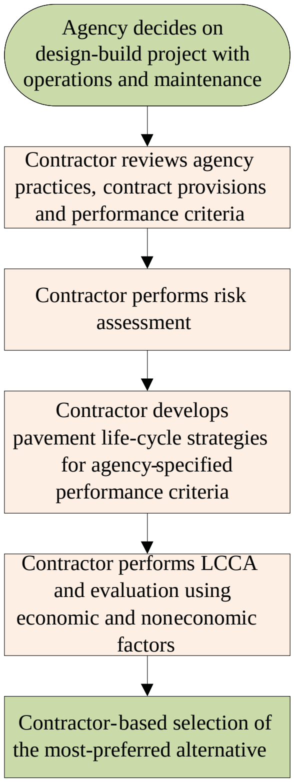

Figure 20. Pavement-type selection for design-build projects with O&M.

Step 4. Developing contractor-specific inputs for use in the selection process.

Step 5. Selecting feasible alternatives considering project-specific constraints (see Figure 3). The contractors may select alternatives from the agency's pool or propose their own alternatives.

Step 6. Developing pavement life-cycle strategies for selected alternatives using contractor-specific inputs and agency-specified performance criteria (see Figure 4).

Step 7. Conducting LCCA using contractor-specific inputs (see Figure 8) and evaluation using economic and noneconomic factors (see Figure 15).

Step 8. Selecting the most-preferred alternative (see Figure 18).

7.5.3 Performance Warranty Projects

Pavement warranties require significant decision making by both agencies and contractors, as they contribute additional risks and benefits to pavement life-cycle costs. There are three types of warranties practiced in the highway industry: materials and workmanship, short-term performance, and long-term performance. Table 12 provides a comparison of the important aspects of the three warranty types.

Materials and Workmanship Warranty

In projects involving materials and workmanship warranty, the contractor is responsible only for material properties and workmanship issues that contribute to poor pavement performance during the warranty period. Since the agency is responsible for pavement-type selection, pavement design, and LCCA, the agency-based process can be followed.

Short-Term Performance Warranty

In short-term performance warranty projects, the agency is responsible for pavement-type selection and structural design requirements. Some agencies, however, may allow the contractor to select the pavement type in addition to design and construction aspects, and thereby allow for innovation. The contractor is responsible for material design, any improvements needed in materials and structural designs, better quality control, and performance issues during the warranty period. Short-term warranties are used in both traditional design-bid-build

Table 12. Comparison of pavement warranty types.

Aspect	Materials & Workmanship	Short-Term Performance	Long-Term Performance
Typical period	2–4 years	5–10 years	10–20 years
Type of specifications	Agency's current standard specifications for specific treatment	Agency-specified minimum materials and construction requirements acceptable for project	Agency-specified minimum structural design, material design, materials, and construction requirements acceptable for project
Agency responsibility	Structural design, material design, evaluation	Structural design, evaluation	Evaluation
Contractor responsibility	Correct defects in pavement caused by elements within their control	Material design, quality control, and pavement performance for warranty period	Structural design, material design, quality control, and pavement performance for warranty period
Acceptance of project	In accordance with agency's normal practices	Initial: construction activities Final: after specified warranty period is completed	Initial: construction activities Final: after specified warranty period is completed

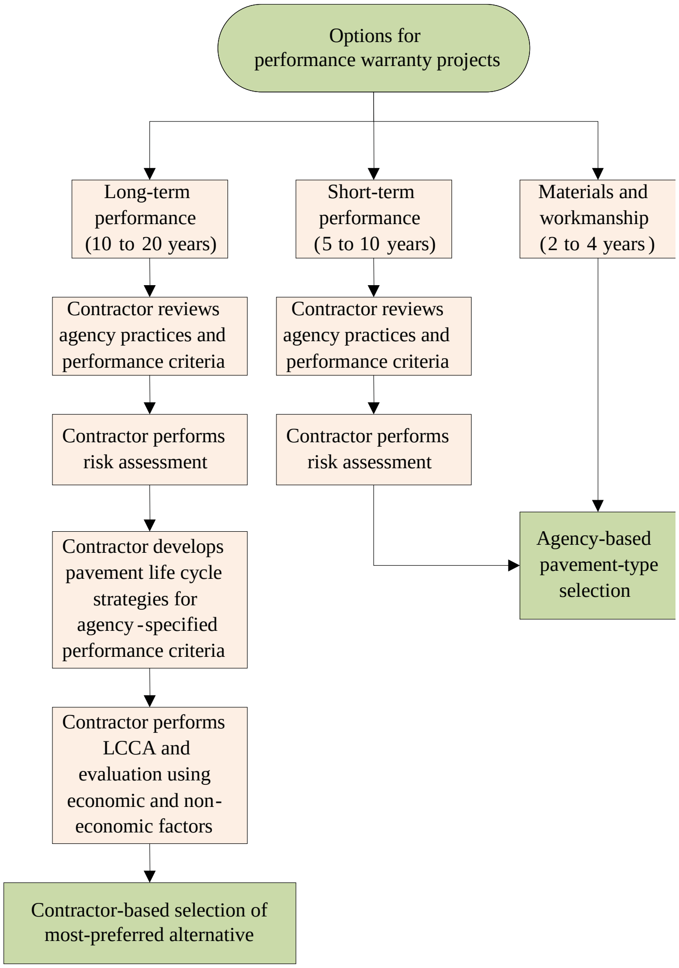

Figure 21. Pavement-type selection for performance warranty projects.

contracts and alternate contracts including design-build and multiparameter bidding.

The agency specifies performance thresholds to monitor pavement performance during the warranty period. In short-term performance warranty projects, the agency-based pavement-type selection process can be followed (see Figure 21). In addition, the contractor may need to perform risk assessment to incorporate risk premiums in the bid price.

Long-Term Performance Warranty

In long-term performance warranty projects, the contractor is responsible for performance issues and planned/unplanned maintenance activities over an extended period (typically, between 10 and 20 years). This type of warranty is used in both traditional and alternate contracting projects, where some projects may involve substantial financial investment from the contractor. However, the contractor generally is not given facility operations control.

In these projects, the contractor is responsible for pavement-type selection, structural design, materials selection and design, quality control, pavement maintenance, rehabilitation strategies, and performance. Contractor-based type selection is considered vital to long-term performance warranty projects, as it allows the contractor to select the most appropriate and cost-effective strategy for meeting performance requirements. The agency is responsible for establishing realistic performance thresholds, monitoring performance and, in some cases, sharing risks. Establishing realistic and achievable performance thresholds based on historical data is critical. Agencies use performance specifications for acceptance in these projects.

The contractor can follow the process presented in Figure 21. The individual steps of the selection process can include:

Step 1. Reviewing contract provisions to identify potential risks (see Figure 17 for steps 1 through 4).
Step 2. Performing risk assessment to develop risk management strategies.
Step 3. Reviewing the agency's pavement-type selection practices, design methodology, and pavement performance data,
Step 4. Developing contractor-specific inputs for use in the selection process.
Step 5. Selecting feasible alternatives considering project-specific constraints (see Figure 3). The contractor may select alternatives from the agency's pool or propose their own alternatives.
Step 6. Developing pavement life-cycle strategies for selected alternatives using contractor-specific inputs and agency-specified performance criteria (see Figure 4).
Step 7. Conducting LCCA using contractor-specific inputs (see Figure 8) and evaluation using economic and noneconomic factors (see Figure 15).
Step 8. Selecting the most-preferred alternative (see Figure 18).

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Glossary

Activity: A specific action performed by the highway agency or the contractor, such as initial construction or major rehabilitation. An activity is defined by its physical costs, its service life, and its effects on highway users. An activity is a component of an alternative.

Administrative Costs: Costs incurred in contract management administration overhead expenses.

Agency: A government organization responsible for initiating and carrying forward a highway program for the general public. May refer to a federal highway agency, state transportation department, metropolitan planning organization, local government organization, and so forth.

Agency Costs: Monies spent by a highway agency for construction or rehabilitation activities.

Alternative Contracting: Type of contract that is executed in ways other than traditional design-bid-build type.

Alternative-Preference Screening Matrix: A decision support tool that provides a structured approach for setting objectives, exploring the strengths and weaknesses of alternatives, prioritizing alternatives, and making the final "best possible" choice(s).

Alternatives: The complete set of initial and future activities that will satisfy the established pavement performance objectives of a project. In pavement-type selection, all alternatives being considered for a single project will equally meet the project's performance requirements.

Analysis Period: The time period used for comparing pavement-type alternatives. An analysis period may contain several maintenance and rehabilitation activities during the life cycle of the pavement being evaluated. The analysis period should not be confused with the pavement design or service life.

Award of Contract: The acceptance of a contractor's bid proposal by the agency.

Bidder: An individual, partnership, firm or corporation formally submitting a proposal for the advertised work or materials.

Commodity Price Adjustment: Adjustments made by the public agency to the contract unit prices of specific materials and supplies under conditions of price volatility.

Competitive Bidding: The process in which the procuring agency is required to advertise and award contracts to the lowest responsible and responsive bidder through open bidding, unless the use of the agency's own labor forces and equipment is more cost-effective.

Construction Contingency Cost: An additional markup cost applied to an estimate to account for undefined, unknown, and uncertain requirements.

Contractor: Private entity that provides design, construction and/or maintenance services to a highway agency. May refer to the design-builder or a concessionaire.

Corrective Maintenance: Activity performed to correct deficiencies that negatively impact the safe, efficient operations of the facility, and future integrity of the pavement section. Corrective maintenance generally is reactive to unforeseen conditions to restore a pavement to an acceptable level of service.

Correlation Analysis: A statistical technique that is used to study the relationship among variables.

Correlation Coefficient: A statistical measure that indicates the strength of the linear association between two variables. A correlation coefficient of +1 indicates that two variables are perfectly related in a positive linear sense, while a value of −1 indicates perfect negative correlation. Values closer to zero indicate poor or no correlation, and other intermediate values indicate partial correlation.

Cost-Based Estimating: A method to estimate the bid cost of a work item by estimating the cost of resources (time, equipment, labor, and materials) for each component task necessary to complete the work item, and then adding a reasonable amount for contractor's overhead and profit.

Depreciation: Loss in the value of an asset.

Design-Bid-Build: A project delivery method in which the public agency provides the design and solicits bids for the construction of the specified design.

Design-Build: A project delivery method in which the public agency combines procurement for both design and construction services into a single contract and from the same private-sector entity.

Design Life: The length of time for which a pavement structure is being designed based on structural distresses and traffic loadings.

Deterministic Analysis: Approach that uses single-point estimates in calculations without regard for the variability of the inputs. The single-point estimates usually are selected based on statistical averages, the most likely scenario, historical evidence, or professional experience.

Discount Rate: The time value of money used as the means of comparing the alternative uses for funds by reducing the future expected costs or benefits to present-day terms. Discount rates are used to reduce various costs or benefits to their present value or to uniform annual costs so that the economics of the various alternatives can be compared (approximately equal to interest minus inflation).

Downside Financial Risk: A chance for cost overrun or financial loss.

Economic Analysis Technique: The approach used in the planning process to analyze the relative costs and benefits of a potential investment. The most common economic analysis techniques include net present value (NPV), benefit/cost (B/C) ratios, internal rate of return (IRR), modified internal rate of return (MIRR) and equivalent uniform annual costs (EUAC).

End-Result Specification: A type of specification in which the agency specifies the final characteristics of the product and provides flexibility to the contractor in achieving it.

Engineering Costs: Costs incurred with design of pavement alternatives, construction engineering, construction supervision, materials testing, and analysis of the pavement.

Equivalent Alternatives: Pavement types that are designed to perform equally, provide the same level of service, over the same performance period, and have similar life-cycle costs.

Expenditure-Stream Diagram: The graphical depiction of expenditures over time associated with various activities in a pavement life cycle. The upward arrows indicate expenditures, whereas the downward arrows indicate benefits.

Family of Pavements: A group of pavements that share similar characteristics such as the pavement type, design features, materials, traffic volume, functional classification, and so on.

Functional Classification: The process by which highways and streets are grouped into classes, or systems, according to the type of service they are intended to provide.

Functional Performance: Ability of the pavement to provide a smooth, comfortable, and safe ride to the road user, as measured by smoothness.

Functional Treatments: Activity to extend the functional performance of an in-service pavement.

Historical Bid-Based Estimating: A method of estimating current unit prices using historical bid data of similar projects from recently awarded contracts.

Incentive/Disincentive: Pay adjustments awarded to the contractor as reward/penalty based on the quality or performance of the finished product.

International Roughness Index: A pavement roughness index computed from a longitudinal profile measurement using a quarter-car simulation at a simulation speed of 50 mph (80 km/h).

Life-Cycle Cost Analysis: An economic assessment of an item, area, system, or facility and competing design alternatives considering all significant costs of ownership over the economic life, expressed in equivalent dollars.

Life-Cycle Cost: The total cost of ownership of a pavement section computed over the analysis period.

Life-Cycle Cost Adjustment Factor: The difference in future costs of two pavement alternatives.

Maintenance: The preservation of the entire roadway, including surface, shoulders, roadsides, structures, and such traffic control devices as are necessary for its safe and efficient utilization.

Maintenance Treatments: Treatment activities intended to correct or preserve a roadway pavement for its safe and efficient utilization.

Materials and Workmanship Type Warranty: A warranty that requires contractors to correct defects in the pavement caused by elements within their control and assumes no contractor responsibility for the design.

Mechanistic–Empirical: A design approach that incorporates the principles of mechanics of solids with empirically derived performance relationships to accomplish the design objectives.

Monte Carlo Simulation: A computational algorithm based on repeated random sampling that often is used in simulating a distribution of likely results.

Net Present Value: The net value of all present and future costs and benefits converted to a single point in time using a discount rate factor.

Pavement Condition: A quantitative representation of pavement distress at a given point in time.

Pavement Life-Cycle Model: A combination of strategies to achieve the desired functional and structural performance level of the pavement over the chosen analysis period. Strategies include the initial construction, structural and functional rehabilitation, preventive maintenance, and corrective maintenance activities.

Performance Specifications: A type of specification that defines the performance characteristics of the final product and links them to construction, materials, and other items under contractor control.

Performance-Trend Analysis: Statistical analysis to determine the longevity of a pavement structure or a rehabilitation strategy using historical data.

Performance Warranty: A contract that requires the contractor to assume full responsibility for repairing or replacing defects in pavements during a prespecified period.

Preventive Maintenance: A planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity).

Plans, Specifications, and Estimates (PS&E): A project document containing contract drawings, project cost estimates, contract provisions, and requirements for facilitating construction and contract control.

Preliminary Engineering: The project development phase involving activities such as environmental review, preparation of construction documents, work zone impacts, development of geometric design, utilities discovery and verification, geotechnical studies for foundation and pavement design, preliminary drainage work, and cost estimates.

Public–Private Partnership (P3): A contractual agreement formed between a public agency and a private-sector entity that allows for greater private-sector participation in the delivery and financing of transportation projects.

Probabilistic Analysis: Approach that considers the inherent variability of inputs in addition to single-point estimates.

Rehabilitation: The act of restoring a pavement to a former condition.

Remaining Service Life: Structural life remaining in the pavement at the end of analysis period.

Request for Proposals: A document issued by the procuring agency to potential bidders detailing the requirements of a specific service or commodity sought on a particular project and soliciting detailed proposals from them. In P3 projects, the request for proposal is often part of a two-step procurement process, where the invitation is issued only to potential bidders meeting desired minimum qualifications in the preliminary process.

Residual Value: Value of the in-place pavement materials less the cost to remove and process the materials for reuse.

Responsive Bid: A bid submittal that meets all the requirements of the advertisement and proposal.

Risk: The potential impact of an uncertain condition or action on project objectives and outcomes.

Risk Allocation: The process of allocating contractual obligations and risks between parties. The fundamental tenets of risk allocation include allocating risks to the party best able to manage them, allocating risks in alignment with project goals, and allocating risks to promote team alignment with customer-oriented performance goals.

Risk Assessment: The systematic process of identifying and determining the qualitative or quantitative impact of risks associated with an activity.

Salvage Value: The value (positive if a residual economic value is realized and negative if demolition costs are accrued) of competing alternatives at the end of the life cycle or analysis period. Typically consists of remaining service life and residual value.

Sensitivity Analysis: The study in which the inputs of a model are changed systematically to assess their effects on the final outcome.

Service Life: The period of time from completion of construction until the structural integrity of the pavement is determined to be unacceptable and rehabilitation/replacement is required.

Stakeholder: Stakeholders in a construction project typically include the owners and users of facilities, government agencies, project managers, contractors, subcontractors, material and equipment suppliers, designers, financial service providers, funding agencies, road users, neighbors, and the general public.

Structural Performance: Ability of the pavement to support anticipated traffic loadings and withstand environmental effects to resist the occurrence of physical distress.

Survival Analysis: A technique that analyzes the probability of nonoccurrence of failure with time or traffic loadings for a family of pavements.

Tornado Plot: Describes how sensitive the value of an output variable is to the input variables of the model.

Traffic Control Costs: Costs incurred in managing vehicular and pedestrian traffic around a construction work zone to ensure safety. Costs include traffic control setup and communications.

Unit Price: The fixed price (including materials, labor, equipment, overhead, and profit) paid by the agency for a specific unit of work described in a contract.

Upside Financial Risk: A chance for cost underrun or financial gain.

User Costs: Costs incurred by highway users traveling on a facility, as well as the costs incurred by those who cannot use the facility because of either agency or self-imposed detour requirements. User costs typically consist of vehicle operating costs, accident costs, and user delay costs. In LCCA, user costs could take the form of delay costs or of changes in vehicle operating costs associated with various alternatives.

Warranty: A written assurance that a product or service provided by a contractor will meet certain specifications and provide desired performance over a specified period of time, as well as the responsibility of the contractor (or a subcontractor or supplier) for the repair or replacement of the deficiencies.

Warranty Ceiling: A contractual ceiling clause that specifies the limits on the warranty terms offered by the contractor, such as a cap on the total project expenditure or the expiration of warranty after *X* number of heavy trucks.

APPENDIX A

Alternative-Preference Screening Matrix Example

This appendix illustrates the application of the alternative-preference screening matrix for pavement-type selection. In the example presented, three qualifying pavement-type alternatives are analyzed using the screening matrix for various evaluation scenarios.

Needs Statement

Assume that an agency has identified three pavement-type alternatives using the process outlined in this Guide. Alternative 1 is similar to Alternative 3, except that Alternative 3 includes some superior material and technological components. Also assume that the surface types in adjacent pavement sections of the proposed project are the same as for Alternative 2. For each alternative, the available information includes the LCCA outputs and the results of economic and noneconomic evaluation.

Table A1 lists the cost estimates for the three alternatives obtained from the LCCA procedure, with future costs adjusted to their present values. As the life-cycle costs are within 10 percent of one another, all three alternatives are qualified as cost-effective strategies for further evaluation.

Table A2 lists the economic and noneconomic factors that the agency identified as important to its goals and project requirements. The economic evaluation of the alternatives establishes their financial viability, while the noneconomic evaluation validates that these alternatives meet at least the minimum project requirements, as well as the agency goals and expectations.

In this example, three hypothetical evaluation scenarios for pavement-type selection are considered, each of which reflects emphasis on different agency goals and project needs, as outlined in Table A3. For each of these scenarios, the user must select the most-preferred pavement-type alternative (i.e., Alternative 1, 2, or 3). Regardless of the scenario, the pavement-type selection aspects, such as the qualifying pavement-type alternatives, cost estimates, and evaluation criteria, should remain the same.

Step 1: Identification and Grouping of Evaluation Factors

First, the evaluation factors identified in Table A2 are grouped as cost considerations, construction/materials considerations, and other considerations (see Table A4).

Step 2: Assignment of Group and Individual Factor Weights

In this step, the evaluation factors and groups are assigned appropriate weights to address the scenarios outlined in Table A3. The importance of evaluation factors and their weights change with varying scenario goals. Table A5 presents the factors that may require additional emphasis (i.e., higher weights) in each scenario.

In Scenario 1, the agency goal is to select an alternative with overall cost-effectiveness and lower initial costs; therefore, additional emphasis is placed on both life-cycle and initial costs. In Scenario 2, the agency priorities include not only the overall cost-effectiveness of an alternative but also the anticipated M&R and future user costs. In addition to cost considerations, the agency emphasizes continuity issues related to surface types of adjacent pavement sections. In Scenario 3, in addition to considering life-cycle costs, the agency considers implementing a new technology that is expected to provide better noise mitigation performance and safety features. Considering the varying agency priorities, the weights to each group are assigned as shown in Table A6.

The cost considerations are heavily weighed at 60 percent in all three scenarios, while the construction/materials considerations and other considerations are given additional importance in Scenarios 2 and 3, respectively.

Table A7 lists the distribution of weights assigned to individual factors within each group for the three scenarios. The table also illustrates the relative importance of individual factors across groups in the overall evaluation of the matrix. The

Table A1. Results of LCCA.

Cost Factor	Alternative 1	Alternative 2	Alternative 3
Initial costs	$3,100	$3,800	$3,500
Present value of future rehabilitation costs	$792	$338	$723
Present value of future maintenance costs	$120	$58	$84
Present value of user costs	$171	$126	$158
Present value of total agency costs	$4,012	$4,196	$4,307
Present value of total costs	$4,183	$4,322	$4,465

Note: All costs are in thousands of dollars per lane mile.

Table A2. Factors considered in the economic and noneconomic evaluation.

Economic Factors	Noneconomic Factors	
• Initial costs • Life-cycle costs • User costs • Future M&R costs	• Roadway/lane geometrics • Continuity of adjacent pavements • Continuity of adjacent lanes • Availability of local materials and experience • Traffic during construction • Stimulation of competition	• Noise • Subgrade soils • Local preference • Safety considerations • Conservation of materials/energy • Maintenance capability • Future needs • Experimental features

Table A3. Agency goals and evaluation scenarios.

Scenario	Agency Goals
1	• To select a cost-effective pavement type with lower initial costs that meets the agency's financial goals and noneconomic criteria
2	• To select a cost-effective pavement type that meets the agency's financial goals and noneconomic criteria • To minimize future costs (maintenance, rehabilitation, and road user costs) • To select a pavement type compatible with those of adjacent sections
3	• To select a cost-effective pavement type with lower initial costs that meets the agency's financial goals and noneconomic criteria • To place additional emphasis on noise mitigation and safety features • May experiment with a new technology if feasible

Table A4. Grouping of economic and noneconomic factors.

Cost Considerations	Construction/ Materials Considerations	Other Considerations
• Initial costs • Life-cycle costs • User costs • Future M&R costs	• Roadway/lane geometrics • Continuity of adjacent pavements • Continuity of adjacent lanes • Availability of local materials and experience • Traffic during construction	• Noise • Subgrade soils • Local preference • Safety considerations • Conservation of materials/energy • Stimulation of competition • Maintenance capability • Future needs • Experimental features

Table A5. Weighing scenarios and agency emphasis factors.

Scenario	Additional Emphasis in Weighing
1	• Initial costs • Life-cycle costs (NPV)
2	• Life-cycle costs (NPV) • Future rehabilitation costs • Future maintenance costs • Future user costs • Continuity of adjacent pavements
3	• Initial cost • Life-cycle cost (NPV) • Future rehabilitation costs • Future maintenance costs • Noise • Safety considerations • Experimental features

factor weights across groups were calculated by multiplying individual factor weights within each group by their corresponding group weights provided in Table A6.

Step 3: Preference Rating of Individual Factors

This step entails preference rating of individual factors for each alternative based on their relative advantages and disadvantages. A comparative evaluation is presented in Tables A8 and A9.

Table A8 lists the difference in cost estimate (from the lowest estimate for this factor among the three alternatives) as a percentage of the lowest estimate for this factor. As noted in

Table A6. Weighing scenarios and group weights.

Scenario	Cost Considerations, %	Construction/ Materials Considerations, %	Other Considerations, %
1	60	20	20
2	60	35	5
3	60	5	35

Table A7. Weighing scenarios and individual factor weights.

Group	Factor	Percent Weights within a Group			Percent Weights across Groups		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Cost considerations	Initial costs	30	20	30	18	12	18
	Life-cycle costs	50	30	50	30	18	30
	User costs	5	10	5	3	6	3
	Future rehabilitation costs	10	25	10	6	15	6
	Future maintenance costs	5	15	5	3	9	3
	Group total	***100***	***100***	***100***	***60***	***60***	***60***
Construction / materials considerations	Roadway/lane geometrics	0	0	0	0	0	0
	Continuity of adjacent pavements	30	60	30	6	21	2
	Continuity of adjacent lanes	0	0	0	0	0	0
	Availability of local materials and experience	30	10	30	6	4	2
	Traffic during construction	40	30	40	8	11	2
	Group total	***100***	***100***	***100***	***20***	***36***	***5***
Other considerations	Noise	10	10	25	2	1	9
	Subgrade soils	20	20	0	4	1	0
	Local preference	10	10	15	2	1	5
	Safety considerations	15	15	25	3	1	9
	Conservation of materials/energy	10	10	10	2	1	4
	Stimulation of competition	25	25	0	5	1	0
	Maintenance capability	10	10	0	2	1	0
	Future needs	0	0	0	0	0	0
	Experimental features	0	0	25	0	0	9
	Group total	***100***	***100***	***100***	***20***	***7***	***36***

Table A8. Comparative evaluation of economic factors.

Economic Factors	Difference in Cost Estimate (%)		
	Alternative 1	Alternative 2	Alternative 3
Initial costs	0	23	13
Present value of future rehabilitation costs	135	0	114
Present value of future maintenance costs	107	0	45
Present value of user costs	35	0	25
Present value of initial and future direct costs	0	5	7
Net present value of initial and future costs	0	3	7

Note: "0" indicates the alternative having the lowest cost estimate for the specific economic factor.

this table, Alternative 1 has the lowest initial costs, direct agency costs, and life-cycle costs among the alternatives; Alternative 2 has the lowest future M&R costs and user costs; Alternative 3 generally ranks between Alternatives 1 and 2, except in the area of life-cycle costs.

Table A9 compares the relative advantages and disadvantages of the alternatives in terms of noneconomic factors. Alternative 2 has advantages over the others in terms of continuity of adjacent pavement but is at a disadvantage regarding subgrade conditions and recycling potential. Alternative 3 is similar to Alternative 1 in many aspects, but it offers better noise mitigation properties and safety features (such as skid resistance and reflectivity) than Alternatives 1 and 2.

Next, we assign preference ratings to evaluation factors based on the advantages that a given alternative offers. In this example, the rating criteria and rating scheme presented in Chapter 5 are used. Alternative 1 has the lowest initial cost among the alternatives (see Table A8); the initial costs of Alternatives 2 and 3 are higher by more than 10 percent. Using the rating criteria, Alternative 1 is rated "high" and the other alternatives are rated "low" for the initial cost factor.

Table A10 lists the evaluation factors considered in this example and their ratings for each of the three alternatives. This set of ratings is common to the three scenarios considered.

Step 4: Scoring Pavement-Type Alternatives

First, the ratings are converted to numerical scores. Next, for each alternative, the unweighted numerical scores are adjusted to weighted scores using the weights tabulated in Table A7. The sum of the weighted scores of factors within each group is the unweighted score for that group.

Using the group weights tabulated in Table A6, the unweighted group scores are adjusted to weighted group scores. The total score of each alternative is then calculated by sum-

Table A9. Comparative evaluation of noneconomic factors.

Noneconomic Factors	Alternative 1	Alternative 2	Alternative 3
Roadway/lane geometrics	No issues	No issues	No issues
Continuity of adjacent pavements	Different but no issues	Same as adjacent pavements	Different but no issues
Continuity of adjacent lanes	No issues	No issues	No issues
Availability of local materials and experience	No issues	No issues	No issues
Traffic during construction	Easy to accommodate	Somewhat difficult to accommodate	Easy to accommodate
Noise	Moderate noise levels	Increased noise levels	Lower noise levels
Subgrade soils	No major issues	Some issues	No major issues
Local preference	No preference	No preference	Some preference
Safety considerations	Good skid resistance but poor reflectivity	Good reflectivity but poor skid resistance	Better reflectivity and skid resistance
Conservation of materials/ energy	More recycling possibilities	Little recycling possibilities	More recycling possibilities
Stimulation of competition	Competition is encouraged	Competition is encouraged	Competition is encouraged
Maintenance capability	Common experience	Common experience	Common experience
Future needs	Easy to accommodate	Easy to accommodate	Easy to accommodate
Experimental features	Common technology	Common technology	No local experience

Table A10. Ratings of economic and noneconomic factors.

Group	Factor	Alternative 1	Alternative 2	Alternative 3
Cost considerations	Initial costs	High	Low	Low
	Life-cycle costs	High	High	High
	User costs	Low	High	Low
	Future rehabilitation costs	Low	High	Low
	Future maintenance costs	Low	High	Low
Construction/ materials considerations	Roadway/lane geometrics	No difference	No difference	No difference
	Continuity of adjacent pavements	Medium-high	High	Medium-high
	Continuity of adjacent lanes	No difference	No difference	No difference
	Availability of local materials and experience	No difference	No difference	No difference
	Traffic during construction	Medium-high	Medium	Medium-high
Other considerations	Noise	Medium	Low-medium	High
	Subgrade soils	Medium-high	Medium	Medium-high
	Local preference	Medium	Medium	High
	Safety considerations	Medium	Medium	High
	Conservation of materials/ energy	Medium-high	Low-medium	Medium-high
	Stimulation of competition	High	High	High
	Maintenance capability	No difference	No difference	No difference
	Future needs	No difference	No difference	No difference
	Experimental features	Low	Low	High

ming the weighted group scores of that alternative. These calculations are repeated for the three scenarios considered in this example. Table A11 summarizes the total scores of each alternative-scenario combination and provides the breakdown of weighted group scores. Tables A12 through A14 present the completed worksheets of the screening matrix for Scenarios 1, 2, and 3, respectively.

Step 5: Interpreting Results

The alternative with the highest score can be selected as the most-preferred alternative for each scenario. Note that the outcomes in these scenarios are different, reflecting changes in agency goals and project needs. In Scenario 1, Alternative 1 is the preferred alternative, largely because of the advantages it provides in initial costs. In Scenario 2, Alternative 2 emerged as the preferred alternative with more weighing on future costs and the surface type continuity factor.

In Scenario 3, there apparently is no major difference in scores between Alternative 1 and Alternative 3. Where two alternatives are comparable, both could be selected as candidates for alternative bidding; however, since the agency priorities in Scenario 3 focus on experimenting with new technology and achieving superior noise and safety performance, Alternative 3 is selected as the most preferred alternative.

Table A11. Summary of screening matrix scores.

Scenario	Group	Alternative 1	Alternative 2	Alternative 3	Preferred Alternative
1	Cost considerations	50.4	45.6	36.0	1
	Construction/materials considerations	11.2	10.8	11.2	
	Other considerations	14.0	12.0	16.8	
	Total score	**75.6**	**68.4**	**64.0**	
2	Cost considerations	36.0	50.4	26.4	2
	Construction/materials considerations	25.2	27.3	25.2	
	Other considerations	3.5	3.0	4.2	
	Total score	**64.7**	**80.7**	**55.8**	
3	Cost considerations	50.4	45.6	36.0	3
	Construction/materials considerations	2.8	2.7	2.8	
	Other considerations	18.2	15.1	34.3	
	Total score	**71.4**	**63.4**	**73.1**	

Note: All values in percent. Highest total scores shaded.

Table A12. Alternative-preference screening matrix worksheet for Scenario 1.

Factors and Groups	Factor Weight	Alternative 1		Alternative 2		Alternative 3	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Group A. Cost considerations							
Initial costs	30.0	High	30.0	Low	6.0	Low	6.0
Life cycle costs	50.0	High	50.0	High	50.0	High	50.0
User costs	5.0	Low	1.0	High	5.0	Low	1.0
Future rehabilitation costs	10.0	Low	2.0	High	10.0	Low	2.0
Future maintenance costs	5.0	Low	1.0	High	5.0	Low	1.0
Group A unweighted total	***100***		***84.0***		***76.0***		***60.0***
Group B. Construction/materials considerations							
Roadway/lane geometrics	0	No difference	0.0	No difference	0.0	No difference	0.0
Continuity of adjacent pavements	30	Medium-high	24.0	High	30.0	Medium-high	24.0
Continuity of adjacent lanes	0	No difference	0.0	No difference	0.0	No difference	0.0
Availability of local materials and experience	30	No difference	0.0	No difference	0.0	No difference	0.0
Traffic during construction	40	Medium-high	32.0	Medium	24.0	Medium-high	32.0
Group B unweighted total	***100***		***56.0***		***54.0***		***56.0***
Group C. Other considerations							
Noise	10	Medium	6.0	Low-medium	4.0	High	10.0
Subgrade soils	20	Medium-high	16.0	Medium	12.0	Medium-high	16.0
Local preference	10	Medium	6.0	Medium	6.0	High	10.0
Safety considerations	15	Medium	9.0	Medium	9.0	High	15.0
Conservation of materials/energy	10	Medium-high	8.0	Low-medium	4.0	Medium-high	8.0
Stimulation of competition	25	High	25.0	High	25.0	High	25.0
Maintenance capability	10	No difference	0.0	No difference	0.0	No difference	0.0
Future needs	0	No difference	0.0	No difference	0.0	No difference	0.0
Experimental features	0	Low	0.0	Low	0.0	High	0.0
Group C unweighted total	***100***		***70.0***		***60.0***		***84.0***
Subtotals	**Group Weights**	**Group Unweighted Total**	**Group Weighted Total**	**Group Unweighted Total**	**Group Weighted Total**	**Group Unweighted Total**	**Group Weighted Total**
A. Cost considerations	60	84.0	50.4	76.0	45.6	60.0	36.0
B. Construction/materials considerations	20	56.0	11.2	54.0	10.8	56.0	11.2
C. Other considerations	20	70.0	14.0	60.0	12.0	84.0	16.8
Grand total	**100**		**75.6**		**68.4**		**64.0**

Note: All values in percent.

Table A13. Alternative-preference screening matrix worksheet for Scenario 2.

Factors and Groups	Factor Weight	Alternative 1		Alternative 2		Alternative 3	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Group A. Cost considerations							
Initial costs	20	High	20.0	Low	4.0	Low	4.0
Life cycle costs	30	High	30.0	High	30.0	High	30.0
User costs	10	Low	2.0	High	10.0	Low	2.0
Future rehabilitation costs	25	Low	5.0	High	25.0	Low	5.0
Future maintenance costs	15	Low	3.0	High	15.0	Low	3.0
Group A unweighted total	***100***		***60.0***		***84.0***		***44.0***
Group B. Construction/materials considerations							
Roadway/lane geometrics	0	No difference	0.0	No difference	0.0	No difference	0.0
Continuity of adjacent pavements	60	Medium-high	48.0	High	60.0	Medium-high	48.0
Continuity of adjacent lanes	0	No difference	0.0	No difference	0.0	No difference	0.0
Availability of local materials and experience	10	No difference	0.0	No difference	0.0	No difference	0.0
Traffic during construction	30	Medium-high	24.0	Medium	18.0	Medium-high	24.0
Group B unweighted total	***100***		***72.0***		***78.0***		***72.0***
Group C. Other considerations							
Noise	10	Medium	6.0	Low-medium	4.0	High	10.0
Subgrade soils	20	Medium-high	16.0	Medium	12.0	Medium-high	16.0
Local preference	10	Medium	6.0	Medium	6.0	High	10.0
Safety considerations	15	Medium	9.0	Medium	9.0	High	15.0
Conservation of materials/energy	10	Medium-high	8.0	Low-medium	4.0	Medium-high	8.0
Stimulation of competition	25	High	25.0	High	25.0	High	25.0
Maintenance capability	10	No difference	0.0	No difference	0.0	No difference	0.0
Future needs	0	No difference	0.0	No difference	0.0	No difference	0.0
Experimental features	0	Low	0.0	Low	0.0	High	0.0
Group C unweighted total	***100***		***70.0***		***60.0***		***84.0***
Subtotals	**Group Weights**	**Group Unweighted Total**	**Group Weighted Total**	**Group Unweighted Total**	**Group Weighted Total**	**Group Unweighted Total**	**Group Weighted Total**
A. Cost considerations	60	60.0	36.0	84.0	50.4	44.0	26.4
B. Construction/materials considerations	35	72.0	25.2	78.0	27.3	72.0	25.2
C. Other considerations	5	70.0	3.5	60.0	3.0	84.0	4.2
Grand total	**100**		**64.7**		**80.7**		**55.8**

Note: All values in percent.

Table A14. Alternative-preference screening matrix worksheet for Scenario 3.

Factors and Groups	Factor Weight	Alternative 1		Alternative 2		Alternative 3	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Group A. Cost considerations							
Initial costs	30	High	30.0	Low	6.0	Low	6.0
Life cycle costs	50	High	50.0	High	50.0	High	50.0
User costs	5	Low	1.0	High	5.0	Low	1.0
Future rehabilitation costs	10	Low	2.0	High	10.0	Low	2.0
Future maintenance costs	5	Low	1.0	High	5.0	Low	1.0
Group A unweighted total	***100***		***84.0***		***76.0***		***60.0***
Group B. Construction/materials considerations							
Roadway/lane geometrics	0	No difference	0.0	No difference	0.0	No difference	0.0
Continuity of adjacent pavements	30	Medium-high	24.0	High	30.0	Medium-high	24.0
Continuity of adjacent lanes	0	No difference	0.0	No difference	0.0	No difference	0.0
Availability of local materials and experience	30	No difference	0.0	No difference	0.0	No difference	0.0
Traffic during construction	40	Medium-high	32.0	Medium	24.0	Medium-high	32.0
Group B unweighted total	***100***		***56.0***		***54.0***		***56.0***
Group C. Other considerations							
Noise	25	Medium	15.0	Low-medium	10.0	High	25.0
Subgrade soils	0	Medium-high	0.0	Medium	0.0	Medium-high	0.0
Local preference	15	Medium	9.0	Medium	9.0	High	15.0
Safety considerations	25	Medium	15.0	Medium	15.0	High	25.0
Conservation of materials/energy	10	Medium-high	8.0	Low-medium	4.0	Medium-high	8.0
Stimulation of competition	0	High	0.0	High	0.0	High	0.0
Maintenance capability	0	No difference	0.0	No difference	0.0	No difference	0.0
Future needs	0	No difference	0.0	No difference	0.0	No difference	0.0
Experimental features	25	Low	5.0	Low	5.0	High	25.0
Group C unweighted total	***100***		***52.0***		***43.0***		***98.0***
Subtotals	**Group Weights**	**Group Unweighted Total**	**Group Weighted Total**	**Group Unweighted Total**	**Group Weighted Total**	**Group Unweighted Total**	**Group Weighted Total**
A. Cost considerations	60	84.0	50.4	76.0	45.6	60.0	36.0
B. Construction/materials considerations	20	56.0	2.8	54	2.7	56	2.8
C. Other considerations	20	52.0	18.2	43	15.1	98	34.3
Grand total	**100**		**71.4**		**63.4**		**73.1**

Note: All values in percent.

APPENDIX B

Example of Pavement-Type Selection in Alternate Bidding

This appendix illustrates how pavement-type selection is made in alternate bidding projects using the process proposed in the Guide. The information presented in this example is intended for illustrative purposes only.

Needs Statement

Assume that an agency is in the process of selecting pavement-type alternatives for a reconstruction project on a rural highway. The agency has evaluated the suitability of alternate bidding in this project and intends to use this method of project delivery if at least two qualifying alternatives are identified through the pavement-type selection process.

The agency routinely uses three pavement types for projects of this nature, as approved by the pavement-type selection committee. Project preliminary scoping studies found no engineering constraints in using any of these alternatives.

The agency requires an LCCA of alternatives for all new or reconstruction projects and has established the following inputs for use in the LCCA:

- Analysis period: 45 years.
- Discount rate: 3 percent.
- Computation approach: deterministic.
- Economic analysis technique: NPV.
- User costs are not considered.

The agency applies predefined economic criteria to determine the cost feasibility of alternatives and eliminates alternatives whose initial or life-cycle costs exceed those of the competing alternatives by 20 percent.

The agency has identified three noneconomic factors necessary for evaluation in the selection process:

- Material recycling.
- Stimulation of competition.
- Maintenance experience and capability.

The following steps illustrate the pavement-type selection process.

Step 1: Identify a Pool of Pavement-Type Alternatives

The pavement-type selection committee identifies a broader group of pavement-type alternatives for consideration in the selection process. The committee periodically identifies alternatives based on what does or does not work in their state, region, or district. This step is not required for the selection process at the project level. For this example, the pavement-type alternatives approved by the selection committee are designated Alternatives 1, 2, and 3.

Step 2: Identify Feasible Alternatives for the Project

At the project level, the process begins with the alternatives approved by the pavement-type selection committee. Within this group, pavement types that are considered inappropriate for this project are identified. For this example, all three alternatives are used routinely for the anticipated section traffic level and composition, and there are no issues with the existing pavement condition, historical trends, or roadway peripheral features.

The agency conducts an evaluation of existing pavement type through nondestructive testing and destructive sampling. In this example, the results indicate that there were no significant factors, such as the subgrade type or drainage conditions, that would override the use of these alternatives. During project scoping, the agency also evaluates roadway peripheral features such as changes in vertical profile, overhead clearances, and on-grade structures. In this case, no engineering constraints are found.

Step 3: Develop Pavement Life-Cycle Strategies

For each of the feasible alternatives identified in step 2, the agency develops pavement life-cycle strategies to maintain the desired performance level over the 45-year analysis period.

Table B1. Service-life estimates of pavement types.

Pavement Alternative	Expected Service Life (Years)	
	First Rehabilitation	Subsequent Rehabilitation
1	13	12
2	20	20
3	12	10

The agency first performs the structural designs, estimates the service lives, and identifies the timings and extents of anticipated M&R treatments.

The agency develops pavement designs for the alternatives using the same inputs and design criteria such as daily traffic volume, design life, reliability, and terminal performance with appropriate design procedures.

In routine practice, the agency typically uses statewide pavement management data to develop service life estimates of the initial structure and rehabilitation activities through performance trend analysis. The service life estimates of the three alternatives are presented in Table B1.

The agency identifies the type of major rehabilitation activities for each alternative and sequences their timing based on the service-life estimates (results are provided in Table B2). Major rehabilitation is planned at years 20 and 33 for Alternative 1, at year 25 for Alternative 2, and at years 15, 27, and 37 for Alternative 3. Scheduled maintenance will be performed annually for all the alternatives.

While Alternatives 1 and 2 are expected to have no useful remaining life at the end of the 45-year period, Alternative 3 is likely to have 2 years of unused life, as the scheduled rehabilitation at year 37 will extend its service life by 10 years. Therefore, salvage value is included only for Alternative 3 in the LCCA.

Step 4: Perform LCCA

The agency's LCCA procedure requires the computation of NPV over a 45-year analysis period at a discount rate of 3 percent. While the agency considers salvage value and supplemental costs for traffic control, preliminary engineering, and construction engineering, it does not consider road-user costs in the pavement-type selection process. The agency reports the direct cost estimate of each activity with supplemental costs included.

Table B3 and Table B4 present the direct agency costs for each alternative by the activity type in both real (undiscounted) and discounted terms, respectively. The salvage value for Alternative 3 has been calculated using the straight line depreciation method (see Figure B1). The expenditure-stream diagrams of each alternative are presented in Figure B2 through Figure B4.

The summary of the LCCA is presented in Table B5.

Step 5: Evaluation Using Economic Factors

Upon computing the life-cycle costs, the agency conducts an economic evaluation of alternatives to assess their cost feasibility at the project level as well as the agency level.

The agency first determines the cost feasibility of alternatives at the project level. The agency eliminates an alternative when its initial cost or life-cycle cost is 20 percent higher than that of the lowest competing alternative.

Based on the cost estimates presented in Table B5, the life-cycle cost of Alternative 1 is the lowest. The life cycle costs of Alternatives 2 and 3 are approximately 7 and 16 percent higher

Table B2. Timing and type of M&R activities.

Pavement Alternative	Time at which M&R Strategies will be performed			
	Rehabilitation 1	Rehabilitation 2	Rehabilitation 3	Maintenance
1	Year 20	Year 33		Annual
2	Year 25			Annual
3	Year 15	Year 27	Year 37	Annual

Table B3. Direct agency costs (real dollars).

Pavement Alternative	Initial Structure	Rehabilitation 1	Rehabilitation 2	Rehabilitation 3	Maintenance	Salvage Value
1	$2,650,000	$335,100	$405,000		$2,025/year	
2	$3,100,000	$188,500			$1,951/year	
3	$2,910,000	$357,000	$412,000	$474,000	$2,250/year	-$94,800

Table B4. Direct agency costs (discounted dollars).

Pavement Alternative	Initial Structure	Rehabilitation 1	Rehabilitation 2	Rehabilitation 3	Maintenance	Salvage Value
1	$2,650,000	$185,537	$152,696		$49,650	
2	$3,100,000	$104,357			$47,836	
3	$2,910,000	$229,145	$185,478	$158,782	$55,167	-$25,069

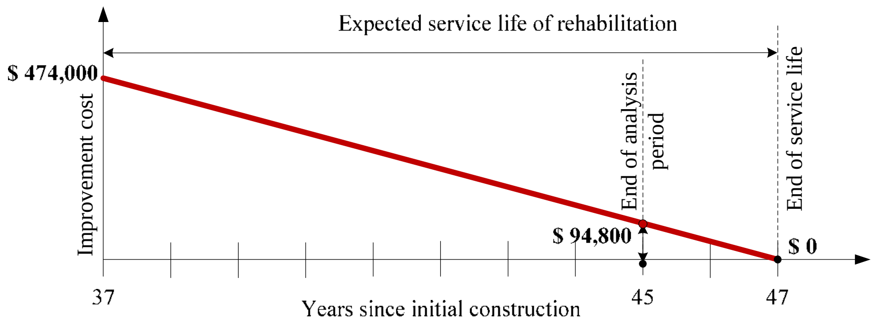

Figure B1. Salvage value calculation for Alternative 3.

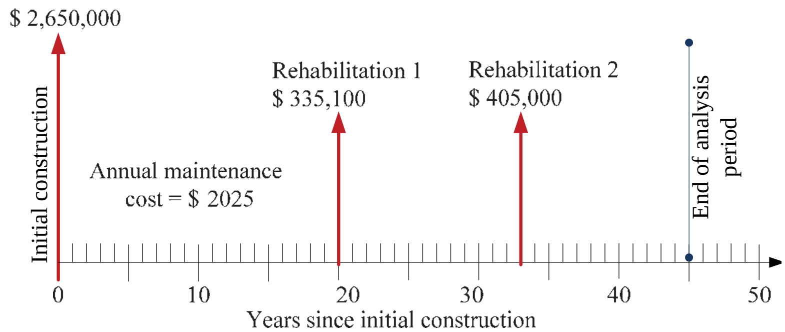

Figure B2. Expenditure-stream diagram for Alternative 1.

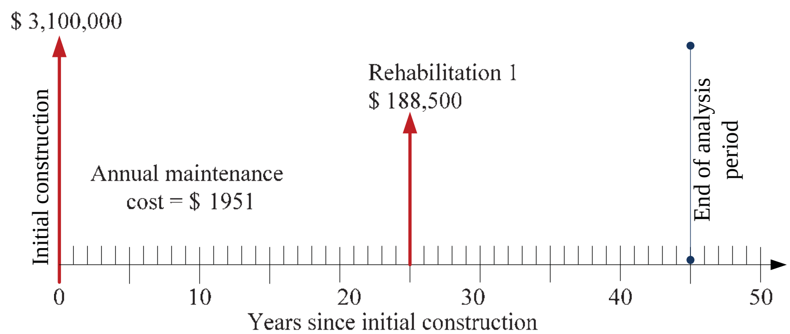

Figure B3. Expenditure-stream diagram for Alternative 2.

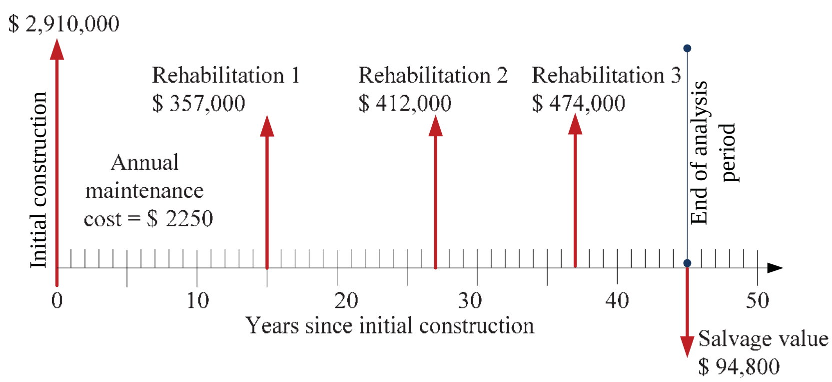

Figure B4. Expenditure-stream diagram for Alternative 3.

Table B5. Results of LCCA.

Cost Factor	Alternative 1	Alternative 2	Alternative 3
Initial costs	$2,650,000	$3,100,000	$2,910,000
Present value of future rehabilitation costs	$338,232	$90,029	$548,336
Present value of future maintenance costs	$49,650	$47,836	$55,167
Present value of total costs	$3,037,882	$3,237,865	$3,513,503

than that of Alternative 1, respectively. Also, the initial cost of Alternative 1 is the lowest. The initial costs of Alternatives 2 and 3 are approximately 17 and 10 percent higher than that of Alternative 1, respectively. Since the initial and life-cycle costs of Alternatives 2 and 3 are within the 20 percent threshold, none of them are eliminated.

The agency then determines if the selection of an alternative would have an adverse impact on the agency's financial goals and the overall system needs. The economic factors include:

- Initial costs.
- Life-cycle costs.
- Annual maintenance costs.
- Future rehabilitation costs.

The agency finds the cost estimates of alternatives comparable and unlikely to have adverse impacts at the agency level and concludes that all three alternatives satisfy its economic evaluation criteria.

Step 6: Evaluation Using Noneconomic Factors

In this step, the agency ascertains whether the risks from noneconomic factors will override inclusion of the alternative. The agency considers the following noneconomic factors necessary for evaluation in the selection process:

- Material recycling—Does the inclusion of this alternative encourage material recycling?
- Stimulation of competition—Does the inclusion of this alternative hinder competition?
- Maintenance capability—Does the maintenance unit have the experience and equipment to maintain this alternative?

Based on its evaluations, the agency concludes that all alternatives meet the evaluation of noneconomic criteria (see Table B6).

Step 7: Weighing of Economic and Noneconomic Factors

Since all the alternatives meet the economic criteria and there are no noneconomic factors to override their inclusion, these alternatives are considered as qualified alternatives. Now these alternatives are compared using an alternative-preference screening matrix to determine if there are considerable differences in the economic and noneconomic aspects of these alternatives. Based on this comparison, if a single alternative emerges as the most advantageous alternative, it is selected for traditional design-bid-build contracting. Otherwise, if two or more alternatives emerge with no significant differences, then these alternatives are considered for alternate bidding.

A detailed discussion of the alternative-preference screening matrix is presented in Appendix A. This section presents only the application of the screening matrix in selecting the preferred pavement types for the project under consideration.

Step 7a. Identification and Grouping Evaluation Factors

The factors considered in the evaluation are presented in Step 5 and Table B6.

Step 7b. Assignment of Group and Individual Factor Weights

The agency's goal is to select the preferred alternative(s) with overall cost-effectiveness and lower initial costs. There-

Table B6. Evaluation of alternatives using noneconomic factors.

Noneconomic Factors	Alternative 1	Alternative 2	Alternative 3
Material recycling	More recycling possibilities	Some recycling possibilities	More recycling possibilities
Stimulation of competition	Encourages competition	Encourages competition	Encourages competition
Maintenance capability	Common experience	Common experience	Common experience

Table B7. Weighing for individual factors and groups.

Group	Factor	Factor Weights within a Group	Factor Weights across Groups
Economic factors	Initial costs	15	12
	Rehabilitation costs	25	20
	Maintenance costs	5	4
	Life-cycle costs	55	44
	Group total	100	80
Noneconomic factors	Material recycling	20	4
	Stimulation of competition	50	10
	Maintenance capability	30	6
	Group total	100	20

Note: All values are in percent.

fore, the agency has assigned 80 percent weight to economic factors and 20 percent to noneconomic factors. Since the agency considers alternate bidding as an option, the agency has placed additional emphasis on life cycle among the economic factors and the stimulation of completion among the noneconomic factors.

Table B7 presents the distribution of weights assigned to individual factors within each group, as well as their relative importance in the overall evaluation of the matrix.

Step 7c. Preference Rating of Individual Factors

In this step, preference ratings are assigned to individual factors based on the comparative evaluation of advantages and disadvantages of each alternative.

Table B8 presents the percent differences in cost estimates for the three alternatives for the various economic factors. As noted, Alternative 1 has the lowest initial and life-cycle costs, while Alternative 2 has the lowest rehabilitation costs. The estimated maintenance costs of all three alternatives are comparable. In terms of noneconomic factors, the comparative advantages and disadvantages can be established based on the information presented in Table B6.

The agency then assigns preference ratings to evaluation factors based on the advantages that a given alternative offers. Table B9 presents the guidelines for rating economic factors. In this example, Alternative 1 has the lowest initial and life-cycle costs among the alternatives, so it is rated "High" for these factors. Similarly, as the life-cycle cost of Alternative 3 is more than 10 percent of the lowest life-cycle costs, the alternative is rated "Low" for life-cycle cost factor. Table B10 presents the complete set of evaluation factors and the ratings for the alternatives considered in this example.

Step 7d. Scoring Pavement-Type Alternatives

In this step, the preference ratings are converted to numerical scores. Next, for each alternative, the unweighted numerical scores are adjusted to weighted scores using the weights tabulated in Table B7. Then the unweighted group scores are

Table B8. Comparative evaluation of economic factors.

Economic Factors	Difference in Cost Estimate (%)		
	Alternative 1	Alternative 2	Alternative 3
Initial costs	0	17	10
Present value of future rehabilitation costs	276	0	509
Present value of future maintenance costs	4	0	15
Net present value of life-cycle costs	0	7	16

Note: "0" indicates the alternative having the lowest cost estimate for the specific economic factor.

Table B9. Agency's rating of economic factors.

Factor	Eliminate	Low	Medium	High
Initial costs	Cost > 20 %	Cost >10% and <20 %	Cost >5% and ≤10 %	Cost ≤ 5 %
Rehabilitation costs		Cost >10% and <20 %	Cost >5% and ≤10 %	Cost ≤ 5 %
Maintenance costs		Cost >10% and <20 %	Cost >5% and ≤10 %	Cost ≤ 5 %
Life-cycle costs	Cost > 20 %	Cost >10% and <20 %	Cost >5% and ≤10 %	Cost ≤ 5 %

Note: The percentage differences of cost items are calculated to their corresponding lowest value of the alternatives.

Table B10. Ratings of economic and noneconomic factors.

Group	Factor	Alternative 1	Alternative 2	Alternative 3
Economic factors	Initial costs	High	Low	Medium
	Rehabilitation costs	Low	High	Low
	Maintenance costs	High	High	Low
	Life cycle costs	High	Medium-high	Low
Noneconomic factors	Material recycling	Medium-high	Medium	Medium-high
	Stimulation of competition	High	High	High
	Maintenance capability	No difference	No difference	No difference

Table B11. Summary of the alternative-preference screening matrix scores.

Group	Alternative 1	Alternative 2	Alternative 3	Preferred Alternative
Economic factors	64.0	61.6	20.8	1 & 2
Noneconomic factors	13.2	12.4	13.2	
Total score	77.2	74.0	34.0	

Note: All values in percent.

Table B12. Alternative-preference screening matrix worksheet.

Factors and Groups	Factor Weight	Alternative 1		Alternative 2		Alternative 3	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Group A. Economic factors							
Initial costs	15	High	15.0	Low	3.0	Medium	9.0
Future rehabilitation costs	25	Low	5.0	High	25.0	Low	5.0
Future maintenance costs	5	High	5.0	High	5.0	Low	1.0
Life cycle costs	55	High	55.0	Medium-high	44.0	Low	11.0
Group A unweighted total	***100***		***80.0***		***77.0***		***26.0***
Group B. Noneconomic factors							
Material recycling	20	Medium-high	16.0	Medium	12.0	Medium-high	16.0
Stimulation of competition	50	High	50.0	High	50.0	High	50.0
Maintenance capability	30	No difference	0.0	No difference	0.0	No difference	0.0
Group B unweighted total	***100***		***66.0***		***62.0***		***66.0***
Subtotals	**Group Weights**	**Group Unweighted Total**	**Group Weighted Total**	**Group Unweighted Total**	**Group Weighted Total**	**Group Unweighted Total**	**Group Weighted Total**
A. Economic factors	80	80.0	64.0	77.0	61.6	26.0	20.8
B. Noneconomic factors	20	66.0	13.2	62	12.4	66	13.2
Grand total	**100**		**77.2**		**74.0**		**34.0**

Note: All values in percent.

adjusted to weighted group scores. Table B11 summarizes the total scores for the alternatives considered in this example, and Table B12 presents the completed worksheets of the screening matrix.

Step 7e. Interpreting Results

As noted in Table B11, Alternative 1 ranks firsts, followed by Alternatives 2 and 3. Alternatives 1 and 2 have nearly similar scores, but Alternative 3 has a much lower score (primarily because of the rehabilitation cost requirements). Therefore, Alternative 3 can be eliminated.

The initial cost for Alternative 1 is about 7 percent less than that for Alternative 2, and both alternatives have comparable scores. This situation is ideal for alternate bidding. By leaving the decision of selecting the final pavement type to the contractors, there is potential for savings in initial costs and gain from the competition between the industries.

Therefore, the agency considers Alternative 1 and Alternative 2 as equivalent pavement types and selects these alternatives for alternate bidding.

Step 7f. Calculate Bid Adjustment Factor

The agency then determines the bid adjustment factor for alternatives based on the difference in the present value of their future costs. Using the estimates presented in Table B5, the agency calculates the bid adjustment factor for the project as follows:

Future costs of Alternative 1 (Present value) =
$338,232 + $49,650 = $387,882.
Future costs of Alternative 2 (Present value) =
$90,029 + $47,836 = $137,865.
Bid adjustment factor = difference in future costs =
$387,882 – $137,865 = $250,017.

APPENDIX C

Example of Pavement-Type Selection in Design-Build Operations & Maintenance Projects

This appendix illustrates an example of the contractor-based selection in design-build O&M projects using the process proposed in Chapter 7.

Needs Statement

Assume that an agency is procuring a design-build O&M contract for reconstructing a 15-mile segment of a six-lane urban interstate highway. The facility serves as the primary route of the growing urban traffic, and the agency would like to reduce traffic disruptions as much as possible. The agency has identified funding mechanisms for the project and has decided to procure contractor services for design, construction, operations, and maintenance phases of the project for a period of 40 years. The agency is in the process of developing contract provisions addressing pavement-related needs for inclusion in the RFP.

Agency's Internal Assessment

As noted, the agency has identified the contracting type and the overall scope of contractor involvement in this project. While the agency retains the financing responsibilities of the project, the agency plans to procure contractor services in design, construction, and facility management with a single contract.

The agency performs an impact assessment to identify pavement-related risks in accomplishing project goals and successful execution of the contract. Based on the evaluation, the agency identifies strategies to manage them. The agency's evaluation culminates with contract provisions in the RFP that specify requirements for the project and the bid proposal. The key aspects of the process are summarized as follows:

- Pavement-type alternatives—The agency evaluates the pavement types currently used in its jurisdictions to determine if any of these alternatives should not be considered for this project. The agency considers all alternatives to be adequate and finds none of them to be restricted in this project. The agency also makes a decision to allow consideration of other pavement alternatives that are neither routinely used nor restricted in the RFP, if proposed by the bidders. The agency prepares a statement reflecting this provision such as:

  The agency considers the following alternatives adequate for this project:
  - *Alternative 1 (conventional)*
  - *Alternative 2 (conventional)*
  - *Alternative 3 (long-life)*
  - *Alternative 4 (long-life)*
  - *Alternative 5 (composite)*

  If proposed by the bidder, the agency will also consider another pavement type and determine its suitability and acceptability to the agency's pavement-type selection committee.
- LCCA program—The agency requires bidders to conduct an LCCA of the feasible alternatives used in the selection process. The bidders are required to submit documentation of the process identifying the inputs and assumptions used. The agency recommends that bidders use FHWA's RealCost software.
- Pavement design procedures—The agency allows bidders to use any nationally recognized procedure in developing pavement structural designs, but detailed documentation of the design calculations must be provided for approval and/or acceptance. The documentation should include all design inputs that are used to arrive at the pavement selections, including a narrative on how the inputs are determined.
- Service-life estimates of initial pavement and structural rehabilitation—The agency recommends that bidders follow agency guidelines in developing expected service lives of various pavement types and rehabilitation activities, as these estimates were developed using the agency's

pavement management data. The agency will allow bidders to make appropriate adjustments to these estimates but must be provided documentation supporting any deviations from the agency guidelines. The agency will then evaluate the reasonableness of these deviations.

- Type and timing of maintenance and functional rehabilitation—The agency recommends using the agency's guidelines in determining the type and timing of maintenance and functional rehabilitation activities. Should the bidders deviate from the standard agency practices, documentation supporting the deviations is necessary. The agency will then evaluate the reasonableness of these deviations.
- Initial costs—The agency has established standard protocols for bid analysis to determine if the bids are reasonable and responsive or if re-advertisement is necessary. If needed, the agency may compare the bid prices against historic cost models.
- Commodity prices, inflation, and macroeconomic risks—The agency typically uses Consumer Price Index (CPI) based inflation forecast models to predict short-term inflationary effect on materials, labor, and equipment. Considering the ineffectiveness of these models in predicting long-term trends, the agency recognizes the need for risk sharing with the potential contractor. Since the contract is executed for a 40-year period, the sharing of macroeconomic risks is necessary to get reasonably priced bids. The agency develops the following strategies for managing monetary risks associated with pavements:
  - The agency will pay the contractor a supplement if the future rehabilitation costs exceed 10 percent of the bid amount.
  - The agency will revise payments annually for scheduled maintenance, consistent with inflationary trends.
  - The agency prefers a pavement type with lower future costs and overall lower life cycle costs.
- Supplementary costs—The agency finds no risks in supplementary costs.
- Future costs for maintenance and rehabilitation—The agency will make adjustments to payments to reflect increases in commodity prices, prevailing labor rates, and equipment only. The agency will not pay for any unscheduled maintenance or rehabilitation not presented in the proposal.
- Work zone costs—Since the facility is expected to carry heavy traffic, the user cost component is expected to be significant. The agency develops the following strategies for managing work zone related risks:
  - The agency identifies 10-hour road closure as the standard strategy for traffic maintenance. Based on this strategy, the agency develops a baseline scenario for project completion and determines daily road user costs.
  - The agency then allows the bidders to propose alternate work-zone lane-closure strategies in their submittal. The agency will evaluate the strategy proposed in each submittal against the baseline scenario and score them accordingly.
  - The agency will specify a lane rental fee for this project. The rental fee will be determined based on the daily road user costs for the selected work zone strategy.
  - The agency prefers a pavement type with minimal future interventions.
- Noneconomic factors—The agency did not find any risks with noneconomic factors when the pavement types in the agency's list are used.
- Projected traffic volume—The agency forecasts the traffic volume to grow between 2 and 6 percent annually. The agency requires the contractor to use a 4 percent growth rate for developing structural designs and user costs. Should the traffic growth exceed this value, the agency will make financial adjustments to the contract.
- Performance criteria—The agency requires the contractor to maintain the pavement at a threshold performance level. The contractor is required to maintain the facility at all times meeting the following criteria:
  - IRI ≤ 140 inches/mile.
  - Average rut depth in wheel paths ≤ 0.25 inches.
  - Faulting ≤ 0.25 inches.

  The agency requires the contractor to submit the results of pavement condition surveys conducted annually.
- Hand-back criteria—On hand back, the agency requires the contractor to demonstrate that the pavement has at least 5 years of remaining useful life. The agency also specifies the method to be adopted in calculating the remaining useful life.
- The agency establishes evaluation criteria for contractor-proposed pavement types (see Table C1). The agency uses an adjusted bid method (life-cycle cost of an alternative/technical score) for approving the contractor-proposed pavement type.

The agency then develops the RFP that includes identified strategies and requirements and advertises for bidding.

Table C1. Agency's evaluation criteria.

Evaluation Factor	Criteria	Weights
Overall technical feasibility	Pass/Fail	Not required
Feasibility of initial costs	Pass/Fail	Not required
Adequacy of structural designs	Pass/Fail	Not required
Adequacy of M&R activities	Pass/Fail	Not required
Annual maintenance costs	Numerical rating	10%
Future rehabilitation costs	Numerical rating	50%
User costs	Numerical rating	30%
Future work zone disruptions	Numerical rating	10%

Contractor's Selection Strategies

Upon the release of the RFP, the contractor reviews the contract provisions and the standard agency practices. The contractor evaluates potential risks and develops bidding strategies accordingly. The key aspects of the contractor's risk assessment and strategies are summarized as follows:

- The contractor evaluates the adequacy of the agency-specified alternatives and the potential for considering other pavement types. The contractor takes into consideration various influencing factors, such as the contract period, hand-back criteria, performance criteria, and estimated service lives and costs of the initial structure and subsequent M&R activities.
- The contractor reviews the agency's M&R guidelines and practices and identifies if any adjustments are warranted.
- The contractor reviews the agency's service-life estimates and identifies any potential adjustments. The contractor considers adding a risk factor to the service-life estimates of alternatives to account for statistical variations in the agency's estimates.
- The contractor reviews the agency's LCCA parameters. To account for the uncertainties in the inputs, the contractor prefers using the probabilistic approach for LCCA.
- Although the agency will share the economic risks associated with future rehabilitation costs, the contractor intends to add a risk factor to account for uncertainties in projected future costs.
- The contractor does not include a risk factor for M&R costs, as the agency shares the risk of economic inflation. Similarly, the initial costs do not have a built-in factor for economic inflation.
- The contractor recognizes that user costs will play a significant factor in determining the winning bid. The contractor performs demand-capacity analysis of the existing traffic patterns to identify optimal lane closure strategies.
- Since the lane closure timings have an impact on project completion time and road user costs, the contractor considers performing further analysis for strategy selection.
- The contractor recognizes the importance of shorter completion time and fewer traffic disruptions for maintenance and rehabilitation activities.

Contractor's Selection of Inputs

Based on the contractor's selection strategies, the contractor finds it necessary to make adjustments to the agency's practices as follows:

- LCCA framework:
  - The agency's process uses a 40-year period, but the contractor adjusted this value to 45 years to account for the 5-year remaining useful-life requirement specified in the hand-back criteria.
  - The contractor uses the probabilistic approach for LCCA.
  - The agency currently uses a discount rate of 3 percent. The contractor reviews the historic discount factor published in OMB Circular A-94 and proposes a triangular distribution for discount factor with 4 percent as the most likely value and 2.5 and 6.5 percent as the minimum and maximum values, respectively.
  - The NPV will be used, to be consistent with the agency practice.
- Service-life estimates: The contractor selects a triangular distribution with a 10 percent variation on either side of the agency's estimated values. For instance, if the expected service life of a pavement is 20 years, the contractor will use a triangular distribution with 20 years as the most likely value and 18 and 22 years as the minimum and maximum service lives, respectively.
- Initial and maintenance costs: The contractor does not use risk factors for initial and scheduled maintenance costs. However, the agency will make annual adjustments to maintenance costs with inflation.
- Future rehabilitation costs: The contractor determines that a 10 percent risk factor to future costs will be optimal to minimize the future losses and maximize the chances of winning the bid. In the LCCA, the contractor uses a probabilistic distribution for future rehabilitation costs that varies uniformly between the projected estimate and the 10 percent above it. For instance, if the expected rehabilitation cost of an alternative is $150,000, the contractor will select a probabilistic distribution in the FHWA RealCost software that varies uniformly between $150,000 and $165,000.
- Project completion time: The contractor estimates the project completion time of initial and subsequent rehabilitation activities assuming a normal production rate associated with 10-hour lane closure (see Table C2).
- User costs: The contractor considers investigating feasible options for the following maintenance of traffic strategies:
  - 5- to 7-hour/day lane closure (only 1 lane open during closure).
  - 10-hour/day lane closure (only 1 lane open during closure).

Table C2. Number of required work zone days.

Activity	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Initial construction	30	35	30	36	40
Rehab 1	7	1	21	1	4
Rehab 2	20	2	0	0	4
Rehab 3	7	3	0	0	0

Note: Number of work zone days required to complete 5 miles of two lanes.

Table C3. Production and cost factors for various lane closure duration.

Lane Closure Duration	Number of Lanes Open During Closure	Production Factor*	Cost Factor**
7-hour/day	1	3	1.05
10-hour/day	1	1 (Normal)	1
16-hour/day	1	0.5	1.15
24-hour/day	2	0.25	1.25

* Project completion time = production factor times normal completion time
** Contractor costs = cost factor times contractor cost under normal completion schedule

– 16-hour/day lane closure (only 1 lane open during closure).
– 24-hour/day lane closure (2 lanes open during closure).

The weekend closure is not considered a feasible option due to lack of alternative routes to handle the heavy traffic on this segment.

- Using data from similar projects, the contractor determines the project completion time based on the productivity rate of 10-hour lane closure. The contractor develops production and cost factors to account for the effect of various lane closure strategies on project completion time and costs, respectively (see Table C3).

Contractor Selection Process

The contractor follows the agency's process for pavement-type selection. The key steps are summarized as follows. In this example, it is assumed that there will not be any non-economic risks associated with the agency-specified pavement types considered in the selection process. Therefore, the steps involving the evaluation of alternatives using noneconomic factors and the alternative preference screening matrix are not required.

Step 1. Identify Feasible Alternatives for the Project

The contractor identifies the following alternatives feasible for this project:

- Alternative 1 (conventional).
- Alternative 2 (conventional).
- Alternative 3 (long-life).
- Alternative 4 (long-life).
- Alternative 5 (composite).

Step 2. Develop Pavement Life-Cycle Strategies

The contractor performs structural designs and identifies life-cycle strategies for each alternative (see Figure C1 through Figure C5). The contractor takes the performance criteria into account in developing life-cycle strategies. The intervention strategies are planned based on the expected deterioration trends of each pavement type in service.

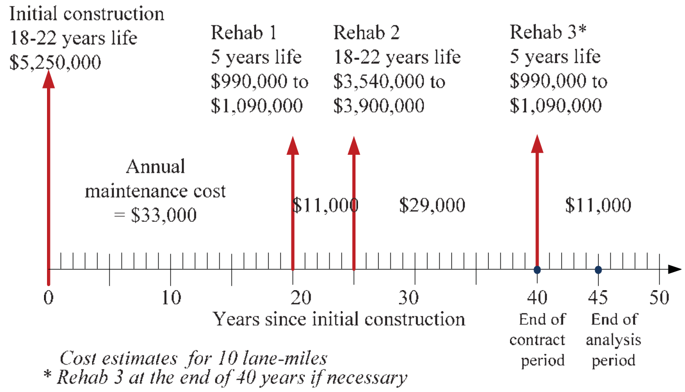

Figure C1. Pavement life-cycle strategies for Alternative 1.

Step 3. Compute Life-Cycle Costs

The contractor then conducts LCCA using FHWA RealCost. The undiscounted direct costs for various life-cycle activities of alternatives are presented in Figure C1 through Figure C5. The direct costs are calculated for 10 lane-miles, while the user costs are calculated for 10-hour lane closure of two lanes in a 5-mile work zone.

Table C4 summarizes the NPV of various alternatives obtained from the probabilistic analysis. Alternative 4 has the lowest life cycle costs, followed by Alternative 5 and Alternative 3. Table C5 presents the summary of estimated user costs of all alternatives obtained from the probabilistic analysis. These estimates are based on the 10-hour lane closure schedule and associated project completion schedule. Alternative 3 has the lowest user costs, followed by Alternative 4 and Alternative 2.

Based on both life-cycle costs and user costs, the contractor considers Alternative 4 as the preferred pavement type.

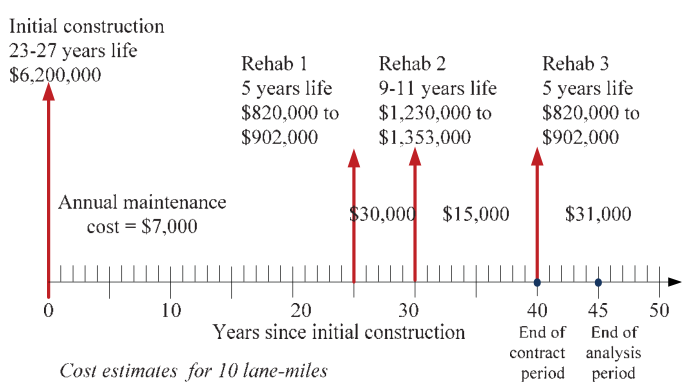

Figure C2. Pavement life-cycle strategies for Alternative 2.

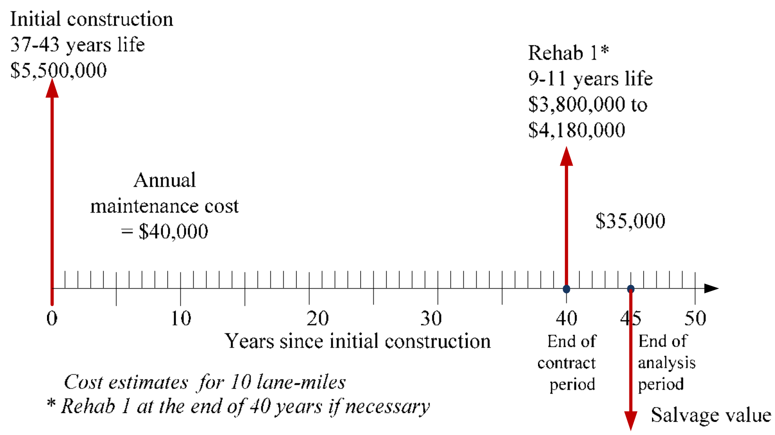

Figure C3. Pavement life-cycle strategies for Alternative 3.

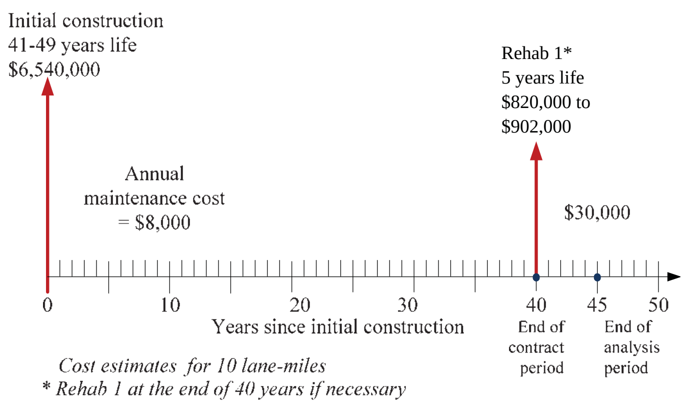

Figure C4. Pavement life-cycle strategies for Alternative 4.

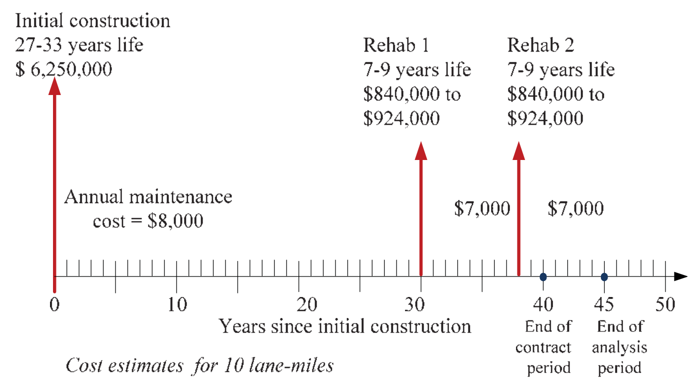

Figure C5. Pavement life-cycle strategies for Alternative 5.

Table C4. Life-cycle cost estimates of feasible alternatives.

Statistics	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Mean NPV	$7,670,000	$7,270,000	$6,920,000	$6,540,000	$6,860,000
Minimum NPV	$6,700,000	$6,740,000	$6,370,000	$6,470,000	$6,550,000
Maximum NPV	$8,780,000	$7,940,000	$7,790,000	$6,780,000	$7,240,000
90th Percentile	$8,210,000	$7,570,000	$7,270,000	$6,600,000	$7,040,000
Percent difference in mean NPV	17%	11%	6%	0% (lowest)	5%

Note: The values in this table indicate direct contractor costs for constructing 10 lane-miles (two lanes in a 5-mile work zone section).

Table C5. User cost estimates of feasible alternatives.

Statistics	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Mean NPV	$372,000	$287,000	$271,000	$287,000	$330,000
Minimum NPV	$312,000	$282,000	$246,000	$287,000	$323,000
Maximum NPV	$441,000	$293,000	$315,000	$288,000	$338,000
90th Percentile	$405,000	$290,000	$287,000	$287,000	$334,000
Percent difference in mean NPV	37%	6%	0%	6%	22%

Note: The values in this table indicate estimated user costs for a 10-hour closure of two lanes of a 5-mile work zone section.

Table C6. User cost estimates of different lane closure strategies.

Lane Closure Duration	Production Factor	Daily User Costs for Initial Construction	User Costs for the Entire Project Duration
7-hour/day	3	$4,010	$144,000
10-hour/day	1	$7,960	$287,000
16-hour/day	0.5	$394,190	$14,190,000
24-hour/day	0.25	$168,760	$6,075,000

Note: The values indicate estimated user costs for a 5-mile work zone section.

Table C7. Agency's evaluation of proposed pavement type.

Evaluation Factor	Criteria	Notes
Overall technical feasibility	Pass	No issues are found.
Initial (first costs)	Pass	Initial costs are high compared to other alternatives but feasible.
Adequacy of structural designs	Pass	No issues are found.
Adequacy of M&R activities	Pass	No issues are found.
Annual maintenance costs	9% (out of 10%)	Annual maintenance costs are low compared to other alternatives.
Future rehabilitation costs	45% (out of 50%)	The expected cost is low. Only one major activity is expected.
User costs	18% (out of 30%)	User costs of Alternative 4 are higher than those of Alternative 3 but acceptable.
Future work zone disruptions	9% (out of 10%)	The probability of future major intervention is low.
Total score = 81% Life-cycle costs of Alternative 4 = $6,540,000 Adjusted bid score = $6,540,000/0.81= $8,074,074		

Note: Total score = 81%; life-cycle costs of Alternative 4 = $6,540,000 (see Table C4); adjusted bid score = $6,540,000/0.81 = $8,074,074.

The contractor also explored the possibility of using different lane closure strategies for Alternative 4 only. The user cost estimates of different lane closure times are presented in Table C6. While the 7-hour lane closure appears desirable for managing work zone traffic, this strategy is expensive for the entire project duration. Similarly, although the 16-hour or 24-hour lane closures would provide for shorter project completion time, these strategies will result in longer queues, excessive delays, and higher user costs. Therefore, the contractor considers 10-hour road closure as the most feasible alternative.

Should the contractor select 10-hour road closure for this project, the agency is expected to use the daily user cost value ($7,960) as lane rental fee for the entire project duration.

Step 4. Selection of Preferred Alternative

The contractor proposes Alternative 4 and 10-hour daily lane closure as the preferred pavement type and the work zone strategy in the bid.

Agency's Evaluation

Upon submission of the contractors' type-selection information, the agency evaluates the technical and cost feasibility of the proposals. Among the scheme of other components, the agency evaluates the pavement type proposed by each bidder using the criteria in Table C1. For the pavement proposed in this example, the agency's evaluation is shown in Table C7.

The agency finds Alternative 4 acceptable for this project for the following reasons:

- It has lower life-cycle costs than other alternatives.
- Although its first costs are higher than those of other alternatives, it will not adversely affect on the overall system needs.
- Because its expected service life is 45 years, the pavement will require minimal interventions apart from scheduled maintenance.
- Its expected costs of scheduled maintenance are lower than those of other alternatives.

Because no or fewer major interventions are required, it will result in fewer traffic disruptions.

ATTACHMENT

Guide for Pavement-Type Selection: Summary of Research Report

CONTENTS

Introduction

Pavement-type selection is one of the challenging engineering decisions that highway administrators face today. They must balance issues of both short- and long-term performance with initial and long-term costs. The traveling public generally does not express strong feelings on the type of pavement constructed, as long as reasonable levels of service, safety, and ride quality are provided. However, highway administrators must deal with the competition that exists between the asphalt and concrete pavement industries. National Cooperative Highway Research Program (NCHRP) Project 10-75 was conducted to develop a rational process for pavement-type selection.

One of the earliest discussions about pavement-type selection was contained in *An Informal Guide on Project Procedures,* published by the American Association of State Highway Officials (AASHO) on November 26, 1960. The guide presented the following list of governing factors to serve as the basis of pavement-type selection:

> "To avoid criticism, if that is possible, any decision as to paving type to be used should be firmly based. Judicious and prudent consideration and evaluation of the governing factors will result in a firm base for a decision on paving type.
>
> A list of such factors comprises the following items:
>
> 1. Traffic.
> 2. Soils characteristics.
> 3. Weather.
> 4. Performance of similar pavements in the area.
> 5. Economics or cost comparison.
> 6. Adjacent existing pavements.
> 7. Stage construction.
> 8. Depressed, surface, or elevated design.
> 9. Highway system.
> 10. Conservation of aggregates.
> 11. Stimulation of competition.
> 12. Construction considerations.
> 13. Municipal preference, participating local government preference and recognition of local industry.
> 14. Traffic safety.
> 15. Availability of and adaptations of local materials or of local commercially produced mixes."

This list served as the basis for selection of pavement type on the Interstate system, as well as the basis for the guidance provided in the 1986 and 1993 editions of the AASHTO *Guide for Design of Pavement Structures.* The list is still relevant today and serves as a foundation for the *Guide for Pavement-Type Selection* prepared in this project. The development of the *Mechanistic–Empirical Pavement Design Guide* (MEPDG), pavement management systems, and extensive maintenance and rehabilitation (M&R) cost records makes the development of more rational and less subjective pavement-type selection procedures possible.

Research Objective, Scope, and Summary

The objective of NCHRP Project 10-75 was to develop a *Guide for Pavement-Type Selection.* The Guide includes processes for making decisions regarding pavement-type selection, for both agency-based and contractor-based type selection. This objective was accomplished in two phases. Work scope and findings are summarized in the following sections.

Phase I included (1) collecting and reviewing information relevant to pavement-type selection processes, (2) identifying and evaluating traditional and innovative processes for pavement-type selection, and (3) developing a plan for incorporating the best practices identified into a practical guide. Phase II utilized the findings of Phase I to develop, test, and illustrate the processes suggested for use in agency- and contractor-based pavement-type selection and then incorporated these processes into a Guide for Pavement-Type Selection.

Information on current pavement-type selection processes used by the state departments of transportation (DOTs) and international highway agencies was obtained through a questionnaire. In addition, state agency web sites were visited to review available policy documents. The questionnaire requested information on how certain factors (pavement performance life, discount rate, agency cost) were developed and other information that was not always apparent in the available published operational documents. Also requested was information on planned changes and ongoing research. Thirty-three state DOTs responded to the survey.

Because the questionnaires elicited limited data on design-build contractor pavement-type selection, additional searches were conducted to locate current research and review request for proposal (RFP) documents that had been issued by state DOTs.

A brief questionnaire also was sent to each of the states' flexible and rigid contractor paving associations requesting feedback on the pavement-type selection procedures used in their respective states.

The information gathered was reviewed, evaluated, and summarized. The initial work plan for developing the *Guide for Pavement-Type Selection* was updated based on this information and implemented in Phase II.

Summary of Findings

Table 1 lists state DOTs' responses regarding the use of pavement-type selection procedures.

Twenty-two of the 35 state DOTs responding have a formal type-selection process that requires the consideration of alternative pavement types on major new and reconstruction projects.

Table 1. State DOT pavement-type selection procedures.

State	Pavement Events Warranting Type Selection			Current Pavement-Type Selection Procedure			
	New Const	Re-Const	Rehab	Length Of Time Current Procedure Has Been Used, Years	Procedure Modified In Last 5 Years?	Modifications To Current Procedure Underway?	Projects Using Alternate Bidding To Select Pavement Type
Alabama	Y	Y	N	≥10	Y	N	<1
Arizona[1]	Y[1]	Y[1]	Y[1]	23	N	N	0
Arkansas	Y	Y	Y	10	Y	N	NR
California	Yes	Yes	Yes	2	No	No	0
Colorado	NR	NR	NR	NR	NR	NR	Considering 1
Delaware	NR	NR	NR	NR	NR	NR	0
Georgia	Y	Y	Y	5	Y	Y	NR
Idaho	Y	Y	Y	≥20	Y	Y	1
Illinois	Y	Y	N	≥20	N	Y	0
Indiana	Y	Y	Y	2	Y	Y	NR
Kansas	Y	Y	Y	≥30	Y	Y	1
Louisiana	Y	Y	NR	NR	NR	NR	44
Maine[2]	N[2]	N[2]	N[2]	N/A	N/A	N/A	0
Maryland	Y	Y	N	3	Y	N	0
Michigan	Y	Y	Y	10	N	N	0
Minnesota	Y	Y	N	≥15	Y	N	0
Missouri	Y	Y	Y	4	Y	N	>100
Montana[3]	N[3]	N[3]	N[3]	N/A	N/A	Y	1
Nebraska[4]	N/A[4]	N/A[4]	N/A[4]	N/A	N/A	N/A	Several
Nevada[5]	Y[5]	N	N	12	N	Y	NR
New Hampshire	Y	Y	Y	10	N	Y	0
New Mexico[6]	Y[6]	Y[6]	Y[6]	>5	Y	Y	0
North Carolina	Y	Y	N	18	N	N	4 to 5
North Dakota	Y	Y	Y	30	N	N	0
Ohio	Y	Y	Y	4	Y	N	2
Pennsylvania	NR	NR	NR	NR	NR	NR	2 to 3
South Carolina	Y	Y	N	5	Y	Y	0
South Dakota	Y	Y	Y	14	N	N	0
Tennessee[7]	Y[7]	Y[7]	Y[7]	20	N	Y	1
Texas[8]	Y[8]	Y[8]	NR	NR	Y	Y	0
Utah	Y	Y	N	Few	Y	N	0
Vermont	Y	Y	N	≥10	Y	Y	0
Washington	Y	Y	N	5	N	N	0
West Virginia	Y	Y	Y	5	N	N	0
Wisconsin	Y	Y	Y	≥15	Y	Y	0

[1] Arizona does not have a formal process for pavement-type selection. However, guidelines are provided in their *Preliminary Engineering and Design Manual*.
[2] Maine has no selection process, since they build only hot-mix asphalt (HMA) pavements.
[3] Montana does not have a formal policy for pavement-type selection since they historically have built only HMA pavements. However, because of recent asphalt price escalation, they are performing informal pavement-type selection.
[4] Nebraska does not have a formal procedure. The decision is based on funding, constructability, traffic, and life cycles.
[5] The Nevada Department of Transportation Director and the Principal Materials Engineer are responsible for type selection. While a life-cycle cost analysis (LCCA) may be made, it is not always considered in the final selection.
[6] New Mexico's procedure is informal with the selection made by a team.
[7] Tennessee's procedure is not documented and is not required for all projects.
[8] In Texas, type selection is ultimately at the District's discretion.
NR = no response; N/A = not applicable.

Of these 22 state DOTs, 21 require a life-cycle cost analysis (LCCA). Ten of the states have specific criteria for considering the results of the LCCA. Ten states stipulate that if the difference in life-cycle costs exceeds a specified amount (ranging from 5 to 20 percent), the lower cost alternative usually will be selected. Michigan DOT is required by law to select the alternative with the lowest life-cycle cost.

Twenty-nine of the 35 responding state DOTs perform LCCA for new construction/reconstruction projects, out of which 22 report having formal procedures, 6 indicate use of a probabilistic process, and 14 indicate consideration of user costs in the analysis. Thirteen DOTs perform LCCA for rehabilitation projects. Most DOTs utilize the net present value (NPV) method for computing life-cycle costs, and most use either a custom-developed spreadsheet or the Federal Highway Administration (FHWA) probabilistic LCCA program Real-Cost. Of the 14 DOTs that consider user costs, most focus on the time delay and vehicle operating cost (VOC) components associated with work zones. In addition, five of these 14 DOTs combine user costs with agency costs to generate a total life-cycle cost, while the other eight DOTs keep the two costs separate. Table 2 summarizes the LCCA approaches used by the responding DOTs.

In addition, most DOTs had some type of process to consider noneconomic factors in making their pavement-type selection when the LCCA did not indicate a clear preference. This process generally was subjective, with the decision being made by either an individual or a selection committee. Noneconomic factors often considered in pavement-type selection include:

1. Traffic.
2. Soils characteristics.
3. Weather.
4. Performance of similar pavements in the area.
5. Economics or cost comparison.
6. Adjacent existing pavements.
7. Stage construction.
8. Depressed, surface, or elevated design.
9. Highway system.
10. Conservation of aggregates.
11. Stimulation of competition.
12. Construction considerations.
13. Local government preference and recognition of local industry.
14. Sustainability.
15. Traffic safety.
16. Availability of local materials or locally produced mixes.

Several state agencies have experimented with alternate pavement-type bidding. In this approach, the bidders are permitted to select a pavement type among two or more equivalent alternatives provided by the agency. The equivalency of alternatives is established by including a bid adjustment factor to account for the difference in discounted future M&R costs between alternatives. With more alternative choices for selection, the agencies are believed to realize significant cost savings from competition in the pavement industry, given the fact that large fluctuations in material costs can occur between the time of design and the bid letting.

In traditional design-bid-build contracts, the contractor delivers construction services as defined in the standard plans and specifications issued by the highway agency. The contractor assumes no responsibility for the delivered product except a limited-time warranty for materials and workmanship quality. The agency assumes the entire responsibility and risk for design, construction, and post-construction performance of the pavement.

With the inception of alternative contracting methods, the contractor's role has extended into nontraditional services such as design, operations and maintenance, and performance warranty. To address the shifts in responsibilities and risks effectively, agencies use contract provisions to communicate the project scope, performance/design criteria, and other requirements in the RFP. The contractor is obligated to provide the product and services specified in the contract provisions with certain technical, cost, time, and quality requirements.

In design-build contracting, the agencies typically have procured contractor services for only design and construction phases of the projects involving limited-time warranties. In the absence of long-term warranties, the agencies assume responsibilities for managing future performance risks. Considering the short turnover period and limited warranty, the agencies usually stipulate the pavement types to be used in a project and/or specify the criteria to be followed in the selection process. However, in projects where contractors have long-term responsibilities for operations and maintenance, agencies have allowed the contractors to specify the pavement types. In such projects, the contractors were required to follow the project requirements specified in the RFP.

Based on the analysis of the Phase I findings, it was concluded that the pavement-type selection process should have the following key components:

- Criteria specifying the type of projects for which the pavement-type selection process should be applied.
- A formal process for the identification of pavement-type alternatives to be considered. The selection of potential alternatives should be based on a comprehensive and transparent process involving the agency, contractors, and the paving industry. It is expected that alternatives reflect national practices, regional experience, type and size of projects, and type of traffic the pavement is expected to carry. To maximize the economic value, the agency should consider alternatives that stimulate competition and incorporate

Table 2. State DOT LCCA procedures.

State	Perform LCCA	LCCA Approach					LCCA Package Used				
		NPV	EUAC	Deterministic	Probabilistic	Consider User Costs	Use State-Developed Spreadsheet/Software	FHWA Probabilistic Spreadsheet RealCost	State-Customized Version of RealCost	Proprietary/ Industry Software	AASHTO Darwin
Alabama	Y	Y	N	Y	N	N	N	N	N	N	Y
Arizona	Optional	Y	N	Y	N	Y	N	Y	N	N	N
Arkansas	Y	Y	N	Y	N	N	Y	N	N	N	N
California	Y	Y	N	Y	N	Y	N	N	Deterministic only	No	No
Colorado	Y	Y	N	N	Y	Y	N	Y	N	N	Y
Delaware	Optional	N	Y	Y	Y	Y	N	Y	N	N	N
Georgia	Y	Y	Y	Y	N	Y	Y	N	N	N	N
Idaho	Y	Y	Y	Y	N	N	Y	N	N	N	N
Illinois	Y	N	Y	Y	N	N	Y	N	N	N	N
Indiana	Y	Y	Y	N	Y	N	N	Y	N	N	N
Kansas	Y	Y	N	Y	N	Y	Y	N	N	N	N
Louisiana	Y	Y	N	Y	N	Y	N	N	Y	N	N
Maine	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maryland	Y	Y	N	N	Y	Y	N	Y	Y	N	N
Michigan	Y	N	Y	Y	N	Y	Y	N	N	N	N
Minnesota	Y	Y	N	Y	N	N	Y	N	N	N	N
Missouri	Y	Y	N	Y	N	N	Y	N	N	N	N
Montana	Optional	Y	N	Y	N	N	Y	N	N	N	N
Nebraska	Optional	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Nevada	Optional	Y	N	Y	N	N	Y	N	N	N	N
New Hampshire	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
New Mexico	Optional	Y	N	Y	N	Y	Y	N	N	N	N
North Carolina	Y	N	Y	Y	N	N	Y	N	N	N	N
North Dakota	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ohio	Y	Y	N	Y	N	N	Y	N	N	N	N
Pennsylvania	Cost > $15M	Y	Y	Y	N	Y	Y	N	N	N	N
South Carolina	Y	Y	N	Y	Y	Y	Y	Y	N	N	N
South Dakota	N	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Tennessee	N	Y	Y	Y	N	N	Y	Y	N	Y	Y
Texas	Optional	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Utah	Y	Y	N	Y	N	N	Y	Y	N	N	N
Vermont	Y	Y	N	Y	N	Y	N	Y	N	N	Y
Washington	Y	Y	N	Y	Y	Y	N	Y	N	Y	N
West Virginia	Y	Y	N	Y	N	N	N	N	N	N	Y
Wisconsin	Y	N	Y	Y	N	N	Y	N	N	N	N

Note: EUAC = equivalent uniform annual costs; NA= not applicable; NR = no response.

innovative approaches. This activity should be overseen by a pavement-type selection committee composed of agency design, construction, and maintenance personnel.

- Procedures for the estimation of pavement service life. Techniques range from expert modeling using the opinions of experienced engineers to detailed performance-prediction modeling using historical performance data to develop survival curves.
- A framework for the LCCA. The analysis period should be sufficiently long to distinguish any differences between pavement alternatives and long enough such that each alternative pavement strategy includes at least one future major rehabilitation event. The discount rate should be based on economic factors established by the agency or the Office of Management and Budget (OMB) Circular A-94 Appendix C. The process must include procedures for estimating current and future costs. Both agency and user costs should be evaluated, and supplemental costs such as those incurred for contract administration, engineering, and traffic control may be considered if significantly different for pavement-type alternatives. However, user and agency costs should be evaluated separately, because the dollar value of user costs often is significantly greater than that of agency costs. The LCCA methodology may be computed deterministically or probabilistically, and general guidance such as that developed by Walls and Smith (1998) should be followed in the development of the procedures.
- An alternative screening matrix should be utilized to weigh both the economic (initial, rehabilitation, maintenance, and user costs) and noneconomic (geometrics, pavement and lane continuity, traffic during construction, availability of local materials, local preference, noise, safety, sustainability) factors in comparing alternatives. The factors and ratings should be established based on local conditions.
- Alternate bidding is a variation of the design-bid-build process, where the agency provides complete designs for two or more equivalent pavement alternatives and selection is based on the alternative receiving the lowest bid. Alternate bidding should be used for projects having alternatives with equivalent designs where the analysis of economic and noneconomic factors does not indicate a clear preference between alternatives.
- In design-build projects (where the contractor assumes no operational responsibilities and provides no extended warranty), the agency is responsible for risks associated with future performance. In such cases, the agency stipulates the preferred pavement alternative(s) or specifies the criteria for contractor-based selection. In either case, the contractor can follow the agency's selection process (including life-cycle assumptions) or any other similar process accepted by the agency.
- On alternative contracting projects (design-build, design-build with operations and maintenance, and long-term performance warranty methods), the agency should perform a risk analysis to determine the contractor's scope and how stringent the contract provisions for pavement-type selection should be.
- In design-build projects involving operations and maintenance responsibilities and long-term performance warranty, the contractor assumes the risks associated with post-construction for an extended period of time. In such cases, the contractor selection process is stipulated largely by the performance criteria specified in the RFP.
- If a considerable length of time elapses between the original pavement-type selection and a call for bids, the selection should be reviewed to ensure that conditions have not changed.

An overview of the process is shown in Figure 1.

The *Guide for Pavement-Type Selection* developed under this project contains a comprehensive set of procedures, including an alternative preference screening matrix that highway agencies can use to develop pavement-type selection policies and processes. Each step is described, and the factors that should be considered are identified. Because of differences in agency decision-making processes, it is expected that each agency will adapt these procedures to meet its specific needs.

Details on research performed in this project are documented in the project research report, available on the *NCHRP Report 703* web page at http://www.trb.org/Main/Blurbs/165531.aspx.

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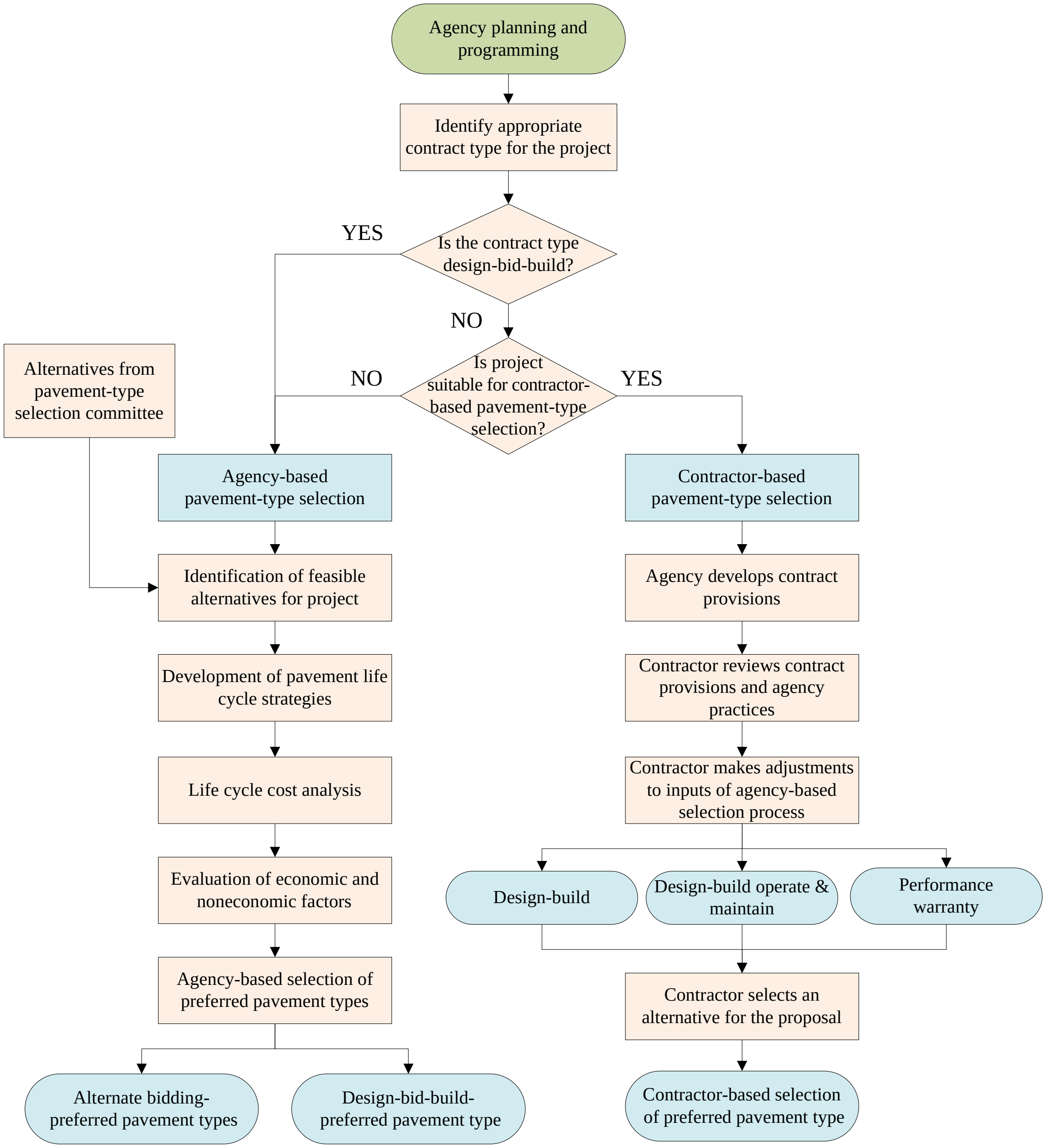

Figure 1. Overview of the pavement-type selection process.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation