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LIFE CYCLE COST ANALYSIS FOR INDOT PAVEMENT DESIGN PROCEDURES

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LIFE CYCLE COST ANALYSIS FOR INDOT PAVEMENT DESIGN PROCEDURES

Introduction

Many highway pavements in Indiana are nearing the end of their service lives and are experiencing unprecedented levels of traffic loading. Given the uncertainty of sustained funding for highway replacement, rehabilitation and maintenance, this situation necessitates the use of balanced decision-making tools to arrive at long-term and cost-effective investments. LCCA, a technique founded on economic analysis principles, is useful because it enables evaluation of overall long-term economic efficiency between competing alternative investments and consequently has important applications in pavement design and management. LCCA driving forces include ISTEA 1991 which required the consideration of life-cycle costing in pavement design and engineering and TEA-21 which encouraged the development of LCCA procedures on NHS projects.

Previous studies conducted in Indiana and elsewhere suggest that more effective long-term pavement investment decisions could be made at lower cost with adoption of LCCA principles. Chapter 52 of the Indiana Design Manual has since 1997 included a detailed section on the use of LCCA, but does not include user cost impacts. As such, highway user costs during regular highway usage as well as during work-zone periods, for instance, are not always included in the state's pavement investment decisions. Also, there is a need to enhance FHWA's *RealCost* LCCA software in order to make it more versatile, more flexible and more specific to the needs of Indiana, particularly with regard to cost estimation of various treatments

using local historical data, and development of alternative feasible strategies (treatment types and timings) for pavement rehabilitation and maintenance.

The study documented or developed several sets of alternative pavement design and preservation (rehabilitation and maintenance) strategies consistent with existing or foreseen Indiana practice. This was done using two alternative criteria: trigger values (thresholds based on pavement condition) and preset intervals of time (based on treatment service lives). These strategies were developed using a variety of tools such as review of historical data, existing standards in the INDOT Design Manual, and a survey of experts. The study also developed an automated mechanism for estimating the cost of each strategy by computing the costs of constituent treatments on the basis of INDOT contractual unit rates and line items. As an alternative, treatment costs were also estimated using aggregate (per lane-mile) historical contractual aggregate costs.

The study carried out enhancements to FHWA's *RealCost* LCCA software package in a bid to render it more applicable to Indiana practice. Users of the enhanced software (*RealCost-IN*) are herein provided a convenient means not only to input various pavement design and life cycle preservation strategies, but also to easily estimate expected costs of pavement designs and preservation treatments.

Findings

The present study does not specifically identify any pavement design or preservation as optimal but makes available a methodology for pavement LCCA decision-making on the basis of costs and preservation practices peculiar to Indiana. Nevertheless, it is expected that the determination of the optimal mix of pavement design and preservation strategy, if desired, would be addressed at the implementation stage of this project. The present study found that with a few enhancements, FHWA's current LCCA methodology can be adapted for use by INDOT for purposes of decision support for pavement investments in Indiana. The present study proceeded to make needed enhancements to the existing FHWA methodology and software thereby rendering it more versatile, flexible and specific to Indiana practice. Such enhancements are in the form of a mechanism by which the user can estimate the cost of each specified pavement design and preservation activity on the basis of line items and their unit rates, thus obviating the cumbersome task of determining such costs independently and importing them as inputs for the software as required by the existing FHWA package. In another enhancement, interactive menus were made available to enable the software user to define pavement preservation strategies over pavement life cycle. The software estimates the agency and user costs associated with a given pavement design and preservation strategy over the entire life cycle of the pavement. Other enhancements

made to the software included improved graphics, enhanced reporting of analysis results, and capability to simultaneously carry out analysis for more than two alternatives. User and Technical Manuals were prepared to facilitate the use of the enhanced software. The enhanced LCCA methodology and software are useful for (i) identifying or developing alternative INDOT pavement designs and strategies for pavement rehabilitation and maintenance, (ii) estimating the life-cycle agency and user costs associated with any given strategy under consideration, (iii) comparative evaluation of several alternative combinations of pavement design, rehabilitation and maintenance and selecting the optimal combination over a given analysis period. The enhanced methodology and software are applicable to existing pavements in need of some rehabilitation treatment, and also for planned (new) pavements.

In its current form, the LCCA methodology may be used for comparisons across pavement design alternatives provided appropriate preservation strategies are input for each alternative design. On the other hand, within each pavement design, the methodology appears to favor parsimonious preservation strategies (such strategies obviously are least expensive) that are not adequately penalized for their resulting inferior pavement condition over the life cycle. This is an area that merits further scientific inquiry.

Implementation

The products of the present study are in the form of (i) a study report that documents the entire research effort including a review of available literature and similar packages for LCCA, documentation of existing pavement design alternatives, development of alternative rehabilitation and maintenance strategies, agency and user cost analysis, and (ii) an LCCA software package which is a modified version of the existing FHWA *RealCost* LCCA software package, enhanced for consistency with Indiana practice, (iii) a Users Manual for the *RealCost-IV* software package, (iv) a Technical Manual that provides, for the interested user, theoretical

background to the various concepts used in the software package.

Implementation of the study results would entail the revision of the Indiana Design Manual to include other LCCA issues that are not covered in the present design manual. The Technical Manual provides methodologies to update the existing service lives of typical preservation treatments used at INDOT. More importantly, implementation would entail the use of the software package to develop and evaluate the life cycle agency and user costs associated with a given pavement design alternative, and therefore to select the optimal pavement design

and life-cycle M&R schedule for any given pavement section in the state of Indiana.

Personnel from INDOT's Pavement Design office (of the Materials and Tests Division), Pavement Management Unit of the Program Development Division and the Pavement Steering Committee are expected to play lead roles in the implementation process. Other divisions that may be expected to be directly or indirectly associated with the study implementation are the Operations Support Division, Planning and Programming Division, Design Division, and the Systems Technology Division. Each implementor is expected to play a specific role. INDOT's pavement design and pavement steering committee is expected to use the study product as a decision-support tool in selecting appropriate designs for any given pavement section in Indiana on the basis of life-cycle agency and user costs. Also, INDOT's PMS operators, given a planned or existing pavement design, are hereby given a tool that could help in deciding the best schedule of rehabilitation and maintenance over the life or remaining life of the pavement. In the current era of overall asset management where it is sought to integrate maintenance and pavement management, it is expected that personnel at INDOT's Operations Support Division would

take due cognizance of LCCA-recommended maintenance treatments for a given new or existing pavement and would tie in their work programs with PMS programs in a manner that would minimize duplication. Furthermore, any long-term assessment of financial needs by INDOT's Planning and Programming Division for pavement preservation could be done on the basis of optimal practice as identified using the LCCA package, rather than using historical or current practice. INDOT's System Technology Division is also expected to play a leading role in implementing the study product because they may be responsible for maintaining the enhanced software and to provide the necessary supporting hardware. With LCCA, INDOT's Pavement Management Unit and Planning Division can have better justification for such planning and prioritization of pavement work.

The initial effort towards implementing the study products should focus on further strengthening of existing links between INDOT's pavement design units, pavement management units, the Operations Support Division, and the Pavement Steering Committee.

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LIST OF ACRONYMS

AADT	Average Annual Daily Traffic
AAMEX	Average Annual Maintenance Expenditure
AASHTO	American Association of State and Highway and Transportation Officials
ACPA	American Concrete Pavement Association
APA	Asphalt Pavement Alliance
CPR	Concrete Pavement Restoration
CNDX	Cumulative Freeze Index
CTAADT	Cumulative Average Annual Daily Truck Traffic
ESAL	Equivalent Single Axle Load
FHWA	Federal Highway Administration
HERS	Highway Economic Requirement System
HMA	Hot-Mix Asphalt
INDOT	Indiana Department of Transportation
IRI	International Roughness Index
ISTEA	Intermodal Surface Transportation Equity Act of 1991
JPCP	Jointed Plain Concrete Pavement
JRCP	Jointed Reinforced Concrete Pavement
LCCA	Life Cycle Cost Analysis
M&R	Maintenance and Rehabilitation
NCHRP	National Cooperative Highway Research Program
PCCP	Portland Cement Concrete Pavement
PCR	Pavement Condition Rating
PJ	Performance Jump
PM	Preventive Maintenance
PMS	Pavement Management System
PSI	Present Serviceability Index
RSL	Remaining Service Life
TEA-21	Transportation Equity Act for the 21st Century

CHAPTER 1 INTRODUCTION

1.1 Background and Problem Statement

Increasing costs associated with highway pavement construction, rehabilitation, and repair, coupled with shortfalls in highway revenue has led highway agencies to seek requisite decision making tools that utilize economic and operations research techniques to arrive at long-term and cost-effective investments. One of such tools is Life Cycle Cost Analysis (LCCA). LCCA, a technique founded on the principles of economic analysis, helps in the evaluation of overall long-term economic efficiency between competing alternative investment options [AASHTO, 1986], and has important applications in pavement design and management.

The Federal Highway Administration (FHWA) has always encouraged the use of LCCA in analyzing all major investment decisions where such analyses are likely to increase the efficiency and effectiveness of investment decisions. The current FHWA position on LCCA for pavement design evolved from ISTEA 1991 which required the consideration of life-cycle costing in the design and engineering of pavements, among other facilities. Other LCCA driving forces include the NHS Designation Act of 1995 (that specifically required states to conduct LCCA and Value Engineering Analysis on NHS projects whose costs exceed a certain threshold), and TEA-21 (which removed LCCA requirements established in the NHS Act, but required the development of LCCA procedures on NHS projects) [FHWA, 1998].

Previous studies conducted in Indiana and other states strongly suggest that more effective long-term investment decisions could be made at lower cost if LCCA were adopted properly [Al-Mansour and Sinha, 1994; Mouaket et al., 1992, Peterson, 1985, Darter et al., 1987]. Since 1997, Chapter 52 of the Indiana Design Manual has included a detailed section on the use of LCCA, but this section does not include the impact of user costs on LCCA. As such, highway user costs during regular highway usage as well as during work-zone periods, for instance, are not always included in the state's pavement investment decisions. Due cognizance of such issues would enable the inclusion of the "benefits" (reduction in user costs) perspective as well as the traditional agency "cost" perspective in the analysis of alternative actions. Furthermore, the explicit effect of maintenance in reducing life cycle costs needs to be examined in detail. Most LCCA studies failed to give maintenance its due consideration primarily because of lack of in-house or contractual maintenance data. In recent times, increasing availability of maintenance cost and effectiveness data (typically

made available by vastly improved state pavement and maintenance management systems) coupled with renewed emphasis on preventive maintenance on NHS roads, has made it more feasible to give major maintenance (such as thin overlays, micro-surfacing, and seal coating) its due consideration in LCCA. Current data on unit costs, traffic characteristics, state of practice for strategy development and other data related to highway condition and usage are also important for LCCA.

The present study does not develop a new methodology and software for LCCA for pavement design. Rather, FHWA's existing LCCA methodology and software package (*RealCost*) have been reviewed vis-à-vis INDOT's unique data requirements (on treatment costs, effectiveness and strategies) and other existing LCCA methods and packages, and areas have been identified for subsequent enhancements. As such, the present study has, as much as possible, tailored FHWA's existing LCCA methodology and software package to suit current and foreseeable INDOT pavement design and pavement management practice.

1.2 LCCA at Network and Project Levels

The application of engineering economy principles to pavement engineering occurs at two levels: Network and project level. *Network level analysis* involves management type functions such as establishing priorities for various design or construction projects, determining the optimal use of limited funds, and selecting optimum maintenance policies for the entire network and assessing network level impacts of alternative pavement investment policies. The advantage of network level analysis is that it allows for the minimization of the overall costs while maximizing utility [Seeds, 1980]. However, such analysis does not always consider all factors associated with design at project level. INDOT's PMS currently uses a network level package (D-TIMS) that incorporates life-cycle concepts in pavement investment analysis for the entire state highway network.

Project level analysis generally provides criteria for the selection of an optimum pavement design strategy for a specific section of road. Project level models are typically comprehensive, dealing with technical concerns and requiring detailed information [Haas et al., 1994]. FHWA's LCCA package for pavement design procedures conducts life-cycle costs analysis at a project level. The present study aims at producing a comprehensive project-level tool for making pavement design and preservation decisions on a life-cycle basis, using FHWA's existing LCCA methodology and software as a basis. The systems approach for pavement LCCA modeling typically includes the entire management and decision-making process for design, construction, and maintenance, at both the project and network levels. The major task is to select pavement designs and preservation

strategies that will provide an acceptable level of service to the user over a given period of time at a minimum overall cost.

Network level and project level management systems are inter-dependent. For example, one of the many functions of a pavement management system (PMS) at the network level is to identify pavement sections within a network of pavements that require maintenance action. Subsequently, the project level may be responsible for determining the optimum maintenance strategy for each pavement section identified at network level. After the maintenance strategy is selected and implemented for a particular pavement section, feedback is provided to both the network and project management levels.

1.3 Study Objectives

The purpose of the present study is to:

- review LCCA methodologies and software packages from FHWA and other sources for evaluation of pavement design and preservation strategies,
- identify areas of any needed enhancements of the FHWA LCCA software package for applicability to pavement design and management practice in Indiana, such as treatment types and strategies, costs and effectiveness,
- document any such needed modifications in a study report and implement the needed modifications.

The primary audience for the study is INDOT's pavement design engineers at the Materials and Tests Division, operators of INDOT's Pavement Management System, and possibly, INDOT's Operations Support Division (which administers the agency's maintenance management system). The study product makes available to the pavement design engineers a rational and impartial tool to select the most cost-effective pavement design type and configuration under a given set of traffic and environmental conditions. Also, the study product offers the pavement managers and engineers an LCCA-based decision support system for selection of optimal rehabilitation and maintenance strategies over pavement life cycle, given pavement design and environmental attributes, functional class, loading, and climatic conditions. In effect, by providing a balanced LCCA approach, the product of this research hereby provides INDOT with a rational tool to make efficient and effective highway pavement investment decisions.

1.4 Scope of the Study

The present study covers only pavement investment decisions on the 11,200 mile state highway network in the state of Indiana. Local and county roads are excluded. All geographical locations of pavement on the state highway network, representing a wide range of climatic and terrain conditions from the relatively cold, dry and flat north, to the warmer, wetter, and hilly south, are considered in the study, as data was drawn from sections located at all such locations. Indiana's major pavement types, namely, asphalt (flexible), concrete (rigid), and o asphalt-over-concrete composites are considered in the present study. Also, the study focuses on mainline items and excludes shoulder design and rehabilitation/maintenance.

1.5 Overview of the Study Approach

To achieve the stated study objectives, the project followed a sequence of work activities as shown in Figure 1-1. This started with a comprehensive literature review and state of practice survey of LCCA in pavement design and management, review of documented information on existing software programs, detailed working review of FHWA's LCCA package, review of theoretical considerations in LCCA, collection and collation of requisite data at various INDOT divisions and units involved in pavement and maintenance management and planning. The study utilized data obtained to develop models for cost (agency and user) and effectiveness associated with various pavement reconstruction, rehabilitation and maintenance activities. The study identified pavement families, design alternatives for each strategy, and utilizes results from a variety of complementary approaches to develop pavement rehabilitation and maintenance strategies over pavement life cycle. These work activities formed the basis for the modification of the FHWA LCCA software to suit existing and foreseeable pavement design and management practices in Indiana.

Figure 1.1 Overall Study Approach

1.6 Organization of this Report

In Chapter 2, a review of past literature on LCCA applications in pavement design and management are presented. Chapter 3 identifies relevant features, scope and limitations of existing LCCA software packages. Also, FHWA's LCCA software package is reviewed in detail, and areas are identified for possible modification for Indiana practice. Chapter 4 defines the major pavement families considered in the study, while Chapter 5 identifies the various pavement design alternatives for each pavement family. Chapter 6 discusses the various ways by which maintenance and rehabilitation treatment effectiveness can be measured and how such effectiveness relates to increased pavement longevity and subsequent impacts on life cycle costs. Strategies for pavement rehabilitation and maintenance, obtained through a variety of approaches (such as historical plots using data from PMS and contracts databases, design manual guidelines, and questionnaire surveys) are provided in Chapter 7. Chapter 8 presents an analysis of agency costs, from which the costs of any combination of pavement design alternative and rehabilitation/maintenance strategy can be determined. In Chapter 9, the user costs associated with pavement M&R work zones and regular (non work zone) usage are determined, from safety and delay perspectives. Chapter 10 gives due cognizance to the fact that pavement LCCA inputs behave in a stochastic rather than deterministic manner, and discusses how such real life stochasticism could be incorporated in LCCA. Using information gleaned from Chapters 4-12, Chapter 12 documents appropriate recommendations made for enhancements to FHWA's existing LCCA software package (*RealCost*). In Chapter 13, the enhanced FHWA software package is used to carry out LCCA for selected pavement sections in Indiana using given pavement designs, preservation (M&R) strategies, actual traffic data, and recent INDOT cost data. In Chapter 14, the entire research effort is summarized and implementation issues are discussed to facilitate usage of the enhanced package for pavement investment decisions. A copy of the modified FHWA LCCA software package, named *RealCost-IN* and an accompanying users' manual are provided as an addendum to this report.

CHAPTER 2 REVIEW OF LITERATURE RELATED TO PAVEMENT LCCA

2.1 Historical Background

In 1960, the American Association of State Highway Officials (AASHO) in its “Red Book” introduced the concept of life-cycle cost-benefit analysis to highway investments decisions, thereby establishing the concept of economic evaluation of highway improvements at the planning level. In the next major advancement in life-cycle cost analysis, Winfrey [1963] consolidated available data on vehicle operating cost into a format usable by highway planners for developing life-cycle costing procedures. Also during the 1960s, two projects advanced the application of life-cycle cost principles to pavement design and pavement-type selection: (i) the National Cooperative Highway Research Program (NCHRP) investigated the promotion of the LCCA concept [Lytton and McFarland, 1974], and (ii) the Texas Transportation Institute (TTI) and the Center for Highway Transportation Research developed the Flexible Pavement System (FPS), a methodology and computer program used to analyze and rank alternative flexible pavement designs by overall life-cycle cost [Hudson and McCullough, 1970]. Subsequently, Texas DOT developed the Rigid Pavement System (RPS), which is similar to FPS in that it performs a life-cycle cost analysis of rigid pavements and ranks alternative designs by their total life-cycle costs [Kher et al., 1971].

In a fairly recent survey of state practices, FHWA indicated that 28 of the responding 38 States use some form of LCCA in their pavement investment decisions [FHWA, 1994]. It also showed that fewer than half of these 28 States included user costs in their LCCA. Comparison of these survey results to a similar earlier effort [Peterson, 1985] show that states are increasingly embracing and applying LCCA concepts in pavement design.

Various editions of the AASHTO Pavement Design Guide [AASHTO, 1986; AASHTO, 1993] encourage the use of the life-cycle costing concept, and provide detailed discussions about the various costs that should be considered in life-cycle cost analysis. The AASHTO Design Guide contains a chapter on the economic evaluation of alternative pavement design strategies. The present chapter includes an outline of the basic concepts of life-cycle costing, a discussion of the various agency and user costs associated with highway pavement projects, and discussions of economic evaluation methods and the discount rate.

The pavement policy of the FHWA requires life-cycle economic analysis to be taken into account in the selection of preservation alternatives [FHWA, 1998]. To comply with this policy statement, agencies typically use project life-cycle costing to select MR&R treatments for proposed MR&R projects. By selecting the treatment types and timings associated with the least life cycle cost for each proposed project, and choosing the optimal combination of treatments, the goal of cost-effective overall asset management can be realized. Furthermore, FHWA policy on economic analysis encourages state agencies to weigh life cycle costing against needs of the entire system, explaining that funding limitations make such considerations more critical than ever.

2.2 Legislative Requirements for LCCA

In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) required “the use of life-cycle costs in the design and engineering of bridges, tunnels, or pavements” [ISTEA, 1991] in both metropolitan and statewide planning. As such, the FHWA encouraged state departments of transportation to perform life-cycle cost analysis on all pavement projects that exceeded \$25 million.

The National Highway System (NHS) Designation Act of 1995 required state highway agencies to conduct a life-cycle cost analysis (LCCA) of each NHS “high-cost usable project segment”. Section 303 of the NHS Designation Act legislatively defined LCCA as “a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future cost, such as maintenance, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment.” The term “high-cost” referred to usable project segments estimated to cost \$25 million or more, and a “usable project segment” was defined as “a portion of highway which a State proposed to construct, reconstruct or improve that when completed could be opened to traffic independent of some larger overall project” [Kane, 1996].

The FHWA position on LCCA was further defined in its Final Policy Statement on LCCA published in 1996 [FHWA, 1996] which identified LCCA as a decision support tool. Although LCCA was only officially mandated in a very limited number of situations, FHWA has always encouraged the use of LCCA in analyzing all major investment decisions where such analyses are likely to increase the efficiency and effectiveness of investment decisions whether or not they meet specific LCCA-mandated requirements [FHWA, 1998].

The 1998 Transportation Equity Act for the 21st Century [TEA-21, 1998] removed the requirement for state highway agencies to conduct LCCA. However, FHWA policy continued to recommend LCCA as a decision support tool, emphasizing that the results are not decisions “in and of themselves”. In other words, the logical analytical framework this type of analysis promotes is as

important as the LCCA results themselves [Walls and Smith, 1998]. Therefore, state highway agencies are still encouraged to use LCCA when making investment decisions. A stated objective of TEA-21 is to expand knowledge of LCCA implementation issues such as:

- Establishment of an appropriate analysis period and discount rates,
- Valuation and computation of user costs,
- Determination of tradeoffs between reconstruction and rehabilitation,
- Establishment of methodologies for balancing higher initial costs of new technologies, and
- Improved or advanced materials against lower maintenance costs.

In the FHWA Interim Technical Bulletin, Walls and Smith [1998] provide technical guidance and recommendations on good practice in conducting LCCA in pavement design. It also incorporates Risk Analysis, a probabilistic approach to describe and account for the uncertainties inherent in the decision process. It deals specifically with the technical aspects of long-term economic efficiency implications of alternative pavement designs. The Bulletin is intended for state highway agency personnel responsible for conducting and/or reviewing pavement design LCCAs.

2.3 General Literature on LCCA

The present study started with an extensive search and review of published information on the use of LCCA in pavement design as well as related concepts such as reliability and risk, pavement performance, cost estimation, etc. More reviews of LCCA literature are provided in the present report: each subsequent chapter (representing a major subject area of the study) starts with a literature review and discussion relevant to that subject area.

2.3.1 Past Studies on Methods Used to Evaluate Cost-effectiveness for LCCA

Cost-effectiveness evaluation is an economic evaluation technique for comparing that which is sacrificed (cost) to that which is gained (effectiveness) for the purpose of evaluating alternatives. It generally includes procedures and concepts that involve comparing input costs to outcomes, whether or not such outcomes are priced. Cost-effectiveness can be measured in the short-term (i.e., for one or more treatments administered at a given time), or in the long-term (i.e., for several treatments carried out over an extended period of time, such as the pavement service life). One application of cost effectiveness evaluation is Life Cycle Cost Analysis. Cost-effectiveness concepts may be

considered more appropriate for long-term evaluation compared to that of the short term. Long-term evaluation is typically characterized by a multiplicity of alternative strategies (each consisting of a unique set of treatment types and timings), and each alternative strategy has a unique overall cost and effectiveness (benefit). In the short-term, however, cost-effectiveness may be appropriate in only a few cases, e.g., where it is sought to compare two alternative treatments to address a given pavement distress, such as crack sealing with traditional sealant or with crumb rubber. Outcomes of each strategy could be benefits, returns, satisfaction, or progress towards stated objectives. Some cost-effectiveness analyses proceed on the basis that, although the cost can be presented in dollars, the effectiveness of these costs in producing desirable goals and results can be described only in qualitative terms because not all the benefits and adverse consequences can be presented on a dollar basis [Mouaket and Sinha, 1991].

The literature review showed that from an economist's viewpoint, effectiveness evaluation could be carried out in two ways: the first approach is based on seeking the maximum benefits for a given level of investment (the maximum benefit approach); the second approach seeks the least cost for effective treatment of problems (least cost approach). The first approach is often used in capital investment decisions while the second is considered more appropriate for evaluation of maintenance investments.

Maximum "Benefit" Approach

This approach is often used for evaluation of capital investment projects as such activities typically involve a single large investment that is associated with significant elements of uncertainty and where the cost of each alternative is the same. Consequently, the assessment of exact benefits is very difficult. Furthermore, the measures of effectiveness for such projects are often difficult to identify and complex to define due to the long duration of such activities and spillover effects [Mouaket and Sinha, 1991]. Over the past two decades, much research has been carried out to define measures for evaluating benefits of capital improvements and the idea has been further extended for some maintenance activities. These benefits include reduced travel times, reduced tort liability, reduced vehicle operating and maintenance costs, increased motorist comfort and safety, reduced rate of pavement deterioration, and reduced or deferred capital expenditures through preservation of capital [Geoffroy, 1996].

In the context of pavement management, most of the research efforts utilize the performance curve concept. All the fore-mentioned benefits could be represented by the area under the performance time curve. The rationale for this approach is simple: a consistently well maintained pavement (a gently sloping performance curve, yielding a large area under that curve) provides the

user greater benefits than a bad pavement (a steep performance curve having a small underlying area). Because the benefits of a well-maintained pavement are numerous and difficult to quantify in monetary terms, the area under the performance curve could be used as a surrogate for user benefits. Another way of measuring benefit is to estimate the extended remaining service life by carrying out that improvement, i.e., time taken for the pavement to deteriorate to a certain threshold level.

Least Life Cycle Cost Approach

Pavement maintenance investments are often smaller in value and take a relatively short period for completion compared to capital improvements. Also, their impacts are experienced immediately after completion. In the short-term evaluation of corrective maintenance “investments” the least cost approach may be considered most appropriate, as all the alternatives are considered to provide the same benefit. For example, faced with occurrence of severe cracking on a localized section of road, a field engineer considers the possible options (all of which have the same “benefit” of reinstating that section to the original condition), such as crack filling and partial depth patching. He then selects the most cost-effective alternative as that which has the least cost. This methodology assumes that all the corrective maintenance strategies being compared provide the same level of service, and that the preferred option is one that minimizes life cycle costs.

Combination of Cost and “Benefit” Approaches

In evaluating pavement reconstruction, preservation and maintenance, it is recommended to use a combination of maximum benefit and least cost. NCHRP Synthesis 223 [Geoffroy, 1996] suggests that both benefits accrued to the users and the cost incurred to provide those benefits, be considered. That study states that when the benefits and costs can be quantified in monetary terms, a benefit-cost analysis can be made. Life cycle cost *and* “benefit” analysis, which requires the conversion of all factors into economically measurable units, is one of the most powerful tools available for measuring effectiveness of various maintenance activities [Peterson, 1989]. The present study followed this approach. It may be argued that benefits are cost reductions, and that benefits are implicitly covered under the term “life cycle cost analysis”. As such, the use of the term LCCA in the present study includes the consideration of benefits. To perform life cycle costs analysis for the present study, it was essential to identify the various agency and user cost components and to predict the amount of such costs.

Life cycle cost analysis in pavement management has been used in one of two ways: first, as the least present-worth of the life cycle cost and benefit [Chong and Phang, 1988], and second, as the least annualized life cycle return, calculated in perpetuity [Sharaf et al., 1988]. A basic life cycle

cost analysis procedure was used to determine the cost-effectiveness of network level maintenance and rehabilitation treatments [Darter et al., 1987]. The selected strategy was one that yielded the least equivalent annual cost per unit area of pavement. Also, life cycle costing was used to quantify the effect of deferring maintenance and rehabilitation of pavements based on data obtained from U.S. military installations [Sharaf et al., 1988]. Another application of life cycle costing was in Ontario, where it was used to evaluate the life-cycle cost-effectiveness of strategies involving crack sealing [Joseph, 1992]. Other studies in Indiana included one in which this technique was used to evaluate the cost-effectiveness of chip and sand sealing activities [Mouaket and Sinha, 1991].

In a study that evaluated the effectiveness of various preventive maintenance strategies, effectiveness was measured on the basis of equivalent annual cost of the strategy and the extra service life as a benefit [Hicks et al., 1997]. A decision model was developed that allows users to assign weights not only to material costs and service life benefits, but also to other cost and benefit factors that suit the needs of the decision-maker. For each set of traffic and distress conditions, the alternative with the highest weighted score was selected as the best preventive maintenance treatment under those conditions. Decision trees were developed for various levels of distress types and traffic loading.

In developing budget optimization techniques for PAVER (the U.S. Army Corps of Engineers Pavement Management System), the area under the condition-time curve was used as a measure of performance [Shahin et al., 1985]. Also, Kher and Cook [1987] used the area under the performance curve as a surrogate for user benefits, for the Ontario MTC's Program Analysis of Rehabilitation System. Joseph [1992] used the area under the performance curve combined with the average annual daily traffic (AADT) and road section length to compare the life-cycle cost-effectiveness of preventive maintenance strategies. The area under performance-time curve concept was used to establish a long-term funding allocation procedure for the San Francisco Bay Area Metropolitan Transportation Commission [Darter et al., 1987]. The New York State Department of Transportation has used the area under the pavement performance curve to compare the life-cycle cost-effectiveness of alternative preventive maintenance strategies [Geoffroy, 1996]. It is clear that the concept of using the area under the performance curve or the extension in facility life to represent the benefit of pavement repair is well established within this field.

2.3.1 Past Studies on Effectiveness of Alternative Pavement Design, Rehabilitation and Maintenance Strategies on the Basis of LCCA

Brief descriptions of past studies that assessed the effectiveness of various pavement design, preservation and maintenance strategies, are presented below. Features of these studies that are relevant to the present study are also identified.

A FHWA/State of Utah study was carried out to investigate the cost-effectiveness of pavement rehabilitation design strategies [Anderson et al., 1979]. The model framework used in the study had four phases: Phase 1 was a pavement condition and analysis module that considered data pertinent to the various highway sections and identified deficient sections that needed further analysis in the next phase. In Phase 2, appropriate maintenance and rehabilitation strategies were selected for candidate sections identified in Phase 1. Phase 3 calculated the benefits and costs of each strategy for each section and ranked the strategies in relative order. In Phase 4, the strategies were selected on a network basis. The study utilized relationships that tie user cost to PSI and maintenance costs to PSI, by road class. According to the study report, the model was primarily designed for rehabilitation strategy analysis, but could be modified to handle preventive maintenance practices. That study provided useful hints in the formulation and evaluation of maintenance strategies for the present study.

In a study that investigated feasible pavement design alternatives for Wisconsin DOT, Corvetti and Owusu-Ababio [1999] used LCCA principles to evaluate the costs and benefits of one specific design each for flexible and rigid pavements over their respective life-cycles, and demonstrated that existing LCCA procedures at WisDOT can include certain pavement designs that were obviously not considered in the initial development of LCCA at WisDOT.

The LTPP and other SHRP-related research programs were started in 1984 with the objective of providing the tools to better understand pavement behavior with a goal of better management of highway infrastructure without major increases in financial resource [Smith et al., 1993; Hadley, 1994; Hanna, 1994]. This effort sought to answer fundamental questions about climatic effects, maintenance practices, long-term load effects, material variations and construction practices by carrying out an intensive long-term study of a large number of actual pavement and field conditions. The Specific Pavement Studies #4 (SPS-4) experiment which is a part of the overall LTPP study, was specifically designed to investigate the effectiveness of the following common preventive maintenance treatments on rigid pavements: undersealing, joint sealing, and crack sealing. It is expected that analysis of pavement performance data obtained from these sites will help quantify the ability of different maintenance treatments to extend service life or reduce distress rates

[Hadley, 1994]. This experiment also sought to examine the effects of various environmental regions, subgrade type (fine-grained or coarse-grained), traffic rate, base type (dense granular or stabilized), and pavement type (plain or reinforced) on preventive maintenance of rigid pavements. It is also expected that with long-term monitoring of the LTPP sites, more concrete conclusions can be made about treatment effectiveness in LCCA context.

The FHWA [2002] cautions that the lowest LCC option may not necessarily be the best, and that other considerations such as risk, available budgets, and political and environmental concerns need to be taken into account, and that LCCA provides critical information to the overall decision-making process, but not the final answer.

2.4 Chapter Summary

The conduction of a literature review was vital for the present study. It was shown that the concept of life cycle costing in pavement investment decisions has matured over the past four decades, and most states have embraced the application of LCCA concepts in their decision-making.

The literature review also showed that LCCA applications in pavement investments has received strong legislative support, particularly in the 1990s, and has received deserved attention from highway related organizations such as AASHTO, FHWA, and NCHRP. The literature review also described past efforts that have used LCCA concepts to assess long-term cost-effectiveness of alternative pavement design, rehabilitation and maintenance decisions. The review shows various ways by which the costs and effectiveness of such alternative decision have been measured and how these two parameters have been combined to yield an appropriate measure for cost-effectiveness. The chapter also briefly discusses the future benefits of national experimental programs such as the LTPP SPS and GPS studies that show much promise in providing data to address pending LCCA issues such as treatment effectiveness (in terms of service life). Finally, it has been cautioned in the literature that while the alternative with the lowest life cycle cost should be sought, that may not necessarily be the best option, and that other considerations such as risk, available budgets, and political and environmental concerns may need to be taken into account.

This chapter presented only a general overview of literature pertaining to LCCA use. Reviews of past literature specific to other LCCA issues (such as existing software packages, alternatives strategies for pavement design and preservation, agency and user cost computations, and probabilistic aspects) are discussed at various relevant chapters of the report.

CHAPTER 3 REVIEW OF EXISTING PAVEMENT LCCA SOFTWARE

3.1 Introduction

Over the past few decades, various agencies and institutions have developed methodologies for pavement life cycle cost analysis, and some of these organizations have gone a step further to develop computer programs for their LCCA methodologies to facilitate the analysis. Organizations that have supported the development of LCCA for pavement design and management include AASHTO, the Asphalt Institute, the American Concrete Paving Association, the Asphalt Pavement Alliance, the World Bank, and the Texas Transportation Institute. The next section discusses details of selected LCCA programs for pavement design and management.

3.2 Existing LCCA Packages

3.2.1 DARWin – AASHTO

The DARWin Pavement Design System is a project level LCCA program that automates the AASHTO design equations. The life cycle cost module of DARWin considers project dimensions, initial construction costs, preprogrammed rehabilitation strategies (up to five), and the pavement salvage value at the end of its service life. DARWin then discounts all construction costs and salvage value to the present and reports the net present value of the project. The program provides a life cycle cost analysis based on agency costs associated with specific projects and incorporates a database for managing materials, material properties, costs, and other aspects of pavement design and construction.

3.2.2 Flexible Pavement System and Rigid Pavement System — Texas DOT

The computer programs Flexible Pavement System and Rigid Pavement System were developed in the late 1960s by the Texas Transportation Institute and the Center for Highway Research [Wilde et al., 1999]. The current Rigid Pavement Rehabilitation Design System (RPRDS) is a modification of the original RPS-3 program. The FPS program has been updated many times and is now in its 19th version, with an upcoming release built on Microsoft Windows platform. The variance of all influential variables is determined and the variability of the overall life cycle cost is

subsequently estimated. In addition, both programs make use of performance models to determine the level of pavement distress in the pavement at various points in time.

3.2.3 EXPEAR – FHWA

The computer program EXPEAR was developed in 1989 by the University of Illinois under a FHWA Project [Hall et al., 1989]. The program performs project level evaluation and utilizes data obtained through visual condition surveys. The program recommends rehabilitation techniques that include reconstruction and resurfacing, among others. However, EXPEAR does not consider user costs or other indirect impacts of the recommended rehabilitation techniques.

3.2.4 LCCOST– Asphalt Institute

The Pavement Life Cycle Cost Analysis Package (LCCOST), developed in 1991 by the Asphalt Institute, calculates pavement life-cycle costs incurred over a selected analysis period of up to 50 years. Five alternative pavement strategies can be considered at any one time. This program considers the initial cost of construction, multiple rehabilitation actions throughout the design life, and user delay at work zones during initial construction and subsequent rehabilitation activities. In addition to these considerations, the program considers routine maintenance (optional) that will be applied each year between rehabilitation activities. Traditionally, routine maintenance has been excluded from life cycle cost methodologies because many departments of transportation do not maintain easily accessible routine maintenance records for individual highway segments. The LCCOST models also consider salvage value of the pavement and of the individual materials that make up the layers. However the program does not consider pavement performance or pavement structure characteristics.

3.2.5 PRLEAM – Ontario MOT

The Pavement Rehabilitation Life-Cycle Economic Analysis (PRLEAM) was developed by the Ministry of Transportation of Ontario and the University of Waterloo in 1991. The immediate objective of this software was to meet the needs of the Ministry for evaluating life-cycle costs for pavement rehabilitation and maintenance. It can evaluate up to three rehabilitation alternatives, each having up to six treatment cycles. Other alternatives beyond the first three can be analyzed in additional runs of the program. The model also has a checking program that determines whether the inputs are within their built-in boundary values. An important feature of the PRLEAM software is its role in decision-support for selection of the most cost-effective rehabilitation improvement strategy for

improving a highway project. The inclusion of maintenance costs, user delay costs and salvage value of materials at the end of the analysis period is optional.

3.2.6 LCCP/LCCPR – Maryland

The University of Maryland developed a set of life cycle cost analysis programs that analyze flexible and rigid pavements [Rada and Witczak, 1987; Witczak and Mirza, 1992]. These programs incorporate user operating costs associated with pavement roughness among others. These programs were intended for project-level analysis but are considered better suited for use in pavement management on a network level. They are not used to compare alternative pavement designs.

3.2.7 Highway Design and Maintenance Standards Model – World Bank

The Highway Design and Maintenance Standards Model (HDM-III) computer program was developed by the World Bank for evaluating highway projects, standards, and programs in developing countries [Harral, 1979]. HDM-III is designed to make comparative cost estimates and economic evaluations of alternative construction and maintenance scenarios (including alternative time-staged strategies) either for a given road section or for an entire road network. The program considers that the costs of construction, maintenance, and vehicle operation are functions of road characteristics such as vertical alignment, horizontal alignment and road surface condition. Various costs types are calculated by estimating quantities and using unit costs to estimate total costs. An updated version of the program (HDM-IV) is currently available.

3.2.8 Queue and User Cost Evaluation of Work Zones (QUEWZ)

The QUEWZ model is a tool for evaluating highway work zone lane closures [Zaniewski et al., 1981; Memmott and Dudek, 1984]. The QUEWZ model is not a life cycle cost program. However, because it can be used to calculate user costs associated with work zones during maintenance and rehabilitation activities, it is deemed useful for analysis of life cycle strategies that involve such activities. QUEWZ simulates traffic flow through freeway segments, both with and without a work zone lane closure, and estimates changes in traffic flow characteristics and additional road user costs resulting from a lane closure whose time schedule and lane configuration are described by the user. The QUEWZ model has gone through many updates and in its current form, it provides user costs (including time delay and vehicle operating costs) on a daily basis. The models, which are based on vehicle operating cost relationships developed by Zaniewski et al. [1981], also predict vehicle emissions based on speed and time spent in queues.

3.2.9 MicroBENCOST – Texas Transportation Institute

The computer program MicroBENCOST was developed by the Texas Transportation Institute in 1993, under NCHRP Project 7-12 [McFarland et al., 1993]. This program analyzes many types of projects including pavement rehabilitation, added lane capacity, bridge projects, and bypass projects. A benefit/cost analysis that considers specific project alternatives or otherwise is carried out. While the program can be used to compare different alternatives, its main function is to evaluate the benefits and costs of constructing a particular project.

3.2.10 Cal B/C – California DOT

The California Life-Cycle Benefit/Cost (Cal-B/C) Analysis Model offers a simple and practical method for preparing economic evaluations on prospective highway and transit improvement projects within the State of California. The model is capable of handling several general highway projects, such as lane additions, and more specific projects, such as HOV lanes, passing/truck climbing lanes, or intersections. The model can also handle several transit modes, including passenger rail, light rail, and bus. Cal-B/C was developed in a spreadsheet format (MS Excel) and is designed to measure, in real dollar terms, the four primary categories of benefits that result from highway and transit projects: travel time savings, vehicle operating cost savings, accident cost savings, and emission reductions.

Users have the option of including the valuation of vehicle emission impacts and induced demand in the analysis. The results of the analysis are summarized on a project-by-project basis using several measures: life-cycle costs, life-cycle benefits, net present value, benefit-cost ratio (benefits/costs), rate of return on investment, and project pay back period (in years). These results are calculated over the life of the project, which is assumed to be twenty years. In addition, the model calculates and displays first-year benefits.

3.2.11 Pavement LCCA Package – ACPA

The American Concrete Paving Association (ACPA) developed a spreadsheet-type analysis program that is used with Microsoft Excel to analyze both rigid and flexible pavements. The spreadsheet requires that the user inputs preprogrammed rehabilitation activities, from which simple user-cost analysis is performed, with all costs discounted to the present.

The ACPA spreadsheet considers user costs using values from NCHRP Report 133 [Curry and Anderson, 1972] and from Winfrey's Economic Analysis for Highways [Winfrey, 1969]. The spreadsheet computes the level of time delay and other user costs by requiring the user to input the number of days expected for construction, the number of lanes to remain open, and other aspects of

traffic control and traffic volumes. The spreadsheet incorporates reliability by requiring the user to input not only the expected values of most variables, but also a “plus or minus” value representing a 90% confidence level. Thus, the spreadsheet uses risk analysis to determine the 90% confidence level in the total discounted costs expected over the pavement life cycle.

3.2.12 Pavement LCCA Package – IDAHO DOT

Idaho’s LCCA software package is an Excel-based program that was tailored largely to suit conditions in Idaho, but could be modified for other states. This software has a very comprehensive agency cost input structure, as it requires the user to input cost data at the level of line items. The software has a dynamic graphics feature that automatically illustrates the layer configuration of a selected pavement design alternative. It also displays selected pavement rehabilitation and maintenance activities as an activity profile on a time line. Another good feature of the Idaho software is that it is able to convert units across the English and metric systems, and saves the user the burden of such computations. However, the software does not consider user costs, and can only analyze one alternative at a time. The software is for project-level pavement life-cycle cost analysis. Furthermore, the user friendliness of the Idaho software could be improved considerably.

3.2.13 Pavement LCCA Package – Asphalt Pavement Alliance

The APA LCCA software is based on a Microsoft Excel spreadsheet, and generally seems to be more user friendly than most other LCCA software packages. Furthermore, it has an elaborate module for work-zone user costs computation, and updates the values of travel time using the current CPI and the base CPI. Furthermore, the APA LCCA software optimizes work-zone timing to minimize user costs based on the hourly traffic distribution and the work-zone duration. Shortcomings of the APA software includes its limited analysis capacity: only four alternatives can be analyzed at a time, and only up to ten work-zone activities can be analyzed for each alternative. Also, user costs during normal operation of the pavement are not considered. Also, the APA software makes no provision for the user to specify trigger values (an alternative to preset intervals), in the formulation of rehabilitation and maintenance strategies. Finally, the software is not flexible to accommodate different analysis periods for different alternatives.

3.2.14 D-TIMS Pavement LCCA Package – Indiana DOT

INDOT’s pavement management engineers currently use D-TIMS to help make pavement investment decisions at a network level. D-TIMS utilizes trigger values of pavement condition in its formulation of M&R strategies, and consequently recommends specific treatments when specific

distresses reach certain thresholds. The software also has built-in constraints to schedule treatments in a feasible manner. In its current form, D-TIMS is capable of utilizing user cost data in the form of VOC.

3.2.15 *RealCost* LCCA Package – FHWA

FHWA's *RealCost* software is based on a Microsoft Excel spreadsheet, and is obviously the most versatile package compared to the other existing LCCA packages. It has a detailed work-zone user costs computation. Unlike the APA software, it does not update the values of travel time using the current CPI and the base CPI and does not optimize work-zone timing to minimize user costs based on the hourly traffic distribution and the work-zone duration. Such computations are left externally to the user. Shortcomings of the *RealCost* software include its limited analysis capacity: only two alternatives can be analyzed at a time. Also, the *RealCost* software considers only time intervals of treatments (service lives) and therefore has no provision for the user to specify trigger values (an alternative to preset intervals), in the formulation of rehabilitation and maintenance strategies. The software requires the user to externally determine strategies for subsequent input in the software. Also, the software, in its present version, leaves the task of cost computation to the user. The estimated cost is then input by the user for the rest of the analysis. It would be useful for *RealCost* to be enhanced such that the user is provided with a drawdown list of alternative pavement design, rehabilitation, and maintenance strategies which may be adopted or modified as the user desires. Also, cost computation can be a burdensome task, and it would be useful for *ReaCost* to include a mechanism to help users estimate pavement project costs.

3.2.16 Other Pavement LCCA Software Packages

Other life cycle cost analysis computer programs and methodologies include LCC1, a program from Pennsylvania [Uddin et al., 1986], and non-automated methodologies from Alabama [Saraf et al., 1991], Ohio [Miller, 1984], Australia [Ockwell, 1990], and Egypt [El-Farouk and Sharaf, 1988].

3.3 Chapter Summary

(Merits and Limitations of Existing LCCA Methodologies and Software Packages)

There are some limitations associated with the use of most existing LCCA models. One such limitation is the exclusion of user costs in the analysis. User costs are costs incurred by the highway user, and include accident costs, delay cost, and vehicle operating costs (such as fuel, tires, engine oil, and vehicle maintenance). Many LCCA methods and software excluded user costs obviously because

such costs are typically difficult to quantify and the values associated with user costs are often disputed.

Another limitation in many existing pavement LCCA models is the non-consideration of preventive maintenance treatments as a criterion in strategy formation. Many LCCA researchers and practitioners argue that because preventive maintenance is a relatively “new” preservation strategy for pavements, data relating to the long-term benefits are still being collected. At this time, there are only a limited number of models that attempt to quantify the long-term effectiveness of preventive maintenance treatments, either in the form of performance jump or service life extension. Therefore they argue that incorporation of preventive maintenance in LCCA models is a challenge.

Finally, accounting for the uncertainty of input parameters in LCCA is considered complicated, and is therefore often ignored. Traditionally, LCCA models treat input variables as discrete, fixed values where a conservative “best guess” of the value of each input parameter is used to compute a single deterministic result. A sensitivity analysis is often performed to assess the effects of various input parameters on the model results. However, the sensitivity analysis does not necessarily reveal areas of uncertainty that may be a critical part of the decision making process. In this situation, it is difficult to ascertain which alternative has the “true” lowest life-cycle cost [Walls and Smith, 1998]. Risk analysis is a technique that could be used by LCCA to address the issue of uncertainty and could allow the decision-maker to weigh the probability of any particular outcome that may occur. Unlike most LCCA packages, the current FHWA package duly incorporates probabilistic approaches to LCCA.

CHAPTER 4 CATEGORIZATION OF PAVEMENT SECTIONS

4.1 Introduction

For purposes of the present study, a highway “pavement structure” is considered to be the part of road profile that lies directly on the finished subgrade and includes all paved surfaces. The present study does not include shoulder work. Currently, there is considerable variation in terminologies used for pavement types, across agencies, departments within INDOT, and even from one individual to another. For instance, the term “bituminous” is used in most documents at INDOT’s Contracts Division and INDOT’s DSS, while divisions associated with pavement management and design utilize the term “hot mix asphalt”. The present study strives to identify where such inconsistencies in terminologies exist, and in some cases, uses several alternative terms to describe an activity to avoid ambiguity. On the basis of the material used for the pavement structure, pavements in Indiana can generally be described as asphalt (flexible), concrete (rigid), or asphalt-over-concrete composite pavements. On the basis of the number of layers (each laid at a different pavement age), pavements may be also be categorized as single layer PCC, single layer AC, or multi-layer pavements (overlays). Figure 4-1 shows the various sub-types of each type of pavement, while Figure 4-2 and 4-3 show the distribution of these pavement types in Indiana.

There are two kinds of concrete pavements in the state from the perspective of material continuity: Jointed and Continuous. Most jointed concrete pavements in the state are plain (JPCP), but some older concrete pavements are reinforced (JRCP). There are relatively very few continuously reinforced concrete pavements (CRCP) left in the state, notable among which is SR-37 (one direction only) in Monroe County. CRCP pavements are noted for their relatively long service lives, but have been associated with hard-to-repair distresses in their old age. “Single layer” asphalt pavements are those that have received no overlay since their initial construction. Composite pavements consist of layers having different materials, and may be asphalt-over-concrete or concrete-over-asphalt. Asphalt-over-concrete composite pavements could be an HMA overlay of an existing concrete pavement that (i) has received no treatment (traditional overlay (TRD)), (ii) has been cracked and sealed (CAS) or (iii) has been rubblized (RUB) prior to the overlay. The issue of final pavement type yielded by rubblization and overlay is a philosophical one. On one hand, it may be argued that such pavements are asphalt-over-concrete composite pavements. On the other hand, it may be argued that

such pavements are rather asphalt pavements because rubblization yields a porous base material that cannot really be referred to as an underlying concrete layer. concrete-over-asphalt (white-topped pavements) constitute a very small fraction of the network.

The percentage of asphalt pavements increases from northern to southern Indiana, while the total mileage of asphalt-over-concrete overlay pavements decreases from northern to southern Indiana. The total mileage and percentage of concrete pavements are higher in central Indiana compared to the southern and northern regions of the state.

1. INDOT Design Manual describes this as a "composite" pavement.

Figure 4-1 Major Pavement Types on Indiana's State Highway Network

Figure 4-2 Distribution of Dominant Pavement Types, Indiana State Highway Network [Highway Statistics, 2001]

Figure 4-3 Distribution of Dominant Pavement Types by Road Class [INDOT PMS Database, 2001]

Pavement maintenance and rehabilitation practices (and consequently, resources expended for such repairs) vary by pavement type. The current study on LCCA for pavement design in Indiana therefore duly considered not only the spatial distribution of pavement surface types in the state at a given point in time, but also examined the trends of such distribution over the past years. From Figure 4-4, it is seen that there has been an increasing trend towards the use of asphalt overlays over existing concrete pavements (a practice typically termed “blacktopping”): For most part of the 1990-1999 period, approximately 200 miles of existing concrete roads, on the average, received asphaltic surface overlay annually. There have been a few attempts at using PCC overlays on existing asphalt-surfaced pavements (“whitetopping”) as well as on existing concrete pavements (bonded or unbonded overlays), however the use of this relatively new technology is still not widespread.

Figure 4-4 Temporal Distribution of Pavement Surface Types, 1992-1999

4.2 Development of Pavement Families for the Present Study

4.2.1 Categorization by Surface Type

Asphalt Pavements

Asphalt pavements have a surface layer that consists entirely of an asphalt/aggregate mix laid over a granular treated or untreated base layer, and sometimes a subbase layer (typically, untreated natural gravel). For purposes of the present study, an asphalt pavement is one where all layers (surface, base and sub-base) contain an asphaltic binder in varying proportions and aggregate gradations and quality). Also, a rubblized concrete (rigid) pavement overlaid with HMA is considered an asphalt pavement, as rubblization yields a material that can be described as a porous base course.

Rigid (Concrete) Pavements

In Indiana, concrete pavements may be jointed or continuous, plain or reinforced. Jointed plain concrete pavements (JPCP) have transverse joints typically spaced at 5.5 m maximum (in Indiana) and are constructed steel dowel bars across transverse joints and steel tiebars across longitudinal joints. Jointed reinforced concrete pavements (JRCP) have transverse joints typically spaced more than 20 ft apart. The reinforcement (welded wire fabric or deformed steel bars) comprises about 0.15 to 0.25 percent of the slab cross-sectional area. Continuously reinforced concrete pavements (CRCP) do not have transverse joints, other than the transverse construction joints placed at the end of each day's paving and at abutting pavement ends and bridges. Continuously reinforced concrete pavements have a considerably higher steel content than jointed reinforced concrete pavements – typically 0.6 to 0.8 percent of the cross-sectional area. Transverse reinforcing steel is often used to support the longitudinal steel during construction and to control any random longitudinal cracks that may develop. All three types of concrete pavements are typically constructed on a layer of untreated or treated granular layer (sometimes referred to as “subbase”). In some cases, an additional but lower-quality natural gravel or crushed rock layer is used to separate the granular layer from the subgrade.

Composite (Asphalt-on-concrete Overlay) Pavements

Most asphalt-overlaid concrete pavements in the state of Indiana were originally constructed as concrete pavements, and later resurfaced with an asphalt overlay after many years of service. With the exception of widening and lane-additions for composite sections, there are practically no new pavement sections in Indiana where both layers of the composite pavement were constructed at the same time. For certain projects in states such as Illinois (Zeyer, 2001) there have been recent attempts

to construct new “composite” long life (40 years) pavements, with a 12-inch layer of crushed rock (PGE) followed by a 6-inch layer of asphalt topped by a 12-inch PCC layer.

As seen from Figure 4-4, the share of asphalt-over-concrete pavements in the state highway network increased rapidly over the last decade. While such pavements (together with asphalt pavements) may be generally categorized by some practitioners as “flexible” pavements by virtue of their topmost surface material type, some of their rehabilitation activities are not applicable to asphalt pavements, and it may be necessary to consider such composite pavements as a pavement family that is distinct from those without an underlying concrete slab.

4.2.2 Categorization by Road Class

For consistency with current INDOT PMS practice, the present study categorized all state highway roads in Indiana on the basis of their route type (Interstate vs. non Interstate) and NHS status (NHS or Non-NHS). The roads sections were therefore placed in the following road classes:

- Interstates (INT)
- NHS Non-Interstate (NIN)
- Non-NHS (NNN)

The National Highway System, which was established by legislation in 1995, is a collection of Interstate and other selected roads based on their importance to the national economy and defense. All Interstates are on the National Highway System. Interstates are associated with the highest levels of pavement loading, because operators of larger vehicle classes (FHWA classes 4 and above) prefer such highways or are prohibited from using certain sections of lower class due to bridge weight restrictions. Interstates attract long distance heavy load traffic because of their low levels of accessibility, high levels of mobility, and superior geometric standards. Non-NHS roads (mainly consisting of state roads and a few US roads) generally have the lowest levels of traffic loading. The design and construction standards for NHS Non-Interstates roads (consisting of several US roads and a few state roads) generally appear to lie in between these two extremes, but nearer to that of Non-NHS roads. Also, the design and construction standards are highest for Interstates, and lowest for Non-NHS pavements.

4.2.3 Definition of Pavement Families for the Study

Based on the surface type and route type (including NHS status) criteria as discussed above, the nine pavement families to be used for the present study (and their respective sizes) are shown in

Table 4-1. It is seen that most state highways have asphalt pavements. Also, a majority of the pavements belong to the non NHS category. Interstates seem to constitute a large majority of asphalt-over-concrete composite pavements.

Table 4-1 Pavement Families and Sizes

Pavement Classification		Size by Pavement Surface Type (miles)		
		Concrete	Asphalt	Asphalt-on-Concrete
Road Class	Interstates	172	94	903
	NHS Non-Interstate	259	387	1051
	Non NHS	631	6158	1485

Figure 4-5 Pavement Families and Sizes on the Indiana State Highway Network
[Highway Statistics, 2003]

4.3 Chapter Summary

Pavement design and maintenance and rehabilitation practices vary by pavement characteristics such as surface type and road class. As such, the present chapter categorizes state highway pavements into groups or “families” on the basis of similar major characteristics (pavement types and road class). In doing so, the thorny issue of pavement type terminology is addressed. The chapter also provides information on the relative share of each pavement family to the overall state highway. The geographical and temporal trends in pavement type mileage and fractions are also presented. The categorization of Indiana’s pavements into families for LCCA purposes was done with a view for consistency with the Indiana Design Manual (which categorizes pavements by surface type, road class, and traffic).

CHAPTER 5 PAVEMENT DESIGN ALTERNATIVES

5.1 Introduction

In the current Indiana pavement design process, candidate pavement projects are typically proposed by the districts and reviewed by INDOT's Program Development Division and are evaluated for the appropriate treatment the pavement type and thickness of a proposed pavement structure is generally determined by giving due consideration to subgrade conditions, expected traffic loading, and economic considerations. Also, the pavement design engineer takes into consideration the route type.

Pavement design is carried out not only for new construction (replacement of entire pavement structure from subgrade up) but also to determine the appropriate thickness of new overlays as part of pavement rehabilitation or resurfacing projects. As such, the present study includes pavement design alternatives for both new construction and resurfacing of existing pavements. Project scopes may be driven by non-pavement issues such as budget constraints, capacity, safety, drainage, short or long term needs, truck loadings, or geometric deficiencies. According to the INDOT Design Manual, a pavement reconstruction project includes removal of the existing pavement structure, including any base or subbase layer, and preparation of the subgrade prior to placing a new pavement structure. The Manual recommends that pavement sections associated with structural deficiencies should be reconstructed, while structurally sufficient pavements are candidates for rehabilitation-type projects such as resurfacing. Projects requiring 50 percent or more new pavement are generally considered for complete reconstruction. Figure 5.1 presents a schematic representation of alternative pavement layer types (and respective thickness boundary values) after pavement reconstruction or replacement that is consistent with current INDOT Pavement Design practice. Also, Figure 5-2 shows the alternative pavement layers types (new overlays only) for existing pavements.

Asphaltic Concrete Pavement

PCC Pavement

Legend

Dense Graded Granular Course

Notes:

1. Minimum thicknesses guided by traffic loading considerations
 2. Refers to maximum parameters that are typically encountered during pavement design at INDOT.
 3. Maximum thicknesses guided by economic considerations.
- Source of Information: INDOT Design Manual [2002], INDOT Material and Tests Division.

Figure 5-1 Boundary Values for Design of New Pavements at INDOT

INDOT's Design Manual states that the minimum thicknesses are 300mm and 225mm for HMA pavements and concrete slab pavements, respectively, on the State Highway System. The Manual recommends that new composite pavements (typically used for widening sections for existing roadways) should follow a design consistent with that for the existing pavement. The Manual further recommends adjustment of these minimum thicknesses by ± 100 mm for HMA, and ± 50 mm for PCCP, based on the preliminary design year traffic information and the minimum thickness shown on the INDOT Typical Sections (Appendix 1).

5.2 Pavement Design Alternatives at Selected States

The Structural Number (SN) equation [AASHTO, 1993] suggests that there is an infinite number of combinations of layer thicknesses of the various paving materials that will satisfy the Structural Number requirement specified in the Design Procedure. The number of potential solutions is reduced somewhat when considering the practical limitations of placing the various pavement layers. In the state of Kentucky for instance, typical ranges of layer thicknesses of common AC pavement layer materials given in the Pavement Design guide used are as follows: 1.25 to 1.5 inches (32 to 39mm) per course for AC Surface and Binder; 2.0 to 5.0 inches (51 to 129 mm) per course for AC base depending on the class. Also, the aggregate base of 4 to 6 inches (103 to 154 mm) per course is used prior to laying the AC base.

In a study that investigated feasible pavement design alternatives for Wisconsin DOT, Croveti and Owusu-Ababio [1999] demonstrated that existing LCCA procedures at WisDOT can include certain pavement designs that were not considered in the initial development of pavement design LCCA at WisDOT, such as thick AC (150mm (5.8 inches or more) and thin PCC pavements (225mm (8.75 inches) or less). From that research, a valuable lesson for all state DOTs is that any initial effort for LCCA in pavement design should be carried out for as many material and thickness types as possible, so that future questions of LCCA applicability to certain designs can be avoided.

In California, experimental test sections were constructed on the I-710 using several design options [Beckman Center, 1998]. The section of reference was about 4.8 km (3 mile) long where the designers based their project on using the existing PCC pavement and base, but repairing and patching slabs where needed. The team proposed a 200-mm (8-in) hot-mix asphalt overlay, composed of 154 mm (6 inches) of coarse graded stone matrix asphalt wearing course. The pavement structure consisted of 19mm (0.75 inches) new open graded friction course, 50.8

mm (2 inches) new SMA fine grade, 152.4mm (5.9 inches) SMA course grade 200mm (7.8 inches) recycled PCC and 200mm (7.8 inches) recycled PCC.

The Georgia DOT has successfully used a similar combination of mixes for 5 years and found it capable of bridging the joints, broken slabs, and transverse longitudinal joints in the pavements where natural faulting occurs with no evidence of reflective cracking. It was concluded that two applications of milling-and-resurfacing treatment would be needed during the pavement's 40-year life to sustain the wearing surface.

In the state of Illinois, the IDOT is hoping to extend the life of its roads to 40 years by adopting a new pavement design [Zeyer, 2001]. Three miles of pavement on I-290 and a stretch I-270 from Route 157 west to I-55 merge, was replaced with a new pavement using the new design. The new pavement consisted of a compacted "dirt" sub-base, overlaid by a minimum of 12-in. of crushed rock (porous granular embankment (PGE)), followed by a 6-inch (154 mm) layer of asphalt, and finally topped by a 12- to 13-inch (308 to 334 mm) layer of continuously reinforced concrete. It was expected that tighter specifications for materials (such as less susceptibility of cement and aggregates to alkali reactivity) would lead to extended pavement life. The Illinois 40-year pavement concept is still at design phase and construction work was scheduled to start in 2003. Over its 4-year life, the reconstructed I-290 section is expected to carry 263,000 vehicles per day, of which approximately 7% are trucks.

5.3 Pavement Design Alternatives for the Present Study

5.3.1 New Pavements

Development of alternate pavement designs should typically take due consideration of minimum and maximum thicknesses of the constituent layers for each pavement type. Other alternate pavement designs can be considered where specific project considerations indicate a need.

Based on INDOT pavement classifications, pavement design alternatives for reconstruction of asphalt and concrete pavements (Figures 5-2 and 5-3, respectively) were developed in the present study. INDOT's minimum and maximum thickness design criteria were considered as the boundary cases and incremental thickness in between were used to arrive at a number of alternatives. This way, the costs and benefits (service lives) associated with various thicknesses of each pavement type and layer configuration, can be investigated over pavement life cycle.

Figure 5-2 Design Alternatives for New HMA Pavement

Figure 5-3 Design Alternatives for New PCC Pavement

5.3.2 Existing Pavements

Development of alternative pavement designs for resurfacing existing pavements should typically take due consideration of minimum and maximum thicknesses of the new layers for each pavement type (Figures 5-4 and 5-5). Based on INDOT pavement classifications, pavement design alternatives for resurfacing existing asphalt and concrete pavements were developed in the present study. INDOT's minimum and maximum thickness design criteria were considered as the boundary cases and incremental thickness in between were used to arrive at a number of alternatives and subsequently to investigate the costs and benefits (service lives) associated with various thicknesses of each pavement type and layer configuration.

Figure 5-4 HMA Overlay Design Alternatives for Existing Asphalt (Flexible) Pavements

Figure 5-5 PCCP Overlay Design Alternatives for Existing Concrete (Rigid) Pavements

			DESIGN ALTERNATIVES FOR EXISTING PCC PAVEMENTS										
			12	13	14	15	16	17	18	19	20	21	22
HMA Surface		Thickness (mm)	35	35	35	35	35	35	35	35	35	35	35
		Material Weight/sq.yd											
HMA Intermediate		Thickness (mm)	65	65	65	65	65	65	65	65	65	65	65
		Material Weight/sq.yd											
HMA Base		Thickness (mm)	200	225	250	275	300	325	350	375	400	425	450
		Material Weight/sq.yd											
Existing Concrete Pavement													
Total Pavement Thickness (mm)			300	325	350	375	400	425	450	475	500	525	550
Illustration

Figure 5-6 HMA Overlay Design Alternatives for Existing Concrete (Rigid) Pavements

5.4 Chapter Summary

The present chapter duly recognizes that pavement design is carried out not only for new construction (replacement of entire pavement structure from subgrade up) but also for existing pavements (to determine the appropriate thickness of new overlays as part of pavement rehabilitation or resurfacing projects). As such, the chapter presents pavement design alternatives for both new construction and resurfacing of existing pavements. This has been done on the basis of current and foreseeable INDOT practice. The chapter presents details of alternative pavement layer types (and respective thickness boundary values) for new and as well as for existing pavements.

CHAPTER 6 PRESERVATION TREATMENT EFFECTIVENESS

6.1 Introduction

The previous chapter describes the pavement design alternatives for each pavement type while the present chapter focuses on the effectiveness of preservation treatments (the next chapter then discusses the alternative sets of rehabilitation and maintenance strategies over the pavement life cycle that could be analyzed for each design alternative). Any given strategy consists of one or more treatments, and each rehabilitation treatment in the strategy is associated with a jump in performance and consequently extension in pavement service life. It is therefore possible to determine the overall cost-effectiveness associated with each strategy, over the pavement life cycle and consequently to identify the optimal M&R strategy. This can be done for several alternative strategies for each pavement design alternative for existing or new pavements.

In its current form, the FHWA's *RealCost* LCCA software asks the user to directly input the performance of the preservation treatments in terms of their service lives. Determination of preservation treatment service lives is a pavement management issue. As such, it was not within the scope of the present study. It is expected that INDOT's PMS would, at a future time, furnish the requisite service lives for use as an input in LCCA. This chapter discusses the issue of preservation treatment effectiveness in the context of past studies in Indiana and elsewhere and sheds light on how existing preservation effectiveness values used at INDOT may be updated by the PMS operators to reflect current materials and construction processes.

6.2 Literature Review – Effectiveness of Preservation Treatments

The effectiveness of pavement rehabilitation or maintenance is a key input in pavement LCCA. Effectiveness of a treatment may be assessed in the short-term, as a jump in performance or reduction in the rate of deterioration [Labi and Sinha, 2003], or may be assessed over a relatively longer period. Long-term assessments of preservation effectiveness are typically more applicable to LCCA, particularly within the context of FHWA's existing LCCA software procedures.

Assessment of preservation treatment effectiveness over the long term (typically over the life of the treatment) is usually measured in one of three ways:

- life of the treatment (or extension in pavement service life),
- average pavement condition over the treatment life, or
- area under the performance curve (within the treatment life period).

Effectiveness may be measured by estimating the extension in remaining service life due to the preservation treatment, i.e., time taken for the pavement to deteriorate to a certain threshold level. This is also referred to as the *treatment life*, or *treatment service life*. The treatment life may be determined using expert opinion, or using performance curves (developed from historical data) and a treatment performance threshold. The average-condition method, on the other hand, requires only condition data over the treatment life. FHWA's *RealCost* LCCA software expresses preservation treatment effectiveness in the form of service lives – the more effective a treatment, the greater the service life value that is entered by the user. The user needs to externally determine the service life of the treatment before running the program. As a possible enhancement to the existing software package, it would be useful for the user to have, as part of the software tools, a drawdown list of all typical preservation treatments and their associated service lives. The service lives available in INDOT's Design Manual Chapter 52 could be updated for this purpose. Furthermore, it would be useful to collect data and carry out a probabilistic analysis of service lives for each treatment to obtain the nature of probability distribution of service lives, as well as its statistical parameters such as mean and standard deviation. This way, more reliable values of service life for each treatment can be obtained for LCCA purposes.

The area-under-curve approach is more data intensive than the other two approaches, but is based on a rather simple rationale -- a consistently well maintained pavement (a gently sloping performance curve, yielding a large area under that curve) provides the user greater benefits than a bad pavement (a steep performance curve having a small underlying area). Because the benefits of a well-maintained pavement are numerous and difficult to quantify in monetary terms, the area under the performance curve could be used as a surrogate for user benefits. The area under the performance curve is a representation of both average condition and extension in service life, and may be considered as the best measure of effectiveness, compared to the other two measures. However, the area-under-curve approach requires collection of condition data and development of performance models, and finding the area using calculus or manual means. In the past, several

studies have utilized the area-under-curve concept. In developing budget optimization techniques for PAVER (the U.S. Army Corps of Engineers Pavement Management System), the area under the condition-time curve was used as a measure of performance [Shahin et al., 1985]. Also, Kher et al. [1985] used the area under the performance curve as a surrogate for user benefits, for the Ontario Ministry of Transportation and Communication's Program Analysis of Rehabilitation System. Joseph [1992] used the area under the performance curve combined with the average annual daily traffic (AADT) and road section length to compare the cost-effectiveness of preventive maintenance strategies. With the concept of PSI-ESAL loss (where the performance measure was PSI, and the "time" scale was represented by cumulative loadings applied to the pavement) benefits were represented by the area under the PSI-load curve [Fwa and Sinha, 1987]. The area under performance-time curve concept was used to establish a funding allocation procedure for the San Francisco Bay Area Metropolitan Transportation Commission [Smith et al., 1987]. The New York State Department of Transportation has used the area under the pavement performance curve to compare the cost-effectiveness of alternative preventive maintenance strategies [Geoffroy, 1992]. In the present study, the effectiveness of preservation treatments was expressed in terms of their service lives. This was done to ensure consistency with the LCCA software procedures.

6.2.1 Findings from Past Studies

In formulating time-based strategies, it may be beneficial to have knowledge of the service lives of various pavement treatments. Hicks et al. [2000] offered some intervals for selected treatments on AC pavements (Table 6-1). Geoffroy [1996] summarized information on treatment service lives (Table 6-2). Labi and Sinha [2002] provided a summary of service lives of low-level treatment as perceived by INDOT pavement managers at a sub-district level (Table 6-3).

Table 6-1 Optimum Time for Applying Selected Treatments on Asphalt Pavements

Treatment	Years
Fog Seals	1-3
Crack Seals	2-4
Chip Seals	5-7
Slurry Seals	5-7
Thin Overlays (including surface recycling)	5-10

Source: [Hicks et al., 2000]

Table 6-2 Service Life of Maintenance Treatments: Summary of Selected Published Information

Agency	Treatment	Service Life (approx.)	Comments, Source and Reference
Indiana DOT	Chip Seal	4 years average	For pavement in good condition. [Feighan, et al., 1986]
	AC crack seal	2.2 years average	
Ontario MTC	AC Rout and Seal	2-5 years	[Joseph et al., 1992]
New York State DOT	PCC Joint & Crack Filling	2 years	[New York State DOT, 1992]
	PCC Joint & Crack Sealing	8 years	
	AC Rout & Crack seal	5 years	
	AC Crack filling	2 years	
	Thin Overlay	8 years	
	Surface Treatment	3 years median	
NCHRP	Chip Seal	1-6 years	[Shuler, 1984]
	Slurry Seal	1-6 years	
	Micro-surfacing	4-6 years	
	Thin Overlay	> 6 years	
FHWA	Micro-surfacing	5-7 years	[Raza, 1994]
	Slurry Seal	3-5 years	
	Thin Overlay	8-11 years	
	Chip Seal	4-7 years	
Oregon DOT	Chip Seal	3-6 years	[Parker, 1993]
U.S. Corps of Engineers	Slurry Seal	3-6 years	[Brown, 1988]
	Surface Treatment	3-6 years	
	Crack seal	3-5 years	

AC as used here refers to asphalt or flexible pavements

PCC as used here refers to existing rigid pavements

Source: [Geoffroy, 1996].

Table 6-3: Application Criteria and Benefits of Preventive Maintenance Treatments

Pavement Type	Treatment	Average Age at 1 st Application (Years)	Average Frequency of Application (Yearly Interval)	Average Perceived Treatment Life (Years)
Rigid	Joint Sealing	8	6	10
	Crack Sealing	6	4	6
	Under-drain Maintenance	1	2	2
Asphalt	Crack Sealing	3	4	3
	Chip Sealing	7	5	6
	Sand Sealing	12	4	5
	Crumb Rubber Sealing	2	NI	NI
	Micro-surfacing	15	NI	3
	Thin HMA Overlay	17	11	11
Asphalt-on-Rigid Composite	Under-drain Maintenance	1	1	2
	Crack Sealing	2	3	4
	Chip Sealing	10	5	5
	Sand Sealing	12	4	5
	Crumb Rubber Sealing	1.5	NI	NI
	Micro-surfacing	15	NI	3
	Thin HMA Overlay	20	11	9

Note: 1) NI- not indicated. 2) All values rounded-off to the nearest integer.

Source: [Labi and Sinha, 2002(2)].

The effectiveness of rehabilitation and maintenance treatments is also being investigated using data from the LTPP and other SHRP-related research programs [Smith et al., 1993; Hadley, 1994; Hanna, 1994]. It is expected that analysis of pavement performance data obtained from these sites will help quantify the ability of different maintenance treatments to extend service life or reduce distress rates [Hadley, 1994]. At the current time, it seems that not enough data has been generated to determine the service lives of various preservation treatments. However, initial findings suggest that it is more cost-effective to apply preservation treatments throughout the life of the pavement rather than allow the pavement to deteriorate to a point where major rehabilitation is needed, and that if modest-cost surface treatments are applied at the right time in the decay cycle, service life can be extended over a much longer time. This way the need for major rehabilitation is delayed, and the extra costs, hazards, and inconvenience associated with work zones due to frequent rehabilitation, are avoided.

The Supplemental Maintenance Effectiveness Research Program (SMERP), a Texas research effort carried out to closely monitor the effectiveness of selected preservation treatments demonstrated that both treatment type and treatment timing (as regards pavement condition at time of treatment) were critical in the effectiveness of maintenance treatment applications. A comprehensive study on preventive maintenance carried out for the state of New York determined that the strategy with preventive maintenance was 3.65 times more cost-effective than that without preventive maintenance. A long-term research project in Wisconsin reports that PCC pavements with unsealed joints performed better than pavements with sealed joints, and that contraction joint sealing costs are not cost-effective [Shober, 1986; Shober, 1997]. This finding is contrary to the observational experience of most pavement and maintenance engineers which indicates that sealing of pavement joints and cracks is beneficial because it reduces the amount of water infiltrating through the crack. Shober argues that the need to seal PCC pavement joints is so ingrained in the US pavement culture and is so apparently sound from a theoretical perspective that it has been considered an unchallengeable truth. He states that those who have challenged it have been viewed as having conducted poor research. Shober explains that the “truth” of keeping water and incompressibles out of joints may have had a basis when PCC pavements were built directly on the subgrade, but since the advent of base courses the need to seal joints has not been proven.

Rajagopal and George [1991] employed time-series pavement performance data to develop mechanistic empirical models to predict the immediate jump in pavement condition after treatment and the rate of pavement deterioration after treatment. Pavement condition rating (PCR)

an aggregate statistic of both roughness and distress was used as a measure of serviceability. Using these performance jump and performance trend models, the study further evaluated the effect of timing on the effectiveness of various levels of treatment, such as surface treatment, thin overlays, and thick overlays. Life cycle analysis of each of the three treatments applied at various condition levels indicated that if repairs are performed while the pavement is in the “slow rate” phase of pavement deterioration, the condition after repair is greater and also life cycles are greatly increased.

6.2.2 Measuring Preservation Treatment Effectiveness - Current State of Practice at INDOT

Chapter 52 of INDOT’s Design Manual defines typical performance lives of various treatments for use in LCCA. The design life is the estimated service life of the pavement, as such, for the LCCA the design lives are recommended for use for the various initial, maintenance, or rehabilitation options as described in Table 6-4 below. For maintenance/rehabilitation treatments indicated on this table, it is worth noting that the design life is not the time to first application, but rather gives an indication of the subsequent time a treatment (or a higher level treatment) would be needed.

Table 6-4 Recommended Design Life for LCCA [INDOT Design Manual]

Pavement Treatment	Design Life (years)
New PCCP	30
Concrete Pavement over Existing Pavement	25
New Full Depth HMA	20
HMA Overlay over Rubblized PCCP	20
HMA Overlay over Asphalt Pavement	15
HMA Overlay over Cracked and Sealed PCCP	15
HMA Overlay over CRC Pavement	15
HMA Overlay over Jointed Concrete, Sawed and Sealed Joints	15
HMA Overlay over Jointed Concrete	12
PCCP Joint Sealing	8
Thin Mill and Resurface of Existing Asphalt	8
Concrete Pavement Rehabilitation (CPR) Techniques	7
Microsurface Overlay	6
Chip Seal	4
Asphalt Crack Sealing	3

INDOT's Design Manual states that the estimated design life may be varied based on engineering judgment of the existing conditions, past performance, or the condition of the drainage system. It further states that the design life of the pavement should be varied to test the LCCA for sensitivity, and that the design lives used for the sensitivity analysis should be documented [INDOT Design Manual, 2002]. Determining the reasonableness of the design lives provided in Table 6-4 is beyond the scope of the present study. It is expected that INDOT PMS will be in a position to update these values at a future date when adequate temporal data is available for such purpose.

6.3 Updating Treatment Lives of Preservation Treatments for INDOT LCCA

There may be a current or future need to update the LCCA treatment service lives provided in the INDOT Design Manual in Table 6-4 to (i) reflect any new preservation treatments or (ii) update such service lives in light of improved materials and construction processes that may translate to service lives higher than those currently indicated in the manual. With regard to new preservation treatments, INDOT's pavement steering committee has developed a new list of standard treatments for which service lives may be determined. The issue of service life determination of preservation treatments is an interesting one, and there are quite a few methodologies that can be used to estimate the service life of pavement preservation treatments, as shown in Figure 6-1. At the current time, data of adequate temporal span are not available to carry out analysis of treatment service lives. However, it was found necessary to include in this report, a description of how such analysis could be carried out should the data become available in future. The details, requirements, merits, and demerits of each approach are discussed in subsequent paragraphs.

Figure 6-1: Alternative Methodologies for Service Life Determination

6.3.1 Estimation of Preservation Treatment Service Life based on Time Interval

This approach simply involves measurement of the time interval that passes between a preservation treatment and the next similar or higher preservation treatment (Figure 6-2).

Figure 6-2: Estimation of Preservation Treatment Service Life based on Time Interval

For each of several pavement sections that received the given preservation treatment, the service life can thus be determined, and expressed as an average value or as a function of pavement, traffic and weather characteristics. The advantage of this approach lies in its economy:

no pavement performance/condition data is needed to establish service lives in this manner. However, for this approach to work, preservation treatment contract records spanning a considerable span of time should be available for each pavement. This is generally not the case at INDOT even though the Research Team has made earnest efforts in trying to obtain such data.

6.3.2 Estimation of Preservation Treatment Service Life based on Pavement Condition

The service life of a preservation treatment can be determined by estimating the amount of time that passed before the treated facility reverted to the state before treatment or to a pre-specified condition threshold state. This could be done using time series or cross sectional data.

(a) The Time Series Approach

In this approach, the performance/condition of each individual facility (pavement section) that has received a specific preservation treatment is monitored over time. The time interval between the time of treatment and the time at which condition falls below the condition before treatment (Figure 6-3(a)) or a pre-specified condition (Figure 6-3(b)), is measured as the service life of the preservation treatment. If a pre-specified condition is used, the pavement condition at time of treatment may be lower than that threshold (as shown in the illustration) or may be higher than the threshold. This approach is data intensive: performance/condition data is needed over a considerable span of time for each pavement section.

Figure 6-3: Estimation of Treatment Service Life based on Time-Series Condition Data

This may be repeated for several facilities that received the treatment in question, and the service lives thus obtained can simply be processed to give an average service life for that treatment, or may be expressed as a function of pavement, traffic, weather and other attributes, for that preservation treatment.

(b) The Cross Sectional Approach

In this approach, the performance/condition (at any single given year only) of several facilities that received a specific treatment is used. As such facilities typically have a wide range of ages at the year in question it is possible to obtain a performance models that relate facility condition to facility age. Using such functions, it is possible to determine the average service life associated with the preservation treatment under investigation.

In the absence of time series data spanning an appreciable length of time as is the case at INDOT PMS, the cross section approach seems preferable over the time series approach of determining preservation service lives. However, before the approach can be used, two pieces of information are necessary:

- A *performance model* for the pavement section, either a non-increasing index such as PSI (as illustrated in Figure 6-4 below) or a non increasing index such as IRI.
- A *threshold value of pavement condition*, often called a trigger value for each treatment. At most state DOTs, such trigger values are typically generated from surveys of pavement experts. Trigger values may also be determined from a review of historical data (conditions at which a treatment was applied) but such approach may be misleading because of the typical wide variations in pavement conditions at times of application.

Figure 6-4: Estimation of Treatment Service Life based on Cross-Sectional Condition Data

(c) Panel Data

This approach, consistent with the pooling of data across years, is similar to that for cross-sectional data, with the exception that performance data for more than one year, rather than just one year, are used for developing the performance model for pavements that received a specific treatment. Such analysis is susceptible to problems of auto-correlation, and it is important that appropriate statistical and econometric tools are employed to detect and correct for any such problems.

6.4 Chapter Summary

Any pavement preservation strategy consists of one or more treatments and their respective timings, and each constituent treatment yields a jump in performance which translates to an extension in pavement service life. In its current form, the FHWA's *RealCost* LCCA software asks the user to directly input the performance of the rehabilitation treatments in terms of their service lives. The present chapter duly recognizes that determination of preservation treatment service lives is a pavement management issue and falls outside the study scope. However, the chapter discusses the issue of preservation treatment effectiveness in the context of past studies in Indiana and elsewhere, and provides methods by which such effectiveness values may be updated when requisite data becomes available. The next chapter uses the results of the present chapter to identify pavement preservation strategies and shows how the overall cost and effectiveness of each strategy can be estimated on the basis of the costs and effectiveness of the constituent treatments.

CHAPTER 7 STRATEGIES FOR PAVEMENT REHABILITATION AND MAINTENANCE

7.1 Introduction

For each pavement design alternative, there are several alternative sets of rehabilitation and maintenance strategies over the pavement life cycle. For purposes of the present study, a strategy is defined as a combination of activity types and their respective timings. In some literature, the terms “schedule”, “activity profile” and “activity time line” have been used synonymously with the term “strategy”. Each strategy addresses the following questions:

- Which activities should be carried out (treatment type), and
- When each activity should be carried out (treatment timings).

As any given strategy consists of one or more treatments, the total cost of the constituent treatments can be calculated for that strategy. Also, each treatment in the strategy is associated with a jump in performance (which can also be translated as a reduction in the rate of deterioration, and consequently pavement life extension). It is therefore possible to determine the overall cost-effectiveness associated with each strategy, over the pavement life cycle and consequently to identify the optimal M&R strategy. This can be repeated for several alternative strategies for a given pavement design alternative, either for existing or new pavements. In its current form, FHWA’s LCCA software gives due consideration to agency and user costs, but does not offer to the user a set of preservation treatments and their associated effectiveness (service lives). As such, the user needs to establish the effectiveness externally and input such data in the program.

7.1.1 Some Definitions

As a prelude to further discussion on strategy formulation for the present study, it is necessary to define some terms as used in the current and subsequent chapters of the report.

A *pavement rehabilitation strategy* is defined as a combination of resurfacing activities applied at various times within pavement construction life cycle. Construction life-cycle is defined as the period between two consecutive reconstruction activities. In the present study, rehabilitation strategies have been formulated for new pavements as well as existing pavements. A schematic illustration of a pavement rehabilitation strategy is provided in Figure 7-1 below. Rehabilitation treatments are shown as thick vertical lines. For purposes of the present study, rehabilitation is a resurfacing treatment involving a structural HMA overlay, a concrete overlay, or concrete pavement restoration.

(a) New Pavement (Illustration depicting only one Rehabilitation within Life-cycle)

(b) Existing Pavement ("current year" position shown only for illustrative purposes)

Figure 7-1 Rehabilitation and Construction Life-cycles for New and Existing Pavements

A *pavement maintenance strategy* is defined as a combination of maintenance activities applied at various times within pavement rehabilitation life-cycle. A *rehabilitation life-cycle* is defined as the period between construction and rehabilitation or between rehabilitation and reconstruction (see Figure 7-2). Pavement maintenance strategies typically consist of treatments of a preventive (proactive) nature, such as crack sealing, chip sealing, and thin overlays. Such preventive treatments are applied before the onset of significant structural deterioration (O'Brien, 1989). In past studies, corrective (reactive) maintenance treatments have generally been excluded from strategy formulations because it has been argued that unlike preventive maintenance, they are typically carried out not in anticipation of distress, but to address distress that have already occurred and therefore cannot be included in a strategy unless the occurrence of structural distress types can be reliably predicted.

(a) Rehabilitation during Construction Life Cycle (Illustration)

(b) Preventive Maintenance during Rehabilitation Life Cycle (Illustration)

Figure 7.2 Illustration of Rehabilitation Life Cycle and Sample Maintenance Strategy

7.2 Literature Review on State of Practice of Strategy Formulation

Most state DOTs have developed decision support tools for selecting appropriate maintenance or rehabilitation treatments at various phases in pavement life, examples of which are provided in Appendix 4. While most strategies were developed primarily for rehabilitation treatments, an increasing number of states are including timing of selected preventive maintenance activities in their strategies because data on the cost and effectiveness of preventive treatments are becoming increasingly available. Decision trees (also sometimes presented in tabular or matrix form) have typically been used for identifying an appropriate maintenance or rehabilitation treatment to address a given state of pavement deterioration [FHWA 1998, 1997] or expected state (given pavement age). According to the FHWA, such decision tools are typically characterized by a set of sequential logical rules and criteria, and are largely based on past experience and expert opinions of pavement managers and engineers. Typically, criteria used in such tools include the following:

- Pavement surface type and thickness,
- Pavement age or condition (expressed in terms of an aggregate/disaggregate index, often indicating levels of load and non-load distresses),
- Route type or class, and
- Level of general or truck traffic.

When pavement age is used, the strategy is described as one based on “preset time intervals”, or as a “time-based strategy” and typically involves the use of treatment service lives. However, when pavement condition is used, the strategy is termed as “trigger value” or “distress-based” strategy. Decision trees and tables typically reflect the decision processes historically used by the agency, and may be generally consistent with documented guidelines in pavement management or design guide literature, experience of pavement managers at districts and sub-districts, or a combination of both sources. Advantages of decision trees include the flexibility to modify the decision criteria (treatment types and timings), the capability to generate consistent recommendations, and the relative ease with which the selection process can be explained and programmed. Hicks et al. [1997] state that decision trees can be used effectively in the selection/identification of suitable preventive maintenance treatments as well as routine preservation and rehabilitation options.

A downside of decision trees based on historical practice is that they are often designed to spotlight only a few treatments that may have worked well in the past, and may not be effective guides to implementation of new/improved treatments that may be more effective. Furthermore, use of decision trees does not ensure that only optimal treatments are selected. Simulation or optimization techniques that duly consider the cost and effectiveness of each constituent treatment may be necessary to derive the most cost effective selection of treatment types and timings [Hicks, et. al. 2000; Labi and Sinha, 2002].

Hicks et al. [2000] presented a simplified maintenance and rehabilitation decision tree for asphalt pavements (Figure 7-3), using five criteria as the basis for treatment selection. In noting that certain environmental conditions and traffic levels inherent in their simplified decision tree may influence the original determination of the recommended treatments, the researchers advised users to exercise caution in applying any such simplified decision tree for any exclusive conditions. Appendix 4 provides further examples of decision trees for pavement treatments. The review of the state of practice revealed that many decision trees utilize composite distress criteria (such as PCI) to further simplify the selection process, but such decision trees may not always appropriately address actual distress conditions, particularly at the higher levels of deterioration associated with pavement rehabilitation.

In the decision tree shown in Figure 7-3, it is seen that in case of little or no structural deterioration, the selected treatments are aimed at enhancing the functional performance and preserving pavement life. However, if the pavement exhibits signs of structural deterioration through the manifestation of fatigue cracking or rutting, then the selected treatments are geared more at improving pavement structural performance. The decision tree also duly considers the effect of the environment which is often manifest through the development of transverse, longitudinal, and block cracks (due to asphalt pavement ageing and thermal stresses associated with daily temperature cycles), and recommends treatments that prevent moisture intrusion and retard the rate of surface crack progression. The extent levels in Figure 7-3 are defined as follows:

Low – The amount of cracking is so slight that there is little question of crack sealing feasibility.

Moderate – The cracking has achieved a level where sealing alone may not be cost-effective.

High – The extent of cracking is so great that crack sealing would definitely not be cost effective and some other remedial work is required.

Figure 7-3 also gives due consideration to surface wear: asphalt pavement surface deterioration that is attributable to tire wear (such as polishing) and material degradation (such as

raveling. The figure recommends surface removal and/or cover provision (these could include functional overlay, thin overlay, seal coating, micro-surfacing). Surface wear severity levels are defined as follows:

- Low – Surface texture and frictional resistance are minimally affected.
- Moderate – Surface texture and frictional resistance are significantly affected. The potential for wet weather accidents is increased.
- High – Surface texture and frictional resistance are heavily affected. The probability of wet weather accidents is near (or above) the unacceptable level.

Structural Deterioration	Environmental Cracking Extent	Surface Wear Severity	Recommended Treatment
No	Low	Low	Crack Seal
		Moderate	Surface Treatment (Single Chip Seal)
		High	Crack Seal and 40 mm Overlay
	Moderate	Low	Crack Seal
		Moderate	Crack Seal plus 40 mm Overlay
		High	Mill and Fill 50 mm
	High	Low	Mill and Fill 40 mm
		Moderate	Mill and Fill 50 mm
		High	Mill and Fill 50 mm
Yes	Fatigue Cracking Extent	Rutting Severity	Recommended Treatment
	Low	Low	Mill and Fill 40 mm
		Moderate	Mill and Fill 50 mm
		High	Mill and Fill 75 mm
	Moderate	Low	Mill 50 mm Overlay 75 mm
		Moderate	Mill 75 mm Overlay 100 mm
		High	Mill 100 mm Overlay 125 mm
	High	Low	Mill 100 mm Overlay 150 mm
		Moderate	Remove HMA, Repair Base and Repave
		High	Total Reconstruct

Figure 7.3a Simplified M&R Decision Tree for Asphalt Pavements [Hicks et al., 2000]

Wheel-path cracking associated with the cumulative effects of wheel loads is a clear indication of structural deterioration and loss of load carrying capacity in a pavement. In Figure 7-3, this is addressed using rehabilitation treatment that largely replaces the asphaltic surface layer (and, in some cases, the underlying base course.) The extents of structural distress are defined as follows:

- Low – Less than one percent of the wheel-path area exhibits load-associated cracking, which may start as single longitudinal cracks.
- Moderate – At least 1 and up to 10 percent of the wheel-path area exhibit cracking, likely in an interconnected pattern. The rate of crack progression is increasing.
- High – Ten percent or more of the wheel-path area exhibits load-associated cracking. Rapid progression to 100 percent of the wheel-path area is likely.

The decision tree in Figure 7-3 also addresses rutting distresses which may be attributable to poor quality material (improper mix design or improper construction) and is generally confined to the top 50 to 70 mm of the pavement. If the structural design is inadequate or the pavement is overloaded, rutting can take place in the underlying pavement layers and natural subgrade soil. Figure 7-3 selects pavement rehabilitation treatments to replace the deteriorated/deformed layers on the assumption that the rutting is confined to the top HMA surface layer. The three rut severity levels are defined as follows:

- Low – Rut depth is less than 6 mm. Problems with hydroplaning and wet weather accidents are unlikely.
- Moderate – Rut depth is in the range of 7 to 12 mm. Inadequate cross slope can lead to hydroplaning and wet weather accidents.
- High – Rut depth is greater than 13 mm. The potential for hydroplaning and wet weather accidents is significantly increased.

Hicks et al., [1997] also provided various versions of decision trees for preventive maintenance treatment selection. Some of these variations independently address pavement roughness, rutting, cracking, and raveling/weathering. In various parts, the figure shows decision criteria that include roughness and average daily traffic (ADT) level, rutting causes, cracking type structural condition. Another example of a decision tree for preventive maintenance was developed by Michigan DOT [MDOT, 1999] and is presented in Figure 7-4. Decision trees have

also been developed at Westrack [NCHRP, 1998] and by the states of New York [NYDOT, 1993] and Minnesota [Hicks et al., 2000] and are presented in Appendix 4.

a) Decision tree for roughness.

b) Decision tree for rutting.

c) Decision tree for cracking.

d) Decision tree for raveling and weathering.

Figure 7-3b Preventive Maintenance Decision Tree Based on Michigan DOT Capital Preventive Maintenance Program [MDOT, 1999]

Some states have defined their rehabilitation and maintenance strategies in the form of a decision table (or decision matrix). Like decision trees, decision tables are comprised of a set of rules or criteria to arrive at an appropriate maintenance or rehabilitation treatment, but their structure makes them capable of storing more information in a smaller space. In a FHWA study that investigated the effectiveness of preventive maintenance treatments, Zaniewski and

Mamlouk [1996] presented a simple decision matrix for preventive maintenance treatments (Table 7-1).

A relatively detailed decision matrix was constructed from the opinions and experiences of a number of engineers who toured the SHRP SPS-3 and 4 test sections in the Southern Region of the U.S. [Hicks et al., 2000]. It represents the average expert opinion on the most appropriate preventive maintenance treatment for a specific set of project conditions. It was found that the selection of an appropriate maintenance treatment generally depends on the following factors:

- Type and extent of distress
- Climate
- Traffic loading
- Cost of treatment
- Expected life
- Availability of qualified contractors
- Availability of quality materials
- Time of year of placement
- Pavement noise
- Facility downtime
- Surface friction.

Obviously, in selecting the most cost effective preventive maintenance treatment for given set of conditions, it is imperative to have a clear understanding of the effectiveness of each potential treatments. Indeed, the most appropriate treatment is likely to differ from agency to agency. As such, the literature review of state of practice of strategy formulation is only for purposes of general guidance. Rather than choosing strategies formulated by other states, the present study proceeded to solicit the expert opinions of INDOT pavement engineer and managers, consulted the Indiana Design Manual for general guidelines on the subject, and also carried out historical plots of pavement condition to ascertain the trigger values at which various treatments were carried out. Decision tables utilized by agencies in California and Ohio, and the U.S. Forest Service, Asphalt Institute, and the U.S. Army Corps of Engineers are presented in Appendix 4.

Table 7-1 Flexible Pavement Preventive Maintenance Treatments

Category of Distress	Type of Distress	Potential Actions
Cracking	Fatigue Cracking	Not a candidate for preventive maintenance
	Block Cracking (low to moderate)	Thin cold treatment, chip seal, thin hot-mix overlay
	Edge Cracking	Crack treatment
	Longitudinal Cracking	Crack treatment
	Reflection Cracking at Joints	Crack treatment
	Transverse Cracking	Crack treatment
Patching and Potholes	Patch/Patch Deterioration	Extensively patched pavements are not good candidates for preventive maintenance
	Potholes	Pothole pavements are not good candidates for preventive maintenance
Surface Defects	Rutting – Densification of Pavement	Fill ruts with microsurfacing or strip chip seal, then thin cold treatment or chip seal
	Rutting – Unstable Asphalt Concrete	Preventive maintenance can not repair problem
	Shoving	Unstable pavement, not a candidate for preventive maintenance
	Bleeding	Sand seal, chip seal, microsurfacing
	Polished Aggregate	Thin cold treatment, chip seal, thin hot-mix overlay
	Raveling	Fog seal, thin cold treatment, chip seal, thin hot-mix overlay

Source : [Zaniewski and Mamlouk, 1996]

Rather than using trigger values of condition/distresses, some previous studies have formulated strategies and expressed such strategies in a tabular or tree form in terms of predefined time intervals for each treatment. In a few state DOTs, both pavement trigger values and preset intervals have been used for strategy formulation, for instance, carry out crack sealing anytime the cracking index reaches a certain threshold, or every three years, whichever comes first. Hicks et al. [2000] offer some intervals for selected treatments on AC pavements as shown in Table 6-1 in Chapter 6. In formulating time-based strategies, it may be beneficial to have knowledge on the service lives of various pavement treatments. Geoffroy [1996] summarized information on treatment service lives (see Table 6-2 in Chapter 6).

Figure 7-5 provides a general illustration of the timing of various levels of pavement treatments based on pavement condition (which is largely a function of time or age). The actual timing for the various interventions may vary depending on traffic level and environment. As such, each agency is encouraged to develop their own optimal timing for maintenance treatments to minimize life-cycle costs [FHWA, 1998]. Table 7-2 provides a sample strategy based on time intervals.

Figure 7.4 Timing of Maintenance and Rehabilitation Treatments [Hicks et al., 2000]

7.2.1 Benefits and Limitations of Decision Trees/Matrices for Pavement M&R

Some benefits and limitations in using the decision trees/matrices for formulating pavement M&R strategies either for trigger values or preset intervals are listed below. [Hicks et al., 2000].

a) Benefits

1. Makes use of existing experience
2. Works well for local conditions
3. Good as a project-level tool

b) Limitations

1. Not always transferable from agency to agency
2. Limits innovation or use of new treatments
3. Hard to incorporate all factors which are important (e.g., competing projects, functional classification, remaining life)
4. Difficult to develop matrix that can incorporate multiple pavement distress types (i.e., does not always address the actual distress conditions)
5. Does not include more comprehensive evaluation of various feasible alternatives and LCC analysis to determine most cost effective strategy
6. Not good for network evaluation

Table 7-2 Freeway Preventive Maintenance Strategies at the Province of Ontario

Scheme	Design Life (yrs)	Year of Treatment	Maintenance Treatment
Scheme A	20	10	Reseal 10% of all joints Concrete
		15	Reseal 20% of all joints
		20	REHABILITATION
	25	10	Reseal 10% of all joints
		15	Reseal 20% of all joints
		20	Reseal 20% of all joints
Scheme B Composite joints	18	25	REHABILITATION
		3	Rout and seal 70% of transverse joints
		7	Rout and seal 30% of transverse joints and 30% of longitudinal
		11	Rout and seal 70% of longitudinal joints
		15	Reseal 30% of sealed cracks
		18	REHABILITATION
		21	Rout and seal 70% of transverse joints
		25	Rout and seal 30% of transverse joints and 30% of longitudinal
		29	Rout and seal 70% of longitudinal joints
Scheme C Full Depth	15	3	Rout and seal 250 m of transverse cracks and 250 m centerline crack
		7	Rout and seal 250 m of centerline and 520 m of transverse cracking
		11	Mill 25 mm and patch with 25 mm OFC (5%)
		15	REHABILITATION
		18	Rout and seal 250 m of transverse cracks and 250 m centerline cracks
		22	Rout and seal 250 m of centerline and 520 m of transverse cracking
		27	REHABILITATION
Scheme D	15	3	Rout and seal 250 m of transverse cracks and Deep Strength 750 m centerline cracks
		7	Rout and seal 250 m of centerline and 520 m of transverse cracking
		11	Mill 25 mm and patch with 25 mm OFC (5%)
		15	REHABILITATION
		18	Rout and seal 250 m of transverse cracks and 750 m centerline cracks
		22	Rout and seal 250 m of centerline and 520 m of transverse cracking
		27	REHABILITATION

Source: [Geoffroy, 1996]

7.3 Background Issues for Developing Rehabilitation and Maintenance Strategies for INDOT LCCA

7.3.1 Strategy Treatment Criteria

(a) Rehabilitation Treatment Types

These are applied to the pavement in a bid to increase its structural strength. In some literature, rehabilitation *treatments* have been termed as rehabilitation “strategies”. However, for purposes of the present study, a clear demarcation is drawn between these two terms. Also, in the present study, the term “pavement rehabilitation” includes resurfacing and concrete pavement restoration. Resurfacing generally refers to structural HMA overlays, bonded or unbonded PCC overlays.

Functional Treatment (INDOT Design Manual Chapter 52, Section 7.04(02))

“A functional treatment of an asphalt or PCCP pavement is applied with the objective of restoring pavement smoothness to near new condition on a pavement that is structurally sufficient. An HMA functional treatment consists of an intermediate course (placement of which is preceded by milling) and a surface course. A PCCP functional treatment may consist of an HMA overlay, or concrete pavement restoration (CPR) to correct functional distresses. CPR may consist of crack sealing, partial; and full depth patching, resealing of joints, undersealing, diamond grinding, or retrofit dowel bars.”

Structural Treatment (INDOT Design Manual Chapter 52, Section 7.04(03))

“A structural treatment of an asphalt or PCCP pavement strengthens the existing structure to current design requirements and restores the pavement smoothness to new condition. An HMA structural treatment will consist of base, intermediate and surface courses, with milling of the existing pavement. A PCCP with structural failure may be rehabilitated with slab reduction techniques such as cracking and seating or rubblization and overlay.”

(b) Maintenance Treatment Types

These are applied to the pavement in a bid to improve its ride quality. In some literature, maintenance treatments have been labeled as maintenance “strategies”. In the present study, a clear distinction is drawn between these two terms. From a preliminary review of available literature on the practices of preventive and corrective maintenance, a list and description of “standard” preventive and corrective maintenance treatments in Indiana are provided below

(Tables 7-3 and 7-4). For each preventive or corrective maintenance treatment, the diagram indicates whether that activity is typically executed by in-house forces (under force-account), or whether it is given out on contract (under capital expenditure account).

Table 7-3 Typical Pavement Treatment Categories and Types

INTERVAL AND FUNDING			ROUTINE MAINTENANCE		PERIODIC MAINTENANCE		REHABILITATION	RECONSTRUCTION
Function: ROI E	COVERAGE	LEVFL	FORCE-ACCOUNT	BY CONTRACT	FORCE-ACCOUNT	BY CONTRACT		
Preventive Treatments	Only Affected Locations	Localized	N/A	Under-sealing Stitching	Crack Sealing Bump Repair	N/A	N/A	N/A
	Entire Surface	Thin coat	N/A	N/A	Chip Sealing Sand Sealing	Chip Sealing	N/A	N/A
		Laying thin material	N/A	N/A	N/A	Microsurfacing	N/A	N/A
Corrective Treatments/ Rehabs	Only Affected Locations		Patching (Shallow and Deep)	Patching (Shallow and Deep)	Patching (Shallow and Deep)	Patching (Shallow and Deep)	Concrete Pavement Restoration	N/A
	Entire Surface		N/A	N/A	N/A	N/A	Resurfacing	New Pavement

Source: Labi, 2001

Table 7-4 Typical Rehabilitation and Maintenance Treatments

Pavement Surface Type	Possible Rehabilitation(resurfacing) Treatments	Possible Preventive Maintenance Treatments	Possible Corrective Maintenance Treatments
Asphalt	Cold Milling and Resurfacing	Thin resurfacing: Thin asphalt overlay/inlay Micro-surfacing Ultra-thin concrete overlay	Shallow Patching
	Hot or cold in-place Recycling	Seal Coating: Chip/Sand Sealing (low-vol.) Localized: Crack Sealing, Bump Grinding	Deep Patching
Concrete	Resurfacing (thick HMA overlay) of existing slab	Thin resurfacing: Thin asphalt overlay Ultra-thin concrete overlay	Full-depth slab repair (deep patching)
	Rubblization of existing slab followed by resurfacing		
	Crack-and-Sealing of existing slab followed by resurfacing (thick HMA Overlay)	Minor (i.e., Localized): Crack Sealing Fault Grinding Under-sealing Retrofitting (Stitching)	Partial Depth Slab Repair (Shallow Patching)
	Bonded Concrete Overlay of existing slab		
	Unbonded Concrete Overlay of Existing Slab Concrete Pavement Restoration (CPR)		
Composite (asphalt-on-concrete)	Resurfacing (thick HMA overlay)	Thin resurfacing: Thin asphalt overlay	Shallow Patching
	Milling off existing AC overlay, followed by resurfacing	Thin HMA inlay Micro-surfacing Ultra-thin concrete overlay	Deep Patching
	Milling off existing AC overlay, followed by rubblization of underlying slab followed by resurfacing		
	Milling off existing AC overlay, followed by crack-and-sealing of underlying slab followed by resurfacing (thick HMA Overlay)	Seal Coating: Chip/Sand Sealing (low-vol.) Localized: Crack Sealing, Bump Grinding, Sawing and Sealing	

7.3.2 Strategy Timing Criteria

Timings of strategies can be based on pre-defined intervals of time or usage, or condition triggers, as illustrated in Figure 7-6.

Figure 7.5 Timing Criteria for Formulation of Pavement M&R Strategies

(a) Strategy Timings Based on Preset Time Intervals (Treatment Service Lives)

A strategy may consist of activities planned at preset intervals which may be regular or irregular. Irregular intervals are typically associated with treatment applications at large intervals (lower frequency) of application for younger pavements, and small intervals (higher frequency) for older pavements. The intervals may be based on cumulative loading only (where weather effects on pavement deterioration are relatively little), cumulative weather severity (where loading effects are relatively little) or both cumulative loading and weather effects (where both factors play a significant role in pavement deterioration).

Chapter 52 of INDOT's Design Manual defines typical performance lives of various treatments for use in LCCA (see Table 7.7 in Chapter 6). These treatment service life values may be used as a guide for formulation of strategies based on time intervals.

From the literature review of current practices in many state highway agencies, it was found that most pavement repair strategies have been based on preset time intervals rather than load or weather intervals. This may be considered apt, for two reasons:

- Age is considered a surrogate for accumulated loading and weather effects, and
- Data on traffic loading and weather effects are relatively difficult to collect.

While preset intervals proffer a convenient way to formulate strategies, such approaches must be used with caution as they may be prone to certain problems such as possible inconsistency with field conditions -- the use of preset intervals for formulating strategies implicitly assumes that pavement condition follows a pattern than can be predicted on the basis of time, accumulated loading or accumulated weather effects. While this may generally be true, the success of this approach for a specific project depends on the integrity of this age/condition relationship, and may be weakened by subsequent changes in the highway environment such as better materials, heavier loadings than expected, unusually bad weather, etc.

The opinion of pavement managers and engineers may be solicited for establishing or confirming the service lives of preservation treatments. Such opinion considered vital because such personnel are at the forefront of pavement rehabilitation and maintenance policy implementation, and have therefore acquired intimate and first-hand knowledge about the performance and acceptable values of various pavement distress types. It is therefore expected that the field experience of such personnel can add much to the knowledge base on trigger values needed to elicit specific pavement rehabilitation or maintenance actions.

(b) Strategies based on Condition Triggers for Treatments

In condition trigger based strategies, a specific activity is carried out anytime a selected measure of pavement condition or performance reaches a certain threshold value. The measure of pavement condition may be aggregate or disaggregate. If strategies based on trigger values are to be used, it is important that the highway agency monitors pavement condition or performance regularly so that points of treatment application will not be missed. Such monitoring can be done in two ways:

Field monitoring. Here, the pavement condition/performance is monitored directly by field personnel, in the form of regular monitoring of either aggregate distresses (roughness, ride quality) or disaggregate distresses (such as crack density, raveling, etc.). Such monitoring may be carried out using automated equipment (typically for roughness measurements) or simple condition rating forms. At sub-district and district level in Indiana, strategies for preventive maintenance are mostly based on pre-defined intervals of time, but it can be argued that their manner of strategy formulation evolved over the

years from the implicit use of condition trigger levels that were acquired through years of experience and training of sub-district personnel.

Desk monitoring. Here, the pavement condition/performance of a particular pavement section is monitored using pavement performance or condition models developed for a family of pavement to which the pavement section belongs.

Whether field monitoring or desk monitoring is used, the measure used can be either an aggregate index (a single value that represents the overall condition of the pavement, such as PCR, PSI, PQI, or IRI), or disaggregate (a value that indicates the frequency and severity of an individual distress type, such as rutting, faulting, and cracking).

Aggregate measures: The use of condition triggers strategies using aggregate measures seems to be popular in many highway agencies. In such formulations, maintenance or rehabilitation treatments are carried out anytime the aggregate measure falls below a certain threshold or “trigger value”. An advantage of using aggregate measures (over disaggregate measures) lies in their economy: there is no need to carry out separate desk or field monitoring of each indicator of pavement distress. However, a disadvantage is that aggregate measures only give an indication of overall pavement condition/performance and fail to provide the distribution of the various distresses. For example, a concrete pavement with an IRI of 120 in/mile may have a relatively high incidence of faulted joints and a relatively small incidence of patching, or may have a relatively low incidence of faulted joints and a relatively high incidence of patching. Therefore it is difficult (and indeed likely, misleading) to formulate a strategy that assigns a specific treatment to address a pavement whose current condition/performance reaches that of the trigger value.

Disaggregate measures: In light of the problems associated with the use of aggregate measures of pavement condition for formulating pavement repair strategies based on trigger values, the use of disaggregate measures such as Aggregate Cracking Index (ACI), Rutting Index (RI), Faulting Index (FI) etc. are generally considered superior to that of aggregate values. If the pavement is monitored regularly through field or desk techniques, an appropriate treatment can be carried out anytime the index value of a

given distress type is found to fall below a certain threshold, or trigger value. In order for this type of strategy formulation to be effective, (i) there should be a known and generally accepted treatment that is identified as most appropriate for addressing a specific distress, (ii) there should be an established trigger value for the distress type, at which a specific action should be taken. The first question is answered by the use of uniform distress identification and remediation manuals through the state highway agency. To address the second problem, many agencies have resorted to the use of expert opinion through surveys and interviews of pavement experts and past performance plots [FHWA, 1998]. A review of available literature showed that agencies using this method of strategy formulation have developed condition trigger values and appropriate treatments without providing adequate details on how the trigger values were developed.

Trigger-value based strategies are typically presented in a decision table or tree form, specifying the threshold values by attributes such as pavement type, functional class, and traffic levels. The opinion of pavement managers and engineers may be solicited for establishing or confirming the trigger values for preservation treatments. In the present study, strategies based on trigger values were developed using a questionnaire survey, guidelines in INDOT's design manual, and historical plots of past pavement performance at time of treatment.

Problems associated with the use of trigger values for strategy formulation include:

Lack of Established Trigger Values: The lack of established trigger values constitutes the most serious impediment to the use of trigger values for strategy formulation. For instance, at what level of IRI should we carry out thin HMA overlay? At what level of cracking should we carry out crack sealing? At what level of faulting should we grind the joints? Inability to answer such questions is probably one of the reasons why many agencies have resorted to the use of strategies involving preset intervals of time or usage.

Lack of Current Monitoring Data: Successful application of pavement rehabilitation strategies based on trigger values hinges on the availability of current pavement condition data, so that appropriate measures can be taken anytime the existing condition/performance reaches a certain threshold. If such data is unavailable or unreliable, treatments are likely to be applied long before they are needed (leading to wastage of funds) or may be applied long after they are needed (translating to poor

surface condition and subsequently, excessive user costs). In many state DOT's, current pavement condition data are generally available for most sections identified for the Pavement Management System operation.

Lack of Data for Modeling: In cases where the state agency carries out desk monitoring (rather than field monitoring) through the use of pavement performance or distress progression models, it is necessary to have adequate data from which such models can be developed. If historical data on individual distresses or aggregate indices of condition or performance were available, it would be possible to plot time series trends for distress and for each pavement. That way, it would be possible to monitor the pavement distress levels of performance using such models, and apply requisite treatments whenever the distress levels or performance reaches the trigger value. To obviate this problem, cross sectional (instead of time series) models may be used: For any given year, there are pavements of similar characteristics but with different ages ranging from zero to over 15 years, therefore models can be developed and used as a means of monitoring pavement distress or performance/condition from the office desk.

Matching of Distresses Types and Treatments: If disaggregate measures are used for strategy formulation, it is imperative to have a treatment to address each distress condition. Situations may be encountered where more than one distress are addressed by the same treatment, or where one distress is addressed by more than one treatment. In the former case, the different service lives of the treatments may cause a dilemma as to when to apply the treatment, but a typical recourse would be to apply the treatment at the least service life of all such treatments, even though such approach may be uneconomical. In the latter case, the choice of appropriate treatment may be subjective and therefore based on engineering judgment and experience.

7.4 Developed Strategies for INDOT LCCA

The literature review on the state of practice of time-based strategy formulation served as an important guide in the formulation of time-based strategies for the present study. Information was also sought from INDOT's current edition of the Design Manual, pavement expert opinion, and plots of pavement condition over time. Unfortunately, the performance plots were of little

temporal span and were not useful in determining treatment service lives for developing time-based strategies. As such, the present study utilized expert opinion (through questionnaire surveys) and information from INDOT's Design Manual (Chapter 52 and 56) to arrive at preset interval pavement treatment M&R for the study. It is worth noting that in its current form, the FHWA LCCA software, in its current form, utilizes preset intervals (treatment service lives) and not trigger values, but could be enhanced to include the latter as an alternative.

7.4.1 Strategies based on Preset Time Intervals

Strategies based on preset intervals of time were developed largely from the following sources:

- Information collected in a Year 2000 questionnaire survey of INDOT's districts,
- Information in INDOT's Pavement Design Manual Chapter 52, and
- Review of published material on rehabilitation and maintenance treatment lives.

Due to the limited nature of the temporal data on pavement performance, service lives of treatments on the basis of actual data could not be established for the present study.

(a) Time-based Strategies for New Pavements

Using preset intervals of time, the present study developed pavement treatment strategies for various new pavement types and loading categories. These are presented in Figures 7-2- to 7-8. These strategies are presented only for the purposes of discussion and could be possibly modified in future by INDOT's Pavement Steering Committee.

(b) Time-based Strategies for Existing Pavements

Pavement treatment strategies developed in the present study for existing asphalt and rigid pavements. These are presented in Figures 7-9 and 7-10. These strategies are presented only for the purposes of further discussion and could be possibly modified in future by INDOT's Pavement Steering Committee.

Strategy 1 **Strategy 2**

Figure 7-6 Time-Based Strategies for New HMA Pavements, Interstates (ESALs > 30 million)

Strategy 1 **Strategy 2**

Figure 7-7 Time-Based Strategies for New HMA Pavements, Interstates (ESALs 10-30 million)

Strategy 1 **Strategy 2**

Figure 7-8 Time-Based Strategies for New HMA Pavements, NHS Non-Interstates (ESALs > 30 million)

Strategy 1 **Strategy 2**

Figure 7-9 Time-Based Strategies for New HMA Pavements, NHS Non-Interstates (ESALs 10-30 million)

Strategy 1 **Strategy 2**

Figure 7-10 Time-Based Strategies for New HMA Pavements, Non NHS (ESALs 1 - 10 million)

Strategy 1 **Strategy 2**

Figure 7-11 Time-Based Strategies for New HMA Pavements, Non-NHS (ESALs < 1 million)

Strategy 1 **Strategy 2**

Figure 7-12 Time-Based Strategies for New PCC Pavements, All Classes

Strategy 3 **Strategy 4**

Figure 7-12 (continued) Time-Based Strategies for New PCC Pavements, All Classes

Strategy 1 **Strategy 2**

Figure 7-13 Time-Based Strategies for Existing Asphalt Pavements, All Classes

Strategy 3 **Strategy 4**

Figure 7-13 (continued) Time-Based Strategies for Existing Asphalt Pavements, All Classes

Strategy 1 **Strategy 2**

Figure 7-14 Time-Based Strategies for Existing Concrete (Rigid) Pavements, All Classes

Strategy 3 **Strategy 4**

Figure 7-14 (continued) Time-Based Strategies for Existing Concrete (Rigid) Pavements, All Classes

7.4.2 Development of Strategies based on Condition Triggers

The development of rehabilitation and maintenance strategies for the study was based on material obtained from the following sources:

- Information collected from a questionnaire survey of pavement experts at INDOT and Purdue University,
- Relevant information in INDOT's Pavement Design Manual Chapter 56, and
- Literature review of published material on condition/performance triggers established in other state highway agencies for application for rehabilitation and maintenance,
- Plots of past performance/condition data over time to determine the levels at which specific treatments were applied. Results from this approach were interpreted with caution, because such plots often reflect factors other than engineering need.

Figures 7-15 to 7-23 present the determination of the levels at which specific treatments were applied based on plots of historical performance/condition involving IRI, rutting and cracking. The marked variability in pavement condition at which any given treatment was carried out clearly indicates that past decisions to undertake such pavement treatment were very inconsistent, and in some cases, unintuitive. For instance, the average level of pavement condition at which treatments were applied vary widely from year to year, and seems to be dependent on the availability of funding rather than engineering reasons. Also, the application of some low level treatments have been done at better levels of pavement condition compared to the levels at which major treatments were applied.

Recognizing that the historical plots alone cannot provide a rational basis for formulation of condition trigger based strategies, the present study developed such strategies using the results of a questionnaire survey, the INDOT pavement condition manual, and the historical plots and summarized charts (Figures 24-34). Tentative trigger-based strategies have been presented as Tables 7-5 to 7-10. The intent of providing these trigger-based strategies is for discussion at this stage. These strategies are not necessarily intended for the immediate use in the state of practice. Rather, they have been included in this report only for didactic purposes and may be used for practice only after future further analysis and development by INDOT's PMS.

Figure 7-15 Temporal Trends in Trigger Values for Surface Treatment, PM

Figure 7-16 Temporal Trends in Trigger Values for HMA Overlay, PM

Figure 7-17 Temporal Trends in Trigger Values for HMA Overlay, Functional

Figure 7-18 Temporal Trends in Trigger Values for HMA Overlay, Structural

Figure 7-19 Temporal Trends in Trigger Values for Resurfacing (Partial 3R)

Figure 7-20 Temporal Trends in Trigger Values for Crack & Seat and HMA Overlay

Figure 7-21 Temporal Trends in Trigger Values for Rubblize & HMA Overlay

Figure 7-22 Temporal Trends in Trigger Values for Pavement Rehabilitation (3R/4R)

Figure 7-23 Temporal Trends in Trigger Values for Pavement Replacement

Hot Mix Asphalt (HMA) Pavements

Composite Pavements

Portland Cement Concrete (PCC) Pavements

Figure 7-24 Summary of Historical IRI Trigger Values for Interstate Treatments

Hot Mix Asphalt (HMA) Pavements

Composite Pavements

Portland Cement Concrete (PCC) Pavements

Figure 7-25 Summary of Historical IRI Trigger Values for NHS Non-Interstate Treatments

Hot Mix Asphalt (HMA) Pavements

Composite Pavements

Portland Cement Concrete (PCC) Pavements

Figure 7-26 Summary of Historical IRI Trigger Values for Non-NHS Treatments

Hot Mix Asphalt (HMA) Pavements

Composite Pavements

Figure 7-27 Summary of Historical Rut Trigger Values for Interstate Treatments

Hot Mix Asphalt (HMA) Pavements

Composite Pavements

Figure 7-28 Summary of Historical Rut Trigger Values for NHS Non-Interstate Treatments

Hot Mix Asphalt (HMA) Pavements

Composite Pavements

Figure 7-29 Summary of Historical Rut Trigger Values for Non-NHS Treatments

Hot Mix Asphalt (HMA) Pavements

Composite Pavements

Portland Cement Concrete (PCC) Pavements

Figure 7-30 Summary of Historical PCR Trigger Values for Interstate Treatments

Hot Mix Asphalt (HMA) Pavements

Composite Pavements

Portland Cement Concrete (PCC) Pavements

Figure 7-31 Summary of Historical PCR Trigger Values for NHS Non-Interstate Treatments

Hot Mix Asphalt (HMA) Pavements

Composite Pavements

Portland Cement Concrete (PCC) Pavements

Figure 7-32 Summary of Historical PCR Trigger Values for Non-NHS Treatments

Figure 7-33 Summary of Historical Trigger Values for Resurfacing (Partial 3R Standards)

Figure 7-34 Summary of Historical Trigger Values for Pavement Rehabilitation 3R-4R

Table 7-5: Strategy based on Trigger Values - Asphalt Interstate Pavements

Overall Condition	Rutting	Level of Cracking		
		Light	Moderate	Severe
Excellent IRI < 80	Light	Do Nothing	Seal Cracks	N/A
	Moderate	N/A	N/A	N/A
	Severe	N/A	N/A	N/A
Good 80 < IRI < 114	Light	Do Nothing	Seal Cracks	Mill and Fill 1"
	Moderate	Thin HMA Overlay 1.5"	Mill and Fill 1.5"	Mill and Fill 2"
	Severe	Thin HMA Overlay 2"	N/A	N/A
Fair 115 < IRI < 149	Light	N/A	N/A	Mill and Fill 2.5"
	Moderate	HMA Overlay 2.5"	HMA Overlay 3"	Mill 1.5" and HMA Overlay 4"
	Severe	HMA Overlay 3.5"	Mill 1.5" and HMA Overlay 3"	Pavement Replacement
Poor IRI > 150	Any	Pavement Replacement	Pavement Replacement	Pavement Replacement

Table 7-6 Strategy based on Trigger Values - Asphalt NHS Non-Interstate Pavements

[illegible]

Table 7-7 Strategy based on Trigger Values – Asphalt Non-NHS Pavements

[illegible]

Table 7-8 Strategy based on Trigger Values - Concrete (Rigid) Interstate Pavements

Overall Condition	Faulting	Level of Cracking		
		Light	Moderate	Severe
Excellent IRI < 80	Light	Do Nothing	Do Nothing	Seal Cracks
	Moderate	N/A	N/A	N/A
	Severe	N/A	N/A	N/A
Good 80 < IRI < 114	Light	Do Nothing	Do Nothing	Seal Cracks
	Moderate	Diamond Grinding	Seal Cracks Diamond Grinding	Seal Cracks Diamond Grinding
	Severe	Diamond Grinding Retrofitting (LTR)	N/A	N/A
Fair 115 < IRI < 149	Light	N/A	Concrete Pavement Restoration	PCC Overlay Bonded
	Moderate	Diamond Grinding Retrofitting (LTR)	Concrete Pavement Restoration	Seal Cracks Diamond Grinding PCC Overlay (Unbonded)
	Severe	Concrete Pavement Restoration	Seal Cracks Diamond Grinding PCC Overlay (Unbonded)	Seal Cracks Diamond Grinding PCC Overlay (Unbonded)
Poor IRI > 150	Any	Pavement Replacement	Pavement Replacement	Pavement Replacement

[illegible]

Table 7-10 Strategy based on Trigger Values - Concrete (Rigid) Non-NHS Pavements

[illegible]

7.5 Chapter Summary

The literature review on the state of practice of time-based strategy formulation served as an important guide in the formulation of time-based strategies for the present study. Information was also sought from INDOT's current edition of the Design Manual, pavement expert opinion, and plots of pavement condition over time. The first batch of performance plots showed the temporal trends of historical trigger values (that is, values of pavement condition at which each treatment was carried out at each individual segment and over the years) and the second batch showed the average trigger value by treatment for all segments and all years. The performance plots were of little temporal span and were not useful in determining treatment service lives for developing time-based strategies. Also, the performance plots were of little value in determining trigger values for condition-based strategies because they yielded trigger values that showed a large amount of variation, inconsistencies and discrepancies across the years and even across similar pavement sections. As such, the present study utilized expert opinion (through questionnaire surveys) and information from INDOT's Design Manual (Chapter 52 and 56) to arrive at preset intervals for M&R for new and existing pavements. These strategies are presented only for the purposes of discussion and could be possibly modified in future by INDOT's PMS Engineer or Pavement Steering Committee for use in INDOT's pavement management or LCCA procedures. It is worth noting that in its current form, the FHWA LCCA software, in its current form, utilizes preset intervals (treatment service lives) and not trigger values, but could be enhanced to include the trigger values as an alternative method of defining preservation treatments for LCCA.

CHAPTER 8 AGENCY COST ANALYSIS FOR LCCA

8.1 Introduction

The management of any civil infrastructure is associated with costs incurred by the responsible agency including initial costs associated with feasibility studies, engineering design, construction, operation of the facility, maintenance and rehabilitation, and disposal costs. In the context of LCCA for pavement design, preliminary costs such as feasibility and engineering studies are excluded, as they are typically common among all pavement alternatives. As such, the present study categorizes costs by those associated with only two major phases of infrastructure management: construction costs and maintenance costs.

Cost analysis is a cardinal element of any LCCA study. Initial cost is no longer considered the sole criterion in evaluation of a pavement projects or the selection of project alternatives. In the current state of pavement design and management practice, all costs incurred over the life of the pavement are considered. These include rehabilitation and maintenance costs, and salvage value (the subject of user cost is addressed in a separate chapter of this report). However, the changing value of money over time means that some adjustment has to be made to bring all such costs to constant dollar.

8.1.1 Maintenance Costs

These costs are incurred to preserve the capital investments made in the pavement infrastructure and to ensure that the pavement provides a satisfactory level of service to its users. At INDOT, “lane-wide” pavement maintenance work such as thin HMA overlay, and micro-surfacing are typically carried out by contract where it is supervised by the INDOT districts. On the other hand, “localized” pavement maintenance such as shallow patching, crack sealing, joint and bump grinding, and under-drain cleaning are typically done in-house by INDOT sub-districts on a force account basis. A few localized treatments such as PCC slab under-sealing and load transfer restoration of PCC slabs are typically done by contract. Some maintenance treatments such as chip sealing, PCC patching, and wedge and leveling (referred to as “premix leveling” in

sub-district terminology) are carried out both in-house and by contract. Levels of maintenance range from routine work that typically addresses local distresses such as patching, to costly high level work such as thin overlays to retard deterioration and correct minor non-structural distresses. As sub-districts carry out maintenance such as chip sealing that are periodic in nature, the term “routine maintenance” appears to be headed to extinction, as it no longer has a one-to-one association with the sub-districts. Work done by sub-districts is now often more appropriately described as “force-account” or “in-house” maintenance. In categorizing maintenance by its role, most current literature use the terms “preventive maintenance” (which may be routine or periodic), or “corrective maintenance” (which may also be routine or periodic). Maintenance costs may be expressed in two ways:

1. Average unit accomplishment costs per treatment, for example, the cost of shallow patching is \$365.72 per ton of material, and the cost of thin (2 inch) HMA overlay is \$62,753 per lane-mile of material laid. Unit accomplishment costs are expressed in various units such as work done (or material laid) per ton (shallow patching, deep patching, premix leveling), per count (under-drain maintenance, joint/bump grinding), per mile (longitudinal crack sealing), and per lane-mile (crack sealing, seal coating, micro-surfacing, thin overlay). Unlike for lane-wide treatments (such as overlays), it is obviously not prudent to report unit accomplishment costs of localized treatments (such as patching) per lane-mile due to the variation that would be brought by sections of varying distress levels. Unfortunately, crack sealing treatments at sub-district level are reported per lane-mile, and are thus associated with very high levels of variation. Section 8.4.1 presents information on the unit accomplishment costs of various maintenance treatments typically used at INDOT, either at sub-district or contract level.
2. Average costs of all maintenance treatments received by a pavement of a given type and age. For example, a 10 year old PCC pavement is estimated to have an average annual maintenance cost of \$590 per lane-mile. As such, average annual maintenance expenditure (AMEX) can be reported for each pavement type between periods of rehabilitation or resurfacing. AMEX models are useful because in the absence of unit accomplishment cost data, they can be used to determine the maintenance costs associated with each pavement type given pavement age and other characteristics such as region, functional class, and rural/urban location. Section 8.4.2 presents details of AMEX models that were developed for INDOT in a recent JTRP study [Labi and Sinha, 2002].

8.1.2 Construction/Rehabilitation Costs

These are the costs incurred in all phases of the design and construction of the facility. They include costs associated with initial activities such as feasibility studies, surveying, geometric and pavement design services, and ROW acquisition. A major portion of capital costs is borne by construction of the pavement, including earthworks, drainage structures, etc. For purposes of LCCA for pavement design, the present study considers only those costs that do not vary by pavement design and preservation alternative. These are the cost of initial construction, and any subsequent rehabilitation (overlays, pavement restoration), but excluding maintenance costs. Like maintenance costs, capital costs may be reported per treatment activity (unit accomplishment costs of capital works) or by pavement section considering all types of treatments the pavement receives in the time period between initial construction and the next reconstruction. For example, on the average, resurfacing a PCC pavement costs, say \$500 per lane-mile per year over its entire “primary” life-cycle. This is the average annualized capital (resurfacing) expenditure (ACEX) for that pavement type between periods of reconstruction. For LCCA, unit accomplishment costs of capital work are typically used, such as \$ per lane-mile of resurfacing, milling and pavement replacement, rubblization and HMA overlay, etc. In the absence of unit accomplishment cost data, ACEX data can be used to obtain rough estimates of capital work a specific type of pavement is expected to receive over its entire life cycle.

8.1.3 Operating Costs

Agency operating costs are excluded from the present study, as they are not expected to vary by pavement design and preservation alternative. However, user costs associated with the operation of the pavement infrastructure (specifically, vehicle operating costs) vary significantly by pavement design and preservation alternative, and may be considered in LCCA after the relationships between pavement condition and roughness have been fully established.

Capital and maintenance costs may be categorized the kind of work done, or accomplishment (Figure 8-1). In such categorization, a more general way is to report costs of each work category per lane-mile (see Table 8.1). For example, the cost of 4-inch HMA resurfacing may be approximately \$0.2 million per lane-mile. This typically includes all costs associated with a contract for a given work category, and covers not only materials and workmanship, but also includes contractors mobilization, overheads, profits, and supervision.

Capital and maintenance costs may also be reported by work item (typically referred to as “line items” at INDOT), as shown in Appendix 2.

Figure 8-1 Possible Categorization of Agency Costs

8.2 Review of Available Literature on SHA Agency Costs

8.2.1 Cost of Specific Rehabilitation and Maintenance Treatments

Collura et al. [1993] provided cost estimates for chip seals and hot-mix asphalt overlays based on 24 chip seal projects and 47 overlay projects in the New England region. The average cost of a chip seal was \$0.80/yd² with a standard deviation of \$0.32, while the average cost of an overlay was \$30.36/ton with a standard deviation of \$3.88. The hot-mix asphalt overlays consisted of two categories: 0.5-inch overlays and 1- to 1.5-inch overlays.

The IDAHO and APA LCCA software packages provide unit costs of selected maintenance and rehabilitation treatments. Also, values of unit treatment costs were obtained from the INDOT website, AASHTO Unit Rates File, and other sources. Such information was collected to ascertain that the cost data collected during the current study was reasonable and within expected ranges.

8.2.2 Overall Maintenance Costs by Pavement Type and Age

Al-Mansour and Sinha [1994] developed routine pavement maintenance cost models based on pavement condition and traffic volumes. Using pavement condition (PSI) in lieu of age, they established the following logarithmic cost equation:

$$\begin{aligned} \log AMC &= 10^{4.023 - 0.4621*PSI} && \text{For roads with AADT} > 2,000 \\ \log AMC &= 10^{3.7781 - 0.4252*PSI} && \text{For roads with AADT} \leq 2,000 \end{aligned}$$

where: AMC = annual roadway or shoulder maintenance expenditure (\$/lane-mile),
 PSI = PSI at time of maintenance

Maintenance costs may be expressed as a function of pavement condition (as see in THE equations above) or may be expressed as a function of pavement age. FHWA states that routine maintenance costs increases as a structure ages [FHWA, 2002], as illustrated in Figure 8-2. Recent research in Indiana seems to support the conceptual trend of maintenance cost increase with pavement age as stated by FHWA. [Labi and Sinha, 2002].

Figure 8-2 Conceptual Illustration of Increasing Maintenance Costs with Pavement Age [FHWA, 2002]

8.3 Construction and Rehabilitation Costs at INDOT

A key aspect of the present study was the collection of current data on various pavement construction, rehabilitation, and maintenance data. This was done by collating information from INDOT's DSS, pavement management system, operations support division, and contracts division. This section focuses on the costs associated with pavement construction and rehabilitation. Table 8-1 provides unit accomplishment costs (in constant dollar at year 2000, per lane-mile) of major pavement replacement and resurfacing treatments undertaken at INDOT on a contract basis. This table presents the summary statistics (average, standard deviation, minimum and maximum values) over a recent 6-year period (1996-2001). In Figure 8-3, the main costs are presented, for pavement replacement and resurfacing. It can be seen that the cost of a new PCC pavement (replacement) is approximately \$1.26 million per lane-mile, while that for a new AC pavement is \$1.03 million. For resurfacing existing asphalt pavements, costs range from about \$23,000 per lane-mile for micro-surfacing to about \$207,000 per lane-mile for multiple HMA structural overlays. Also, the data shows that existing asphalt pavements have been milled and overlaid with a single structural HMA layer at \$97,000 per lane-mile, while a simple thin HMA overlay (which is, strictly speaking, a preventive maintenance treatment) costs approximately \$63,000 per lane-mile. For PCC pavements, the data showed that it costs almost \$780,000 to rubblize a lane-mile of PCC and to provide structural HMA overlay, which is almost twice the cost of PCCP overlay over existing concrete (approximately \$481,000). The most inexpensive resurfacing option for existing PCC pavements is to crack and seat the pavement, and to provide it a structural HMA overlay (\$90,000 approx., per lane-mile). The indicated costs are for typical thicknesses of the treatments. Further data search is underway so that such costs can be categorized by the treatment material thicknesses as laid.

With the wide variation in unit costs across alternative treatments (particularly of the resurfacing options), it seems reasonable to assume that the more expensive treatments are more likely to afford the pavement a greater degree of benefits (either in the form of increased service life (measured by the time it takes the performance curve to reach a certain threshold), or generally increased pavement condition (as reflected by area under the performance curve). As such, the implicit assumption (as in most existing LCCA software packages) that each resurfacing option is associated with the same benefits, seems to be unduly restrictive, and the use of LCCA package without accounting for differences in effectiveness may lead to consistent recommendations to adopt the least cost treatment to the detriment to pavement condition and at

the expense of user satisfaction. The present study therefore makes a strong recommendation that performance curves should be developed to reflect the performance jumps of various intervening treatments within the pavement life, and to assess the reduction in their rates of deterioration after treatment, so that life-cycle benefit (negative costs) can be assessed and given due consideration.

Source: 1997-2001 data from INDOT Contracts Division)

Figure 8.3 Units Costs of Major Pavement Treatments by Contract (1997-2001 data from INDOT Contracts Division)

Table 8-1 Units Costs of Pavement Treatments by Work Designation and Category

Work Category	Work Type	Work Designation	Nr. Of Sections	UNIT COST (PER LANE-MILE), Year 2000 constant \$			
				Average	Minimum	Maximum	Std Dev
G (Road Construction)	G000	Road Construction	1	\$18,261,716	\$18,261,716	\$18,261,716	
	G210	New Road, Paving Only	4	\$1,299,558	\$432,441	\$2,001,393	\$774,526
	G211	New Road, Concrete Paving Only	2	\$1,426,664	\$697,446	\$2,155,882	\$1,031,269
	G310	New Road Construction	28	\$2,227,116	\$330,353	\$6,918,933	\$1,767,409
	G311	New Road Construction, Concrete	15	\$1,121,373	\$204,143	\$3,423,406	\$921,756
	G410	Added Travel Lanes	62	\$1,918,362	\$146,696	\$21,292,838	\$3,130,986
	G411	Added Travel Lanes, Concrete	4	\$1,582,978	\$258,140	\$2,859,316	\$1,125,605
	G412	Added Travel Lanes, Bituminous	2	\$719,679	\$254,884	\$1,184,474	\$657,319
	G610	Auxillary Lane Construction	2	\$308,658	\$223,178	\$394,138	\$120,887
	G611	Auxillary Lanes, Acel & Dcel Or Passing	1	\$926,645	\$926,645	\$926,645	
J100-199 (Pavement Repair or Rehabilitation)	J000	Pavement Repair Or Rehabilitation	36	\$129,518	\$8,717	\$1,941,216	\$318,480
	J100	Patch And Rehab Pavement	3	\$92,441	\$24,939	\$189,165	\$85,925
	J111	'Full Depth Patching, Bituminous	1	\$37,519	\$37,519	\$37,519	
	J112	'Full And Shallow Depth Patching, Bit	1	\$30,313	\$30,313	\$30,313	
	J120	Patch And Rehab Concrete Pavement	2	\$104,932	\$25,770	\$184,093	\$111,951
	J121	'Full Depth Patching, Concrete	10	\$917,123	\$18,535	\$7,849,122	\$2,441,822
	J122	'Full And Shallow Depth Patching, Conc	1	\$257,270	\$257,270	\$257,270	
	J124	'Reseal Joints And Patch Conc Pvmnt	6	\$63,858	\$14,126	\$162,390	\$56,126
J200-299 (Pavement Resurfacing, Non-3R/4R Stds)	J200	Resurface (Non-3r/4r Standards)	1017	\$136,516	\$1,686	\$3,005,028	\$248,973
	J210	Resurface Bit. Over Bit. Pavement	17	\$348,769	\$38,321	\$3,837,295	\$909,219
	J211	'Bit Overlay, Thin Lay	25	\$62,753	\$17,679	\$279,795	\$65,549
	J212	Bit Overlay, Multiple Structural Lays	90	\$207,088	\$16,632	\$1,035,173	\$228,292
	J213	Mill Surface And Bit Overlay	99	\$96,926	\$2,421	\$1,753,357	\$199,489
	J214	'Mill Full Depth And Bit Overlay	6	\$1,400,508	\$17,095	\$5,836,342	\$2,220,115
	J215	Microsurface (Microtexture)	6	\$23,320	\$11,018	\$67,939	\$21,971
	J216	'Widen Pavement And Bit Overlay	2	\$213,677	\$98,459	\$328,896	\$162,943
	J220	Resurface Concrete Pavement	2	\$135,944	\$133,553	\$138,335	\$3,381
	J221	'Crack And Seat & Bit Overlay	4	\$90,380	\$1,963	\$187,458	\$100,420
	J222	'Rubble Existing Pvmnt & Bit Overlay	3	\$780,654	\$628,778	\$973,115	\$175,719
	J223	'Concrete Overlay Existing Conc Pvmnt	1	\$480,718	\$480,718	\$480,718	
	J224	Concrete Overlay Existing Bit Pvmnt	9	\$40,447	\$13,218	\$73,316	\$22,924
J300-399 (Pavement Rehabilitation, 3R/4R Stds)	J300	Pavement Rehabilitation (3r/4r Standard)	178	\$568,472	\$32,967	\$4,291,667	\$727,709
	J310	Road Reconstruction	4	\$1,681,725	\$442,015	\$2,927,353	\$1,066,796
	J311	'Mill Bit, Crack & Seat W/Mod. And Safety	5	\$464,530	\$310,787	\$837,347	\$212,839
	J312	'Crack & Seat Conc.Pvmnt. W/Mod & Sfty	5	\$458,733	\$1,241	\$1,603,869	\$653,245
	J313	'Repair Conc Pvmnt & Bit Ovrlay W/Mod & Sf	3	\$472,056	\$222,243	\$683,838	\$233,136
	J314	'Rubble & Asph. Overlay, W/Mod. & Sfty	4	\$461,856	\$282,653	\$684,389	\$169,638
	J315	'Concrete Overlay W/Mod. And Safety	1	\$1,875,480	\$1,875,480	\$1,875,480	
	J316	'Other Methods Of Rehabing Pavement	3	\$280,659	\$261,052	\$306,132	\$23,105
J400 (Wedge & Level)	J410	Wedge And Level Only	47	\$43,674	\$2,375	\$846,386	\$124,267
L (Pavement Replacement)	L000	Pavement Replacement	9	\$1,741,325	\$304,863	\$4,373,530	\$1,173,396
	L110	'Pavement Replacement, Concrete	1	\$1,033,388	\$1,033,388	\$1,033,388	
	L111	'Pavement Replacement, New Concrete	3	\$1,264,847	\$440,124	\$2,315,404	\$957,820
	L210	'Pavement Replacement, Asphalt	3	\$1,029,908	\$21,527	\$2,223,529	\$1,112,627

8.4 Maintenance Costs at INDOT

8.4.1 Maintenance Costs by Treatment Type (Unit Accomplishment Cost Models)

Long-term maintenance policies typically involve strategies that are simply a “collection” of one or more maintenance treatment types carried out at various points in time on a given pavement. Maintenance treatment unit accomplishment cost (UAC) models typically express the cost of a treatment in terms of dollars per unit output (tons, lane-miles, linear miles, etc). For a given maintenance treatment, the variation in unit accomplishment costs are typically due to variations in pavement attributes (such as location, condition, etc) on one hand, and treatment attributes such as type (alternative material or process), work source (in-house or by-contract) on the other hand. Using treatment levels and annualized cost data for various maintenance treatments received by pavements within the study period, models were developed in a recently completed JTRP study [Labi and Sinha, 2002] to estimate the unit costs of various treatments. Table 7.3 provides summarized statistics of the models. All costs indicated are in constant dollar (\$1995) but can be updated to current values using an appropriate factor. The major source of the data is annual reports generated by INDOT’s maintenance management system and contracts files at INDOT Program Development Division. Further details of the maintenance cost models are available in Labi and Sinha [2002].

Table 8-2 Summary Statistics of Unit Accomplishment Costs of In-house Maintenance Treatments (\$1995 Dollars) at Sub-district Level [Labi and Sinha, 2002]

Treatment Type	Units	Mean	Maximum	Minimum	Standard Deviation	Coefficient of Variation
Crack Sealing ¹	Lane-miles	444	2446	20	630.55	117.51%
Crumb Rubber Sealing	Lane-miles	714.21	1041.65	396	192.64	26.97%
Joint/Bump Grinding	Number	73.00	307.15	20	40.61	55.61%
Under-drain Maintenance	Number	5	8	3	1.54	24.54%
Seal Coating	Lane-miles	4799	5,624	2116	7622.61	158.81%
Shallow Patching	Tons	302	424	169	78.63	26.11%
Deep Patching	Tons	227	397	124	90.11	39.63%
Premix Leveling	Tons	70	88	52	10.89	15.63%

1. Refers to crack sealing cost at average level of cracking distress

Table 8-3 Summary Statistics of Unit Accomplishment Costs of (\$2000) Contractual Maintenance Treatments [INDOT, 2003]

Treatment Type	Units	Mean	Maximum	Minimum	Standard Deviation	Coefficient of Variation
Microsurfacing	Lane-miles	23,320	67,939	11,018	21,971	94.22%
Thin HMA Overlay	Lane-miles	62,573	279,795	17, 679	65,549	104.75%
Patching Full Depth Plain Concrete Pvm	yd ²	108.39	132.63	83.85	20.98	19.36%
Patching Full Depth Reinf. Concrete Pvm	yd ²	108.77	139.74	62.00	26.20	24.09%
Patching Full Depth CRC Pvm	yd ²	114.42	127.11	101.73	17.94	15.68%
HMA Wedge and Level	Tons	40.98	108.46	19.76	14.34	35.00%

8.4.2 Maintenance Costs by Pavement Section and Age (Average Annual Maintenance Expenditure (AAMEX) Models)

Pavement average annual maintenance expenditure (AMEX) models estimate the level of maintenance that a pavement section is expected to receive annually, given the attributes of the pavement, such as age, type, functional class, etc. In past studies, pavement condition has been used a surrogate for age. AMEX models may be needed for the present study because they enable the imputation of annual maintenance expenditure data for pavement sections lacking such data. In a wider role at INDOT, such models can be used for maintenance budgeting purposes. Expenditures are expressed in terms of constant dollar (\$1995), but may be expressed in current dollar using an appropriate factor. Also, expenditures are given in terms of dollars per lane-mile, as lane-widths generally do not vary significantly with functional class.

In a recent JTRP study for INDOT [Labi and Sinha, 2002] AMEX models were developed for the three main pavement surface types: Asphalt, rigid (concrete), and asphalt-on-concrete composite pavements. Maintenance expenditure values used in the modeling included all pavement maintenance work regardless of work source (by contract or in-house), application cycle (periodic and routine), or treatment role (preventive and corrective).

8.5 Nominal Dollars vs. Constant Dollars

In the FHWA LCCA Technical Bulletin, Walls and Smith [1998] state that future costs and benefits can be estimated using constant or nominal dollars. Constant dollars, typically referred to as real dollars, reflect dollars with the same or constant purchasing power over time. In such cases, the cost of performing an activity would not change as a function of the future year in which it is accomplished. For example, if hot-mix asphalt concrete (HMAC) costs \$40/ton today, then \$40/ton should be used for future year HMAC cost estimates. Nominal dollars, on the other hand, reflect dollars that fluctuate in purchasing power as a function of time, and are typically used to account for general price increases due to inflation. The estimated cost of an activity, in nominal dollars, would change as a function of the future year in which it is accomplished. In this case, if HMAC costs \$40/ton in a given year, and inflation were 5%, then HMAC cost estimates for 1 year from the given year would be \$42/ton.

Walls and Smith further state that while LCCA can be conducted using either constant or nominal dollars, there are two cautions: First, in any given LCCA, constant and nominal dollars cannot be mixed in the same analysis (i.e., all costs must be in either constant dollars or all costs must be in nominal dollars). Second, the discount rate (discussed below) selected must be consistent with the dollar type used (i.e., use constant dollars and discount rates or nominal dollars and discount rates). Good practice suggests conducting LCCA using constant dollars and real discount rates. This combination eliminates the need to estimate and include an inflation premium for both cost and discount rates.

8.6 Chapter Summary

The inclusion of a methodology to facilitate agency cost estimation was a major requirement in the modification of FHWA's existing LCCA package. This chapter discussed the various ways by which agency costs are typically determined for LCCA purposes.

Estimation of construction and rehabilitation costs was done specific to each construction or rehabilitation treatment. Two alternative methodologies are provided: one using a per-lane mile approach using historical aggregated contract data, and the other that builds the costs upward from their primary line item prices. It is cautioned that the latter does not include economy-of-scale effects and contractor's mobilization and profits. If economy-of-scale, profits and mobilization do not vary significantly by alternative, then these parameters may be excluded as doing so would have little impact on the choice of the best alternative.

Estimation of maintenance costs was done (i) specific to each maintenance treatment using the two alternative methodologies described above for rehabilitation, and (ii) specific to pavement classes rather than treatments, where the expected average annual maintenance expenditure for a pavement is provided on the basis of its age and other characteristics.

CHAPTER 9 USER COST ANALYSIS FOR LCCA

9.1 Introduction: Dimensions of Highway User Cost

User costs are costs incurred by the highway user over the life of the project depend on the highway improvements and associated maintenance and rehabilitation strategies over the analysis period. User costs form a substantial part of the total transportation costs [Greenwood et al., 2001] for highway investments and can often be the major determining factor in life-cycle cost analysis. There are two dimensions of highway user cost:

- user cost *categories* (workzone user costs and non workzone user costs), and
- user cost *components* (vehicle operating costs, travel time costs, crash costs and environmental costs).

The overlapping nature of these dimensions is illustrated in Table 9-1 below, while Figure 9-1 shows the conceptual relationship between user costs and pavement age.

Table 9-1 User Cost Dimensions (Conceptual)

		User Cost Categories	
		User Costs during Workzone Operations	User Costs during Normal Operations (Non Workzone) ²
User Cost Components	Vehicle Operating Costs	*	*
	Travel Time Costs	*	*
	Crash Costs	* ¹	*

1. Little difference between crash costs of workzones and normal operations is expected
2. For normal operations, little difference in vehicle operating costs and crash costs between competing pavement design alternatives, is expected [Walls and Smith, 1998].

Figure 9-1: Relationship between User Costs and Pavement Age [FHWA, 2002]

9.1.1 User Cost Categories

In analyzing the life cycle costs of pavement design alternatives, it is often necessary to determine user costs that are incurred during normal operations (non work zone) of the highway, and those that are incurred during work zone operations.

Normal operations category of user costs reflects highway user costs associated with using a facility during periods free of construction, maintenance, or rehabilitation (i.e., workzone activities) that restrict the capacity of the facility. User costs in this category are a function of pavement performance (roughness). During normal operations, there is little difference between crash costs and delay costs resulting from pavement design decisions. Furthermore, as long as the pavement performance levels remain relatively high and performance curves associated with the alternative pavement designs are similar, there should be little if any difference between vehicle operating costs [FHWA, 1998]. Most research on VOC rates as a function of pavement performance has been conducted by the World Bank. For example, a study in New Zealand showed that additional VOC's (relative to a roughness-free road) begin to accrue around an IRI of 170 inches per mile (which corresponds to approximately 2.5 PSI using INDOT's PSI-IRI conversion equation [Gulen et al., 1994]. There are virtually no pavements on the Indiana state highway network with a PSI of 2.5, because any pavement with such level of service is deemed to be ready for rehabilitation or reconstruction.

It may be argued that the World Bank study was carried out for pavements with high IRI values, and are therefore valid only for pavement sections within that range of performance. It is therefore worthwhile to investigate the effect of low roughness levels on user cost. FHWA [1998] states that the effect of pavement condition on user operating cost at low roughness is not well documented. Efforts have been made by NCHRP 1-33 and Cornell University (for New York State DOT) to establish the impacts of roughness on user costs at low roughness ranges. FHWA [1998] cautions that even if user operating cost differentials are finally established between smooth and very smooth roads, the analyst must still overcome the difficulty in estimating projected year-by-year performance differences between alternative pavement design and rehabilitation strategies.

As such, the FHWA's Interim Technical Bulletin [FHWA, 1998] does not address the estimation of user VOC differentials during normal operations.

Workzone category of user costs are the increased VOC, delay, and crash costs to highway users resulting from construction, maintenance, or rehabilitation work zones. User costs in this category are a function of the configuration, duration, timing, and scope of the work zone, and also depend on the volume and operating characteristics of the traffic stream. Unlike that for normal operations, the FHWA [1998] considers that the user costs for workzones can vary considerably by pavement design, rehabilitation and maintenance alternative and therefore merit focus in pavement design LCCA .

9.1.2 User Cost Components

Figure 9.2 presents the main components of the user costs. The first component of user costs relates to vehicle operating costs (VOC), which involve elements of vehicle operation that result in costs incurred by the vehicle owner such as fuel consumption, oil consumption, tire wear, vehicle maintenance, vehicle depreciation, and spare parts. Speed changes and queuing alter the consumption of these items, particularly those related to fuel.

Figure 9-2 Components of Road User Costs

The second component involves travel time costs, which are associated with trips made during uncongested periods, travel delay costs. Travel delays include delays at intersections/interchanges due to congestion and delays at railroad grade crossings. The third component is related to crash costs, which include costs of fatality, injury and property damage. The fourth component relates to environmental costs, which include air pollution through emissions and other tailpipe pollutants and noise pollution.

9.2 Literature Review of Existing Methods for Estimating Various User Costs

9.2.1 Normal Operations (Non Workzone) Vehicle Operating Costs

Vehicle operating costs are mileage-dependent costs of running automobiles, trucks, and other motor vehicles on the highway, including the expenses of fuel, tires, engine oil, maintenance and the portion of vehicle depreciation attributable to highway mileage traveled. Factors affecting vehicle operating costs include vehicle type, vehicle speed, speed changes, gradient, curvature, and pavement surface.

Vehicle operating costs have long been of interest to engineers since they form a significant portion of road user costs. This has resulted in the development of a wide range of models for vehicle operating costs computation.

(a) FHWA HERS Model for VOC Estimation

HERS was developed for the FHWA to analyze highway widening, as well as pavement and alignment improvement projects. HERS uses a fairly complex methodology in which VOCs are calculated for seven vehicle types (two automobiles types and five truck types) as a function of fuel, oil, tires, maintenance and repair, and, mileage-based depreciation. The process is done in three steps, which include:

- Constant speed operating cost which are calculated as a function of average speed, average grade, and pavement condition
- Excess operating costs due to speed change cycles
- Excess operating costs due to the road curvature.

The results of these three steps are summed up to give the total vehicle operating costs.

$$VOC = \sum_{vt=1}^n (CSOPCST_{vt} + VSOPCST_{vt} + COPCST_{vt})$$

Where $CSOPCST_{vt}$ is the constant speed operating cost for vehicle type vt ; $VSOPCST_{vt}$ is the excess operating cost due to speed change cycles or speed variability for vehicle type vt and $COPCST_{vt}$ is the excess vehicle operating cost due to curves for vehicle type vt . The model relies upon consumption rates and cost values that were originally derived by Zaniewski et al. [1982], of the Texas Research Foundation for the FHWA.

(b) HDM-4 Model for VOC Estimation

The World Bank Highway Development and Management Tool (HDM-4) estimates fuel consumption and tire wear by the mechanistic approach [Greenwood et al., 2001]. In this approach, fuel consumption is expressed as a function of vehicle power, which in turn is predicted as a function of vehicle speed and highway and vehicle characteristics. Such characteristics include engine power, rolling resistance of tires, and aerodynamic drag coefficients. This mechanistic model for fuel consumption is defined in the HDM-4 as follows [Greenwood et al., 2001]:

$$IFC = \max(FC_{min}, \xi Pt_{tot} (1 + dFUEL))$$

Where IFC is the instantaneous fuel consumption in ml/s; FC_{min} is the minimum fuel consumption in ml/s; ξ is the fuel-to-power efficiency factor in ml/kW/s; Pt_{tot} is the total vehicle power requirements; $dFUEL$ is the additional fuel due to accelerations. The theory behind such an approach is that the user can incorporate technological developments into the modeling. However, it remains clear that predicting maintenance and repair costs is not a function of technology alone, but also depends on the economic values for prices and capital. These are somewhat more difficult to model in a form that allows easy transfer over time.

(c) MicroBENCOST Model for VOC Estimation

In the MicroBENCOST model, VOCs are calculated by obtaining a consumption rate according to vehicle type (auto, truck, or bus) and grade, for each component (fuel, oil, tire wear, maintenance and repair, and depreciation). Total VOC for each component are found by applying an equation that includes facility length, traffic volume, and the relevant component cost. A value for idle VOC is also calculated for each component of VOC and multiplied by their unit costs to

give the total idle-time. These values are each multiplied by a pavement adjustment factor, and finally summed across components for the base and alternate cases.

$$VOC = \sum_{i=1} (UVOC_{(fuel)i} + UVOC_{(oil)i} + UVOC_{(tire)i} + UVOC_{(dep.)i} + UVOC_{(main.)i}) * KVMT_i$$

Where $UVOC_{(fuel)i}$ is fuel-related unit vehicle operating costs of vehicle class i (\$/1000 VMT); $UVOC_{(oil)i}$ is oil-related unit vehicle operating costs of vehicle class i (\$/1000 VMT); $UVOC_{(tire)i}$ is tire-related unit vehicle operating costs of vehicle class i (\$/1000 VMT); $UVOC_{(dep.)i}$ is depreciation-related unit vehicle operating costs of vehicle class i (\$/1000 VMT); $UVOC_{(main.)i}$ is Maintenance and repair-related unit vehicle operating costs of vehicle class i (\$/ 1000 VMT); $KVMT$ is the total vehicle miles of travel of vehicle class i in 1000's.

9.2.2 Travel Time Costs

Travel time costs refer to the value of time spent in travel and include costs to businesses of time by their employees, vehicles and goods, and costs to consumers of personal (unpaid) time spent on travel, including time spent parking and walking to and from a vehicle. Travel-time savings is an important component of user benefits because savings in travel time are often the greatest potential benefit of transport improvement. Studies have shown that the value of time is sensitive to a variety of factors such as income level, type of trip made, time of day or amount of time saved and congestion. There are some popular approaches for estimating value of time. These approaches include modal choice approach, route choice approach, speed choice approach, travel demand approach and travel time budget approach. This section reviews four models used for valuing travel time.

(a) FHWA HERS Model for Travel Time Estimation

The HERS model uses separate values of travel time for each class of vehicles (e.g., autos, 4-tire trucks, 6-tire trucks, etc.). Heavy trucks (more than four tires) are assumed to be used only for work, so the value of time for heavy trucks equals the actual work value of time, which HERS calculates from wages and benefits, vehicle costs, and inventory costs. Light-duty vehicles are assumed to be used both for work and other trip purposes, so the value of time is computed by taking the weighted average of on-the-clock travel time and off-the-clock time. Non-work travel, including commuting, personal business, and leisure, is valued at 60 percent of the wage rate. HERS values the travel time of auto passengers (other than the driver) at 45 percent of the wage rate. For autos and four-tire trucks, separate values are used for urban and rural travel (rural hours

are valued more highly because average vehicle occupancy is higher in rural areas). Although travelers place a higher value on time spent in delay (due to stress, etc.) than free-flow, the HERS model does not use different values.

(b) MicroBENCOST Model for Travel Time Estimation

The MicroBENCOST model uses the same basic travel time costs as used in the HERS model. The model however takes into consideration travel delay costs. These are additional unit time and vehicle operating costs as the travel speed goes down due to capacity, geometric and operational constraints. The delays considered are delays at intersections/ interchanges, delay at railroad grade crossings and delay for incidents and workzones. Discomfort costs as a result of vehicle stopping, congestion and rough pavement are also included in MicroBENCOST model which are added to the travel time costs.

(c) HDM-4 Model for Travel Time Estimation

Travel Time is estimated in the HDM-4 models as follows [Greenwood, et. al, 2001]. The models establish the number of hours per 1000 veh-km for passenger working and non-working time, crew time, and cargo time. The travel time is given as.

$$\text{Travel Time} = PWH + PNH + CH + CARGOH$$

Where *PWH* is the annual number of working passenger hours per 1000 veh-km; *PNH* is the annual number of non-working passenger hours per 1000 veh-km; *CH* is the number of hours per crew member per 1000 veh-km; *CARGOH* is the annual number of cargo handling hours per 1000 veh-km. These values are multiplied by the appropriate unit cost for time to establish the total time cost. To account for the speed-flow effects, traffic-influenced speed was used in the calculations. The individual values are multiplied by the portion of the year that the flow is at each of those speeds and added to get the total annual cost.

(d) QUEWZ Model for Incidents and Work Zones for Delay Costs Estimation

The QUEWZ model analyzes traffic flows through freeway work zones and estimates the traditional road user costs and queue lengths as they relate to lane closures. It can be applied to basic freeway segments having as many as six lanes in each direction, and can analyze any number of lanes closed in one or both directions. QUEWZ, specifically designed for highway work zone analysis, has been used to estimate user costs attendant on various lane closure

strategies. QUEWZ analyzes traffic flows through work zones using traditional macroscopic techniques. It first estimates speeds and queuing characteristics both with and without the work zone and then estimates the additional road user costs generated by the work zone [Krammes, et. al, 1993].

Table 9-2 presents the updated values of time for different vehicles using the values generated by FHWA [1998] as base values.

Table 9-2 Value of Time [FHWA, 1998]

Value of Time	1996 Value	Escalation Factor	2000 Value
Passenger Cars	\$11.78	1.098	\$12.84
Single Unit Trucks	\$19.64	1.098	\$21.41
Combination Trucks	\$19.64	1.098	\$21.41

The updated values were obtained using an escalation factor which is given as [FHWA, 1998],

$$Escalation\ Factor = \frac{CPI_{current\ year}}{CPI_{base\ year}}$$

where

$CPI_{current\ year}$ - All Items Component of the CPI for 2000 = 172.2

$CPI_{current\ year}$ - All Items Component of the CPI for 1996 = 156.9

9.2.3 Crash Costs

Crash costs are costs related to motor vehicle traffic crashes. They include fatality, injury and Property Damage Only (PDO) costs. Usually these costs are estimated by multiplying the number of crashes for each crash type by the average cost per crash. The FHWA *RealCost* Software does not consider crash costs for LCCA obviously because an FHWA study (Construction Cost and Safety Impacts of Workzone Traffic Control Strategies) concluded that there were no significant impacts on crash rates due to workzones. Nevertheless, various research efforts have attempted to provide models for crash costs estimation, particularly during normal operations. Some of the methodologies in use for computing crash costs are discussed in the

following sections. As these are for normal operations, they do not vary by pavement design and preservation alternative and are therefore added here only for academic purposes.

(a) FHWA HERS Model for Crash Costs Estimation

The HERS model for crash costs contain crash rates by traffic level and crash category (i.e., fatality, injury, and PDO) for five urban and five rural types of facilities. These rates are combined with estimates of crash costs to obtain the total crash cost for a given facility. The model contains one value for fatality crashes and ten values each for injury and PDO crashes. The injury and PDO costs vary according to the five urban and rural facility types.

(b) MicroBENCOST Model for Crash Costs Estimation

The MicroBENCOST model uses crash rates for each of twelve possible facility types. Rates are arranged in tables according to average annual daily traffic (AADT) and peak versus off-peak travel. To estimate crash costs, the crash rate is multiplied by AADT, project length, and the crash cost for each of the three crash types (i.e., fatality, injury, and PDO). A minimum and maximum estimate of crash cost is used to generate a range of values for risk analysis. The crash cost function is given as follows:

$$Crash\ Costs = \sum_{i=1}^n \sum_{j=1}^m (UAC_{ij} \times Crash\ Rates_{ij} \times LEN \times AADT)$$

Where UAC_{ij} is the unit crash costs for crash type j of cost category i ; $Crash\ Rates_{ij}$ are the crash rates for crash type j of cost category i ; i is the crash cost category, including highway segment, intersection /interchange, railroad crossing, and bridge; j is the crash type, including fatality, injury, and property damage only; LEN is the length of project.

9.2.4 Environmental Costs

Environmental effects are those external costs that are incurred by people other than road users. Environmental externalities are usually difficult to quantify and are frequently not considered fully in analyzing transportation alternatives. However, environmental impacts as a result of improved transportation facilities and increased vehicle use, particularly air pollution and noise, can impose significant costs and may therefore be incorporated in computations of the user costs for pavement design alternatives. Despite modeling complexities, transportation benefit-cost models such as MicroBENCOST and HDM-4 account for some environmental costs.

(a) MicroBENCOST Model for Environmental Costs Estimation

The MicroBENCOST model estimates the value of air pollution effects associated with highway investment. Effects are estimated for carbon monoxide (CO) only. The model uses lookup tables of emission rates at various speeds for three vehicle types (small vehicles, buses, and trucks). Using an estimate of average travel speed, MicroBENCOST interpolates between values in the lookup tables to identify unique emission rate for carbon monoxide (CO) for each vehicle type, for both peak and non-peak periods. Vehicle miles traveled are multiplied by emission rates (in grams per mile) for each vehicle class, for each time period, and summed to estimate the total volume of carbon monoxide (CO) emitted. The volume of carbon monoxide (CO) in tons is then multiplied by the value of CO pollution (in dollars per ton) to estimate total environmental costs.

(b) HDM-4 Model for Environmental Costs Estimation

The environmental effects model of the HDM-4 is a more comprehensive model than of MicroBENCOST. It generates the environmental costs based on three major environmental effects: Air pollution from vehicle emissions, noise pollution and energy effects. The HDM-4 model primarily estimates effect of the following air pollutants associated with vehicle emissions: Hydrocarbons (HC), Carbon Monoxide (CO), Carbon Dioxide (CO₂), Nitric Oxides (NO_x), Sulphur Dioxide (SO₂), Lead (Pb) and Particulate Matter (PM). The model predicts the emission rates (g/km) as follows:

$$TPE_i = EOE_i \times CPF_i$$

Where TPE_i is the tailpipe emissions in g/km for emission type i ; EOE_i is the engine out emission in g/km for emission type i and CPF_i is the catalyst pass fraction for emission type i .

9.2.5 Workzone Vehicle Operating Costs

Work zone operations results in three types of vehicle operating costs, which include speed change vehicle operating costs, stopping vehicle operating costs and idling vehicle operating costs [FHWA, 1998].

(a) Speed Change Vehicle Operating Costs (VOC)

This is the additional vehicle operating cost associated with decelerating from the upstream approach speed to the work zone speed and then accelerating back to the approach speed after leaving the work zone. It is given by

$$\text{Speed Change VOC} = \sum_i^n (Nveh_i \times USCCost_i)$$

where

$Nveh_i$ = number of vehicles affected by the speed change for vehicle class i in 1000 veh

$USCCost_i$ = added cost of speed changes for vehicle class i in \$/1000 veh

i = vehicle class

n = number of vehicles classes

(b) Stopping Vehicle Operating Costs (VOC)

This is the additional VOC associated with stopping from the upstream approach speed and accelerating back up to the approach speed after traversing work zone. It is given by

$$\text{Stopping VOC} = \sum_i^n (Nveh_i \times USCost_i)$$

where

$Nveh_i$ = number of vehicles affected by stopping for vehicle class i in 1000 veh

$USCost_i$ = added cost of stopping for vehicle class i in Hours/1000 veh

i = vehicle class

n = number of vehicles classes

(c) Idling Vehicle Operating Costs (VOC)

This is the additional vehicle operating cost associated with stop-and-go driving in the queue. It is given by

$$\text{Idling VOC} = \sum_i^n (Nveh_i \times UICost_i)$$

where

$Nveh_i$ = number of vehicles idle for vehicle class i in 1000 veh

$UICost_i$ = added cost of idling for vehicle class i in \$/1000 veh-hr

- i = vehicle class
 n = number of vehicles classes

The total vehicle operating costs is thus given by:

$$VOC_{work-zone} = (Speed\ ChangeVOC + StoppingVOC + IdlingVOC) \times N$$

Where N = total number of days for the workzone operations

9.2.6 Travel Delay Costs

Travel delay costs constitute a significant proportion of road user costs. The NHCPR report 456 states that travel time savings is usually the primary user benefit for transportation projects. In quantifying travel delays for workzone operations, four types of delay costs are considered. They include speed change delay, reduced speed delay, stopping delay and queue delays [FHWA, 1998].

(a) Speed Change Delay Costs

This is the additional time required to decelerate from the upstream approach speed to the workzone speed and then accelerate back to the initial approach speed after traversing the work zone. It is given by: $Speed\ Change\ Delay\ Cost = \sum_i^n (Nveh_i \times SCTime_i \times DCost_i)$

where

- $Nveh_i$ = number of vehicles delayed by the speed change for vehicle class i in 1000 veh
 $SCTime_i$ = added time for the speed changes for vehicle class i in Hrs/1000 veh
 $DCCost_i$ = delay cost rate for vehicle class i in \$/veh-hr
 i = vehicle class

(b) Reduced Speed Delay Costs

This is the additional time required to traverse the work zone at the lower posted speed. It depends on the upstream and work zone speed differential and length of the work zone. It is given by: $Reduced\ Speed\ Delay\ Cost = \sum_i^n (Nveh_i \times RSTime_i \times DCost_i)$

where

- $Nveh_i$ = number of vehicles delayed by the reduced speed for vehicle class i in 1000 veh

$RSTime_i$	= added time for the reduced speed for vehicle class i in Hrs/1000 veh
$DCost_i$	= delay cost rate for vehicle class i in \$/veh-hr
i	= vehicle class
n	= number of vehicles classes

(c) *Stopping Delay Costs*

This is the additional time required to come to a complete stop from the upstream approach speed and accelerate back to the approach speed after traversing the work zone. It is

given by: $Stopping\ Delay\ Cost = \sum_i^n (Nveh_i \times STime_i \times DCost_i)$

where

$Nveh_i$	= number of vehicles delayed by stopping for vehicle class i in 1000 veh
$STime_i$	= added time for stopping for vehicle class i in Hrs/1000 veh
$DCost_i$	= delay cost rate for vehicle class i in \$/veh-hr
i	= vehicle class
n	= number of vehicles classes

(d) *Queue Delay Costs*

This is the additional time required to go through the queue that is formed as a result of the workzone. It is given by

$$Queue\ Delay\ Cost_i = \sum_i^n (Nveh_i \times QTime_i \times DCost_i)$$

where

$Nveh_i$	= number of vehicles delayed by queuing for vehicle class i in 1000 veh
$QTime_i$	= queue delay for vehicle class i in Hrs/1000 veh
$DCost_i$	= delay cost rate for vehicle class i in \$/veh-hr
i	= vehicle class

The total Travel Delay Costs is thus given by

$$Delay\ Cost_{work-zone} = (Speed\ Change\ DC + Reduced\ Speed\ DC + Stopping\ DC + Queue\ DC) \times N$$

9.3 Issues Associated with User Costs for Workzone Operations

The Highway Capacity Manual defines a workzone as an area of a highway where highway preservation activities impinge on the number of lanes available to traffic or affect the operational characteristics of traffic flowing through the area. Such preservation activities, which include construction, maintenance and rehabilitation programs, have a number of different effects on the traffic stream on a roadway which can significantly affect road user costs for different pavement designs [FHWA, 1998]. These effects include reductions in operating speeds and reduction in the road capacity, which may result in queue development and consequently travel delays and increased vehicle operating costs. User costs for workzone operations are influenced by variety of factors. These include the type of infrastructure, and workzone characteristics, type of work, and available sight distance. As the vehicle flow at work zones increases the impacts on speed and safety rise substantially and rapidly. It is therefore necessary to model these impacts and how it translates into estimates of user costs. This section discusses the elements that comprise a typical work zone, relates these relevant elements to vehicle speed, and the models for the computation of these impacts on user costs for this study.

9.3.1 Workzone Characteristics

The major characteristics of work zones and the traffic that flows through them are: work zone geometry, traffic volumes, lane capacities, duration, timing of lane closures, vehicle speeds and the availability and physical traffic characteristics of alternative routes. An outline of the characteristics of work zones, traffic flow and how they affect user costs and other aspects of the transportation system is discussed below.

(a) Workzone Geometry

A work zone is effectively the entire section of roadway on which traffic controls relating to construction work have been placed, including any temporary traffic control devices [Lewis, 1989]. From a systems perspective, a workzone should include detour options for traffic to flow at exit points distant from the work site. A work zone consists of the following elements:

- *User Information Zone* – In this zone, the road user is informed of the impending construction zone and given directions for traveling safely through it.
- *Approach Zone, Including Detour Exits* – This is a variable portion of the work zone where vehicle behavior, particularly speed and direction, may change as a result of the work zone.

- *Non-recovery Zone* – This is the distance required to execute an avoidance maneuver, or the point beyond which the motorist cannot avoid the hazard unless erratic maneuvers are undertaken.
- *Construction Zone* – This zone consists of a buffer zone where there is no work activity or equipment and materials. The construction activity site itself is then established where work is being undertaken.
- *Termination Zone* - This zone immediately follows a work zone, where vehicles accelerate back to their normal cruising speeds.

(b) Workzone Duration

The duration of highway construction and maintenance works and their corresponding workzone duration vary significantly according to the type of preservation treatment being undertaken and the scope of the project such as the length of the contract and the number of roadway lanes. For the present study, we hypothesize that if the duration of a pavement preservation treatment can be obtained using attributes of the project such as the length and the number of lanes of roadway then the workzone duration for the that treatment can be obtained. This is due to the fact that the workzone duration bears a direct relationship to the contract duration. As such, models were developed for the contract duration per lane-mile for each type of pavement preservation treatment.

Determination of Workzone Duration

Step 1: Determination of Contract Duration from Contract Size

The contract duration per lane-mile (*CDL*) is given as:

$$CDL = \frac{\text{Contract Duration}}{SLEN \cdot LN}$$

Where *SLEN* is the length of the contract section in miles and *LN* is the number of lanes of the contract section. Figures 9.3 – 9.5 below illustrates the models developed and the summary results are presented in Table 9.3.

Figure 9-3 Contract Duration Model for Thin HMA Overlay

Figure 9-4 Contract Duration Model for Microsurfacing

Figure 9-5 Contract Duration Model for PCCP Cleaning and Sealing Joints

Table 9-3 Contract Duration Models

Treatment	Model	Variable	t-statistic	R-squared
Microsurfacing	$CDL = 76.519 \cdot SLEN^{-1.1839}$	$SLEN$	-12.548	0.708
Thin HMA Overlay	$CDL = 94.612 \cdot SLEN^{-0.8847}$	$SLEN$	-6.352	0.734
PCCP Cleaning and Sealing Joints	$CDL = 47.069 \cdot SLEN^{-0.9974}$	$SLEN$	-7.823	0.645

The model results showed that the length of the contract section ($SLEN$) is a significant predictor of the contract work duration per lane-mile for preventive maintenance treatments. It was found that all models for the contract duration per lane-mile of preventive maintenance treatments were best described using the power regression of the form $y = Ax^{-b}$ as indicated by the t-statistic and the R-squared values for the models. For the Microsurfacing model, the t-statistic for estimated coefficient of the independent variable is -12.548 with an overall R-squared value of 0.708. The t-statistic for Thin HMA Overlay is -6.352 with an overall R-squared value of 0.734 while that for PCCP Cleaning and Sealing Joints is -7.823 with an overall R-squared value of 0.645.

The negative sign of the t-statistic for $SLEN$ in the models indicate that the contract duration per lane-mile for preventive maintenance treatments decreases as the length of the contract section increases. This can be attributed to the effects of economies of scale. The duration of a contract comprises not only on the period of actual work on the road but also time spent for mobilization and other administrative activities. The time for mobilization and other administrative activities is usually a fixed time for most contract activities of this nature and does not depend on the section length of the contract. Any increase in the contract length will increase the total time for the contract. However the time for the mobilization and other administrative activities per unit length will be reduced thereby reducing the contract duration per lane mile. The high R-squared values obtained for the models indicate a relatively good overall model goodness-of-fit.

Step 2: Determination of Workzone Duration from Contract Duration

Having found a methodology for determining the contract duration in the preceding section, it is now necessary to determine the workzone duration given the contract duration. A

literature search on the subject yielded no information on the relationship between workzone duration and contract duration. Also, efforts to obtain such data from INDOT were futile. From the construction experience of the Research Team members, an educated guess of 0.65 was used as the factor that related contract duration to workzone duration. As such, the contract duration (estimated from the contract size) was multiplied by 0.65 to yield the workzone duration which is subsequently used for user cost computations.

(c) Number of Opened and Closed Lanes

The number of opened and closed lanes is important contributors to per-lane work zone capacity reduction. The per-lane work zone capacity might decrease as the number of closed lanes increases, and it might increase as the number of opened lanes increases.

(d) Vehicle Speeds

Road users traveling through a work zone undergo speed changes that are determined based on the lane width and other physical characteristics of the workzone. Road users traveling through a work zone undergo speed changes that are determined based on the lane width and other physical characteristics of the workzone. Figure 9-6 [Greenwood et al., 2001] illustrates the various speed changes that road users undergo during workzone operations.

Source: [Greenwood et al., 2001].

Figure 9-6 Speed Changes during Work-Zone Operations

Vehicles traveling at an approach speed in advance of the work zone are forced to decelerate to the workzone speed. If there is a queue, the vehicle will be stationary for some intervals and moving up through the queue in others. Once they reach the front of the queue, it will accelerate up to the speed at which it will travel through the work zone. Upon reaching the end of the work zone, the vehicle will again accelerate back to its initial speed. Speeds are important because they relate directly to vehicle operating costs and to loss of time (and, hence, to delay costs). Also, speed changes, particularly those that result in vehicle idling, produce higher levels of emissions. Finally, the transitional zone, particularly related to the non-recovery area, is typically one where higher accident rates are recorded [Wilde et al., 1999] as vehicles merge into the constrained flows through the work zone.

It is important for the analyst to determine which of these situations exist at a workzone for a given pavement construction or rehabilitation project. For instance, the example in Table 9-4 provides the operating conditions (and consequently, which user cost components to consider) for a typical project.

Table 9-4: User Costs under various Queuing at Workzone Situations

Operating Conditions	Traffic Effects	Speed Change From Normal	Traversing	
			Workzone	Queue
No Work Zone, No Queue		None	None	None
Work Zone, No Queue		Vehicle and Delay	Delay	None
Work Zone, Queue		Vehicle and Delay	Delay	Idling and Delay
No Work Zone, Queue Dissipating		Vehicle and Delay	None	Idling and Delay

9.3.2 Steps for Workzone User Cost Calculations

FHWA's *RealCost* software provides a convenient step-by-step calculation of workzone highway user costs. These steps involve the theory of user cost computation that have been discussed in a previous section of this chapter. As mentioned earlier, nonworkzone user costs typically do not vary by alternative and are therefore omitted. Also, crash costs are not considered as recent research showed little impact of workzones on crash rates. The steps, which are largely reproduced from an FHWA LCCA document titled "Pavement LCCA – Software Workshop", are discussed below.

Step 1 (Determine Inputs)

The three inputs to be determined are:

- Traffic Demand (AADT, hourly distribution, and vehicle classes)
- Normal and Work zone Characteristics (workzone hours of operation, work zone length, construction duration, capacities, speeds)
- Dollar Values of Travel and Delay Time (User delay time, vehicle idling and operating costs)

Vehicle classification is important for user cost estimation because certain vehicle class (trucks) affect the traffic flow and have higher user costs than passenger cars. Also, the capacities of the roadway at different time periods are needed. This includes capacities under normal operations, work zone, and under queue dissipation conditions. The speed during normal operations and workzones are needed because they are used to determine speed changes which lead to delay and vehicle operating costs. The value of user time is necessary for the computation of user delay costs.

Step 2: Determine Hourly Demand and Capacity

This step involves the determination of hourly demand and capacity. Two tasks are carried out here (i) conversion of AADT to hourly traffic distribution (which is equal to the product of AADT, directional factor, and hourly distribution), (ii) development of hourly capacities (which is the product of the number of lanes open and the capacity per lane). With good planning and public relations, workzone demand can substantially be reduced.

Step 3: Determine Hourly Operating Conditions

This step involves the following tasks:

- comparison of demand and capacity
- determination of the queue rate (demand less capacity). If this value is positive, it tells the rate at which vehicles are added to the queue. If it is negative, it tells how fast the queue shrinks.
- determination of workzone conditions (such as workzone with no queue, no workzone with no queue, etc.)

Step 4: Determine Hourly Cost Traffic Effects and Cost Components

The work zone operating conditions dictate the traffic effects and therefore the values of the user cost components. A matrix such as that provided below helps to determine at which periods the

various traffic effects exist and therefore provide a guide as to which user costs will need to be calculated for each hour.

Table 9-5: User Costs under a Sample Workzone Schedule

Time Periods	Operating Conditions	Cost Components		
		Speed Change	Traversing:	
			Work Zone	Queue
Midnight – 5:00AM	Work Zone, No Queue	Vehicle & Delay	Delay	None
5:00AM – 9:00AM	No Work Zone, No Queue	None	None	None
9:00AM – 3:00PM	Work Zone, Queue	Vehicle & Delay	Delay	Vehicle & Delay
3:00PM – 8:00PM	No Work Zone, Queue Remaining	Vehicle & Delay	None	Vehicle & Delay
8:00PM - Midnight	Work Zone, No Queue	Vehicle & Delay	Delay	None

Step 5: Determine for each Hour, the Number of Vehicles that Endure an Adverse Traffic Effect

At this step, we determine for each hour, the number of vehicles that:

- (i) change speed due to slowing down or stopping for a work zone or queue. This is equal to the hourly demand in hours when a workzone or queue exists.
- (ii) traverse the workzone (when a work zone is in effect). This is the lesser number of the hourly demand or the workzone capacity. Vehicles that are not able to traverse the workzone add to the queue. Step 5 (ii) applies in hours when a workzone is in existence but does not apply when there is no work zone and the queue is dissipating.
- (iii) traverse a queue (when a queue exists). This is the lesser number of the hourly demand or the workzone capacity. In FHWA's RealCost model, vehicles are charged the cost of traversing the queue when they leave the queue. Vehicles that do not traverse stay in the queue, awaiting their opportunity to exit the queue (and be "charged"). Step 5 (iii) applies in hours when a queue exists or when a queue is dissipating.

Step 6: Convert the Traffic Effects to Dollars

This involves the calculation of vehicle costs for (i) speed change (ii) traversing the workzone, and (iii) traversing the queue. This is done for each vehicle class (automobiles, single unit trucks, and combination trucks).

Step 7: Sum the User Costs for the Workzone Duration

This involves summing up the user costs associated with the following situations:

- Workzone Speed Change VOC
- Workzone Speed Change Delay
- Workzone Reduced Speed Delay
- Queue Stopping Delay
- Queue Stopping VOC
- Queue Added Travel Time
- Queue Idle Time

It is therefore clear that user cost calculations in LCCA are a function of agency work zone frequency traffic, capacity, speed, workzone characteristics, and the values of travel time. All user costs are in the form of VOCs and delay, as crash costs are not considered for reasons stated earlier.

9.4 Issues with User Costs under Non-Workzone Operations (Regular Highway Usage)

These are highway user costs associated with using the facility during periods free of construction, maintenance and/or rehabilitation. User cost under non-workzone operations is a function of the differential pavement performance (roughness) of the various alternatives. Under non-workzone operations vehicle operating costs (VOC) form the main constituent of the user costs. These costs are not considered in the current version of the FHWA software, but are herein discussed for purposes of possible future consideration in the software. The VOC is computed using the HERS model (FHWA 1999) for computation of benefits of potential transportation improvements. The HERS model uses three classes of operating costs to derive estimates of VOC. They include

- Constant-Speed Operating costs
- Excess Operating Costs due to speed-change cycles; and
- Excess Operating Costs due to curves.

(a) *Constant-Speed Operating Costs*

This computes the VOC as a function of average effective speed, average grade, and Pavement Serviceability Rating (PSR) for each vehicle type (vt) per thousand vehicle miles. The Constant-Speed Operating Costs ($CSOPCST$) is given as:

$$CSOPCST_{vt} = CSFC \times PCAFFC \times \frac{COSTF_{vt}}{FEAF_{vt}} + CSOC \times PCAFOC \times \frac{COSTO_{vt}}{OCAF_{vt}} + CSTW \times PCAFTW \times \frac{COSTT_{vt}}{TWAF_{vt}} \\ + CSMR \times PCAFMR \times \frac{COSTMR_{vt}}{MRAF_{vt}} + CSVD \times PCAFVD \times \frac{COSTV_{vt}}{VDAF_{vt}}$$

where

$CSOPCST_{vt}$ = constant speed operating cost for vehicle type vt

$CSFC$ = constant speed fuel consumption rate (gallons/1000 miles)

$CSOC$ = constant speed oil consumption rate (quarts/1000 miles)

$CSTW$ = constant speed tire wear rate (% worn/1000 miles)

$CSMR$ = constant speed maintenance and repair rate (% of average cost/1000 miles)

$CSVD$ = constant speed depreciation rate (% of new price/1000 miles)

$PCAFFC$ = pavement condition adjustment factor for fuel consumption

$PCAFOC$ = pavement condition adjustment factor for oil consumption

$PCAFTW$ = pavement condition adjustment factor for tire wear

$PCAFMR$ = pavement condition adjustment factor for maintenance and repair

$PCAFVD$ = pavement condition adjustment factor for depreciation expenses

$COSTF_{vt}$ = unit cost of fuel for vehicle type vt

$COSTO_{vt}$ = unit cost of oil for vehicle type vt

$COSTT_{vt}$ = unit cost of tires for vehicle type vt

$COSTMR_{vt}$ = unit cost of maintenance and repair for vehicle type vt

$COSTV_{vt}$ = depreciable value for vehicle type vt

$FEAF_{vt}$ = fuel efficiency adjustment factor for vehicle type vt

$OCAF_{vt}$ = oil consumption adjustment factor for vehicle type vt

$TWAF_{vt}$ = tire wear adjustment factor for vehicle type vt

$MRAF_{vt}$ = maintenance and repair adjustment factor for vehicle type vt

$VDAF_{vt}$ = depreciation adjustment factor for vehicle type vt

(b) *Excess Operating Costs due to Speed-Change Cycles*

This computes the VOC due to Speed-Change Cycles that occur as a result of stop signs or traffic signals. The overall formula for the excess cost due to Speed-Change Cycles (*VSCOPCST*) is given as:

$$VSCOPCST_{vt} = VSFC \times \frac{COSTF_{vt}}{FEAF_{vt}} + VSOC \times \frac{COSTO_{vt}}{OCAF_{vt}} + VSTW \times \frac{COSTT_{vt}}{TWAF_{vt}} + VSMR \times \frac{COSTMR_{vt}}{MRAF_{vt}} + VSVD \times \frac{COSTV_{vt}}{VDAF_{vt}}$$

where

- $VSCOPCST_{vt}$ = excess operating cost due to speed variability for vehicle type vt
- $VSFC$ = excess fuel consumption rate due to speed variability (gallons/1000 miles)
- $VSOC$ = excess oil consumption rate due to speed variability (quarts/1000 miles)
- $VSTW$ = excess speed tire wear rate due to speed variability (% worn/1000 miles)
- $VSMR$ = excess speed maintenance and repair rate due to speed variability (% of average cost/1000 miles)
- $VSVD$ = excess depreciation rate due to speed variability (% of new price/1000 miles)
- $COSTF_{vt}$ = unit cost of fuel for vehicle type vt
- $COSTO_{vt}$ = unit cost of oil for vehicle type vt
- $COSTT_{vt}$ = unit cost of tires for vehicle type vt
- $COSTMR_{vt}$ = unit cost of maintenance and repair for vehicle type vt
- $COSTV_{vt}$ = depreciable value for vehicle type vt
- $FEAF_{vt}$ = fuel efficiency adjustment factor for vehicle type vt
- $OCAF_{vt}$ = oil consumption adjustment factor for vehicle type vt
- $TWAF_{vt}$ = tire wear adjustment factor for vehicle type vt
- $MRAF_{vt}$ = maintenance and repair adjustment factor for vehicle type vt
- $VDAF_{vt}$ = depreciation adjustment factor for vehicle type vt

(c) Excess Operating Costs due to Curves

For sections with average effective speeds below 55 mph, the effects of curves are estimated using the individual tables from Zaniewski et al. (1982). For sections with average effective speeds above 55 mph, the effects of curves are estimated using equations fit to the Zaniewski values given for speeds of 55 to 70 mph and for 2 degrees of curvature or more. The

excess cost due to curves (*COPCST*) for each vehicle type on sections with average effective speed greater than 55 mph is calculated with the following equation:

$$COPCST_{vt} = CFC \times \frac{COSTF_{vt}}{FEAF_{vt}} + CSTW \times \frac{COSTT_{vt}}{TWAF_{vt}} + CSMR \times \frac{COSTMR_{vt}}{MRAF_{vt}}$$

where

$COPCST_{vt}$ = excess operating cost due to curves for vehicle type vt

CFC = excess fuel consumption rate due to curves (gallons/1000 miles)

$CSTW$ = excess tire wear rate due to curves (% worn/1000 miles)

$CSMR$ = excess maintenance and repair rate due to curves (% of average cost/10³ miles)

$COSTF_{vt}$ = unit cost of fuel for vehicle type vt

$COSTT_{vt}$ = unit cost of tires for vehicle type vt

$COSTMR_{vt}$ = unit cost of maintenance and repair for vehicle type vt

$FEAF_{vt}$ = fuel efficiency adjustment factor for vehicle type vt

$TWAF_{vt}$ = tire wear adjustment factor for vehicle type vt

$MRAF_{vt}$ = maintenance and repair adjustment factor for vehicle type vt

9.5 Chapter Discussion

The FHWA [1998] provides a detailed sample analysis of work zone user costs on the basis of the following components – speed change VOC, speed change delay costs, workzone reduced speed delay, stopping VOC, queue idling VOC, and queue speed delay costs. These costs were calculated for each of three vehicle classes – passenger cars, single-unit trucks, and combination trucks. The first three components (speed change VOC, speed change delay costs, workzone reduced speed delay) reflect the user cost associated with free flow, while the remaining four components represent the forced-flow queuing costs. The FHWA analysis showed that high user costs are not an LCCA problem, but are a traffic control problem. The analysis also showed that over 90% of the user costs typically result from the queue delay component. An additional 5% is typically associated with the queue idling costs and another 2% is from the queue stopping VOC and delay. Against this background, the FHWA report states that approximately 97% of user costs could be avoided if preemptive measures were taken to avoid queue formation. The FHWA report provided a sample analysis where it was shown that the queuing situation could be drastically reduced if the workzone operations were limited to evening work between 7pm and 7am. The

report argued that making the contractor work in nighttime hours would not adversely affect their productivity because midday delays of construction traffic would be avoided. The FHWA suggests that other alternatives to lower workzone user costs include adding capacity prior to the development of large traffic demands, accelerating contractor production to reduce the overall duration the workzone is in place, and limiting the overall frequency of rehabilitation activities.

9.6 Chapter Summary

This chapter identified the various components of user costs, and discussed methods for computation of such costs. It was duly noted that certain users costs (such as vehicle operating costs during normal (non workzone) operations, safety, and noise costs) are not expected to vary significantly by LCCA alternative and may therefore be excluded from the analysis, as is done in FHWA's current LCCA software package. As such, only workzone user costs were given prominent coverage in the chapter. Such costs are due to increased VOC and delay to highway users resulting from construction, maintenance, or rehabilitation activities. The contributions of workzone configuration, duration, timing, and scope of the work zone, and volume and operating characteristics of the traffic stream to workzone user costs were discussed in the chapter.

The duration of highway construction and preservation activities and their corresponding workzone durations vary significantly by the type of treatment being undertaken and the project scope. The chapter therefore presents models that were developed to estimate expected contract duration and workzone duration for each type of treatment.

The chapter also presents FHWA's LCCA methodology for step-by-step calculation of workzone highway user costs. These steps involve determination of three key inputs (traffic demand, normal and work zone characteristics, and values of travel and delay time. The steps also involve determination of hourly parameters (demand, capacity, operating conditions, and cost), traffic effects and cost components. For each hour of workzone duration, the methodology determines the number of vehicles that endure an adverse traffic effect, converts the traffic effects to dollars, and sums up the user costs for the workzone duration

CHAPTER 10 SOME LCCA ISSUES (ANALYSIS PERIOD, RSL, SALVAGE VALUE, AND DISCOUNTING)

This chapter discusses issues involving important LCCA input parameters such as the analysis period, discount rate, remaining service life, and salvage value.

10.1 Analysis Period

Like all transportation assets, highway pavements are designed and constructed so that they can provide service for a long period of time. The service life of a facility may generally be defined as the time (or cumulative value of some usage parameter such as loading) that elapses between initial construction and the next construction, and typically exceeds one decade for highway pavements. The facility service life depends on the minimum level of service and the rate of facility deterioration. The overall service life of a facility may be considered an aggregation (sometimes overlapping) of the service life of the pavement design (assuming zero maintenance) and the individual service lives of various rehabilitation and maintenance treatments that comprise the preservation strategy. Competing pavement design alternatives may each have a different service life. As such, in order to make an impartial comparison between alternatives, it is useful to either express all costs and benefits in their equivalent annual value, or utilize a fixed time frame for all alternatives. In the latter case, such fixed time frame is referred to as the analysis period or time horizon. In the ideal case, the analysis period is equal to the overall facility service life, but in many cases, is less or more than the service life.

It has been shown in past research that for a valid analysis, the analysis period should be of sufficient length to show what activities (in the period between construction activities) will be required to maintain an acceptable level of service [Walls and Smith 10998]. Also, the FHWA cautions that the analysis period should not drive the decision, and asserts that a robust decision can be made only if the analysis period is of sufficient length. In other words, if a sufficiently long analysis period is used for the analysis, incremental changes in the analysis period are not likely to change the decision supported by the LCCA. Walls and Smith [1998] state that the LCCA analysis period should be sufficiently long to reflect long-term cost differences associated with reasonable design strategies, and that the analysis period should generally always be longer than the pavement design period, except in the case of extremely long-lived pavements. According to Walls and Smith,

the analysis period, as a rule of thumb, should be long enough to incorporate at least one rehabilitation activity. The FHWA's September 1996 Final LCCA Policy statement recommends an analysis period of at least 35 years for all pavement projects, including new or total reconstruction projects as well as rehabilitation, restoration, and resurfacing projects (Federal Register, 1996)

In some cases, a shorter analysis period may be more appropriate, particularly when pavement design or preservation alternatives are developed as a stop-gap measure to “buy time” until total reconstruction. It may be appropriate to deviate from the recommended minimum 35-year analysis period when slightly shorter periods could simplify salvage value computations. For example, if all alternative strategies would reach terminal serviceability at year 32, then a 32-year analysis would be quite appropriate. Walls and Smith [1998] argue that regardless of the analysis period selected, the analysis period used should be the same for all alternatives. However, this issue may be further investigated, because it seems that different analysis periods could be used in cases where EUAC is used as a measure of economic efficiency.

10.2 Remaining Service Life (RSL)

In many cases, LCCA pavement design and preservation scenarios are such that there is some residual pavement level of service at the end of the analysis period. In other words, the pavement can still serve for some more years beyond the analysis period. Some literature refers to such extra service life as *remaining service life*. The FHWA cautions that failing to account for such remaining service lives can result in a biased LCCA output. Figure 10-1 (taken from FHWA's Pavement LCCA Software Workshop document) shows how remaining service life is calculated.

Figure 10-1: Calculation of Remaining Service Life

The figure shows that at the end of the analysis period, there may be some remaining service life from rehabilitation number 2. The RSL is calculated by performing a straight-line depreciation of the cost of the last rehabilitation activity over the course of its expected service life. The RSL is considered as a benefit, or a negative cost that occurs at the end of the analysis period and is therefore discounted to present value and added to the present value of other cost streams.

The application of the RSL concept to agency costs of pavement preservation treatments is generally straightforward and accepted. However, the user costs associated with such activities is not as intuitively obvious [FHWA, 1998]. User costs are less definitive than agency costs, but like agency costs, there is some “benefit” or “avoidance” of user cost due to a RSL: the remaining service life of a preservation activity has the effect of deferring the next expenditure of user costs. Without RSL for user costs, the decision supported by user costs can change as the analysis period changes unless very long analysis periods are used. The FHWA states that using RSL or user costs removes bias from the analysis. The FHWA argues that the user “pain and suffering” was fully experienced and cannot be assuaged at the end of the analysis period. The subsequent imposition of user costs due to the next work zone operations is simply being delayed and some LCCA “benefit” should be recognized and taken for such deferment. Also, the FHWA cautions that User Cost RSL is not User cost salvage value as the latter does not really exist in the true sense of the word.

10.3 Salvage Value

While many sources of literature considers the terms salvage value, residual value, and remaining service life to be synonymous, the FHWA appropriately makes a clear distinction between these terms. The FHWA attaches a physical connotation to the concept of salvage value and argues that it is strictly defined as the value of recovered, recycled or scrap materials, and can only be realized when the entire pavement structure is excavated at the end of the analysis period and the pavement materials are actually reclaimed. In that case, the value of the salvage is treated as a negative agency cost.

10.4 Discounting and Inflation

Costs or benefits (in constant dollars) occurring at different points in time should not be compared without making provisions for the opportunity time value of money. In other words, even if there were no inflation, it should be realized that for instance \$1,000 today is not equivalent to \$1,000 in the next 5 years. This is because the \$1,000 could be invested and could yield some returns. Therefore

\$1,000 today has more value than \$1,000 in the next 5 years. The opportunity time value of money is therefore defined as the economic return that could be earned on funds in an alternative use, and exists independently of inflation. As such, in order to find the worth of today's \$1,000 at a future time, say 5 years from today (or to find the present day value of next 5 years' \$1,000), it is necessary to apply a *discount rate*.

Inflation, on the other hand, is the general price level increase or decrease over time, and is measured using an *inflation rate*.

LCCA expenditures that do not include an inflation component are expressed in real, constant, or base year dollars. Such expenditures are calculated from a base year using a *real discount rate* which accounts only for the opportunity cost/value of time. LCCA expenditure items that include the effects of inflation are expressed in nominal, current, or data year dollars. The FHWA states that nominal discount rates include factors for both opportunity cost/value of time and for inflation. The FHWA cautions that real costs and rates should not be mixed with nominal ones, and recommends the use of real dollars and discount rates. The FHWA further recommends the use of a real discount rate in the range of 3-5 %.

10.5 Chapter Summary

This chapter discusses selected LCCA parameters. It includes a discussion of how such parameters are computed or estimated, and also presents the relationships between such parameters and LCCA outputs as seen in previous studies.

CHAPTER 11 PROBABILISTIC CONSIDERATIONS IN LCCA

As discussed in Chapter 3, most existing LCCA software packages were developed with the assumption that the input parameters are fixed with no variation. However, in reality, there is a great deal of variation associated with the input parameters, and consequently make it difficult to predict outcomes with certainty. A great deal of variability exists in critical input parameters for pavement design (such as soil conditions and traffic growth), strategy formulation (pavement performance, treatment effectiveness (increased service life average condition)), economic analysis (treatment cost estimates and economic factors that drive the discount rate), etc.

This chapter reviews existing literature on the subjects of design reliability, risk analysis, Monte Carlo simulation, and any existing risk-based LCCA models. The chapter then proceeds to examine the details of how risk and uncertainty concepts are incorporated in FHWA's *RealCost* software.

11.1 Literature Review

Reliability Analysis

Lemer and Moavenzadeh [1971], contemplated the uncertainties involved in each aspect of the pavement design process, from planning and design to construction, operation, and maintenance. The authors discussed the significance of including reliability as a design parameter, recognizing that such a consideration has the potential to produce economically efficient pavements.

Reliability was incorporated into the 1986 AASHTO Guide for Design of Pavement Structures using concepts developed by Irick, Hudson, and McCullough [Irick et al., 1987]. Further work on reliability was carried out in the 1993 AASHTO Guide for Design of Pavement Structures [Irick et al. [1987]. It has been realized that pavement design methods can be either deterministic or probabilistic. In a deterministic design method, the designer typically assigns a factor of safety to those parameters that are uncertain or have a significant effect on the final design. However, such traditional design approaches may result in over-design or under-design, depending on the magnitudes of the safety factors applied and the sensitivity of the design procedures [Huang, 1993]. In a probabilistic pavement design method, each design parameter is described by a probability distribution, and the reliability of the design can then be evaluated.

Standard deviations or coefficients of variation have been used in the past to define probability distributions for various traffic and design parameters [Huang \[1993\]](#). The estimated standard deviations of layer thicknesses for four different paving materials are shown in Table 11-1. The estimated coefficients of variation for design period traffic prediction and for performance prediction of flexible pavements are presented in Tables 11.2 and 11.3, respectively.

Table 10-1 Standard Deviations of Layer Thickness for Flexible Pavements [Huang, 1993]

Material	Standard Deviation (inches)
Hot mix asphalt	0.41
Cement-treated base	0.68
Aggregate base	0.79
Aggregate subbase	1.25

Table 10-2 Coefficients of Variation for Design Period Traffic Prediction [[AASHTO, 1985](#)]

Description	Symbol	Coefficient of Variation (percent)
Summation of EALF over % axle distribution	$\sum p_i F_i$	35
Initial average daily traffic	ADT_o	15
Traffic growth factor	G	10
Percentage of trucks	T	10
Average number of axles per truck	A	10
Overall traffic prediction		42

Table 10-3 Coefficients of Variation for Performance Prediction of Flexible Pavements [[AASHTO, 1985](#)]

Description	Symbol	Coefficient of Variation (percent)
Initial serviceability index	p_0	6.7
Surface strength factor	a_1	10.0
Surface thickness	d_1	10.0
Base strength factor	a_2	14.3
Base drainage factor	m_2	10.0
Base thickness	d_2	10.0
Subbase strength factor	a_3	18.2
Subbase drainage factor	m_3	10.0
Subbase thickness	d_3	10.0
Subgrade resilient modulus	M_R	15.0

The reliability of a pavement design is defined in general terms as “the probability that the design will perform its intended function over its design life (or time) and under the conditions (or environment) encountered during operation” [AASHTO, 1993]. One general method for evaluating the reliability of a pavement design is to use traffic, or the number of load repetitions, as the design objective.

The theory behind the reliability concept is based on the traffic prediction, performance prediction, actual traffic, and actual performance. However, at design stage, actual traffic and performance characteristics are not known. Therefore Irick, et al. [1987] provided the following steps for applying the reliability concept to pavement design.

1. Select a performance criterion and a corresponding performance prediction equation.
2. Select values for environmental factors, soil factors, and traffic load factors and substitute the values into the design equation.
3. Select a design period and a design period traffic prediction algorithm. Derive a design period traffic prediction.
4. Select a reliability level, R , assume a process standard deviation, S_o (AASHTO recommends assuming a value of $S_o = 0.45$ for flexible pavement design), and look up the reliability factor, F_R , in a standard normal curve area table.
5. Calculate the design applications and then substitute in the design equation.
6. Calculate alternative designs and select the optimum design.

Risk Analysis

Risk analysis is a description of qualitative and quantitative methods for assessing the impacts of risk and uncertainty on decision situations. Risk analysis addresses three basic questions about risk [Palisade Corporation, 1997]:

- What are the possible outcomes?
- What is the probability of each outcome?
- What are the consequences of decisions based on the knowledge of the probability of each outcome?

Risk analysis combines probabilistic descriptions of uncertain input parameters with computer simulation to characterize the risk associated with possible outcomes [Walls and Smith, 1998; Harnett, 1975]. Most LCCA models that are currently used by state highway agencies treat input variables as discrete, fixed values, and consequently do not reflect the uncertainty that actually characterizes the values of such variables.

In conducting an LCCA, it is important to recognize the uncertainty of input variables and the uncertainty that this variability creates in the results. Such uncertainty is borne out of fluctuations in temporal and spatial characteristics in pavement materials, work quality, environment, traffic, etc., and is reflected in marked variations in costs and effectiveness values of pavement activities. The need to make strategic long-term investment decisions under short-term budget constraints forces state highway agencies to incorporate risk (either implicitly or explicitly) as a criterion in judging courses of action. Also, decision-makers need an analysis tool that exposes areas of uncertainty of which they may not be aware. Based on this new information, the decision-maker then has the opportunity to take mitigating action to decrease exposure to risk.

In effect, risk analysis allows the user to predict the probability of a specific outcome. Values of input variables such as initial construction and subsequent rehabilitation costs, treatment effectiveness (performance jumps and/or extended pavement life) discount rate, etc. are modeled using a probability distribution that best fits the data for the variable. Then, the expected outcome (net life-cycle cost) for a given set of variables and for each possible value of each variable (as defined by its probability distribution) is computed [Herbold, 2000]. This is repeated for several values of the variable within the defined probability distribution. This is easily done using Monte Carlo simulation on a personal computer.

Monte Carlo Simulation

Monte Carlo simulation is an analysis method whereby random sampling procedures are used for treating deterministic mathematical situations. The simulation process allows the user to include the inherent uncertainty associated with each input parameter into the analysis. The output of a Monte Carlo simulation is a probability distribution describing the probability associated with each possible outcome.

The general procedure for a Monte Carlo simulation is shown in Figure 10.1. First, a deterministic model is developed where multiple input variables are used to estimate a single value outcome. The user must be certain that all input parameters used in the analysis are independent of each other. Then, each independent parameter is defined by a probability distribution describing the variability associated with that particular parameter. A random trial process is then initiated to establish a probability distribution function for the deterministic situation being modeled. During each iteration of the process, a value for each parameter is randomly selected from the probability distribution defining that parameter. The random values are entered into the calculation and an output value is obtained. Numerous solutions are obtained by making multiple iterations through the program and obtaining a solution for each iteration. The appropriate number of iterations for an

analysis is a function of the number of input parameters, the complexity of the modeled situation, and the desired precision of the output. The final result of a Monte Carlo simulation is a probability distribution describing the output parameter.

Figure 10-1 General Monte Carlo Simulation Approach [Hutchinson and Bandalos, 1997]

Risk-Based LCCA Models

Only one risk-based LCCA model for pavements was found in the literature. The report by Walls and Smith [1998] recommends procedures for conducting LCCA of pavements, provides detailed procedures for determining work zone user costs, and introduces a risk-based approach to LCCA. The LCCA procedure presented by Walls and Smith [1998] includes eight steps. First, the user must derive alternative pavement design strategies for the analysis period. Next, pavement performance periods and activity timings are determined based on state highway agency experience. Using these inputs, agency and user costs are estimated. Agency costs are determined based on unit prices from previously bid jobs of comparable size. The procedures used for estimating various user cost components were presented in great detail by Walls and Smith [1998] and is described in previous sections. The next step of the LCCA procedure is to develop expenditure stream diagrams (also known as cash flow diagrams) for each pavement design strategy, which help the user to visualize the extent and timing of expenditures. The net present value for each strategy is then

computed by discounting all future costs to the base year and adding these costs to the initial cost. The next step is to analyze the results, which is accomplished by performing a sensitivity analysis on the LCCA results. Finally, the analyst uses the results from the LCCA and the sensitivity analysis to re-evaluate design strategies. The Walls and Smith report [1998] included a risk-based approach for pavement LCCA. The general approach consisted of the following steps.

- i. Identification of the structure and layout of the problem
- ii. Quantification of the uncertainty associated with each input variable using probability distributions.
- iii. Running and
- iv. Sensitivity analysis to determine the effects of various input variables on the model output.
- v. Decision (based on a combination of tolerable level of risk).

11.2 Incorporation of Risk and Uncertainty in LCCA by FHWA's *RealCost* Software

There two ways to perform LCCA: the deterministic approach, and the probabilistic approach. Each of these methods has a different way of incorporating the variability of LCCA input factors and uses different methods to investigate the uncertainty in the outputs. The deterministic approach does this using sensitivity analysis, while the probabilistic approach does it by using simulation.

With deterministic LCCA, only a single value of each input factor is used in the analysis, and the output is also a single number. On the other hand, the probabilistic approach uses a range of values for each input factor and provides a range of values for the output. The range of values for each input factor depends on the probability distribution (and associated parameters of the distribution) for that factor (Figure 11-2). The probability distribution and parameters are derived using historical data, expert opinion, and research.

Use of Sensitivity Analysis in Deterministic Approaches

In sensitivity analysis, a key input factor under investigation is varied incrementally while all other factors are held constant. Such key factors could include the cost of a treatment, the effectiveness of a treatment (FHWA's *RealCost* software utilizes service life as a measure of rehabilitation effectiveness). For each input factor, the analysis is carried out for the entire range of possible values, and the best case, worst case, and most likely case should be identified. A graphical presentation of

the results (LCCA output vs. the input factor) is useful in assessing the impact of any uncertainty of the input factor.

FHWA identifies three drawbacks to the use of sensitivity analyses:

- Difficulty of capturing effects of uncertainty among several variables at once, as combinations of discrete input changes requires a very large number of separate analyses
- Likelihood of occurrence of output values is not captured by sensitivity analyses.

Use of Simulation in Probabilistic Approaches

Unlike approaches used for incorporating uncertainty in deterministic analysis, probabilistic LCCA treats inputs as ranges of values and assigns a likelihood of occurrence to those values and also allows for simultaneous variability among inputs. The outputs of probabilistic LCCA are also ranges of values with calculated likelihoods of occurrence. This is done using simulation, a mathematical technique that captures the effect of natural variability of model inputs on results. Values are randomly sampled from input probability distribution, and each randomly selected input is used to determine a single outcome iteration.

FHWA states that the role of probability in LCCA is threefold:

- Accounts for the variability in input factors such as treatment life, costs, and discount rate, as such variation is more consistent with reality,
- Quantitatively determines the amount of risk in alternative strategy selection,
- Elevates the decision from questioning the inputs to discussing the merits of each alternative.

In absence of ready-made input data from past research, the person carrying out the LCCA needs to collect historical data and carry out a statistical analysis of such data in order to obtain the input values. Such preparatory analysis includes the drawing of frequency and cumulative frequency tables and curves, and probability and cumulative probability tables and curves, and calculation of the measures of central tendency and variability. The coefficient of variation is the standard deviation divided by the mean, and data with less variability that which is relatively close to the expected value of the data.

Figure 11-2: Relationship between Probabilistic Distributions of Input Factors and LCCA Outputs
[FHWA, 1998, 2002]

Common probability distributions that are encountered in LCCA include the normal distribution, the triangular distribution, and the uniform distribution. For any input factor, the analyst will have to plot the probability function using the raw data, and from the resulting shape of the curve, the analyst can determine the most appropriate distribution for the input factor.

After having found the distributions and statistical parameters for all key input factors, the analyst will then be in a position to carry out LCCA simulation modeling using such information. Simulation uses randomly selected sets of values from input probability distributions and calculates many discrete results which are arrayed in the form of a distribution covering all possible outputs.

A variety of tools can be used to investigate the impacts of varying the input factors on the LCCA output. *Correlation* is used to explain the relationship between the input and output variable. A positive correlation between the input and output suggests a direct relationship, while a negative correlation suggests an inverse relationship. A *tornado graph* can be used to determine the relationship of each input to the output, and displays the factors in order of the strengths and directions of their correlation with the LCCA output. *Extreme tail analysis* is used to identify the input factors that “drive” the tails of the distribution of the LCCA output by consistently producing worst case and best case scenarios.

11.3 Chapter Summary

This chapter discusses the variability that exists in critical input parameters for pavement design (such as soil conditions and traffic growth), LCCA strategy formulation (pavement performance, treatment effectiveness (increased service life average condition)), economic analysis (treatment cost estimates and economic factors that drive the discount rate), etc. The chapter also reviews existing literature on the subjects of design reliability, risk analysis, Monte Carlo simulation, and any existing risk-based LCCA models. The chapter also examines the details of how risk and uncertainty concepts are incorporated in FHWA's *RealCost* software.

CHAPTER 12 ENHANCEMENTS TO FHWA LCCA SOFTWARE PACKAGE FOR USE IN INDIANA

12.1 Introduction

A major objective of this present project is to enhance the existing FHWA's LCCA software package for Indiana so that INDOT pavement engineers can easily and conveniently analyze alternative pavement design and preservation investments. The enhanced software is based on the LCCA methodologies presented in the preceding chapters. Specifically, FHWA procedures and equations are used to perform the calculations necessary to estimate the life cycle cost of different alternatives. This chapter describes the existing FHWA software package and the enhancements made therein. The enhanced package for Indiana practice is named "*RealCost-IN*".

12.2 Description of the Existing FHWA LCCA *RealCost* Software

FHWA's LCCA software package is a comprehensive LCCA software package that is based on a Microsoft Excel spreadsheet. It has capability to carry out life cycle cost analysis of pavement design alternatives for a given analysis period. It includes detailed procedures for estimating the workzone user costs associated with a given pavement design and preservation strategy. The software requires that the user input preprogrammed rehabilitation and maintenance activities, over the analysis period with their corresponding costs. The agency and user costs are then computed using the level of time delay and other input values such as the number of days expected for construction, rehabilitation and maintenance, the number of lanes to remain open, and other aspects of traffic control and traffic volumes. The costs are then discounted to the present from which the various competing alternatives can be evaluated and the most appropriate selected. FHWA's software provides an elaborate probabilistic analysis to address the issue of uncertainty and therefore allows the decision-maker to weigh the probability of any possible outcome.

In spite its several merits and capabilities, the existing FHWA LCCA software has a few limitations that include the following:

1. The current version is not flexible to accommodate different overall analysis periods for different alternatives
2. Software can handle only two alternatives at a time

3. Value of some inputs (such as travel time value) time not automatically updated to future years using appropriate CPI.
4. Trigger values (an alternative to “activity life”) are not considered for use as an alternative treatment timing criteria in the formulation of rehabilitation and maintenance strategies.
5. User is not provided a default or modifiable set of pavement design alternatives that are typical of INDOT practice.
6. User is not provided a set of pavement rehabilitation and maintenance strategies (typical of Indiana practice) over life cycle, nor is the User provided a form through a desired set of strategies may be input.
7. User is not provided an automated method to compute agency costs on the basis of line items and their unit rates based on reliable data such as historical INDOT records of such contractual work activities.

12.3 The New *RealCost-IN* Software (Modified *RealCost* for Indiana Practice)

In view of the above limitations, the FHWA software was enhanced as part of the present study, to adapt it for use by INDOT for purposes of pavement investment decision support. With such enhancements, the new software is now more versatile, flexible and specific to Indiana practice. The enhanced software was written using Microsoft Visual Basic.NET, and Structured Query Language (SQL). The program is a PC-based Windows program, and can run in either the Windows 9X or the Windows XP environments.

12.3.1 Enhancements Made to the FHWA *RealCost* LCCA Software

The implemented enhancements include a mechanism for the user to estimate the cost of each construction or preservation activity on the basis of line items and their unit rates, instead of determining such costs independently and importing them as inputs for the software as required by the existing FHWA package. The major sources of the unit cost rates were the contracts files at INDOT Program Development Division, values of unit pay items obtained from the INDOT website, and data from the Unit Rates File in the AASHTO *Estimator* package.

Another enhancement was in the form of menus of default strategies for rehabilitation and maintenance. Such strategies are modifiable by the user. Given a strategy, the software estimates the associated agency and user costs. Other enhancements made to the software included improved graphics, enhanced reporting of analysis results, and capability to simultaneously carry out analysis

for more than two alternatives. A User Manual was prepared to facilitate the use of the enhanced software.

An important issue in life-cycle cost analysis is the relationship between the *values* of agency cost and user cost. Agencies that directly add agency costs to user costs implicitly assume that \$1 of agency cost is equivalent to \$1 of user cost, i.e., the Agency-User Cost-Value Ratio (AUCVR) is equal to 1. However, there is a school of thought that is averse to direct summation of these two cost categories and has argued that only a fraction of user costs should be considered and added to the agency costs. But what fraction should be used? In other words, what is the true AUCVR? With current lack of a universally accepted AUCVR value, some practitioners recommend that the agency and user costs should not be added but should be displayed side-by-side for the decision-maker to examine and make a decision. This may lead to inconsistent decisions across time or across decision-makers. In the present study, the FHWA software was enhanced to allow user to specify the percentage of the user cost to be used in the analysis. Such flexibility enhances the user's ability to interactively determine the most appropriate proportion of the user costs to consider for the analysis. The enhanced software also displays the results of agency costs and user costs separately in the form of bar charts.

The enhanced LCCA methodology and software are useful for (i) identifying alternative INDOT pavement designs, (ii) identifying or developing alternative strategies for pavement rehabilitation and maintenance for a given pavement design, (iii) estimating the life-cycle agency and user costs associated with a given design alternative and preservation strategy, (iv) selecting the optimal combination of design and preservation strategies over a given analysis period. The enhanced methodology and software are applicable to existing pavements in need of some rehabilitation treatment, and also for planned (new) pavements.

Figures 12-1 to 12-10 present snapshots of user interfaces for pavement design and preservation strategy selection, agency cost estimation, workzone user cost configuration, and deterministic and probabilistic outputs in the enhanced software.

This screen is used to select all the various components of the analysis. It also has administrative functions for saving and opening LCCA projects.

Figure 12-1: Revised Main Menu (Switchboard)

Alternatives

Alternative Name: Initial Activity:

Pavement Structure

Layer	Application	Unit ID	Pavement Layers/Binders
1	1	P-UNIT	QC/QA-PCCP, 15 IN.
2	9	INCH	SUBBASE FOR PCCP
3	1	LFT	D-1 CONTRACTION JOINT (Transvers + Longitudinal)
*			

PCC Pavement

Pavement Treatment Strategy

Treatment Strategy	Agency Cost
NEW ROAD CONSTRUCTION (PCCP)	\$335,996
PCCP CLEANING AND SEALING JOINTS 15%-48	\$1,813
PCCP CLEANING AND SEALING JOINTS 60%-17	\$2,417
PCCP CLEANING AND SEALING JOINTS 60%-49	\$3,625
BATCH PCCP & HMA OVERLAY FUNCTIONAL-3.5'-5'-30	\$98,577
HMA OVERLAY FUNCTIONAL-3.5'-30	\$77,192
MILL ASPHALT & HMA OVERLAY FUNCTIONAL-3.5'-50	\$77,048

Powered by Dundas Chart

This form is for adding new alternatives for analysis by selecting the initial activity, type of pavement and other pavement properties. It also provides a link to select the desired pavement.

Figure 12-2: Form for Adding Alternative Scenarios for Pavement Design and Preservation

Generate Strategies

Select Method

☒ Preset Time Intervals ☐ Pavement Condition

Treatment Strategies

Pavement Treatment Strategies	
No.	Strategy
25	HMA-1
26	HMA-2
27	PCC-1
28	PCC-2
29	PCC-3
*	

+ Add ✎ Edit - Delete

Strategy Activity Profile

Activity Profile	
Year	Treatment
0	NEW ROAD CONSTRUCTION (FULL DEPT)
7	CRACK SEALING (5%)
15	CRACK SEALING (10%)
20	HMA OVERLAY, FUNCTIONAL-3.5"
27	CRACK SEALING (5%)
35	CRACK SEALING (10%)
40	HMA OVERLAY, FUNCTIONAL-3.5"
47	CRACK SEALING (5%)
55	CRACK SEALING (10%)
*	

✓ OK... ✕ Cancel

This form is for selecting the desired pavement treatment strategy for the alternatives. It also enables users to edit, add or delete strategies.

Figure 12-3: Form for Selecting Strategies for Pavement Preservation

Pavement Treatments

No.	Treatment	Initial
1	CONCRETE PAVEMENT RESTORATION	☐
2	CRACK & SEAT CMP & HMA OVERLAY-4"	☒
3	CRACK & SEAT CMP & HMA OVERLAY-6"	☒
4	CRACK & SEAT PCCP & HMA OVERLAY-6"	☒
5	CRACK SEALING (10%)	☐
6	CRACK SEALING (5%)	☐
7	DIAMOND GRINDING	☐
8	HMA OVERLAY, FUNCTIONAL-3"	☒
9	HMA OVERLAY, FUNCTIONAL-3.5"	☒
10	HMA OVERLAY, PM	☐
11	HMA OVERLAY, STRUCTURAL-4"	☒
12	HMA OVERLAY, STRUCTURAL-5"	☒
13	HMA OVERLAY, STRUCTURAL-6"	☒
14	MILL & ACQUAT & HMA OVERLAY, FUNCTIONAL 3.5"	☒

Add Treatment Delete Treatment

Pay Items

Layer	Application	Unit ID	Pay Items	Unit	Unit Cost
1	90	KG/M2	QC/QA-HMA, 5, 76, SURFACE, 9.5 mm	TON	\$56.22
2	1	P-UNIT	ASPHALT FOR TACK COAT (R)	SYS	\$.04
3	150	KG/M2	QC/QA-HMA, 5, 76, INTERMEDIATE, 19 mm	TON	\$45
4	1	P-UNIT	ASPHALT FOR TACK COAT (R)	SYS	\$.04
*					

+ Add Pay Item(s) Update Pay Items - Delete Pay Item OK Cancel

This form is for modifying the various pavement treatments. It also enables users to edit, add or delete the treatments in addition selecting the corresponding pay items for each treatment.

Figure 12-4: Form for Specifying Preservation Treatment-specific Details

Pay Items

Pavements

Treatment Name: HMA OVERLAY, FUNCTIONAL-3.5"

List of Pay Items

Select	Description	Unit	Unit Cost
☒	QC/QA-HMA, 5, 76, INTERMEDIATE, C19 mm	TON	\$33.46
☐	QC/QA-HMA, 5, 76, INTERMEDIATE, C25 mm	TON	\$34.4
☐	QC/QA-HMA, 5, 76, SURFACE, 9.5 mm	TON	\$56.22
☐	QC/QA-PCCP	SYS	\$1.11
☐	QC/QA-PCCP, 10 IN.	SYS	\$40
☐	QC/QA-PCCP, 11 IN.	SYS	\$20.17
☐	QC/QA-PCCP, 12 IN.	SYS	\$32
☐	QC/QA-PCCP, 14 IN.	SYS	\$35.33
☐	QC/QA-PCCP, 15 IN.	SYS	\$28.5
☐	REINFORCING BARS, EPOXY COATED	LBS	\$1
☐	REINFORCING STEEL	LBS	\$0.75
☐	REINFORCING STEEL, EPOXY COATED	LBS	\$0.65
☐	REINFORCING STEEL, EPOXY COATED, GRADE 6	LBS	\$0.52
☐	REINFORCING STEEL, GRADE 60	LBS	\$0.45
☐	RUBBLIZED PCCP	SYS	\$4.13
☐	SAWING	SYS	\$5
☐	SUBBASE FOR CEMENT CONCRETE PAVEMENT	CYS	\$42.5
☐	SUBBASE FOR PCCP	CYS	\$29.22
☐	SURFACE MILLING	SYS	\$2.69
☐	SURFACE MILLING, ASPHALT	SYS	\$0.38
☐	SURFACE MILLING, PORTLAND CEMENT CONCRE	SYS	\$8.41
*			

This form is for selecting the corresponding pay items for each pavement treatment.

Figure 12-5: Form for Specifying Pay Items for Preservation Treatments

The screenshot shows a software window titled "frmWzone" with a standard Windows-style title bar (minimize, maximize, close buttons). The window is divided into several sections:

- Pavement Treatments:** A list box containing various pavement treatment options. The selected item is "MILL ASPHALT & HMA OVERLAY, FUNCTIONAL-3.5". Other visible items include ASPHALT PATCHING, PCCP PATCHING, CRACK SEALING (10%), CRACK SEALING (5%), DIAMOND GRINDING, PCCP CLEANING AND SEALING JOINTS (10%), PCCP CLEANING AND SEALING JOINTS (15%), PCCP CLEANING AND SEALING JOINTS (20%), PCCP CLEANING AND SEALING JOINTS (30%), SURFACE TREATMENT, PM, HMA OVERLAY, PM, HMA OVERLAY, FUNCTIONAL-3", HMA OVERLAY, FUNCTIONAL-3.5", PATCH PCCP & HMA OVERLAY, FUNCTIONAL-3.5", HMA OVERLAY, STRUCTURAL-4", HMA OVERLAY, STRUCTURAL-5", HMA OVERLAY, STRUCTURAL-6", MILL ASPHALT, PATCH PCCP & HMA OVERLAY, S, and CONCRETE PAVEMENT RESTORATION.
- Properties:** A section with three input fields:
 - Workzone Length: 1 mi
 - Workzone Speed: 45 mph
 - Workzone Capacity: 1470 vplph
- Workzone Duration:** A section with two radio buttons:
 - ☐ Calculate (Unknown)
 - ☒ Specify (Known) 560 days
 Below the radio buttons is a dropdown menu labeled "Select Workzone Duration Category".
- Lane Closure Periods:** A section with a table for specifying lane closure periods for Inbound and Outbound traffic. The table has 3 rows and 2 columns (Inbound and Outbound). The first row shows values 0 and 23 for both directions. The second and third rows are empty.

	Inbound	Outbound
1	0	23
2		
3		

At the bottom of the window, there are three buttons: "Update Workzone Configuration", "OK", and "Cancel".

This form is for configuring the workzone activities for the various pavement treatments

Figure 12-6: Form for Specifying Treatment-specific Work Zone Details

This gives the results of the analysis. The output also gives the percentage difference between the various alternatives

Figure 12-7: Form for Displaying Results of Deterministic Analyses

The screenshot shows a 'Simulation Analysis' dialog box with the following sections:

- Select Alternative:** A table with columns 'Select' and 'Alternative'.

Select	Alternative
☒	ALTERNATIVE-1
☒	ALTERNATIVE-2
☐	ALTERNATIVE-3
☐	ALTERNATIVE-4
☐	ALTERNATIVE-5
*	

 Below the table is a field for 'Agency Costs Variability' set to 12.50 %.
- Sampling Scheme:**
 - ☒ Random Results
 - ☐ Reproducible Results
 - Seed Value: 2000
- Tail Analysis Percentiles:**
 - Percentile 1: 5
 - Percentile 2: 10
 - Percentile 3: 90
 - Percentile 4: 95
- Iteration:**
 - Number of Iterations: 100
 - Monitor Convergence: ☐
 - Monitoring Frequency (Number of Iterations): 50
 - Convergence Tolerance (%): 2.5
- Status Bar:**
 - Text: 'Checking Input Data for Alternative 2' followed by progress for rows 1-6 (25% to 42% complete) and 'Simulating...'.
 - Progress bar: 64% complete.
 - Buttons: 'Simulate' and 'Close'.

This shows the input form for the probabilistic analysis. The probabilistic outputs are obtained by running the simulation from this form.

Figure 12-8: Probabilistic Input Form

This gives the results of the probabilistic analysis. The output shows the probability density functions and cumulative distribution functions, for agency and user costs of the two alternatives analyzed.

Figure 12-9: Form for Displaying Results of Probabilistic Analyses

This form gives the output distributions of the probabilistic analysis. The output distributions show the correlation coefficients of the outputs indicating the sensitivity of outputs to changes in the inputs.

Figure 12-10: Form for Displaying Output Distributions of Probabilistic Analyses

CHAPTER 13 CASE STUDIES- LCCA FOR PAVEMENT DESIGN

13.1 Details of the Inputs

A set of pavement design alternatives (and rehabilitation and maintenance strategies) were selected and used to demonstrate the use of *RealCost-IN*, the enhanced FHWA LCCA software package. This was done using actual data on traffic and other attributes at a given pavement section located in the state of Indiana. Input data on costs were from actual contract databases at INDOT. These case studies are presented only for purposes of illustration, and not for decision-making. A brief description of the alternatives is hereby provided:

Alternative 1: Construct an 11-inch PCC pavement, and at an appropriate point during the pavement life, rehabilitate the pavement by rubblizing the PCC slab and applying a 4-inch HMA overlay.

Alternative 2: Construct a 15-inch QC/QA AC Pavement, at an appropriate point during the pavement life, and carry out one rehabilitation activity (mill 1.5 inches and HMA Overlay 4 inches)

Alternative 3: Construct a 11-inch PCC pavement and carry out an unbonded PCC overlay within the pavement life.

To illustrate the input data, activity profiles for each alternative, using the *RealCost-IN* software package are presented in the following section.

ALTERNATIVE -1

New Full depth HMA – 15"	<u>Project Details</u>
<div style="display: flex; flex-direction: column; align-items: flex-start;"> <div>1.5" QC/QA HMA Surface</div> <div>2.5" QC/QA HMA Intermediate</div> <div>4" QC/QA HMA Base</div> <div>3" QC/QA HMA Intermediate</div> <div>4" QC/QA HMA Base</div> </div>	<div>State Route US-231</div> <div>Beginning MP 0</div> <div>Ending MP 6.27</div> <div>Number of Lanes for each direction 2</div> <div>Lane Width (ft) 12.00</div> <div>Analysis Period (Years) 40</div> <div>Discount Rate (%) 4.0</div>

ALTERNATIVE -2

<p>New PCCP – 11" (Rubblize)</p> <p>11" PCCP</p> <p>9" Subbase</p>	<p><u>Project Details</u></p> <table> <tr> <td>State Route</td><td>US-231</td></tr> <tr> <td>Beginning MP</td><td>0</td></tr> <tr> <td>Ending MP</td><td>6.27</td></tr> <tr> <td>Number of Lanes for each direction</td><td>2</td></tr> <tr> <td>Lane Width (ft)</td><td>12.00</td></tr> <tr> <td>Analysis Period (Years)</td><td>40</td></tr> <tr> <td>Discount Rate (%)</td><td>4.0</td></tr> </table>	State Route	US-231	Beginning MP	0	Ending MP	6.27	Number of Lanes for each direction	2	Lane Width (ft)	12.00	Analysis Period (Years)	40	Discount Rate (%)	4.0
State Route	US-231														
Beginning MP	0														
Ending MP	6.27														
Number of Lanes for each direction	2														
Lane Width (ft)	12.00														
Analysis Period (Years)	40														
Discount Rate (%)	4.0														

ALTERNATIVE -3

<p>New PCCP – 11" (PCC Overlay)</p> <p>11" PCCP</p> <p>9" Subbase</p>	<p><u>Project Details</u></p> <table> <tr> <td>State Route</td><td>US-231</td></tr> <tr> <td>Beginning MP</td><td>0</td></tr> <tr> <td>Ending MP</td><td>6.27</td></tr> <tr> <td>Number of Lanes for each direction</td><td>2</td></tr> <tr> <td>Lane Width (ft)</td><td>12.00</td></tr> <tr> <td>Analysis Period (Years)</td><td>40</td></tr> <tr> <td>Discount Rate (%)</td><td>4.0</td></tr> </table>	State Route	US-231	Beginning MP	0	Ending MP	6.27	Number of Lanes for each direction	2	Lane Width (ft)	12.00	Analysis Period (Years)	40	Discount Rate (%)	4.0
State Route	US-231														
Beginning MP	0														
Ending MP	6.27														
Number of Lanes for each direction	2														
Lane Width (ft)	12.00														
Analysis Period (Years)	40														
Discount Rate (%)	4.0														

Figure 13-1 Pavement Design Alternatives for the Case Study

Table 13-1 Input Data – Traffic Characteristics

Cars as Percentage of AADT (%)	85
Single Unit Trucks as Percentage of AADT (%)	6
Combination Trucks as Percentage of AADT (%)	9
Annual Growth Rate of Traffic (%)	1.55
Speed Limit Under Normal Condition (mph)	45
No of Lanes in Each Direction During Normal Operation	2
Free Flow Capacity (vphpl)	2047
Rural/Urban	Urban
Queue Dissipation Capacity (vphpl)	1800

Table 13-2 Input Data - Agency Costs

Pavement Treatment	Cost per lane mile (\$1000s)	Total Cost (\$1000s)
New Full Depth HMA - 15"	\$ 309.07	\$ 7,751.54
New PCC Pavement - 11"	\$ 443.41	\$ 11,120.81
Mill 1.5" & HMA Overlay "4"	\$ 93.67	\$ 2,349.13
HMA Overlay, PM	\$ 34.24	\$ 858.71
HMA Overlay, Functional	\$ 77.19	\$ 1,935.97
Rubblize Existing PCCP and HMA Overlay, Structural	\$ 120.07	\$ 3,011.24
PCC Pavement on Existing PCCP	\$ 253.09	\$ 6,347.47
Crack Sealing (5%)	\$ 0.57	\$ 14.21
PCCP Cleaning and Sealing Joints (15%)	\$ 2.42	\$ 60.61

Table 13-3 Input Data - Workzone Characteristics

Pavement Treatment	Workzone Length (miles)	Workzone Speed Limit (mph)	Workzone Period (hours)
New Full Depth HMA - 15"	1	30	0 - 24
New PCC Pavement - 11"	1	30	0 - 24
Mill 1.5" & HMA Overlay "4"	1	30	0 - 24
HMA Overlay, PM	1	30	0 - 24
Rubblize Existing PCCP and HMA Overlay, Structural	1	30	0 - 24
PCC Pavement on Existing PCCP	1	30	0 - 24
Crack Sealing	1	30	0 - 5 21 - 24
PCCP Cleaning and Sealing Joints	1	30	0 - 5 21 - 24

Figure 13-2: Activity Profiles for Each Alternative

13.2 Output Details

The following section presents the LCCA outputs for each alternative, using the enhanced software package for Indiana.

Deterministic Results

The deterministic results for the case study are shown in the figure below. The results indicate that the HMA pavement (Alternative 2) has the lowest present value total cost for a traffic volume of 32,149 vpd.

Figure 13-3: LCCA Results – Agency and User Costs (AADT = 32,149 vpd)

For an increased level of traffic on the roadway (AADT = 45,687 vpd), the results indicate that the second PCC pavement alternative (Alternative 3) has the lowest present value total cost. The results of the analysis are shown below.

Summary							
Present Worth of Costs				Percentage Differences			
Alternatives	Agency Cost	User Cost	Total Cost	Agency Cost	User Cost	Total Cost	
► PCC PAVEMENT-1	\$12,265	\$16,084	\$28,349	%	%	%	
HMA PAVEMENT-1	\$9,754	\$24,362	\$34,115	-26%	34%	17%	
PCC PAVEMENT-2	\$13,197	\$14,209	\$27,406	7%	-13%	-3%	
*							

Method	LCCA Results
☒ Present Worth of Costs	Lowest Present Value Agency Cost HMA PAVEMENT-1
☐ Equivalent Uniform Annual Costs	Lowest Present Value User Cost PCC PAVEMENT-2
	Lowest Present Value Total Cost PCC PAVEMENT-2

Figure 13-4: LCCA Results – Agency and User Costs (AADT = 45,687 vpd)

Probabilistic Results

The probabilistic results for the case study using a traffic volume of 32,149 vpd are shown in the figure below.

Figure 13-5: LCCA Results – Probabilistic Results (Alternatives 1 & 2)

The probabilistic results above show an analysis between Alternative 1 (PCC Pavement-1) and Alternative 2 (HMA Pavement-1).

The following probabilistic results above show the analysis between Alternative 2 (HMA Pavement-1) and Alternative 3 (PCC Pavement-2).

Figure 13-6: LCCA Results – Probabilistic Results (Alternatives 2 & 3)

13.3 Chapter Summary

Using a set of pavement design alternatives and preservation strategies, this chapter demonstrated how the enhanced FHWA LCCA software package (*RealCost-IN*) could be used. Unlike the existing FHWA package, *RealCost-IN* allows the user to input and view customized pavement design and preservation strategies in an interactive manner. For the case study, an actual existing pavement section was used. Actual data on traffic and other attributes at the pavement section were also input in the software. Input data on costs were from actual contract databases at INDOT. Default input data were used where actual data items were not available.

These case studies were presented only for purposes of illustration, and not for decision-making. Several additional case studies where the enhanced software was used to analyze various pavement design and preservation are provided in the Technical Manual (provided as an addendum to this report).

CHAPTER 14 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

14.1 General Summary and Conclusions

The need for LCCA procedures in pavement design and management has come of age because many highway pavements in Indiana are nearing the end of their service lives, are experiencing unprecedented levels of traffic loading, and face uncertainty of sustained funding for their replacement, rehabilitation and maintenance. In this regard, LCCA, a technique founded on economic analysis principles, is useful because it enables evaluation of overall long-term economic efficiency between competing alternative investments and consequently has important applications in pavement design and management. LCCA driving forces include (i) ISTEA 1991 which required the consideration of life-cycle costing in pavement design and engineering, (ii) NHS Designation Act of 1995 which required states to conduct LCCA and Value Engineering Analysis on NHS projects whose costs exceeded a certain threshold, (iii) TEA-21 which removed the NHS Act LCCA requirements but required the development of LCCA procedures on NHS projects, and (iv) Governmental Accounting Standards Board Statement 34 which established new financial reporting requirements for agencies to ensure proper management of state assets, appropriate use of public resources, and operational accountability.

A review of available literature has shown that more cost-effective long-term pavement investment decisions could be made with adoption of LCCA principles. Since 1997, Chapter 52 of the Indiana Design Manual has included a detailed section on the use of LCCA, but does not include the impact of user costs. As such, highway user costs during regular highway usage as well as during work-zone periods, for instance, are not always included in the state's pavement investment decisions. Also, there is a need to enhance FHWA's existing LCCA software in order to make it more versatile, more flexible and more specific to the needs of Indiana, particularly with regard to cost estimation of various treatments using local historical data, and development of alternative feasible strategies (treatment types and timings) for pavement rehabilitation and maintenance.

The present study documented or developed several sets of alternative pavement design, rehabilitation, and maintenance strategies consistent with existing or foreseen Indiana practice. This was done using two alternative criteria: trigger values (thresholds based on pavement condition) and

preset intervals of time (based on treatment service lives). These strategies were developed using a variety of tools such as review of historical data, existing standards in the INDOT Design Manual, and a survey of experts. The study also developed an automated mechanism for estimating the costs of various treatments that comprise a strategy, on the basis of INDOT contractual unit rates and line items. As an alternative, treatment cost estimation was also done using aggregate (per lane-mile) historical contractual costs for each treatment type. The study also carried out enhancements to FHWA's existing LCCA software package in a bid to render it more applicable to Indiana practice. Users of the software in Indiana are hereby afforded an easy means to input various pavement design, rehabilitation and maintenance strategies over a selected life cycle, and also to compute the costs of treatments that constitute a strategy.

The present study was geared towards the development rather than application, of a methodology. As such, the findings of the study relate to the feasibility of the developed methodology for its intended purposes and not to identification of specific optimal practices using the developed methodology. However, it is expected that the determination of the optimal mix of pavement design, rehabilitation and maintenance strategy will be addressed at the implementation stage. It was found that with a few enhancements, FHWA's existing LCCA methodology can be adapted for use by INDOT to provide decision support for pavement investments in the state. The present study proceeded to make such enhancements to the existing FHWA methodology and software and has thus rendered it more versatile, more flexible and more specific to Indiana practice. Such enhancements are in the form of a mechanism for the user to estimate the cost of each construction or preservation activity on the basis of line items and their unit rates, instead of determining such costs independently and importing them as inputs for the software as required by the existing FHWA package. Another enhancement was in the form of menus of available strategies for rehabilitation and maintenance. Such menus could be modified by the user. Given a strategy, the software determines the agency and user costs associated with the strategy. Other enhancements made to the software included improved graphics, enhanced reporting of analysis results, and capability to simultaneously carry out analysis for more than two alternatives. A User Manual was prepared to facilitate the use of the enhanced software.

The enhanced LCCA methodology and software are useful for (i) identifying alternative INDOT pavement designs, (ii) identifying or developing alternative strategies for pavement rehabilitation and maintenance in Indiana, (iii) estimating the life-cycle agency and user costs associated with a given strategy under consideration, (iv) evaluating alternative combinations of pavement design, rehabilitation and maintenance and (v) selecting the optimal combination over a

given analysis period. The enhanced methodology and software are applicable to existing pavements in need of some rehabilitation treatment, and also for planned (new) pavements.

Determination of certain vital LCCA input information (such as trigger values and preservation treatment service lives) is a pavement management issue. As such, it was not within the scope of the present study. The values and methodologies herein presented for determining trigger values and service lives are intended for use only as a guide, and are not binding. These inputs need to be further investigated by INDOT PMS before they can be implemented in LCCA for INDOT pavement design procedures. This report discusses the issue of trigger values and preservation treatment effectiveness in the context of past studies in Indiana and elsewhere and sheds light on how existing values of such key LCCA inputs currently used at INDOT may be updated by the PMS operators to reflect current loading patterns, materials and technology.

It is important to realize that in its current form, the LCCA methodology may be used for comparisons across pavement design alternatives provided appropriate preservation strategies are input for each alternative design. On the other hand, within each pavement design, the methodology appears to favor parsimonious preservation strategies (such strategies obviously are least expensive) that are not adequately penalized for their resulting inferior pavement condition over the life cycle. As such, future enhancements to the LCCA methodology and software may include a way to include the quantitative or qualitative consequences (costs) of inferior pavement condition to duly penalize preservation strategies that comprise relatively few or minor treatments, and the use of appropriate economic efficiency indicators to adequately incorporate such quantitative or qualitative costs.

The products of the present study are in the form of (i) a study report that documents the entire research effort including a review of available literature and similar packages for LCCA, documentation of existing pavement design alternatives, development of alternative rehabilitation and maintenance strategies, agency and user cost analysis, and (ii) an LCCA software package which is an enhanced version of the FHWA's LCCA package, for consistency with Indiana practice, and (iii) a Users Manual for the software package.

Implementation of the study results would entail using the software package to develop and evaluate the life cycle agency and user costs associated with a given pavement design alternative, and therefore to select pavement design (as well as the types and timings of rehabilitation and maintenance treatments over life-cycle) for any specific pavement section in the state of Indiana. Also, implementation would entail the revision of the Indiana Design Manual to include other LCCA issues such as review of treatment service lives using historical data and the methodology presented in this chapter.

Personnel from INDOT's Pavement Design office (of the Materials and Tests Division), Pavement Management Unit of the Program Development Division worked with the research team and the Study Advisory Committee (SAC) throughout the project and are expected to play lead roles in the implementation process. Other divisions that may be expected to be directly or indirectly associated with the study implementation are the Operations Support Division, Design Division, and the Systems Technology Division.

Specifically, INDOT's pavement design team is hereby afforded a decision-support tool for their selection of an appropriate design for a given pavement section in Indiana on the basis of life-cycle agency and user costs. Also, given a planned or existing pavement design, INDOT's PMS operators are hereby given a tool that could help in deciding the best combination of rehabilitation and maintenance types and timings over the life or remaining life of the pavement. At the current age of overall asset management where it is sought to integrate maintenance and pavement management, it is expected that personnel at INDOT's Operations Support Division would take due cognizance of LCCA recommended maintenance treatments for a given new or existing pavement and would tie in their work programs in a manner that avoids duplication or wastage. Furthermore, any long-term needs assessment by INDOT could be done on the basis of optimal practice as determined by the LCCA package, rather than using current practice. Furthermore, INDOT's System Technology Division are expected to play a leading role in implementing the study product because they would be responsible for maintaining the enhanced software and to provide the necessary supporting hardware.

LCCA study results have a bearing on the programming of pavement work. With LCCA, INDOT's Pavement Management Unit and Planning Division can have better justification for any planning and prioritization of pavement work.

The initial effort towards implementing the study products should focus on further strengthening of existing links between INDOT's pavement design unit, pavement management unit, the Operations Support Division, and the Pavement Steering Committee.

14.2 Areas of Recommended Revisions to the INDOT Design Manual Pavement

LCCA Section (Chapter 52)

14.2.1 Definitions

In the “Definitions” sub-section of Section 52-12.02 of the Design Manual, additional definitions could include the following LCCA concepts:

User Cost: Costs incurred by the users of the highway facility. User cost types include vehicle operating costs, delay costs and crash costs. User costs may be incurred during workzone situations or during normal operations of the highway.

Rehabilitation and Maintenance Strategy: The set of rehabilitation treatment types applied at selected times during the life cycle of a pavement, for a given pavement design alternative.

Remaining Service Life: This is the service life or performance that remains beyond the end of the analysis period, for a given alternative.

Deterministic LCCA: This is a traditional approach that applies LCCA procedures and techniques without regard to the variability of the inputs. Deterministic analysis involves the use of a single (most likely) value of each input variable and result in a single set of LCCA outputs.

Probabilistic (Stochastic) LCCA: This approach gives due consideration to the variability of the LCCA input variables. This is also often referred to the “risk analysis” approach. It involves the use of probability distributions of the input variables with computer simulations to generate a range of possible outcomes, each outcome with its likelihood of occurrence.

Sensitivity Analysis: Variation in the level of an input parameter and determining the impact of each level on the LCCA output.

Workzone Operating Conditions: A description of the interaction between work zone status and traffic demand. There are four operating conditions: removed workzone with no queue, removed workzone with queue, existing workzone with queue, and existing workzone with no queue.

Furthermore, as agreed by the SAC during a 2003 meeting, the term *preservation* could be included in the list of LCCA definitions, Section 52-12.02 of the INDOT Design Manual as follows:

Preservation: Any rehabilitation or maintenance treatment applied with an intend to increase pavement condition or extending service life.

14.2.2 Service Lives of Various Preservation (Rehabilitation and Maintenance) Treatments

The “LCCA Design Life” sub-section of Section 52-12.02 of the Design Manual lists the service lives of various treatments. It is not certain how such values were obtained. However, there may be a current need to (i) update the list to reflect any new preservation treatments, (ii) update such service lives in light of improved materials and construction processes that may translate to service lives higher than those currently indicated in the manual. With regard to new preservation treatments, INDOT’s pavement steering committee has developed a new list of standard treatments for which service lives may be determined. The issue of service life determination of preservation treatments is an interesting one, and there are quite a few methodologies that can be used to estimate the service life of pavement preservation treatments, as shown in Chapter 6. At the current time, data of adequate temporal span are not available to implement these methodologies in order to obtain the treatment service lives. However, such methodologies may be used at a future time to determine service lives of current preservation treatments, and to subsequently update the values provided in INDOT Design Manual.

14.2.3 Costs of Various Preservation (Rehabilitation and Maintenance) Treatments

The third paragraph of the “LCCA Design Life” sub-section of Section 52-12.02 of INDOT’s Design Manual states that, “The Materials and Tests Division’s Pavement Design Engineer will maintain a listing of the costs for various maintenance or rehabilitation options identified as part of the proposed LCCA. The designer should utilize these costs to compare life-cycle costs of different pavement treatments.”

The present study appropriately makes available such information for the INDOT Pavement Design Engineer. The costs of various high level preservation treatments (rehabilitation and contractual maintenance activities) are provided at various sections of Chapter 8. All reported cost values are provided as mean values (as well as the standard deviations, minima and maxima) of the treatments using historical data in Indiana. Appendix 2 presents updated historical unit costs of line items that the Pavement Design Engineer may find useful in agency cost determination.

14.2.4 Inclusion of User Costs in LCCA

It is recommended that a section on highway user costs estimation be added to the INDOT Design Manual. Chapter 9 of the present report provides relevant information on user cost estimation for LCCA and other related issues, and may be summarized and inserted into the design manual for this purpose. Inclusion of user costs would enable a more balanced evaluation of competing alternatives.

An important issue in life-cycle cost analysis is the relationship between agency cost and user cost. There is a school of thought that is averse to direct summation of these two cost categories because doing so would be consistent with the implicit assumption that \$1 of agency cost is equivalent to \$1 of user cost. It has been suggested that only a fraction of user costs should be considered and added to the agency costs. But what fraction of the total estimated user cost should be used? 25%, 50%, 75%? Currently, there seems to be no consensus on the best fraction to use, and many analysts typically proceed with the use of a user cost fraction of 100%, and therefore go ahead to add agency cost directly to user cost to obtain overall cost, for each alternative.

The enhanced FHWA *RealCost* software, provides the Users with the flexibility to choose their user cost fraction, and also enables a sensitivity analysis of various user cost fractions on the LCCA output.

14.2.5 Mention of the INDOT-LCCA (the enhanced version of the FHWA LCCA Package)

Another recommended addition to the INDOT Design Manual is the mention of the availability of a software tool, *INDOT-FHWA RealCost*, or *RealCost-IN* which is now available to the INDOT Pavement Steering Committee for decision support in pavement investment decisions.

REFERENCES

- AASHTO. (1986). Guide for Design of Pavement Structures, American Association of State Highway and Transportation Officials, Washington, D.C.
- AASHTO. (1993). Guide for Design of Pavement Structures Part 1, Chapter 3, Life Cycle Cost Analysis for Pavements. American Association of State Highway and Transportation Officials, Washington, D.C.
- Al-Mansour, A.I., and Sinha, K.C., (1994). Economic Analysis of Effectiveness of Pavement Preventive Maintenance, Transportation Research Record 1442, Transportation Research Board, National Research Council, Washington, D.C.
- Anderson, D.I., Peterson, D., Sheppard, L.W., Sy, C.C. (1979). Pavement Design and Rehabilitation Strategies, Project FHWA/UT-79-6, Utah DOT, Government Publications Clearinghouse, Springfield, VA.
- ASTM (1998). American Society of Testing and Materials. Standard Test Method for Airport Condition Index Surveys. D5340-93, Volume 0.403.
- Beckman Center, (1998), Get In, Get Out, Stay Out, Proceeding of The Workshop on Pavement Renewal for Urban Freeways, Irvine, CA.
- Brakey, B. A., (2000). Guidelines for Selection of Rehabilitation Strategies for Asphalt Pavement. Research Report No. CDOT-DTD-R-2000-8, Colorado DOT, Denver, CO.
- Brown, E.R. (1988). Preventive Maintenance of Asphalt Concrete Pavements, Transportation Research Record 1205, Transportation Research Board, National Research Council, Washington D.C.
- Chen, X., Hudson, S., Cumberledge, G., and Perrone, E. (1995). Pavement Performance Modeling Program for Pennsylvania, Transportation Research Record 1508, Transportation Research Board, National Research Council, Washington, D.C.
- Chong, G., and Phang, W.A. (1988). Improved Preventive Maintenance: Sealing Cracks in Flexible Pavements in Cold Regions. Transportation Research Record 1205, Transportation Research Board, National Research Council, Washington, D.C.
- Collura, J., Spring, G., and Black, K.B., (1993). Service Lives and Costs of Local Highway Maintenance and Rehabilitation Treatments, Transportation Research Record 1397, Transportation Research Board, National Research Council, Washington, D.C.
- Corvetti, J.A., and Owusu-Ababio, S. [1999]. Investigation of Fesible Pavement Design Alternatives for WISDOT, Report Nr. WI/SPR 15-99, Madison, WI.
- Curry, D.A. and D.G. Anderson, 1972, "Procedures for Estimating Highway User Costs, AirPollution, and Noise Effects," NCHRP Report 133, Highway Research Board, National Research Council, Washington, D.C.
- Darter, M.I., Smith, R.E., Shahin, M.Y. (1987). Use of Life-Cycle Costing Analysis as a Basis for Determining the Cost-Effectiveness of Maintenance and Rehabilitation Treatments for Developing a

Network Level Assignment Procedure, Proceedings of North American Pavement Management Conference, Toronto, ON.

El-Farouk, A. O. and Sharaf, E. A. (1988). A Life Cycle Cost Based Computer Program for Selection of Optimal Design and Maintenance Alternatives, Pre-Conference Proceedings, 3rd International Road Federation Middle East Regional Meeting (in Arabic and French), Riyadh, Saudi Arabia.

Federal Highway Administration. (1998). Life-Cycle Cost Analysis in Pavement Design- In Search of Better Investment Decisions. Pavement Division Interim Technical Bulletin, FHWA, US DOT, Washington, D.C.

Feighan, K.J., Sinha, K.C., and White, T.D. (1986). Assessment of Routine Maintenance Needs and Operational Use of Maintenance Funds: An Estimation of Service Life and Cost of Routine Maintenance Activities, FHWA/JHRP-86-9, Joint Highway Research Project, School of Civil Engineering, Purdue University, West Lafayette, IN.

FHWA (1989). Federal-Aid Highway Program Manual, Vol. 6. (Pavement Management and Design Policy), Federal Highway Administration, U.S. Department of Transportation.

FHWA (1994). Life Cycle Cost Analysis - Summary of Proceedings - FHWA Life Cycle Cost Symposium, Searching for Solutions: A Policy Discussion Series, No. 12, Federal Highway Administration, Washington, D.C.

FHWA (1996). Life Cycle Cost Final Policy Statement, Federal Register, Vol.61, No.182. Washington, D.C.

FHWA (1997). Pavement Management Analysis, Multi-Year Prioritization. Demonstration Project No. 108, Publication No. FHWA-SA-97-071, Federal Highway Administration, National Highway Institute, Washington, DC.

FHWA (1998). Pavement Management Systems. Participant's Manual, Federal Highway Administration, National Highway Institute, Washington, D.C.

FHWA (1998). Life Cycle Cost Analysis in Pavement Design – In Search of Better Investment Decisions, Report FHWA-SA-98-079. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA [2002]. Life-Cycle Cost Analysis Primer. US Department of Transportation, Washington, D.C.

Fwa, T.F., and Sinha, KC. (1991). Pavement Performance And Life-Cycle Cost Analysis. Journal of Transportation Engineering, Volume: 117, ASCE, Reston, VA.

Geoffroy, D.N., Synthesis of Highway Practice 223: Cost-effective Preventive Pavement Maintenance. Transportation Research Board, National Research Council, Washington, D.C., (1996).

Gulen, S., Woods, R., Weaver, J., and Anderson, V.L. (1994) *Correlation of Pavement Serviceability Rating with International Roughness Index*, Transportation Research Record 1435, Transportation Research Board, National Research Council, Washington, D.C.

Haas, R., Hudson, W.R., and Zaniewski, J., (1994). Modern Pavement Management, Krieger Publishing Company, Malabar, FL.

- Hadley, W.O. (1994) SHRP-LTPP General Pavement Studies: Five Year Report, Strategic Highway Research Program, National Research Council, Washington, D.C.
- Hall, K. T., Connor, J.M., Darter, M.I., and Carpenter, S.H. (1989). Rehabilitation of Concrete Pavement, Volume III — Concrete Pavement Evaluation and Rehabilitation System, Report FHWA-RD-88-073, FHWA, U.S. Department of Transportation, Washington, DC..
- Hanna, A.N. (1994). SHRP-LTPP Specific Pavement Studies: Five Year Report, Strategic Highway Research Program, National Research Council, Washington, D.C.
- Harnett, D.L. (1975). Introduction to Statistical Methods, 2nd Edition, Addison-Wesley, Massachusetts.
- Harral, C. G. (1979). The Highway Design and Maintenance Standards Model (HDM): Model Structure, Empirical Foundations, and Applications, PRTC Summer Annual Meeting, University of Warwick, U.K.
- Herbold, K. Using Monte Carlo Simulation for Pavement Cost Analysis, Public Roads, Nov/Dec 2000.
- Hicks, R.G. and Jackson. D., (1998). Benefits of Pavement Maintenance – An Update. 1998 Western Pavement Maintenance Forum, Sacramento, CA.
- Hicks, R.G., Dunn, K. and Moulthrop, J.S., (1997). Framework for Selecting Effective Preventive Maintenance Treatments for Flexible Pavements, Transportation Research Record 1597, Transportation Research Board, National Research Council, Washington, D.C.
- Hicks, R.G., Moulthrop J.S., and Daleiden J., (1999). Selecting a Preventive Maintenance Treatment for Flexible Pavements. Transportation Research Record 1680, Transportation Research Board, Washington D.C.
- Hicks, R.G., Seeds, S.B., and Peshkin D.G., (2000). Selecting a Preventive Maintenance Treatment for Flexible Pavements. Technical Report for Foundation for Pavement Preservation, accessed on the world wide web at: <http://fp2.org>, on February 15, 2004.
http://www.fhwa.dot.gov/legregs/guidance.html#sec_303a
- Huang, Y.H., (1993). Pavement Analysis and Design, Prentice-Hall, Inc., Englewood Cliffs, NJ.
- Hudson, W. R., and McCullough, B.F. (1970). Systems Approach Applied to Pavement Design and Research, Research Report 123-1, Center for Transportation Research, The University of Texas, Austin, TX.
- Hutchinson, S. and Bandalos, D., (1997). A Guide to Monte Carlo Simulation Research for Applied Researchers,” Journal of Vocational Education Research, Vol. 22.
- Irick, P., Hudson, W.R., and McCullough, B.F. (1987). Application of Reliability Concepts to Pavement Design, Proceedings, Sixth International Conference on the Structural Design of Asphalt Pavements, Vol. I.
- INDOT (2002), Indiana Department of Transportation, Design Manual, Indianapolis, IN.
- ISTEA (1991). Intermodal Surface Transportation Efficiency Act.
- Joseph, P. (1992). Crack Sealing in Flexible Pavements: A Life Cycle Cost Analysis, Report PAV-92-04, Research and Development Branch, Ministry of Transportation, Downsview, ON,.

Kane, A.R. (1996). National Highway System Designation Act; Life-Cycle Cost Analysis Requirements, Federal Highway Administration Internet Site, Washington, DC.

Kher, R. K., Hudson, W.R., and McCullough, B.F. (1971). A Systems Analysis of Rigid Pavement Design, Research Report 123-5, Center for Transportation Research, The University of Texas, Austin, TX.

Kher, R.K., and Cook, W.D. (1987).PARS, The MTC Model for Program and Financial Planning in Pavement Rehabilitation, Proceedings of the North American Pavement Management Conference, Toronto, ON.

Ksaibati, K., Cole, M. and Farrar, M. (1996). Evaluation of Surface Treatment Practices in United States, Transportation Research Record 1545, Transportation Research Board, National Research Council, Washington, D.C.

Labi, S. (2001). Impact of Highway Pavement Maintenance Activities, Ph.D. Dissertation, School of Civil Engineering, Purdue University, West Lafayette, IN.

Labi, S. and Sinha, K.C. (2002). Effect of Routine Maintenance on Capital Expenditures, JTRP Report, Purdue University, West Lafayette, IN.

Labi, S., and Sinha, K.C. (2002). Grassroots Perspectives of Pavement Preventive Maintenance- A State-of-Practice Survey in Indiana, International Journal of Pavements Vol. 1 Nr. 3.

Labi, S. and Sinha, K.C. (2003). Measures of Short-term Effectiveness of Highway Pavement Maintenance, ASCE Journal of Transportation Engineering Vol. 129, Nr. 6, American Society of Civil Engineers, Reston, VA.

Lee, Y., Mohseni, A., and Darter, M.I. (1993). Simplified Pavement Performance Models, Transportation Research Record 1397, Transportation Research Board, National Research Council, Washington, D.C.

Lemer, A.C. and Moavenzadeh, F., (1971). Reliability of Highway Pavements, Highway Research Record 362, Highway Research Board, National Research Council, Washington, D.C.

Lytton, R. L., and McFarland, W.F. (1974). Systems Approach to Pavement Design — Implementation Phase, Final Report, Project 1-10A, National Cooperative Highway Research Program, National Research Council, Washington, D.C.

Markow, M.J. (1991). Life-Cycle Costs Evaluations of Effects of Pavement Maintenance, Transportation Research Record 1276, Transportation Research Board, Washington, D.C.

McFarland, W. F., Memmott, J.L., and Chui, M. L. (1993). Microcomputer Evaluation of Highway User Benefits, National Cooperative Highway Research Program Report 7-12, National Research Council, Washington, DC.

Memmott, J.L., and Dudek, C.L. (1984). Queue and User Cost Evaluation of Work Zones, Transportation Research Record 979, Transportation Research Board, Washington D.C.

Michigan DOT (1999). Capital Preventive Maintenance Program – Guideline. Michigan DOT, Lansing, MI.

Miller, K. (1984). Life Cycle Costing Considerations for Pavements: ODOT's Approach to Life Cycle Costing, Proceedings of the 38th Annual Ohio Transportation Engineering Conference, Ohio State University, Columbus, OH.

Mouaket, I M., and Sinha, K.C. (1990). Cost Effectiveness of Rigid and Composite Highway Pavement Routine Maintenance, FHWA/JHRP-90-15, Joint Highway Research Project, School of Civil Engineering, Purdue University, West Lafayette, IN.

Mouaket, I.M., and Sinha, K.C., Cost Effectiveness of Routine Maintenance on Rigid Pavements, FHWA/JHRP-91-11, Joint Highway Research Project, School of Civil Engineering, Purdue University, West Lafayette, IN (1991).

Mouaket, I.M., Sinha, K.C., and White, T.D.(1992). Guidelines for Management of Chip and Sand Seals Coating Activities in Indiana, Transportation Research Record 1344, Transportation Research Board, Washington, D.C.

National Research Council, Washington D.C. NCHRP (1998). Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction. NCHRP Project No. 9-20 (in progress), National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C.

Novak, E. C. Jr., and Kuo, W.(1992). Life-Cycle Cost Versus Network Analysis, Transportation Research Record 1344, Transportation Research Board, National Research Council, Washington D.C.

New York DOT. (1992).Comprehensive Report on Preventive Maintenance. New York State Department of Transportation, Albany, NY.

NYDOT (1993). Pavement Rehabilitation Manual – Volume II: Treatment Selection. New York State DOT, Materials Bureau, Albany, NY.

NYDOT (1999). Pavement Rehabilitation Manual – Volume III: Preventive Maintenance Treatments and Selection. New York State DOT Materials Bureau, Albany, NY.

O'Brien, L.G. (1989). NCHRP Synthesis of Highway Practice 153: Evolution and Benefits of Preventive Maintenance Strategies, Transportation Research Board, National Research Council, Washington, D.C.

Ockwell, A. (1990). Pavement Management: Development of a Life Cycle Costing Technique, Australian Publishing Service, Canberra, Australia.

Palisade Corporation, @Risk User's Manual, (1997). Palisade Corporation, Newfield, NY. Available: <http://www.palisade.com>

Parker, D. (1993). Evaluation of Performance and Cost Effectiveness of Thin Pavement Surface Treatments, Oregon SP&R Study #5269, Oregon Department of Transportation, Salem, OR.

Peterson, D.E. (1985). NCHRP Synthesis of Highway Practice 122: Life Cycle Cost Analysis of Pavement, Transportation Research Board, National Research Council, Washington, D.C.

Rada, G. R., and Witczak, M.W. (1987). Project Level PMS Life Cycle Cost Model for Flexible Pavements, Sixth International Conference, Structural Design of Asphalt Pavements, Vol. 1: Proceedings, University of Michigan, Ann Arbor, MI.

Rajagopal, A.S., and George, K.P. (1991). Pavement Maintenance Effectiveness, Transportation Research Record 1276, Transportation Research Board, National Research Council, Washington D.C.

Raza, H. (1994) State of the Practice: Design, Construction, and Performance of Micro-surfacing. Report FHWA-SA-94-051, FHWA, U.S. Department of Transportation, Washington D.C.

Reigle, J. A., (2000). Development of an Integrated Project-Level Pavement Management Model Using Risk Analysis, Dissertation, West Virginia University.

Saraf, C. L., Kennedy, J.C., Jr., Majidzadeh, K., and Dudley, S.W. (1991). Life-Cycle Cost Analysis of Ohio Pavement Rehabilitation Demonstration Projects, Transportation Research Record 1307, Transportation Research Board, Washington, D.C.

Seeds, Stephen B., (1980). A Design System for Rigid Pavement Rehabilitation, Thesis, The University of Texas, Austin, TX.

Shahin, M.Y., Kohn, S.D., Lytton, R.L., and McFarland, M. (1985). Pavement M&R Budget Optimization Using the Incremental Benefit-Cost Technique, Proceedings of the North American Pavement Management Conference, Toronto, ON.

Sharaf, E.A., Shahin, M.Y., and Sinha, K.C. (1988). Analysis of the Effect of Deferring Pavement Maintenance, Transportation Research Record 1205, Transportation Research Board, National Research Council, Washington, D.C.

Shober, S.F. (1986). Portland Cement Concrete Pavement Performance as Influenced by Sealed and Unsealed Contraction Joints, Transportation Research Record 1083, Transportation Research Board, National Research Council, Washington, D.C.

Shober, S.F. (1997). The Great Unsealing: A Perspective on Portland Cement Concrete Joint Sealing, Transportation Research Record 1597, Transportation Research Board, National Research Council, Washington, D.C.

Shober, S. F. and Friedrichs, D. A., (1997). A Pavement Preservation Strategy. Presented at the 78th Annual Meeting of Transportation Research Board, Washington DC.

Shuler, T.S. (1984). NCHRP Synthesis Topic 24-10: Asphalt Surface Treatments and Thin Overlays, Transportation Research Board, National Research Council, Washington, D.C.

Simulation Basics, Vanguard Software Corp. Web site,
<http://wwwcf.fhwa.dot.gov/exit.cfm?link=http://www.vanguardsw.com/Dphelp/dph00118.htm>.

Smith, R., Freeman, T., and Pendleton, O. (1993). Pavement Maintenance Effectiveness, Strategic Highway Research Program, National Research Council, Washington D.C.

Syed, I.M., Freeman, T.J., and Smith, R.E. (1998). Effectiveness of Highway Maintenance Treatments Used in Texas, Flexible Pavement Design and Maintenance ASTM STP 1348, P.S. Kandhal and M. Stroup-Gardner, Editors, American Society for Testing and Materials, Philadelphia, PA.

TEA-21 (1998). Transportation Efficiency Act for the 21st Century (TEA-21), H.R. 2400, enacted on June 9th.

Turner, J.D., 1999, "What's a Work Zone?" Public Roads, Vol. 62, No. 6, Asphalt Pages Internet Site, <http://www.asphaltpages.com>.

Uddin, W., Carmichael, R.F., III, and Hudson, W.R. (1986). Life Cycle Analysis for Pavement Management Decision Making — Final Report, Report FHWA-PA-85- 028, Texas Research and Development Foundation.

Walls III, J. and Smith, M.R., (1998). Life-Cycle Cost Analysis in Pavement Design – Interim Technical Bulletin, Report No. FHWA-SA-98-079, Federal Highway Administration, Washington, D.C.

Wilde, W.J., Waalkes, S., and Harrison, R. (1999). Life Cycle Cost Analysis of Portland Cement Concrete Pavements. Report. FHWA/TX-00/0-1739-1, Center for Transportation Research, The University of Texas, Austin, TX.

Winfrey, R. (1963). Motor Vehicle Running Costs for Highway Economy Studies, 3131 North Piedmont Street, Arlington, VA.

Winfrey, R. (1969). Economic Analysis for Highways, International Textbook Co., Scranton, PA.

Witczak, M. W., and Mirza, M. W. (1992). Microcomputer Analysis for Project Level PMS Life Cycle Cost Studies for Rigid Pavements, Final Report, Vols. I and II, Maryland University, College Park, MD.

Zaniewski, J. P., Butler, B.C., Jr., Cunningham, G., Elkins, G.E., Paggi, M., and Machemehl, R. (1981). Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors, Federal Highway Administration-RD80, Washington, D.C.

Zaniewski, J.P. and Mamlouk, M.S., (1996). Preventive Maintenance Effectiveness – Preventive Maintenance Treatments, Instructor's Guide, Report No. FHWA-SA-96-028, Federal Highway Administration, Washington, D.C.

Zaniewski, J.P., and Mamlouk. M.S., (1996). Pavement Maintenance Effectiveness Preventive Maintenance Treatments, Participants Handbook. FHWA-SA-96-127, Federal Highway Administration, Washington, DC..

APPENDIX 1:
TYPICAL CROSS SECTIONS [INDOT Design Manual, 2002]

All Pavement, Including All Shoulders

- ① 90 kg/m² HMA Surface 9.5 mm
- ② 150 kg/m² HMA Intermediate 19.0 mm
- ③ 240 kg/m² HMA Base 25.0 mm
- ④ 250 kg/m² Minimum HMA Intermediate C25.0 mm
- ⑤ 240 kg/m² HMA Base 25.0 mm
- ⑥ Subgrade Treatment
- ⑦ Compacted Aggregate Base
- ⑧ Pipe, Type 4, Circular, 150 mm

FULL DEPTH HMA PAVEMENT,
GREATER THAN OR EQUAL TO 30 MILLION ESALs
Figure 52-13A

APPENDIX 1 (Continued)

Mainline

- ① 90 kg/m² HMA Surface 9.5 mm
- ② 150 kg/m² HMA Intermediate 19.0 mm
- ③ 240 kg/m² HMA Base 25.0 mm
- ④ 165 kg/m² Minimum HMA Intermediate C25.0 mm
- ⑤ 240 kg/m² HMA Base 25.0 mm
- ⑥ Subgrade Treatment
- ⑩ Pipe, Type 4, Circular, 150 mm

Shoulders

- ⑦ 90 kg/m² HMA Surface 9.5 mm
- ⑧ 270 kg/m² HMA Base 25.0 mm
- ⑨ 200 mm Compacted Aggregate Base
- ⑪ Compacted Aggregate Base

FULL DEPTH HMA PAVEMENT,
GREATER THAN OR EQUAL TO 10 MILLION, BUT LESS THAN 30 MILLION ESALs
Figure 52-13B

APPENDIX 1 (Continued)

Mainline Pavement (Section With Shoulders)

- ① 90 kg/m² HMA Surface 9.5 mm
- ② 150 kg/m² HMA Intermediate 19.0 mm
- ③ 150 kg/m² HMA Base 19.0 mm
- ④ 140 kg/m² Minimum HMA Intermediate C19.0 mm
- ⑤ 180 kg/m² HMA Base 19.0 mm
- ⑥ Subgrade Treatment
- ⑩ Pipe, Type 4, Circular, 150 mm

Shoulders

- ⑦ 90 kg/m² HMA Surface 9.5 mm
- ⑧ 270 kg/m² HMA Base 25.0 mm
- ⑨ 150 mm Compacted Aggregate Base

FULL DEPTH HMA PAVEMENT,
GREATER THAN OR EQUAL TO 1 MILLION, BUT LESS THAN 10 MILLION ESALs
Figure 52-13C

APPENDIX 1 (Continued)

Mainline (Section With Shoulders)

- ① 90 kg/m² HMA Surface 9.5 mm
- ② 150 kg/m² HMA Intermediate 19.0 mm
- ③ 480 kg/m² HMA Base 19.0 mm
- ④ Subgrade Treatment

Shoulders

- ⑤ 180 kg/m² HMA Surface 9.5 mm with Seal Coat, 2
- ⑥ 150 mm Compacted Aggregate Base
- Or ⑤ & ⑥ may be replaced by
- 150 mm Minimum Compacted Aggregate Base with Seal Coat, 5

FULL DEPTH HMA PAVEMENT, LESS THAN 1 MILLION ESALs

Figure 52-13D

APPENDIX 1 (Continued)

Mainline (Section With Shoulders)

- ① 90 kg/m² HMA Surface 9.5 mm
- ② 150-330 kg/m² HMA Intermediate 19.0 mm
- ③ 125-200 mm Compacted Aggregate Base
- ① + ② + ③ ≥ 300 mm
- ④ Subgrade Treatment

Shoulders

- ⑤ 180 kg/m² HMA Surface 9.5 mm with Seal Coat, 2
- ⑥ 150 mm Compacted Aggregate Base
- Or ⑤ & ⑥ may be replaced by
- 150 mm Minimum Compacted Aggregate Base with Seal Coat, 5

COMPOSITE HMA/COMPACTED AGGREGATE PAVEMENT
LESS THAN 1 MILLION ESALs

Figure 52-13E

APPENDIX 1 (Continued)

Mainline and Shoulders

- ① PCCP
- ② Subbase for PCCP (75 mm Coarse Aggregate #8 On 150 mm Coarse Aggregate #53)
- ③ Compacted Aggregate Base
- ④ Pipe, Type 4, Circular, 150 mm
- ⑤ Subgrade Treatment
- ⑥ Longitudinal Joint or Longitudinal Construction Joint. Refer to Figure 52-13P for Pavement Joint Options.
- ⑦ Concrete Median Barrier

PCCP SECTION W/PCC SHOULDER, GREATER THAN OR EQUAL TO 30 MILLION ESALs
Figure 52-13F

APPENDIX 1 (Continued)

Mainline

- ① PCCP
- ② Subbase for PCCP (75 mm Coarse Aggregate #8 On 150 mm Coarse Aggregate #53)

Shoulders

- ③ 90 kg/m² HMA Surface 9.5 mm
180 kg/m² HMA Intermediate 19.0 mm
- ④ HMA Base 25.0 mm
- ⑤ Compacted Aggregate Base
- ⑥ Variable Depth Compacted Aggregate Base
- ⑦ Subgrade Treatment
- ⑧ Longitudinal Joint or Longitudinal Construction Joint
- ⑨ Pipe, Type 4, Circular, 150 mm

PCCP SECTION W/HMA SHOULDER, LESS THAN 30 MILLION ESALs

Figure 52-13G

APPENDIX 1 (Continued)

Mainline

- ① PCCP
- ② Subbase for PCCP (75 mm Coarse Aggregate #8 On 150 mm Coarse Aggregate #53)

Shoulders

- ③ 90 kg/m² HMA Surface 9.5 mm
180 kg/m² HMA Intermediate 19.0 mm
- ④ HMA Base 25.0 mm
- ⑤ Compacted Aggregate Base
- ⑥ Variable Depth Compacted Aggregate Base
- ⑦ Subgrade Treatment
- ⑧ Longitudinal Joint or Longitudinal Construction Joint
- ⑨ Pipe, Type 4, Circular, 150 mm

PCCP SECTION W/HMA SHOULDER, LESS THAN 30 MILLION ESALs

Figure 52-13G

APPENDIX 2: Unit Costs for Pavement Repair, by Line Items of
INDOT Contract Bidding Documents

Item Code	Item Description	Unit	Nr. of Sections ¹	Unit Cost Statistics (constant \$, Y2000)			
				Mean	Minimum	Maximum	Std Dev
305-04020	BITUMINOUS MIXTURE FOR PATCHING	TON	21	100.07	46.95	143.65	25.30
310-04013	PATCHING, FULL DEPTH, PLAIN CONCRETE PAV	SYS	7	108.39	83.85	132.63	20.98
310-04014	PATCHING, FULL DEPTH, REINFORCED CONCRET	SYS	7	108.77	62.00	139.74	26.20
310-04016	PATCHING, FULL DEPTH, CONTINUOUSLY REINF	SYS	2	114.42	101.73	127.11	17.94
401-01338	BITUMINOUS SURFACE, SMA, MV	TON	1	48.54	48.54	48.54	
401-01657	BITUMINOUS MIXTURE FOR WEDGE AND LEVEL	TON	2	32.55	27.33	37.77	7.38
401-02222	BITUMINOUS BINDER 8, HV, WITH FIBERS	TON	3	32.16	22.08	39.62	9.06
401-02434	BITUMINOUS BINDER 8C, LV	TON	16	34.65	24.59	76.06	12.96
401-02465	BITUMINOUS MIXTURE FOR WEDGE AND LEVEL,M	TON	1	43.32	43.32	43.32	
401-02684	TEMPORARY BITUMINOUS PAVEMENT	TON	1	42.73	42.73	42.73	
401-02832	BITUMINOUS BINDER 8C, MV	TON	2	29.82	24.34	35.29	7.75
401-03056	BITUMINOUS MIX FOR WEDG+LEVL LV,11,SURFA	TON	3	57.44	55.90	59.63	1.95
401-03100	BITUMINOUS BASE 5C, LV	TON	1	41.03	41.03	41.03	
401-03101	BITUMINOUS BASE 5C, MV	TON	6	35.29	24.59	53.00	11.10
401-03102	BITUMINOUS BASE 5C, HV	TON	9	32.56	25.35	39.16	4.67
401-03150	BITUMINOUS BASE 8C, LV	TON	1	29.85	29.85	29.85	
401-03200	BITUMINOUS BASE 5, LV	TON	12	32.59	19.01	67.58	12.53
401-03201	BITUMINOUS BASE 5, MV	TON	14	32.54	24.34	53.00	8.90
401-03202	BITUMINOUS BASE 5, HV	TON	21	31.20	24.34	50.69	6.05
401-03211	BITUMINOUS BASE 5 OR 5D, MV	TON	1	36.51	36.51	36.51	
401-03219	BITUMINOUS BINDER 8, LV	TON	7	25.75	22.36	29.50	2.69
401-03220	BITUMINOUS BINDER 8, MV	TON	14	24.24	20.12	31.30	3.33
401-03221	BITUMINOUS BINDER 8, HV	TON	2	26.34	26.34	26.34	0.00
401-03229	BITUMINOUS BINDER 8 OR 9, LV	TON	22	31.98	23.67	50.71	8.31
401-03230	BITUMINOUS BINDER 8 OR 9, MV	TON	32	29.42	19.93	57.84	7.85
401-03231	BITUMINOUS BINDER 8 OR 9, HV	TON	19	31.33	20.28	50.31	8.47
401-03238	BITUMINOUS BINDER 9, LV	TON	11	26.46	22.21	32.50	3.45
401-03239	BITUMINOUS BINDER 9, MV	TON	12	35.29	21.25	126.77	29.29
401-03240	BITUMINOUS BINDER 9, HV	TON	4	29.18	24.85	33.47	4.61
401-03247	BITUMINOUS BINDER 11, LV	TON	3	40.91	30.67	58.53	15.32
401-03248	BITUMINOUS BINDER 11, MV	TON	8	28.09	25.61	30.43	1.56
401-03249	BITUMINOUS BINDER 11, HV	TON	2	28.82	28.82	28.82	0.00
401-03263	BITUMINOUS MIXTURE FOR WIDENING, LV	TON	23	49.02	22.64	114.29	28.08

APPENDIX 2: Unit Costs for Pavement Repair, by Line Items of
INDOT Contract Bidding Documents (continued)

Item Code	Item Description	Unit	Nr. of Sections ¹	Unit Cost Statistics (constant \$, Y2000)			
				Mean	Minimum	Maximum	Std Dev
401-03264	BITUMINOUS MIXTURE FOR WIDENING, MV	TON	34	42.00	20.57	106.49	16.49
401-03265	BITUMINOUS MIXTURE FOR WIDENING, HV	TON	3	38.30	29.62	44.72	7.80
401-03301	BITUMINOUS BASE, MV	TON	2	48.98	30.01	67.95	26.82
401-03302	BITUMINOUS BASE, HV	TON	1	95.02	95.02	95.02	
401-03303	BITUMINOUS BASE 5D, LV	TON	30	35.97	23.83	84.48	13.27
401-03304	BITUMINOUS BASE 5D, MV	TON	14	33.41	24.59	44.17	7.65
401-03305	BITUMINOUS BASE 5D, HV	TON	12	31.35	21.24	49.19	7.53
401-03401	BITUMINOUS BINDER, MV	TON	1	33.79	33.79	33.79	
401-03501	BITUMINOUS SURFACE, LV	TON	1	27.84	27.84	27.84	
401-03503	BITUMINOUS SURFACE, HV	TON	1	37.62	37.62	37.62	
401-03545	BITUMINOUS SURFACE 11, LV	TON	55	33.43	19.88	89.43	11.11
401-03560	BITUMINOUS SURFACE 11, MV	TON	77	32.48	23.58	56.35	6.59
401-03575	BITUMINOUS SURFACE 11, HV	TON	31	42.99	24.34	149.07	24.56
401-03590	BITUMINOUS SURFACE 9, LV	TON	4	28.74	26.37	32.60	2.92
401-03605	BITUMINOUS SURFACE 9, MV	TON	2	30.73	29.81	31.64	1.29
401-03620	BITUMINOUS SURFACE 9, HV	TON	3	39.58	39.15	40.06	0.46
401-04213	BITUMINOUS BASE 1 IN., HV	TON	1	27.72	27.72	27.72	
401-04214	BITUMINOUS BINDER 0.750 IN., HV	TON	1	28.06	28.06	28.06	
401-04215	BITUMINOUS SURFACE 0.375 IN., HV	TON	1	42.93	42.93	42.93	
401-04273	BITUMINOUS MIXTURE FOR WEDGE AND LEVEL,	TON	6	41.41	27.43	59.63	11.58
401-04274	BITUMINOUS MIXTURE FOR WEDGE AND LEVEL	TON	42	35.18	23.53	67.58	10.37
401-04290	BITUMINOUS MIXTURE FOR WEDGE AND LEVEL,	TON	29	38.78	22.21	135.27	20.69
401-04525	BITUMINOUS BASE 25.0 mm, HV	TON	3	30.51	25.71	35.50	4.90
401-04526	BITUMINOUS BINDER 0.75 IN., HV	TON	1	33.54	33.54	33.54	
401-04526	BITUMINOUS BINDER 19.0 mm, HV	TON	3	29.37	26.60	30.83	2.40
401-04527	BITUMINOUS BINDER 0.50 IN., HV	TON	1	32.14	32.14	32.14	
401-04527	BITUMINOUS BINDER 12.5 mm, HV	TON	1	31.44	31.44	31.44	
401-04528	BITUMINOUS SURFACE 0.375 IN., HV	TON	2	41.78	36.05	47.51	8.10
401-04528	BITUMINOUS SURFACE 9.5 mm, HV	TON	4	38.99	34.48	45.64	4.91
401-04530	BITUMINOUS BASE 1.0 IN., MV	TON	1	32.36	32.36	32.36	
401-04531	BITUMINOUS BINDER 0.75 IN., MV	TON	2	31.84	31.27	32.41	0.81
401-04533	BITUMINOUS SURFACE 0.375 IN., MV	TON	3	44.56	38.76	54.50	8.65
401-04533	BITUMINOUS SURFACE 9.5 mm, MV	TON	1	38.54	38.54	38.54	

**APPENDIX 2: Unit Costs for Pavement Repair, by Line Items
of INDOT Contract Bidding Documents (continued)**

Item Code	Item Description	Unit	Nr. of Sections ¹	Unit Cost Statistics (constant \$, Y2000)			
				Mean	Minimum	Maximum	Std Dev
401-04536	BITUMINOUS BINDER 0.75 IN., LV	TON	1	39.13	39.13	39.13	
401-04536	BITUMINOUS BINDER 19.0 mm, LV	TON	2	28.90	26.37	31.44	3.59
401-04538	BITUMINOUS SURFACE 0.375 IN., LV	TON	2	34.66	27.95	41.36	9.49
401-04538	BITUMINOUS SURFACE 9.5 mm, LV	TON	2	31.95	29.41	34.48	3.59
401-04605	ASPHALT PAVEMENT MIXTURES, WARRANTED	TON	5	33.78	32.45	35.05	1.21
401-04605	HMA PAVEMENT MIXTURES, WARRANTED	TON	1	37.05	37.05	37.05	
401-04817	HMA BASE 25.0 mm, MAINLINE	TON	16	33.85	25.47	39.13	4.24
401-04819	HMA INTERMEDIATE 12.5 mm, MAINLINE	TON	23	32.43	23.55	44.82	6.12
401-04820	HMA INTERMEDIATE 19.0 mm, MAINLINE	TON	16	30.89	25.35	39.75	4.97
401-04821	HMA SURFACE 9.5 mm, LV, MAINLINE	TON	2	38.39	32.96	43.82	7.68
401-04822	HMA SURFACE 9.5 mm, MV, MAINLINE	TON	19	35.69	26.83	55.62	6.38
401-04823	HMA SURFACE 9.5 mm, HV, MAINLINE	TON	21	40.51	28.90	49.69	4.97
401-04824	HMA BASE 25.0 mm, SHOULDER	TON	22	33.56	25.86	53.67	6.99
401-04825	HMA BASE 37.5 mm, SHOULDER	TON	1	36.10	36.10	36.10	
401-04826	HMA INTERMEDIATE 12.5 mm, SHOULDER	TON	11	31.54	23.28	45.72	5.74
401-04827	HMA INTERMEDIATE 19.0 mm, SHOULDER	TON	9	31.22	25.07	44.23	5.75
401-04828	HMA SURFACE 9.5 mm, LV, SHOULDER	TON	13	39.22	26.62	60.85	10.97
401-04829	HMA SURFACE 9.5 mm, MV, SHOULDER	TON	12	35.24	26.83	48.13	6.97
401-05096	IN-PLACE DRUM MIX RECYCLING	SYS	1	2.53	2.53	2.53	
401-05437	QC/QA HMA BASE 25.0 mm, MAINLINE	TON	88	32.44	19.56	65.46	6.13
401-05453	QC/QA HMA INTERMEDIATE 9.5 mm, MAINLINE	TON	10	29.56	21.56	41.37	6.87
401-05454	QC/QA HMA INTERMEDIATE 12.5 mm, MAINLINE	TON	125	27.42	20.54	46.55	4.24
401-05455	QC/QA HMA INTERMEDIATE 19.0 mm, MAINLINE	TON	209	30.42	19.07	65.46	6.44
401-05456	QC/QA HMA SURFACE 9.5 mm, MAINLINE	TON	424	36.35	22.50	95.28	7.84
401-05457	QC/QA HMA SURFACE 12.5 mm, MAINLINE	TON	47	36.99	28.08	62.37	6.81
401-05458	QC/QA HMA SURFACE 19.0 mm, MAINLINE	TON	1	26.21	26.21	26.21	
401-05459	QC/QA HMA BASE 25.0 mm, SHOULDER	TON	63	30.91	15.37	43.68	5.74
401-05461	QC/QA HMA INTERMEDIATE 9.5 mm, SHOULDER	TON	6	30.76	26.83	37.10	3.78
401-05462	QC/QA HMA INTERMEDIATE 12.5 mm, SHOULDER	TON	25	30.12	22.06	41.41	5.81
401-05463	QC/QA HMA INTERMEDIATE 19.0 mm, SHOULDER	TON	66	30.25	19.07	73.70	8.73
401-05464	QC/QA HMA SURFACE 9.5 mm, SHOULDER	TON	106	35.18	21.52	84.22	8.69
401-05465	QC/QA HMA SURFACE 12.5 mm, SHOULDER	TON	12	37.82	29.67	51.51	7.36
401-05466	QC/QA HMA SURFACE 19.0 mm, SHOULDER	TON	2	26.42	25.88	26.96	0.76
401-05467	MILLED HMA CORRUGATIONS	LFT	61	0.97	0.05	21.36	3.35

**APPENDIX 2: Unit Costs for Pavement Repair, by Line Items
of INDOT Contract Bidding Documents (continued)**

Item Code	Item Description	Unit	Nr. of Sections ¹	Unit Cost Statistics (constant \$, Y2000)			
				Mean	Minimum	Maximum	Std Dev
401-05467	MILLED SHOULDER CORRUGATIONS	LFT	6	0.41	0.18	0.83	0.27
401-06962	QC/QA HMA SURFACE 9.5 mm, MAINLINE, SMA	TON	2	41.13	38.87	43.39	3.20
401-91660	BITUMINOUS MIXTURE FOR WEDGEAND LEVEL 9,	TON	1	23.83	23.83	23.83	
401-91661	BITUMINOUS MIXTURE FOR WEDGE AND LEVEL	TON	1	32.09	32.09	32.09	
401-91826	ASPHALT PLANK	SYS	1	49.15	49.15	49.15	
401-93793	WEDGE AND LEVELING	TON	1	40.25	40.25	40.25	
401-93813	ASPHALT SAND	TON	1	112.98	112.98	112.98	
401-93821	BITUMINOUS SURFACE 11, HV, WITH FIBERS	TON	7	41.41	30.43	57.04	8.21
401-93853	BITUMINOUS BASE 5, HV, WITH FIBERS	TON	2	28.98	27.78	30.18	1.70
401-94492	BITUMINOUS BINDER 8 OR 9, HV, WITH FIBER	TON	1	25.35	25.35	25.35	
401-94845	BITUMINOUS SURFACE 11, MV, WITH FIBERS	TON	1	41.84	41.84	41.84	
401-94960	BITUMINOUS BINDER 8C, HV	TON	4	28.89	26.88	33.47	3.08
401-95441	BITUMINOUS SURFACE 11, MV, MAC 20	TON	1	34.08	34.08	34.08	
401-96011	BITUMINOUS BASE 5, MV, WITH FIBERS	TON	1	34.68	34.68	34.68	
401-96012	BITUMINOUS BINDER, 8 OR 9, HV, WITH FIBE	TON	2	40.40	31.86	48.94	12.07
401-96013	BITUMINOUS BINDER, 8 OR 9, MV, WITH FIBE	TON	1	34.68	34.68	34.68	
401-96377	BITUMINOUS MIXTURE FOR WEDGE AND LEVEL,	TON	2	41.93	39.15	44.72	3.94
401-97738	BITUMINOUS MIXTURE FOR WEDGE AND LEVEL,	TON	6	28.96	26.37	31.30	1.61
401-98804	BITUMINOUS MIXTURE FOR ISLANDS, MV	TON	1	109.55	109.55	109.55	
401-98857	BITUMINOUS BINDER 8 OR 9, HV, WITH FIBER	TON	1	27.78	27.78	27.78	
401-99180	BITUMINOUS MIXTURE FOR SUPERELEVATION	TON	2	33.54	31.86	35.21	2.37
402-01903	BITUMINOUS MIXTURE FOR WEDGE AND LEVEL 1	TON	1	33.29	33.29	33.29	
402-01903	BITUMINOUS MIXTURE FOR WEDGEAND LEVEL 11	TON	2	34.29	32.80	35.78	2.11
402-03226	BITUMINOUS BINDER 8 HAE, LV	TON	2	28.92	28.78	29.07	0.20
402-03235	BITUMINOUS BINDER 8 OR 9 HAE, LV	TON	1	22.75	22.75	22.75	
402-03253	BITUMINOUS BINDER 11 HAE, LV	TON	1	31.07	31.07	31.07	
402-03254	BITUMINOUS BINDER 11 HAE, MV	TON	1	32.03	32.03	32.03	
402-03550	BITUMINOUS SURFACE 11 HAE, LV	TON	3	31.53	29.29	33.54	2.13
402-03565	BITUMINOUS SURFACE 11 HAE, MV	TON	1	31.69	31.69	31.69	
402-03720	MICRO-SURFACING, SURFACE COURSE	SYS	2	1.40	1.16	1.64	0.34
402-03721	MICRO-SURFACING, LEVELING COURSE	SYS	1	0.69	0.69	0.69	
402-04281	BITUMINOUS MIXTURE FOR WEDGEAND LEVEL HA	TON	2	32.99	31.41	34.56	2.23
402-05468	HMA BASE 25.0 mm, MAINLINE	TON	46	46.21	23.84	244.94	35.62
402-05470	HMA BASE C25.0 mm, MAINLINE	TON	39	32.52	19.56	44.21	6.16

**APPENDIX 2: Unit Costs for Pavement Repair, by Line Items
of INDOT Contract Bidding Documents (continued)**

Item Code	Item Description	Unit	Nr. of Sections ¹	Unit Cost Statistics (constant \$, Y2000)			
				Mean	Minimum	Maximum	Std Dev
402-05471	HMA BASE C50.0 mm, MAINLINE	TON	2	31.08	27.07	35.09	5.67
402-05472	HMA INTERMEDIATE 9.5 mm, MAINLINE	TON	5	27.64	24.06	31.33	2.80
402-05473	HMA INTERMEDIATE 12.5 mm, MAINLINE	TON	18	35.74	23.06	64.56	10.83
402-05474	HMA INTERMEDIATE 19.0 mm, MAINLINE	TON	33	36.25	24.13	64.83	9.27
402-05475	HMA INTERMEDIATE C19.0 mm, MAINLINE	TON	13	33.76	24.50	60.83	9.42
402-05477	HMA SURFACE 9.5 mm, MAINLINE	TON	77	43.84	28.02	107.84	13.57
402-05479	HMA SURFACE 12.5 mm, MAINLINE	TON	3	32.98	26.50	39.85	6.69
402-05481	HMA BASE 25.0 mm, SHOULDER	TON	44	40.17	19.39	77.37	12.70
402-05483	HMA BASE C25.0 mm, SHOULDER	TON	12	40.79	21.77	77.37	14.08
402-05485	HMA INTERMEDIATE 9.5 mm, SHOULDER	TON	6	34.77	27.07	46.95	7.42
402-05486	HMA INTERMEDIATE 12.5 mm, SHOULDER	TON	11	31.69	22.56	51.74	9.08
402-05487	HMA INTERMEDIATE 19.0 mm, SHOULDER	TON	27	37.29	19.80	74.09	12.94
402-05488	HMA INTERMEDIATE C19.0 mm, SHOULDER	TON	12	34.03	24.87	54.23	7.62
402-05490	HMA SURFACE 9.5 mm, SHOULDER	TON	49	43.32	23.40	92.62	14.69
402-05492	HMA SURFACE 12.5 mm, SHOULDER	TON	8	38.29	26.90	58.75	9.33
402-05493	HMA SURFACE 19.0 mm, SHOULDER	TON	3	31.27	23.72	38.56	7.42
402-05495	HMA FOR WEDGE AND LEVEL	TON	58	37.97	22.06	70.19	11.06
402-05495	HMA WEDGE AND LEVEL	TON	212	40.98	19.76	108.46	14.34
402-05496	HMA FOR ISLANDS	TON	1	50.13	50.13	50.13	
402-05498	HMA FOR PARKING AREA	TON	7	46.07	26.07	80.21	20.59
402-05542	SPECIAL HMA SURFACE C9.5 mm, MAINLINE	TON	1	36.10	36.10	36.10	
402-07167	ULTRATHIN BONDED WEARING COURSE	TON	1	100.05	100.05	100.05	
406-05520	ASPHALT FOR TACK COAT	TON	199	192.64	10.21	813.33	84.86
406-05520	ASPHALT MATERIAL FOR TACK COAT	TON	6	326.95	143.68	994.74	328.63
501-02578	EXPANSION JOINT WITH LOAD TRANSFER, 1 IN	LFT	4	14.41	9.11	17.89	3.75
501-02578	EXPANSION JOINT WITH LOAD TRANSFER, 25 m	LFT	1	11.93	11.93	11.93	
501-03707	RAISED CORRUGATED ISLAND, CONCRETE	SYS	2	59.86	55.02	64.69	6.84
501-03838	GROOVE PORTLAND CEMENT CONCRETE	SYS	1	4.28	4.28	4.28	
501-04010	CEMENT CONCRETE PAVEMENT FOR PATCHING	SYS	10	120.36	52.68	190.05	41.15
501-04011	CEMENT CONCRETE PAVEMENT FOR PATCHING	SYS	3	140.28	112.17	164.88	26.53
501-04014	PATCHING, FULL DEPTH, REINFORCED CONCRET	SYS	12	100.29	55.45	155.06	27.65
501-04635	MILLED CONCRETE SHOULDER CORRUGATIONS	LFT	3	0.41	0.16	0.89	0.42
501-04842	CEMENT CONCRETE PAVEMENT, REINF., 260mm	SYS	4	56.50	45.34	69.31	10.32

**APPENDIX 2: Unit Costs for Pavement Repair, by Line Items
of INDOT Contract Bidding Documents (continued)**

Item Code	Item Description	Unit	Nr. of Sections ¹	Unit Cost Statistics (constant \$, Y2000)			
				Mean	Minimum	Maximum	Std Dev
501-04870	CEMENT CONCRETE PAVEMENT, PLAIN,	SYS	1	60.07	60.07	60.07	
501-05090	CEMENT CONCRETE PAVEMENT, REINFORCED, 10	SYS	19	53.98	38.68	116.23	18.48
501-05090	CEMENT CONCRETE PAVEMENT, REINFORCED, 250	SYS	12	59.17	37.39	144.17	29.19
501-05091	CEMENT CONCRETE PAVEMENT, REINFORCED, 11	SYS	3	49.10	42.48	53.37	5.81
501-05092	CEMENT CONCRETE PAVEMENT, REINFORCED, 12	SYS	4	56.74	54.22	58.13	1.74
501-05092	CEMENT CONCRETE PAVEMENT, REINFORCED, 30	SYS	8	56.96	40.66	75.59	13.75
501-05093	CEMENT CONCRETE PAVEMENT, REINFORCED, 32	SYS	3	51.30	39.13	68.05	14.99
501-05094	CEMENT CONCRETE PAVEMENT, REINFORCED, 35	SYS	9	60.32	46.74	69.31	8.79
501-05140	CEMENT CONCRETE PAVEMENT, PLAIN, 150 mm	SYS	1	59.54	59.54	59.54	
501-05160	CEMENT CONCRETE PAVEMENT, PLAIN, 8 IN.	SYS	1	48.52	48.52	48.52	
501-05170	CEMENT CONCRETE PAVEMENT, PLAIN, 9 IN.	SYS	2	37.40	34.26	40.53	4.43
501-05179	CEMENT CONCRETE PAVEMENT, PLAIN, 13 IN.	SYS	1	33.22	33.22	33.22	
501-05179	CEMENT CONCRETE PAVEMENT, PLAIN, 325 mm	SYS	5	36.97	33.45	42.06	3.19
501-05180	CEMENT CONCRETE PAVEMENT, PLAIN, 10 IN.	SYS	5	31.26	20.40	49.30	11.39
501-05180	CEMENT CONCRETE PAVEMENT, PLAIN, 250 mm	SYS	4	47.25	18.94	67.00	20.42
501-05181	CEMENT CONCRETE PAVEMENT, PLAIN, 11 IN.	SYS	4	28.26	22.53	33.26	4.64
501-05181	CEMENT CONCRETE PAVEMENT, PLAIN, 275 mm	SYS	2	16.63	0.92	32.34	22.22
501-05182	CEMENT CONCRETE PAVEMENT, PLAIN, 12 IN.	SYS	3	38.16	37.73	38.57	0.42
501-05182	CEMENT CONCRETE PAVEMENT, PLAIN, 300 mm	SYS	11	39.44	24.03	63.55	10.72
501-05191	CEMENT CONCRETE PAVEMENT, PLAIN, 14 IN.	SYS	1	44.55	44.55	44.55	
501-05191	CEMENT CONCRETE PAVEMENT, PLAIN, 350 mm	SYS	8	43.18	32.39	66.71	11.56
501-05230	CEMENT CONCRETE PAVEMENT, PLAIN, HIGH EA	SYS	1	51.41	51.41	51.41	
501-05240	CONTRACTION JOINT, D1	LFT	67	7.92	3.20	20.97	3.22
501-05290	REINFORCING STEEL, PAVEMENT	kg	1	1.56	1.56	1.56	
501-05310	TERMINAL JOINT	LFT	44	90.55	6.81	171.32	37.42
501-05320	CEMENT CONCRETE PAVEMENT FOR PRIVATE DRI	SYS	4	42.57	37.45	48.55	5.81
501-05410	CEMENT CONCRETE PAVEMENT FOR SHOULDER, P	SYS	1	25.64	25.64	25.64	
501-06322	QC/QA PCCP, 275 mm	SYS	3	34.04	23.74	49.98	14.00
501-06323	QC/QA PCCP, 300 mm	SYS	4	24.84	20.10	27.17	3.22
501-06324	QC/QA PCCP, 325 mm	SYS	4	28.74	26.76	30.82	1.71
501-06325	QC/QA PCCP, 350 mm	SYS	3	27.83	27.24	28.18	0.51
501-06326	QC/QA PCCP, 375 mm	SYS	3	35.89	24.37	56.65	18.01
501-06664	QC/QA PCCP, 300 mm FOR SHOULDER	SYS	1	27.17	27.17	27.17	

**APPENDIX 2: Unit Costs for Pavement Repair, by Line Items
of INDOT Contract Bidding Documents (continued)**

Item Code	Item Description	Unit	Nr. of Sections ¹	Unit Cost Statistics (constant \$, Y2000)			
				Mean	Minimum	Maximum	Std Dev
501-06665	QC/QA PCCP, 350 mm FOR SHOULDER	SYS	2	27.66	27.24	28.07	0.59
501-06697	QC/QA PCCP, REIN., 300 mm FOR SHOULDER	SYS	1	53.93	53.93	53.93	
501-06698	QC/QA PCCP, REIN., 350 mm FOR SHOULDER	SYS	2	63.19	55.56	70.81	10.78
501-06914	QC/QA PCCP	SYS	3	102.19	87.47	129.96	24.06
501-07218	QC/QA, PRS, PCCP, 375 mm	SYS	1	24.76	24.76	24.76	
501-51940	PREFORMED JOINT MATERIAL, 1 IN.	LFT	2	6.44	4.87	8.01	2.22
501-90283	CONTRACTION JOINT, D-1, MODIFIED	LFT	1	24.91	24.91	24.91	
501-93683	CEMENT CONCRETE PAVEMENT FOR SHOULDER, P	SYS	1	23.13	23.13	23.13	
501-95038	CEMENT CONCRETE PAVEMENT FOR SHOULDER, 1	SYS	1	21.52	21.52	21.52	
501-95573	LONGITUDINAL JOINT	LFT	1	2.75	2.75	2.75	
501-95901	CEMENT CONC, PAVMNT SHLDR,PLAIN,FD, 350	SYS	2	32.75	28.85	36.64	5.51
501-97067	CEMENT CONCRETE PAVEMENT, PLAIN, FOR BAS	SYS	2	59.55	27.50	91.60	45.32
501-97879	CONTRACTION JOINT, D1, JOINT SEAL	LFT	1	1.19	1.19	1.19	
501-97983	CEMENT CONCRETE PAVEMENT, REINFORCED, 37	SYS	1	74.78	74.78	74.78	
501-98614	CEMENT CONCRETE PAVEMENT FOR DRIVEWAYS,	SYS	1	47.78	47.78	47.78	
502-03516	QA CEMENT CONCRETE PAVEMENT, PLAIN, 275	SYS	2	24.39	21.65	27.12	3.87
502-03516	QA CEMENT CONCRETE PAVEMENT, PLAIN,11 IN	SYS	3	25.28	22.47	30.23	4.30
502-03517	QA CEMENT CONC. PAVMNT FOR SHLDR,PLN,11	SYS	1	28.02	28.02	28.02	
502-03532	QA CEMENT CONCRETE PAVEMENT, PLAIN, 350	SYS	1	30.22	30.22	30.22	
502-03603	QA CEMENT CONCRETE PAVEMENT, PLAIN, 250	SYS	1	32.34	32.34	32.34	
502-03603	QA CEMENT CONCRETE PAVEMENT, PLAIN,10 IN	SYS	2	22.23	21.88	22.58	0.49
502-04540	QA CEMENT CONCRETE PAVMNT,SHOULDER,350mm	SYS	1	30.22	30.22	30.22	
502-04641	QA CEMENT CONCRETE PAVEMENT, REIN.,11 IN	SYS	1	70.43	70.43	70.43	
502-04777	QA CEMENT CONC. PAVEMENT, PLAIN, 325 mm	SYS	3	27.42	25.46	28.98	1.79
502-04778	QA CEMENT CONC. PVMNT FOR SHOUL,PLAI,325	SYS	1	28.98	28.98	28.98	
502-04797	QA CEMENT CONCRETE PAVEMENT, PLAIN,375mm	SYS	1	18.53	18.53	18.53	
502-04959	QA CEMENT CONCRETE PAVEMENT, PLAIN,300mm	SYS	1	25.95	25.95	25.95	
502-06327	PCCP, 250 mm	SYS	3	66.36	54.15	76.63	11.36
502-06328	PCCP, 11 IN.	SYS	1	37.00	37.00	37.00	
502-06328	PCCP, 275 mm	SYS	1	40.13	40.13	40.13	
502-06329	PCCP, 12 IN.	SYS	2	39.57	30.63	48.52	12.65
502-06330	PCCP, 325 mm	SYS	1	41.81	41.81	41.81	
502-06331	PCCP, 350 mm	SYS	5	43.79	37.56	51.22	6.43
502-06999	PCCP, 8 IN.	SYS	1	25.13	25.13	25.13	
610-04291	BITUMINOUS MIXTURE FOR APPROACHES, LV	TON	82	54.11	30.89	212.39	23.17

**APPENDIX 2: Unit Costs for Pavement Repair, by Line Items
of INDOT Contract Bidding Documents (continued)**

Item Code	Item Description	Unit	Nr. of Sections ¹	Unit Cost Statistics (constant \$, Y2000)			
				Mean	Minimum	Maximum	Std Dev
610-04292	BITUMINOUS MIXTURE FOR APPROACHES, MV	TON	78	53.56	1.01	105.35	16.41
610-04293	BITUMINOUS MIXTURE FOR APPROACHES, HV	TON	22	46.52	28.40	86.20	15.21
610-05527	HMA FOR APPROACHES	TON	380	55.84	6.78	254.01	21.75
610-06257	REINFORCED CONCRETE BRIDGE APPROACH,	SYS	2	61.22	57.75	64.69	4.91
610-06257	REINFORCED CONCRETE BRIDGE APPROACH, 250	SYS	8	46.38	37.12	63.11	8.99
610-06258	REINFORCED CONCRETE BRIDGE APPROACH	SYS	3	57.30	42.49	75.25	16.61
610-06259	REINFORCED CONCRETE BRIDGE APPROACH, 300	SYS	3	58.91	45.82	66.61	11.39
610-06262	REINFORCED CONCRETE BRIDGE APPROACH	SYS	5	64.94	58.32	71.08	6.15
610-06263	REINFORCED CONCRETE BRIDGE APPROACH	SYS	2	51.23	44.15	58.32	10.01
610-06460	COMPACTED AGGREGATE, O	TON	1	9.94	9.94	9.94	
610-06460	COMPACTED AGGREGATE, O, 53	TON	1	5.00	5.00	5.00	
610-06461	COMPACTED AGGREGATE, O, 73	TON	2	11.93	9.04	14.82	4.09

APPENDIX 3
Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Avg	Min.	Max.	Std Dev
G000	Road Constr.	610-04291	Bituminous Mixture for Approaches, LV	TON	1	48.00	48.00	48.00	
G000	Road Constr.	610-04292	Bituminous Mixture for Approaches, MV	TON	1	48.00	48.00	48.00	
G310	New Road Constr.	401-03100	Bituminous Base 5C, LV	TON	1	41.03	41.03	41.03	
G310	New Road Constr.	401-03101	Bituminous Base 5C, MV	TON	2	31.13	24.59	37.67	9.25
G310	New Road Constr.	401-03200	Bituminous Base 5, LV	TON	2	33.04	28.62	37.45	6.24
G310	New Road Constr.	401-03201	Bituminous Base 5, MV	TON	1	24.59	24.59	24.59	
G310	New Road Constr.	401-03229	Bituminous Binder 8 or 9, LV	TON	2	34.54	29.18	39.91	7.59
G310	New Road Constr.	401-03230	Bituminous Binder 8 or 9, MV	TON	1	24.93	24.93	24.93	
G310	New Road Constr.	401-03303	Bituminous Base 5D, LV	TON	2	32.62	26.27	38.96	8.97
G310	New Road Constr.	401-03304	Bituminous Base 5D, MV	TON	1	24.71	24.71	24.71	
G310	New Road Constr.	401-03545	Bituminous Surface 11, LV	TON	2	42.87	41.25	44.49	2.29
G310	New Road Constr.	401-03560	Bituminous Surface 11, MV	TON	1	35.49	35.49	35.49	
G310	New Road Constr.	401-04274	Bituminous Mixture for Wedge & Level	TON	1	26.83	26.83	26.83	
G310	New Road Constr.	401-04817	HMA Base 25.0 mm, Mainline	TON	1	39.13	39.13	39.13	
G310	New Road Constr.	401-04819	HMA Intermediate 12.5 mm, Mainline	TON	1	42.48	42.48	42.48	
G310	New Road Constr.	401-04822	HMA Surface 9.5 mm, MV, Mainline	TON	1	55.62	55.62	55.62	
G310	New Road Constr.	401-04824	HMA Base 25.0 mm, Shoulder	TON	1	41.25	41.25	41.25	
G310	New Road Constr.	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	3	32.06	29.14	36.15	3.65
G310	New Road Constr.	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	3	33.53	29.36	38.34	4.53
G310	New Road Constr.	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	3	42.94	38.78	48.20	4.81
G310	New Road Constr.	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	2	33.87	32.87	34.87	1.42
G310	New Road Constr.	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	1	28.21	28.21	28.21	
G310	New Road Constr.	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	1	32.32	32.32	32.32	
G310	New Road Constr.	402-05468	HMA Base 25.0 mm, Mainline	TON	2	37.67	33.71	41.63	5.60
G310	New Road Constr.	402-05470	HMA Base C25.0 mm, Mainline	TON	4	29.06	24.91	33.71	3.66
G310	New Road Constr.	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	2	36.31	36.15	36.47	0.23
G310	New Road Constr.	402-05477	HMA Surface 9.5 mm, Mainline	TON	2	42.35	38.68	46.01	5.18
G310	New Road Constr.	402-05481	HMA Base 25.0 mm, Shoulder	TON	1	38.13	38.13	38.13	
G310	New Road Constr.	406-05520	Asphalt for Tack Coat	TON	1	204.25	204.25	204.25	
G310	New Road Constr.	406-05520	Asphalt Material for Tack Coat	TON	1	202.67	202.67	202.67	
G310	New Road Constr.	501-05090	Cement Concrete Pavement, Reinforced, 10	SYS	5	47.67	40.12	66.32	10.89
G310	New Road Constr.	501-05240	Contraction Joint, D1	LFT	1	6.82	6.82	6.82	
G310	New Road Constr.	501-05310	Terminal Joint	LFT	1	19.40	19.40	19.40	
G310	New Road Constr.	501-05320	Cement Concrete Pavement for Private Dri	SYS	1	37.45	37.45	37.45	
G310	New Road Constr.	502-03516	QA Cement Concrete Pavement, Plain, 11 in	SYS	1	22.47	22.47	22.47	

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Contracts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
G310	New Road Constr.	502-04641	QA Cement Concrete Pavement, Rein., 11 in	SYS	1	70.43	70.43	70.43	
G310	New Road Constr.	610-04291	Bituminous Mixture for Approaches, LV	TON	3	48.82	36.89	55.90	10.39
G310	New Road Constr.	610-04292	Bituminous Mixture for Approaches, MV	TON	1	39.46	39.46	39.46	
G310	New Road Constr.	610-05527	HMA for Approaches	TON	3	50.95	32.76	77.37	23.42
G311	New Road Constr., Concr.	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	27.63	27.63	27.63	
G311	New Road Constr., Concr.	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	1	35.37	35.37	35.37	
G311	New Road Constr., Concr.	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	4	25.76	24.37	27.63	1.59
G311	New Road Constr., Concr.	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	4	29.67	28.03	33.16	2.35
G311	New Road Constr., Concr.	401-05467	Milled HMA Corrugations	LFT	4	0.21	0.19	0.22	0.01
G311	New Road Constr., Concr.	402-05468	HMA Base 25.0 mm, Mainline	TON	2	26.48	23.84	29.11	3.73
G311	New Road Constr., Concr.	402-05470	HMA Base C25.0 mm, Mainline	TON	1	24.38	24.38	24.38	
G311	New Road Constr., Concr.	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	3	28.31	27.10	29.11	1.07
G311	New Road Constr., Concr.	402-05477	HMA Surface 9.5 mm, Mainline	TON	2	35.68	32.35	39.01	4.71
G311	New Road Constr., Concr.	402-05481	HMA Base 25.0 mm, Shoulder	TON	2	28.37	27.63	29.11	1.05
G311	New Road Constr., Concr.	406-05520	Asphalt for Tack Coat	TON	4	177.51	161.73	210.00	22.11
G311	New Road Constr., Concr.	501-02578	Expansion Joint with Load Transfer, 1 in	LFT	2	12.02	9.11	14.92	4.11
G311	New Road Constr., Concr.	501-05090	Cement Concrete Pavement, Reinforced, 10	SYS	1	55.26	55.26	55.26	
G311	New Road Constr., Concr.	501-05091	Cement Concrete Pavement, Reinforced, 11	SYS	1	53.37	53.37	53.37	
G311	New Road Constr., Concr.	501-05181	Cement Concrete Pavement, Plain, 11 in.	SYS	1	22.53	22.53	22.53	
G311	New Road Constr., Concr.	501-05240	Contraction Joint, D1	LFT	4	6.19	6.11	6.27	0.07
G311	New Road Constr., Concr.	501-05310	Terminal Joint	LFT	2	114.29	88.42	140.17	36.59
G311	New Road Constr., Concr.	501-51940	Preformed Joint Material, 1 in.	LFT	2	6.44	4.87	8.01	2.22
G311	New Road Constr., Concr.	501-93683	Cement Concrete Pavement for Shoulder, P	SYS	1	23.13	23.13	23.13	
G311	New Road Constr., Concr.	502-03516	QA Cement Concrete Pavement, Plain, 11 in	SYS	1	23.13	23.13	23.13	
G311	New Road Constr., Concr.	502-03603	QA Cement Concrete Pavement, Plain, 10 in	SYS	2	22.23	21.88	22.58	0.49
G311	New Road Constr., Concr.	610-05527	HMA for Approaches	TON	4	41.51	30.95	52.02	9.48
G410	Added Travel Lanes	305-04020	Bituminous Mixture for Patching	TON	2	88.74	87.64	89.83	1.55
G410	Added Travel Lanes	310-04013	Patching, Full Depth, Plain Concrete Pav	SYS	1	95.00	95.00	95.00	
G410	Added Travel Lanes	401-02434	Bituminous Binder 8C, LV	TON	1	31.22	31.22	31.22	
G410	Added Travel Lanes	401-03101	Bituminous Base 5C, MV	TON	2	27.36	24.59	30.13	3.91
G410	Added Travel Lanes	401-03102	Bituminous Base 5C, HV	TON	4	32.67	27.95	36.15	3.63
G410	Added Travel Lanes	401-03200	Bituminous Base 5, LV	TON	3	34.07	31.77	36.89	2.60
G410	Added Travel Lanes	401-03201	Bituminous Base 5, MV	TON	2	31.74	25.71	37.77	8.52
G410	Added Travel Lanes	401-03202	Bituminous Base 5, HV	TON	4	32.39	27.95	36.15	4.19
G410	Added Travel Lanes	401-03229	Bituminous Binder 8 or 9, LV	TON	5	38.44	26.83	44.72	6.91
G410	Added Travel Lanes	401-03230	Bituminous Binder 8 or 9, MV	TON	2	30.68	24.59	36.77	8.61

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Contracts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
G410	Added Travel Lanes	401-03231	Bituminous Binder 8 or 9, HV	TON	4	42.53	36.77	50.31	6.22
G410	Added Travel Lanes	401-03264	Bituminous Mixture for Widening, MV	TON	1	29.07	29.07	29.07	
G410	Added Travel Lanes	401-03303	Bituminous Base 5D, LV	TON	5	34.91	26.27	39.75	5.75
G410	Added Travel Lanes	401-03304	Bituminous Base 5D, MV	TON	2	33.17	24.59	41.74	12.12
G410	Added Travel Lanes	401-03305	Bituminous Base 5D, HV	TON	4	37.52	27.95	49.19	8.76
G410	Added Travel Lanes	401-03545	Bituminous Surface 11, LV	TON	6	47.77	30.18	89.43	21.25
G410	Added Travel Lanes	401-03560	Bituminous Surface 11, MV	TON	2	37.45	30.18	44.72	10.28
G410	Added Travel Lanes	401-03575	Bituminous Surface 11, HV	TON	5	58.65	39.24	109.55	29.11
G410	Added Travel Lanes	401-04817	HMA Base 25.0 mm, Mainline	TON	3	35.84	35.60	36.15	0.28
G410	Added Travel Lanes	401-04819	HMA Intermediate 12.5 mm, Mainline	TON	3	37.75	36.15	38.76	1.40
G410	Added Travel Lanes	401-04820	HMA Intermediate 19.0 mm, Mainline	TON	1	38.50	38.50	38.50	
G410	Added Travel Lanes	401-04821	HMA Surface 9.5 mm, LV, Mainline	TON	1	43.82	43.82	43.82	
G410	Added Travel Lanes	401-04822	HMA Surface 9.5 mm, MV, Mainline	TON	1	39.44	39.44	39.44	
G410	Added Travel Lanes	401-04823	HMA Surface 9.5 mm, HV, Mainline	TON	2	46.76	43.82	49.69	4.15
G410	Added Travel Lanes	401-04824	HMA Base 25.0 mm, Shoulder	TON	5	36.21	32.48	43.82	4.44
G410	Added Travel Lanes	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	14	33.38	27.90	38.50	3.31
G410	Added Travel Lanes	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	13	34.56	28.94	42.09	4.01
G410	Added Travel Lanes	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	13	46.03	34.20	55.50	5.89
G410	Added Travel Lanes	401-05457	QC/QA HMA Surface 12.5 mm, Mainline	TON	1	42.00	42.00	42.00	
G410	Added Travel Lanes	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	2	37.58	37.28	37.88	0.43
G410	Added Travel Lanes	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	1	55.89	55.89	55.89	
G410	Added Travel Lanes	401-91826	Asphalt Plank	SYS	1	49.15	49.15	49.15	
G410	Added Travel Lanes	401-93813	Asphalt S&	TON	1	112.98	112.98	112.98	
G410	Added Travel Lanes	402-05468	HMA Base 25.0 mm, Mainline	TON	6	34.02	25.61	49.71	8.26
G410	Added Travel Lanes	402-05470	HMA Base C25.0 mm, Mainline	TON	11	31.34	22.00	43.00	6.82
G410	Added Travel Lanes	402-05473	HMA Intermediate 12.5 mm, Mainline	TON	1	26.95	26.95	26.95	
G410	Added Travel Lanes	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	6	38.88	30.56	64.83	12.93
G410	Added Travel Lanes	402-05475	HMA Intermediate C19.0 mm, Mainline	TON	4	33.67	26.42	38.01	5.07
G410	Added Travel Lanes	402-05477	HMA Surface 9.5 mm, Mainline	TON	9	47.75	33.79	65.53	11.34
G410	Added Travel Lanes	402-05481	HMA Base 25.0 mm, Shoulder	TON	6	45.35	30.00	67.00	13.22
G410	Added Travel Lanes	402-05483	HMA Base C25.0 mm, Shoulder	TON	1	28.92	28.92	28.92	
G410	Added Travel Lanes	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	1	74.09	74.09	74.09	
G410	Added Travel Lanes	402-05488	HMA Intermediate C19.0 mm, Shoulder	TON	1	36.00	36.00	36.00	
G410	Added Travel Lanes	402-05490	HMA Surface 9.5 mm, Shoulder	TON	3	68.63	54.00	92.62	20.94
G410	Added Travel Lanes	402-05495	HMA Wedge & Level	TON	8	49.44	22.46	69.46	15.57
G410	Added Travel Lanes	402-05498	HMA for Parking Area	TON	1	67.79	67.79	67.79	
G410	Added Travel Lanes	406-05520	Asphalt for Tack Coat	TON	15	202.34	138.93	370.47	68.60

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Contracts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
G410	Added Travel Lanes	501-02578	Expansion Joint with Load Transfer, 1 in	LFT	2	16.80	15.72	17.89	1.53
G410	Added Travel Lanes	501-03707	Raised Corrugated Isl&, Concrete	SYS	2	59.86	55.02	64.69	6.84
G410	Added Travel Lanes	501-04635	Milled Concrete Shoulder Corrugations	LFT	2	0.54	0.18	0.89	0.50
G410	Added Travel Lanes	501-05090	Cement Concrete Pavement, Reinforced, 10	SYS	7	50.93	39.04	76.69	13.51
G410	Added Travel Lanes	501-05090	Cement Concrete Pavement, Reinforced, 250	SYS	1	64.10	64.10	64.10	
G410	Added Travel Lanes	501-05091	Cement Concrete Pavement, Reinforced, 11	SYS	1	42.48	42.48	42.48	
G410	Added Travel Lanes	501-05170	Cement Concrete Pavement, Plain, 9 in.	SYS	1	40.53	40.53	40.53	
G410	Added Travel Lanes	501-05179	Cement Concrete Pavement, Plain, 13 in.	SYS	1	33.22	33.22	33.22	
G410	Added Travel Lanes	501-05180	Cement Concrete Pavement, Plain, 10 in.	SYS	4	32.86	20.40	49.30	12.49
G410	Added Travel Lanes	501-05181	Cement Concrete Pavement, Plain, 11 in.	SYS	2	28.63	26.83	30.43	2.55
G410	Added Travel Lanes	501-05240	Contraction Joint, D1	LFT	9	7.88	5.05	10.78	2.07
G410	Added Travel Lanes	501-05310	Terminal Joint	LFT	4	87.30	67.08	120.02	22.90
G410	Added Travel Lanes	501-05320	Cement Concrete Pavement for Private Dri	SYS	3	44.28	37.74	48.55	5.75
G410	Added Travel Lanes	501-06322	QC/QA PCCP, 275 mm	SYS	3	34.04	23.74	49.98	14.00
G410	Added Travel Lanes	501-06323	QC/QA PCCP, 300 mm	SYS	3	24.06	20.10	26.46	3.45
G410	Added Travel Lanes	501-06324	QC/QA PCCP, 325 mm	SYS	3	28.92	26.76	30.82	2.04
G410	Added Travel Lanes	501-06326	QC/QA PCCP, 375 mm	SYS	3	35.89	24.37	56.65	18.01
G410	Added Travel Lanes	501-06914	QC/QA PCCP	SYS	3	102.19	87.47	129.96	24.06
G410	Added Travel Lanes	501-07218	QC/QA, Prs, PCCP, 375 mm	SYS	1	24.76	24.76	24.76	
G410	Added Travel Lanes	501-95038	Cement Concrete Pavement for Shoulder, 1	SYS	1	21.52	21.52	21.52	
G410	Added Travel Lanes	502-06328	PCCP, 11 in.	SYS	1	37.00	37.00	37.00	
G410	Added Travel Lanes	502-06331	PCCP, 350 mm	SYS	1	51.22	51.22	51.22	
G410	Added Travel Lanes	610-04291	Bituminous Mixture for Approaches, LV	TON	7	56.15	41.08	74.54	11.80
G410	Added Travel Lanes	610-04292	Bituminous Mixture for Approaches, MV	TON	2	71.05	42.72	99.38	40.06
G410	Added Travel Lanes	610-04293	Bituminous Mixture for Approaches, HV	TON	2	52.23	49.69	54.78	3.59
G410	Added Travel Lanes	610-05527	HMA for Approaches	TON	13	77.24	36.15	180.77	36.69
G410	Added Travel Lanes	610-06257	Reinforced Concrete Bridge Approach, 250	SYS	1	51.65	51.65	51.65	
G410	Added Travel Lanes	610-06258	Reinforced Concrete Bridge Approach	SYS	2	48.32	42.49	54.15	8.25
G410	Added Travel Lanes	610-06263	Reinforced Concrete Bridge Approach	SYS	2	51.23	44.15	58.32	10.01
G411	Added Travel Lanes, Conc.	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	2	34.41	30.69	38.13	5.26
G411	Added Travel Lanes, Conc.	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	1	36.72	36.72	36.72	
G411	Added Travel Lanes, Conc.	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	1	40.32	40.32	40.32	
G411	Added Travel Lanes, Conc.	402-05468	HMA Base 25.0 mm, Mainline	TON	1	39.10	39.10	39.10	
G411	Added Travel Lanes, Conc.	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	2	45.87	43.11	48.63	3.91
G411	Added Travel Lanes, Conc.	402-05477	HMA Surface 9.5 mm, Mainline	TON	2	57.16	54.16	60.16	4.24
G411	Added Travel Lanes, Conc.	402-05481	HMA Base 25.0 mm, Shoulder	TON	4	46.74	30.69	77.37	20.83
G411	Added Travel Lanes, Conc.	402-05483	HMA Base C25.0 mm, Shoulder	TON	2	60.35	43.34	77.37	24.06

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Contracts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
G411	Added Travel Lanes, Concr.	402-05490	HMA Surface 9.5 mm, Shoulder	TON	2	46.93	33.70	60.16	18.71
G411	Added Travel Lanes, Concr.	406-05520	Asphalt for Tack Coat	TON	3	199.16	193.42	210.65	9.95
G411	Added Travel Lanes, Concr.	501-05090	Cement Concrete Pavement, Reinforced, 10	SYS	2	49.07	38.68	59.46	14.69
G411	Added Travel Lanes, Concr.	501-05091	Cement Concrete Pavement, Reinforced, 11	SYS	1	51.46	51.46	51.46	
G411	Added Travel Lanes, Concr.	501-05180	Cement Concrete Pavement, Plain, 10 in.	SYS	1	24.87	24.87	24.87	
G411	Added Travel Lanes, Concr.	501-05181	Cement Concrete Pavement, Plain, 11 in.	SYS	1	33.26	33.26	33.26	
G411	Added Travel Lanes, Concr.	501-05240	Contraction Joint, D1	LFT	4	6.74	4.18	8.29	1.78
G411	Added Travel Lanes, Concr.	501-05310	Terminal Joint	LFT	3	95.26	7.26	171.32	82.68
G411	Added Travel Lanes, Concr.	501-05410	Cement Concrete Pavement for Shoulder, P	SYS	1	25.64	25.64	25.64	
G411	Added Travel Lanes, Concr.	502-03516	QA Cement Concrete Pavement, Plain, 11 in	SYS	1	30.23	30.23	30.23	
G411	Added Travel Lanes, Concr.	502-03517	QA Cement Conc. Pavmnt for Shldr, Pln, 11	SYS	1	28.02	28.02	28.02	
G411	Added Travel Lanes, Concr.	502-03603	QA Cement Concrete Pavement, Plain, 250	SYS	1	32.34	32.34	32.34	
G411	Added Travel Lanes, Concr.	610-05527	HMA for Approaches	TON	3	60.79	54.17	66.32	6.15
G412	Added Travel Lanes, Bit.	401-03202	Bituminous Base 5, HV	TON	1	30.81	30.81	30.81	
G412	Added Travel Lanes, Bit.	401-03231	Bituminous Binder 8 or 9, HV	TON	1	29.57	29.57	29.57	
G412	Added Travel Lanes, Bit.	401-03305	Bituminous Base 5D, HV	TON	1	30.81	30.81	30.81	
G412	Added Travel Lanes, Bit.	401-03575	Bituminous Surface 11, HV	TON	1	37.77	37.77	37.77	
G412	Added Travel Lanes, Bit.	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	36.47	36.47	36.47	
G412	Added Travel Lanes, Bit.	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	1	36.47	36.47	36.47	
G412	Added Travel Lanes, Bit.	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	1	43.11	43.11	43.11	
G412	Added Travel Lanes, Bit.	402-05481	HMA Base 25.0 mm, Shoulder	TON	1	37.58	37.58	37.58	
G412	Added Travel Lanes, Bit.	406-05520	Asphalt Material for Tack Coat	TON	1	143.68	143.68	143.68	
G412	Added Travel Lanes, Bit.	501-04010	Cement Concrete Pavement for Patching	SYS	1	154.74	154.74	154.74	
G412	Added Travel Lanes, Bit.	501-05140	Cement Concrete Pavement, Plain, 150 mm	SYS	1	59.54	59.54	59.54	
G412	Added Travel Lanes, Bit.	501-05170	Cement Concrete Pavement, Plain, 9 in.	SYS	1	34.26	34.26	34.26	
G412	Added Travel Lanes, Bit.	501-97067	Cement Concrete Pavement, Plain, for Bas	SYS	1	91.60	91.60	91.60	
G412	Added Travel Lanes, Bit.	610-04291	Bituminous Mixture for Approaches, LV	TON	1	74.54	74.54	74.54	
G412	Added Travel Lanes, Bit.	610-05527	HMA for Approaches	TON	1	60.79	60.79	60.79	
G610	Auxillary Lane Constr.	401-05454	QC/QA HMA Intermediate 12.5 mm, Mainline	TON	1	26.67	26.67	26.67	
G610	Auxillary Lane Constr.	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	1	29.68	29.68	29.68	
G610	Auxillary Lane Constr.	402-05468	HMA Base 25.0 mm, Mainline	TON	1	26.67	26.67	26.67	
G610	Auxillary Lane Constr.	402-05495	HMA for Wedge & Level	TON	1	40.11	40.11	40.11	
G610	Auxillary Lane Constr.	610-05527	HMA for Approaches	TON	1	45.12	45.12	45.12	
J000	Pvmnt Repair Or Rehab.	310-04013	Patching, Full Depth, Plain Concrete Pav	SYS	1	105.00	105.00	105.00	
J000	Pvmnt Repair Or Rehab.	310-04014	Patching, Full Depth, Reinforced Concret	SYS	1	105.00	105.00	105.00	
J000	Pvmnt Repair Or Rehab.	310-04016	Patching, Full Depth, Continuously Reinf	SYS	1	127.11	127.11	127.11	
J000	Pvmnt Repair Or Rehab.	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	23.96	23.96	23.96	

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Contracts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J000	Pvmnt Repair Or Rehab.	401-05454	QC/QA HMA Intermediate 12.5 mm, Mainline	TON	4	32.61	26.31	39.13	5.74
J000	Pvmnt Repair Or Rehab.	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	9	30.19	22.50	44.12	7.31
J000	Pvmnt Repair Or Rehab.	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	14	40.55	32.28	55.15	7.36
J000	Pvmnt Repair Or Rehab.	401-05457	QC/QA HMA Surface 12.5 mm, Mainline	TON	10	37.18	30.32	49.90	6.90
J000	Pvmnt Repair Or Rehab.	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	3	32.44	23.96	39.13	7.74
J000	Pvmnt Repair Or Rehab.	401-05462	QC/QA HMA Intermediate 12.5 mm, Shoulder	TON	4	33.12	26.31	39.13	5.47
J000	Pvmnt Repair Or Rehab.	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	7	33.38	22.50	64.65	14.82
J000	Pvmnt Repair Or Rehab.	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	9	38.27	32.28	48.42	5.85
J000	Pvmnt Repair Or Rehab.	401-05465	QC/QA HMA Surface 12.5 mm, Shoulder	TON	6	38.42	31.30	51.51	9.21
J000	Pvmnt Repair Or Rehab.	401-05467	Milled HMA Corrugations	LFT	3	2.02	0.15	3.90	1.87
J000	Pvmnt Repair Or Rehab.	401-06962	QC/QA HMA Surface 9.5 mm, Mainline, SMA	TON	1	43.39	43.39	43.39	
J000	Pvmnt Repair Or Rehab.	402-03720	Micro-Surfacing, Surface Course	SYS	1	1.64	1.64	1.64	
J000	Pvmnt Repair Or Rehab.	402-05468	HMA Base 25.0 mm, Mainline	TON	2	65.09	39.79	90.39	35.78
J000	Pvmnt Repair Or Rehab.	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	3	35.75	31.30	44.21	7.33
J000	Pvmnt Repair Or Rehab.	402-05477	HMA Surface 9.5 mm, Mainline	TON	3	56.33	37.17	76.57	19.72
J000	Pvmnt Repair Or Rehab.	402-05481	HMA Base 25.0 mm, Shoulder	TON	2	51.49	44.02	58.97	10.57
J000	Pvmnt Repair Or Rehab.	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	2	31.72	25.33	38.10	9.03
J000	Pvmnt Repair Or Rehab.	402-05490	HMA Surface 9.5 mm, Shoulder	TON	2	43.65	37.17	50.13	9.17
J000	Pvmnt Repair Or Rehab.	402-05492	HMA Surface 12.5 mm, Shoulder	TON	2	37.66	35.21	40.11	3.46
J000	Pvmnt Repair Or Rehab.	402-05495	HMA Wedge & Level	TON	9	56.02	38.29	75.20	14.50
J000	Pvmnt Repair Or Rehab.	406-05520	Asphalt for Tack Coat	TON	4	318.33	112.98	611.38	211.05
J000	Pvmnt Repair Or Rehab.	501-03838	Groove Portl& Cement Concrete	SYS	1	4.28	4.28	4.28	
J000	Pvmnt Repair Or Rehab.	501-05240	Contraction Joint, D1	LFT	3	7.14	5.49	9.95	2.44
J000	Pvmnt Repair Or Rehab.	502-06329	PCCP, 12 in.	SYS	1	30.63	30.63	30.63	
J000	Pvmnt Repair Or Rehab.	610-05527	HMA for Approaches	TON	16	57.37	35.09	75.20	12.22
J100	Patch & Rehab Pvmnt	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	2	39.09	34.35	43.84	6.71
J100	Patch & Rehab Pvmnt	402-05495	HMA Wedge & Level	TON	2	35.70	33.44	37.96	3.20
J100	Patch & Rehab Pvmnt	406-05520	Asphalt for Tack Coat	TON	2	176.26	171.74	180.77	6.39
J100	Patch & Rehab Pvmnt	610-05527	HMA for Approaches	TON	2	84.96	43.39	126.54	58.80
J111	Full Depth Patching, Bit.	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	65.46	65.46	65.46	
J111	Full Depth Patching, Bit.	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	1	65.46	65.46	65.46	
J111	Full Depth Patching, Bit.	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	1	95.28	95.28	95.28	
J111	Full Depth Patching, Bit.	402-05475	HMA Intermediate C19.0 mm, Mainline	TON	1	60.83	60.83	60.83	
J111	Full Depth Patching, Bit.	406-05520	Asphalt for Tack Coat	TON	1	331.12	331.12	331.12	
J112	Full Depth Patching, Bit.	401-04274	Bituminous Mixture for Wedge & Level	TON	1	37.77	37.77	37.77	
J120	Full Depth Patching, Bit.	501-05180	Cement Concrete Pavement, Plain, 250 mm	SYS	1	54.96	54.96	54.96	
J120	Full Depth Patching, Bit.	501-05240	Contraction Joint, D1	LFT	2	8.04	6.23	9.85	2.56

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J121	Full Depth Patching, Conc.	310-04014	Patching, Full Depth, Reinforced Concret	SYS	1	102.57	102.57	102.57	
J121	Full Depth Patching, Conc.	402-05468	HMA Base 25.0 mm, Mainline	TON	1	51.14	51.14	51.14	
J121	Full Depth Patching, Conc.	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	1	59.16	59.16	59.16	
J121	Full Depth Patching, Conc.	402-05477	HMA Surface 9.5 mm, Mainline	TON	2	88.01	68.18	107.84	28.04
J121	Full Depth Patching, Conc.	402-05481	HMA Base 25.0 mm, Shoulder	TON	1	56.15	56.15	56.15	
J121	Full Depth Patching, Conc.	501-04014	Patching, Full Depth, Reinforced Concret	SYS	3	115.38	103.50	127.11	11.81
J121	Full Depth Patching, Conc.	501-05240	Contraction Joint, D1	LFT	1	8.54	8.54	8.54	
J121	Full Depth Patching, Conc.	610-05527	HMA for Approaches	TON	1	79.21	79.21	79.21	
J124	Reseal Joints & Patch Conc Pvt	310-04014	Patching, Full Depth, Reinforced Concret	SYS	1	109.89	109.89	109.89	
J124	Reseal Joints & Patch Conc Pvt	310-04016	Patching, Full Depth, Continuously Reinf	SYS	1	101.73	101.73	101.73	
J124	Reseal Joints & Patch Conc Pvt	402-05495	HMA Wedge & Level	TON	1	58.75	58.75	58.75	
J124	Reseal Joints & Patch Conc Pvt	501-05310	Terminal Joint	LFT	2	72.28	60.74	83.82	16.32
J124	Reseal Joints & Patch Conc Pvt	610-06258	Reinforced Concrete Bridge Approach	SYS	1	75.25	75.25	75.25	
J200	Resurface (Non-3r/4r Stdrds)	305-04020	Bituminous Mixture for Patching	TON	9	92.85	46.95	118.85	23.94
J200	Resurface (Non-3r/4r Stdrds)	310-04013	Patching, Full Depth, Plain Concrete Pav	SYS	1	127.44	127.44	127.44	
J200	Resurface (Non-3r/4r Stdrds)	310-04014	Patching, Full Depth, Reinforced Concret	SYS	2	121.07	103.53	138.62	24.82
J200	Resurface (Non-3r/4r Stdrds)	401-01338	Bituminous Surface, SMA, MV	TON	1	48.54	48.54	48.54	
J200	Resurface (Non-3r/4r Stdrds)	401-01657	Bituminous Mixture for Wedge & Level,	TON	2	32.55	27.33	37.77	7.38
J200	Resurface (Non-3r/4r Stdrds)	401-02434	Bituminous Binder 8C, LV	TON	5	32.10	24.59	39.16	6.66
J200	Resurface (Non-3r/4r Stdrds)	401-02684	Temporary Bituminous Pavement	TON	1	42.73	42.73	42.73	
J200	Resurface (Non-3r/4r Stdrds)	401-03101	Bituminous Base 5C, MV	TON	1	41.74	41.74	41.74	
J200	Resurface (Non-3r/4r Stdrds)	401-03102	Bituminous Base 5C, HV	TON	1	25.35	25.35	25.35	
J200	Resurface (Non-3r/4r Stdrds)	401-03200	Bituminous Base 5, LV	TON	4	27.28	21.24	35.78	6.20
J200	Resurface (Non-3r/4r Stdrds)	401-03201	Bituminous Base 5, MV	TON	4	31.11	24.34	41.74	7.51
J200	Resurface (Non-3r/4r Stdrds)	401-03202	Bituminous Base 5, HV	TON	7	28.74	24.34	37.52	4.71
J200	Resurface (Non-3r/4r Stdrds)	401-03211	Bituminous Base 5 or 5D, MV	TON	1	36.51	36.51	36.51	
J200	Resurface (Non-3r/4r Stdrds)	401-03219	Bituminous Binder 8, LV	TON	7	25.75	22.36	29.50	2.69
J200	Resurface (Non-3r/4r Stdrds)	401-03220	Bituminous Binder 8, MV	TON	12	23.64	20.12	31.30	3.03
J200	Resurface (Non-3r/4r Stdrds)	401-03221	Bituminous Binder 8, HV	TON	2	26.34	26.34	26.34	0.00
J200	Resurface (Non-3r/4r Stdrds)	401-03229	Bituminous Binder 8 or 9, LV	TON	9	26.93	23.83	35.78	3.73
J200	Resurface (Non-3r/4r Stdrds)	401-03230	Bituminous Binder 8 or 9, MV	TON	19	27.37	19.93	37.73	4.62
J200	Resurface (Non-3r/4r Stdrds)	401-03231	Bituminous Binder 8 or 9, HV	TON	7	24.01	20.28	29.07	3.58
J200	Resurface (Non-3r/4r Stdrds)	401-03238	Bituminous Binder 9, LV	TON	11	26.46	22.21	32.50	3.45
J200	Resurface (Non-3r/4r Stdrds)	401-03239	Bituminous Binder 9, MV	TON	11	34.81	21.25	126.77	30.67
J200	Resurface (Non-3r/4r Stdrds)	401-03240	Bituminous Binder 9, HV	TON	1	32.87	32.87	32.87	
J200	Resurface (Non-3r/4r Stdrds)	401-03248	Bituminous Binder 11, MV	TON	8	28.09	25.61	30.43	1.56
J200	Resurface (Non-3r/4r Stdrds)	401-03249	Bituminous Binder 11, HV	TON	2	28.82	28.82	28.82	0.00

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J200	Resurface (Non-3r/4r Stdrds)	401-03263	Bituminous Mixture for Widening, LV	TON	18	51.74	22.64	114.29	30.90
J200	Resurface (Non-3r/4r Stdrds)	401-03264	Bituminous Mixture for Widening, MV	TON	29	41.74	20.57	106.49	16.76
J200	Resurface (Non-3r/4r Stdrds)	401-03301	Bituminous Base, MV	TON	1	67.95	67.95	67.95	
J200	Resurface (Non-3r/4r Stdrds)	401-03303	Bituminous Base 5D, LV	TON	8	43.62	23.83	84.48	20.10
J200	Resurface (Non-3r/4r Stdrds)	401-03304	Bituminous Base 5D, MV	TON	3	32.48	25.84	41.74	8.27
J200	Resurface (Non-3r/4r Stdrds)	401-03305	Bituminous Base 5D, HV	TON	2	23.30	21.24	25.35	2.91
J200	Resurface (Non-3r/4r Stdrds)	401-03401	Bituminous Binder, MV	TON	1	33.79	33.79	33.79	
J200	Resurface (Non-3r/4r Stdrds)	401-03501	Bituminous Surface, LV	TON	1	27.84	27.84	27.84	
J200	Resurface (Non-3r/4r Stdrds)	401-03503	Bituminous Surface, HV	TON	1	37.62	37.62	37.62	
J200	Resurface (Non-3r/4r Stdrds)	401-03545	Bituminous Surface 11, LV	TON	30	28.81	19.88	36.34	3.50
J200	Resurface (Non-3r/4r Stdrds)	401-03560	Bituminous Surface 11, MV	TON	53	30.37	23.58	50.71	5.06
J200	Resurface (Non-3r/4r Stdrds)	401-03575	Bituminous Surface 11, HV	TON	10	32.42	24.34	39.44	4.73
J200	Resurface (Non-3r/4r Stdrds)	401-03590	Bituminous Surface 9, LV	TON	4	28.74	26.37	32.60	2.92
J200	Resurface (Non-3r/4r Stdrds)	401-03605	Bituminous Surface 9, MV	TON	2	30.73	29.81	31.64	1.29
J200	Resurface (Non-3r/4r Stdrds)	401-04213	Bituminous Base 1 in., HV	TON	1	27.72	27.72	27.72	
J200	Resurface (Non-3r/4r Stdrds)	401-04214	Bituminous Binder 0.750 in., HV	TON	1	28.06	28.06	28.06	
J200	Resurface (Non-3r/4r Stdrds)	401-04215	Bituminous Surface 0.375 in., HV	TON	1	42.93	42.93	42.93	
J200	Resurface (Non-3r/4r Stdrds)	401-04273	Bituminous Mixture for Wedge & Level,	TON	2	28.93	27.43	30.43	2.12
J200	Resurface (Non-3r/4r Stdrds)	401-04274	Bituminous Mixture for Wedge & Level	TON	35	34.73	23.53	67.58	10.70
J200	Resurface (Non-3r/4r Stdrds)	401-04290	Bituminous Mixture for Wedge & Level,	TON	22	35.50	22.21	63.51	9.76
J200	Resurface (Non-3r/4r Stdrds)	401-04817	HMA Base 25.0 mm, Mainline	TON	5	31.49	25.47	38.54	5.52
J200	Resurface (Non-3r/4r Stdrds)	401-04819	HMA Intermediate 12.5 mm, Mainline	TON	11	28.96	23.55	34.78	4.20
J200	Resurface (Non-3r/4r Stdrds)	401-04820	HMA Intermediate 19.0 mm, Mainline	TON	6	28.74	25.35	36.75	4.38
J200	Resurface (Non-3r/4r Stdrds)	401-04821	HMA Surface 9.5 mm, LV, Mainline	TON	1	32.96	32.96	32.96	
J200	Resurface (Non-3r/4r Stdrds)	401-04822	HMA Surface 9.5 mm, MV, Mainline	TON	15	34.00	26.83	40.90	4.29
J200	Resurface (Non-3r/4r Stdrds)	401-04823	HMA Surface 9.5 mm, HV, Mainline	TON	3	34.66	28.90	40.57	5.83
J200	Resurface (Non-3r/4r Stdrds)	401-04824	HMA Base 25.0 mm, Shoulder	TON	8	34.15	26.37	53.67	8.74
J200	Resurface (Non-3r/4r Stdrds)	401-04825	HMA Base 37.5 mm, Shoulder	TON	1	36.10	36.10	36.10	
J200	Resurface (Non-3r/4r Stdrds)	401-04826	HMA Intermediate 12.5 mm, Shoulder	TON	5	31.25	26.37	33.79	2.87
J200	Resurface (Non-3r/4r Stdrds)	401-04827	HMA Intermediate 19.0 mm, Shoulder	TON	5	30.39	26.37	33.79	3.38
J200	Resurface (Non-3r/4r Stdrds)	401-04828	HMA Surface 9.5 mm, LV, Shoulder	TON	5	42.52	31.19	60.85	12.13
J200	Resurface (Non-3r/4r Stdrds)	401-04829	HMA Surface 9.5 mm, MV, Shoulder	TON	6	36.03	26.83	48.13	8.15
J200	Resurface (Non-3r/4r Stdrds)	401-05096	in-Place Drum Mix Recycling	SYS	1	2.53	2.53	2.53	
J200	Resurface (Non-3r/4r Stdrds)	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	10	32.97	24.45	47.17	7.38
J200	Resurface (Non-3r/4r Stdrds)	401-05453	QC/QA HMA Intermediate 9.5 mm, Mainline	TON	8	29.67	21.56	41.37	7.77
J200	Resurface (Non-3r/4r Stdrds)	401-05454	QC/QA HMA Intermediate 12.5 mm, Mainline	TON	100	26.84	20.54	46.55	4.12
J200	Resurface (Non-3r/4r Stdrds)	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	76	27.95	19.07	63.50	6.01

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J200	Resurface (Non-3r/4r Std rds)	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	234	33.32	22.50	57.03	5.81
J200	Resurface (Non-3r/4r Std rds)	401-05457	QC/QA HMA Surface 12.5 mm, Mainline	TON	24	36.31	28.08	62.37	8.05
J200	Resurface (Non-3r/4r Std rds)	401-05458	QC/QA HMA Surface 19.0 mm, Mainline	TON	1	26.21	26.21	26.21	
J200	Resurface (Non-3r/4r Std rds)	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	7	28.72	15.37	34.72	6.74
J200	Resurface (Non-3r/4r Std rds)	401-05461	QC/QA HMA Intermediate 9.5 mm, Shoulder	TON	5	31.25	26.83	37.10	4.00
J200	Resurface (Non-3r/4r Std rds)	401-05462	QC/QA HMA Intermediate 12.5 mm, Shoulder	TON	16	28.61	22.06	41.41	5.78
J200	Resurface (Non-3r/4r Std rds)	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	16	26.24	19.07	32.66	4.64
J200	Resurface (Non-3r/4r Std rds)	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	33	33.08	21.52	54.23	7.72
J200	Resurface (Non-3r/4r Std rds)	401-05465	QC/QA HMA Surface 12.5 mm, Shoulder	TON	4	40.10	34.23	45.19	4.53
J200	Resurface (Non-3r/4r Std rds)	401-05466	QC/QA HMA Surface 19.0 mm, Shoulder	TON	2	26.42	25.88	26.96	0.76
J200	Resurface (Non-3r/4r Std rds)	401-05467	Milled HMA Corrugations	LFT	9	0.52	0.08	3.51	1.12
J200	Resurface (Non-3r/4r Std rds)	401-06962	QC/QA HMA Surface 9.5 mm, Mainline, SMA	TON	1	38.87	38.87	38.87	
J200	Resurface (Non-3r/4r Std rds)	401-91660	Bituminous Mixture for Wedge & Level 9,	TON	1	23.83	23.83	23.83	
J200	Resurface (Non-3r/4r Std rds)	401-91661	Bituminous Mixture for Wedge & Level	TON	1	32.09	32.09	32.09	
J200	Resurface (Non-3r/4r Std rds)	401-93793	Wedge & Leveling	TON	1	40.25	40.25	40.25	
J200	Resurface (Non-3r/4r Std rds)	401-93821	Bituminous Surface 11, HV, with Fibers	TON	3	36.69	30.43	41.92	5.82
J200	Resurface (Non-3r/4r Std rds)	401-93853	Bituminous Base 5, HV, with Fibers	TON	2	28.98	27.78	30.18	1.70
J200	Resurface (Non-3r/4r Std rds)	401-94492	Bituminous Binder 8 or 9, HV, with Fiber	TON	1	25.35	25.35	25.35	
J200	Resurface (Non-3r/4r Std rds)	401-94845	Bituminous Surface 11, MV, with Fibers	TON	1	41.84	41.84	41.84	
J200	Resurface (Non-3r/4r Std rds)	401-95441	Bituminous Surface 11, MV, MAC 20	TON	1	34.08	34.08	34.08	
J200	Resurface (Non-3r/4r Std rds)	401-96011	Bituminous Base 5, MV, with Fibers	TON	1	34.68	34.68	34.68	
J200	Resurface (Non-3r/4r Std rds)	401-96012	Bituminous Binder, 8 or 9, HV, with Fibe	TON	1	31.86	31.86	31.86	
J200	Resurface (Non-3r/4r Std rds)	401-96013	Bituminous Binder, 8 or 9, MV, with Fibe	TON	1	34.68	34.68	34.68	
J200	Resurface (Non-3r/4r Std rds)	401-96377	Bituminous Mixture for Wedge & Level,	TON	1	39.15	39.15	39.15	
J200	Resurface (Non-3r/4r Std rds)	401-97738	Bituminous Mixture for Wedge & Level,	TON	2	29.85	28.40	31.30	2.05
J200	Resurface (Non-3r/4r Std rds)	401-98804	Bituminous Mixture for Isl&S, MV	TON	1	109.55	109.55	109.55	
J200	Resurface (Non-3r/4r Std rds)	401-98857	Bituminous Binder 8 or 9, HV, with Fiber	TON	1	27.78	27.78	27.78	
J200	Resurface (Non-3r/4r Std rds)	401-99180	Bituminous Mixture for Superelevation	TON	1	31.86	31.86	31.86	
J200	Resurface (Non-3r/4r Std rds)	402-01903	Bituminous Mixture for Wedge & Level 1	TON	1	33.29	33.29	33.29	
J200	Resurface (Non-3r/4r Std rds)	402-01903	Bituminous Mixture for Wedge & Level 11	TON	2	34.29	32.80	35.78	2.11
J200	Resurface (Non-3r/4r Std rds)	402-03226	Bituminous Binder 8 HAE, LV	TON	2	28.92	28.78	29.07	0.20
J200	Resurface (Non-3r/4r Std rds)	402-03235	Bituminous Binder 8 or 9 HAE, LV	TON	1	22.75	22.75	22.75	
J200	Resurface (Non-3r/4r Std rds)	402-03253	Bituminous Binder 11 HAE, LV	TON	1	31.07	31.07	31.07	
J200	Resurface (Non-3r/4r Std rds)	402-03254	Bituminous Binder 11 HAE, MV	TON	1	32.03	32.03	32.03	
J200	Resurface (Non-3r/4r Std rds)	402-03550	Bituminous Surface 11 HAE, LV	TON	3	31.53	29.29	33.54	2.13
J200	Resurface (Non-3r/4r Std rds)	402-03565	Bituminous Surface 11 HAE, MV	TON	1	31.69	31.69	31.69	
J200	Resurface (Non-3r/4r Std rds)	402-04281	Bituminous Mixture for Wedge & Level HA	TON	2	32.99	31.41	34.56	2.23

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J200	Resurface (Non-3r/4r Stdrds)	402-05468	HMA Base 25.0 mm, Mainline	TON	13	53.18	23.96	244.94	60.16
J200	Resurface (Non-3r/4r Stdrds)	402-05471	HMA Base C50.0 mm, Mainline	TON	1	27.07	27.07	27.07	
J200	Resurface (Non-3r/4r Stdrds)	402-05472	HMA Intermediate 9.5 mm, Mainline	TON	4	27.97	24.06	31.33	3.12
J200	Resurface (Non-3r/4r Stdrds)	402-05473	HMA Intermediate 12.5 mm, Mainline	TON	9	38.17	27.33	64.56	12.20
J200	Resurface (Non-3r/4r Stdrds)	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	8	35.47	24.13	50.13	9.34
J200	Resurface (Non-3r/4r Stdrds)	402-05477	HMA Surface 9.5 mm, Mainline	TON	24	39.62	28.58	53.50	6.86
J200	Resurface (Non-3r/4r Stdrds)	402-05479	HMA Surface 12.5 mm, Mainline	TON	1	39.85	39.85	39.85	
J200	Resurface (Non-3r/4r Stdrds)	402-05481	HMA Base 25.0 mm, Shoulder	TON	11	39.60	23.96	69.18	13.05
J200	Resurface (Non-3r/4r Stdrds)	402-05483	HMA Base C25.0 mm, Shoulder	TON	1	45.12	45.12	45.12	
J200	Resurface (Non-3r/4r Stdrds)	402-05485	HMA Intermediate 9.5 mm, Shoulder	TON	3	37.63	27.07	46.95	10.00
J200	Resurface (Non-3r/4r Stdrds)	402-05486	HMA Intermediate 12.5 mm, Shoulder	TON	10	30.46	22.56	51.74	8.54
J200	Resurface (Non-3r/4r Stdrds)	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	13	36.48	25.77	65.77	12.28
J200	Resurface (Non-3r/4r Stdrds)	402-05488	HMA Intermediate C19.0 mm, Shoulder	TON	1	54.23	54.23	54.23	
J200	Resurface (Non-3r/4r Stdrds)	402-05490	HMA Surface 9.5 mm, Shoulder	TON	24	37.36	28.58	56.25	7.86
J200	Resurface (Non-3r/4r Stdrds)	402-05492	HMA Surface 12.5 mm, Shoulder	TON	5	40.83	32.77	58.75	10.43
J200	Resurface (Non-3r/4r Stdrds)	402-05493	HMA Surface 19.0 mm, Shoulder	TON	2	35.04	31.52	38.56	4.97
J200	Resurface (Non-3r/4r Stdrds)	402-05495	HMA for Wedge & Level	TON	40	37.35	22.06	62.67	10.90
J200	Resurface (Non-3r/4r Stdrds)	402-05495	HMA Wedge & Level	TON	115	39.66	22.01	108.46	14.91
J200	Resurface (Non-3r/4r Stdrds)	402-05496	HMA for Isl&S	TON	1	50.13	50.13	50.13	
J200	Resurface (Non-3r/4r Stdrds)	402-05498	HMA for Parking Area	TON	6	42.45	26.07	80.21	19.96
J200	Resurface (Non-3r/4r Stdrds)	402-07167	Ultrathin Bonded Wearing Course	TON	1	100.05	100.05	100.05	
J200	Resurface (Non-3r/4r Stdrds)	406-05520	Asphalt for Tack Coat	TON	103	180.40	10.21	451.94	61.34
J200	Resurface (Non-3r/4r Stdrds)	501-02578	Expansion Joint with Load Transfer, 25 M	LFT	1	11.93	11.93	11.93	
J200	Resurface (Non-3r/4r Stdrds)	501-04010	Cement Concrete Pavement for Patching	SYS	1	190.05	190.05	190.05	
J200	Resurface (Non-3r/4r Stdrds)	501-04014	Patching, Full Depth, Reinforced Concret	SYS	5	100.29	56.08	155.06	36.27
J200	Resurface (Non-3r/4r Stdrds)	501-04842	Cement Concrete Pavement, Reinf., 260mm	SYS	1	59.50	59.50	59.50	
J200	Resurface (Non-3r/4r Stdrds)	501-05090	Cement Concrete Pavement, Reinforced, 250	SYS	1	144.17	144.17	144.17	
J200	Resurface (Non-3r/4r Stdrds)	501-05092	Cement Concrete Pavement, Reinforced, 12	SYS	1	54.22	54.22	54.22	
J200	Resurface (Non-3r/4r Stdrds)	501-05092	Cement Concrete Pavement, Reinforced, 30	SYS	1	41.29	41.29	41.29	
J200	Resurface (Non-3r/4r Stdrds)	501-05182	Cement Concrete Pavement, Plain, 12 in.	SYS	1	37.73	37.73	37.73	
J200	Resurface (Non-3r/4r Stdrds)	501-05182	Cement Concrete Pavement, Plain, 300 mm	SYS	1	63.55	63.55	63.55	
J200	Resurface (Non-3r/4r Stdrds)	501-05230	Cement Concrete Pavement, Plain, High Ea	SYS	1	51.41	51.41	51.41	
J200	Resurface (Non-3r/4r Stdrds)	501-05240	Contraction Joint, D1	LFT	5	10.78	5.97	15.24	3.56
J200	Resurface (Non-3r/4r Stdrds)	501-05310	Terminal Joint	LFT	4	87.53	6.81	125.22	54.39
J200	Resurface (Non-3r/4r Stdrds)	502-06327	PCCP, 250 mm	SYS	1	54.15	54.15	54.15	
J200	Resurface (Non-3r/4r Stdrds)	502-06328	PCCP, 275 mm	SYS	1	40.13	40.13	40.13	
J200	Resurface (Non-3r/4r Stdrds)	502-06330	PCCP, 325 mm	SYS	1	41.81	41.81	41.81	
J200	Resurface (Non-3r/4r Stdrds)	610-04291	Bituminous Mixture for Approaches, LV	TON	52	51.57	32.61	101.42	13.44
J200	Resurface (Non-3r/4r Stdrds)	610-04292	Bituminous Mixture for Approaches, MV	TON	62	51.68	1.01	86.08	14.39

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J200	Resurface (Non-3r/4r Stdnds)	610-04293	Bituminous Mixture for Approaches, HV	TON	8	47.21	30.43	70.99	15.50
J200	Resurface (Non-3r/4r Stdnds)	610-05527	HMA for Approaches	TON	203	53.34	22.60	130.63	17.86
J200	Resurface (Non-3r/4r Stdnds)	610-06257	Reinforced Concrete Bridge Approach, 250	SYS	1	49.98	49.98	49.98	
J200	Resurface (Non-3r/4r Stdnds)	610-06262	Reinforced Concrete Bridge Approach	SYS	1	69.15	69.15	69.15	
J200	Resurface (Non-3r/4r Stdnds)	610-06460	Compacted Aggregate, O	TON	1	9.94	9.94	9.94	
J200	Resurface (Non-3r/4r Stdnds)	610-06460	Compacted Aggregate, O, 53	TON	1	5.00	5.00	5.00	
J200	Resurface (Non-3r/4r Stdnds)	610-06461	Compacted Aggregate, O, 73	TON	2	11.93	9.04	14.82	4.09
J210	Resurface Bit. Over Bit. Pvmnt	310-04014	Patching, Full Depth, Reinforced Concret	SYS	1	139.74	139.74	139.74	
J210	Resurface Bit. Over Bit. Pvmnt	401-03229	Bituminous Binder 8 or 9, LV	TON	1	27.39	27.39	27.39	
J210	Resurface Bit. Over Bit. Pvmnt	401-03240	Bituminous Binder 9, HV	TON	1	24.85	24.85	24.85	
J210	Resurface Bit. Over Bit. Pvmnt	401-03265	Bituminous Mixture for Widening, HV	TON	1	40.57	40.57	40.57	
J210	Resurface Bit. Over Bit. Pvmnt	401-03545	Bituminous Surface 11, LV	TON	1	29.63	29.63	29.63	
J210	Resurface Bit. Over Bit. Pvmnt	401-03575	Bituminous Surface 11, HV	TON	1	26.88	26.88	26.88	
J210	Resurface Bit. Over Bit. Pvmnt	401-03620	Bituminous Surface 9, HV	TON	1	40.06	40.06	40.06	
J210	Resurface Bit. Over Bit. Pvmnt	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	3	36.78	30.63	41.58	5.60
J210	Resurface Bit. Over Bit. Pvmnt	401-05454	QC/QA HMA Intermediate 12.5 mm, Mainline	TON	3	30.49	26.41	33.80	3.76
J210	Resurface Bit. Over Bit. Pvmnt	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	5	33.49	20.79	45.19	9.37
J210	Resurface Bit. Over Bit. Pvmnt	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	13	37.92	26.21	52.49	7.61
J210	Resurface Bit. Over Bit. Pvmnt	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	2	41.09	38.50	43.68	3.66
J210	Resurface Bit. Over Bit. Pvmnt	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	1	37.33	37.33	37.33	
J210	Resurface Bit. Over Bit. Pvmnt	401-99180	Bituminous Mixture for Superelevation	TON	1	35.21	35.21	35.21	
J210	Resurface Bit. Over Bit. Pvmnt	402-05470	HMA Base C25.0 mm, Mainline	TON	2	37.80	34.92	40.67	4.07
J210	Resurface Bit. Over Bit. Pvmnt	402-05472	HMA Intermediate 9.5 mm, Mainline	TON	1	26.32	26.32	26.32	
J210	Resurface Bit. Over Bit. Pvmnt	402-05477	HMA Surface 9.5 mm, Mainline	TON	2	28.67	28.02	29.33	0.93
J210	Resurface Bit. Over Bit. Pvmnt	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	1	20.79	20.79	20.79	
J210	Resurface Bit. Over Bit. Pvmnt	402-05490	HMA Surface 9.5 mm, Shoulder	TON	2	34.16	23.40	44.92	15.22
J210	Resurface Bit. Over Bit. Pvmnt	402-05495	HMA Wedge & Level	TON	12	39.57	32.42	55.02	6.80
J210	Resurface Bit. Over Bit. Pvmnt	406-05520	Asphalt for Tack Coat	TON	7	166.29	117.50	203.37	28.79
J210	Resurface Bit. Over Bit. Pvmnt	610-04291	Bituminous Mixture for Approaches, LV	TON	1	53.10	53.10	53.10	
J210	Resurface Bit. Over Bit. Pvmnt	610-04293	Bituminous Mixture for Approaches, HV	TON	1	36.51	36.51	36.51	
J210	Resurface Bit. Over Bit. Pvmnt	610-05527	HMA for Approaches	TON	9	63.77	40.11	85.08	17.13
J211	Bit Overlay, Thin Lay	401-03545	Bituminous Surface 11, LV	TON	1	42.73	42.73	42.73	
J211	Bit Overlay, Thin Lay	401-03560	Bituminous Surface 11, MV	TON	1	35.18	35.18	35.18	
J211	Bit Overlay, Thin Lay	401-03575	Bituminous Surface 11, HV	TON	1	38.36	38.36	38.36	
J211	Bit Overlay, Thin Lay	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	39.42	39.42	39.42	

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J211	Bit Overlay, Thin Lay	401-05454	QC/QA HMA Intermediate 12.5 mm, Mainline	TON	1	30.08	30.08	30.08	
J211	Bit Overlay, Thin Lay	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	2	31.04	28.69	33.40	3.33
J211	Bit Overlay, Thin Lay	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	13	39.64	31.01	54.11	6.39
J211	Bit Overlay, Thin Lay	401-05457	QC/QA HMA Surface 12.5 mm, Mainline	TON	4	36.69	33.99	39.77	2.91
J211	Bit Overlay, Thin Lay	401-05467	Milled HMA Corrugations	LFT	1	0.80	0.80	0.80	
J211	Bit Overlay, Thin Lay	402-05468	HMA Base 25.0 mm, Mainline	TON	1	31.08	31.08	31.08	
J211	Bit Overlay, Thin Lay	402-05473	HMA Intermediate 12.5 mm, Mainline	TON	1	25.43	25.43	25.43	
J211	Bit Overlay, Thin Lay	402-05477	HMA Surface 9.5 mm, Mainline	TON	4	35.72	31.64	42.88	5.16
J211	Bit Overlay, Thin Lay	402-05481	HMA Base 25.0 mm, Shoulder	TON	1	32.39	32.39	32.39	
J211	Bit Overlay, Thin Lay	402-05485	HMA Intermediate 9.5 mm, Shoulder	TON	1	30.32	30.32	30.32	
J211	Bit Overlay, Thin Lay	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	1	44.63	44.63	44.63	
J211	Bit Overlay, Thin Lay	402-05490	HMA Surface 9.5 mm, Shoulder	TON	2	57.92	39.01	76.83	26.74
J211	Bit Overlay, Thin Lay	402-05495	HMA for Wedge & Level	TON	1	33.09	33.09	33.09	
J211	Bit Overlay, Thin Lay	402-05495	HMA Wedge & Level	TON	13	43.48	28.02	63.07	10.23
J211	Bit Overlay, Thin Lay	406-05520	Asphalt for Tack Coat	TON	10	193.55	159.41	230.49	26.01
J211	Bit Overlay, Thin Lay	501-05240	Contraction Joint, D1	LFT	1	10.39	10.39	10.39	
J211	Bit Overlay, Thin Lay	501-05310	Terminal Joint	LFT	2	125.12	117.13	133.10	11.29
J211	Bit Overlay, Thin Lay	502-06327	PCCP, 250 mm	SYS	1	76.63	76.63	76.63	
J211	Bit Overlay, Thin Lay	502-06331	PCCP, 350 mm	SYS	1	41.04	41.04	41.04	
J211	Bit Overlay, Thin Lay	610-04292	Bituminous Mixture for Approaches, MV	TON	1	105.35	105.35	105.35	
J211	Bit Overlay, Thin Lay	610-05527	HMA for Approaches	TON	16	66.52	44.02	97.13	17.68
J211	Bit Overlay, Thin Lay	610-06257	Reinforced Concrete Bridge Approach, 250	SYS	3	45.78	37.12	63.11	15.00
J212	Bit Overlay, Multiple Structrl Lays	401-03200	Bituminous Base 5, LV	TON	1	27.08	27.08	27.08	
J212	Bit Overlay, Multiple Structrl Lays	401-03265	Bituminous Mixture for Widening, HV	TON	1	44.72	44.72	44.72	
J212	Bit Overlay, Multiple Structrl Lays	401-03303	Bituminous Base 5D, LV	TON	1	27.08	27.08	27.08	
J212	Bit Overlay, Multiple Structrl Lays	401-03545	Bituminous Surface 11, LV	TON	1	30.01	30.01	30.01	
J212	Bit Overlay, Multiple Structrl Lays	401-04290	Bituminous Mixture for Wedge & Level,	TON	1	32.80	32.80	32.80	
J212	Bit Overlay, Multiple Structrl Lays	401-04819	HMA Intermediate 12.5 mm, Mainline	TON	1	24.60	24.60	24.60	
J212	Bit Overlay, Multiple Structrl Lays	401-04823	HMA Surface 9.5 mm, HV, Mainline	TON	1	37.67	37.67	37.67	
J212	Bit Overlay, Multiple Structrl Lays	401-04827	HMA Intermediate 19.0 mm, Shoulder	TON	1	25.07	25.07	25.07	
J212	Bit Overlay, Multiple Structrl Lays	401-04828	HMA Surface 9.5 mm, LV, Shoulder	TON	1	31.70	31.70	31.70	
J212	Bit Overlay, Multiple Structrl Lays	401-04829	HMA Surface 9.5 mm, MV, Shoulder	TON	1	29.08	29.08	29.08	
J212	Bit Overlay, Multiple Structrl Lays	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	3	26.61	19.56	31.18	6.19
J212	Bit Overlay, Multiple Structrl Lays	401-05453	QC/QA HMA Intermediate 9.5 mm, Mainline	TON	1	28.12	28.12	28.12	
J212	Bit Overlay, Multiple Structrl Lays	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	13	28.20	23.36	39.82	5.18
J212	Bit Overlay, Multiple Structrl Lays	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	15	33.81	25.72	49.13	6.36
J212	Bit Overlay, Multiple Structrl Lays	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	2	28.81	24.82	32.80	5.64
J212	Bit Overlay, Multiple Structrl Lays	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	1	38.80	38.80	38.80	
J212	Bit Overlay, Multiple Structrl Lays	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	1	42.88	42.88	42.88	

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J212	Bit Overlay, Multiple Structrl Lays	401-05467	Milled HMA Corrugations	LFT	1	0.10	0.10	0.10	
J212	Bit Overlay, Multiple Structrl Lays	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	1	32.09	32.09	32.09	
J212	Bit Overlay, Multiple Structrl Lays	402-05490	HMA Surface 9.5 mm, Shoulder	TON	2	58.29	45.12	71.47	18.63
J212	Bit Overlay, Multiple Structrl Lays	402-05495	HMA for Wedge & Level	TON	6	34.76	27.57	42.11	5.12
J212	Bit Overlay, Multiple Structrl Lays	402-05495	HMA Wedge & Level	TON	6	28.36	25.40	32.81	2.63
J212	Bit Overlay, Multiple Structrl Lays	406-05520	Asphalt for Tack Coat	TON	5	195.38	167.22	214.40	22.99
J212	Bit Overlay, Multiple Structrl Lays	501-04014	Patching, Full Depth, Reinforced Concret	SYS	1	110.83	110.83	110.83	
J212	Bit Overlay, Multiple Structrl Lays	610-04291	Bituminous Mixture for Approaches, LV	TON	1	46.71	46.71	46.71	
J212	Bit Overlay, Multiple Structrl Lays	610-04293	Bituminous Mixture for Approaches, HV	TON	1	54.66	54.66	54.66	
J212	Bit Overlay, Multiple Structrl Lays	610-05527	HMA for Approaches	TON	11	45.03	32.28	68.83	10.98
J213	Mill Surface & Bit Overlay	305-04020	Bituminous Mixture for Patching	TON	5	110.34	55.90	143.65	37.20
J213	Mill Surface & Bit Overlay	401-03200	Bituminous Base 5, LV	TON	1	67.58	67.58	67.58	
J213	Mill Surface & Bit Overlay	401-03202	Bituminous Base 5, HV	TON	1	50.69	50.69	50.69	
J213	Mill Surface & Bit Overlay	401-03230	Bituminous Binder 8 or 9, MV	TON	4	26.92	22.92	29.81	3.36
J213	Mill Surface & Bit Overlay	401-03231	Bituminous Binder 8 or 9, HV	TON	1	29.58	29.58	29.58	
J213	Mill Surface & Bit Overlay	401-03240	Bituminous Binder 9, HV	TON	1	25.56	25.56	25.56	
J213	Mill Surface & Bit Overlay	401-03264	Bituminous Mixture for Widening, MV	TON	2	54.06	37.12	70.99	23.95
J213	Mill Surface & Bit Overlay	401-03304	Bituminous Base 5D, MV	TON	1	38.67	38.67	38.67	
J213	Mill Surface & Bit Overlay	401-03545	Bituminous Surface 11, LV	TON	3	28.89	23.76	37.52	7.51
J213	Mill Surface & Bit Overlay	401-03560	Bituminous Surface 11, MV	TON	7	35.26	25.71	44.42	7.13
J213	Mill Surface & Bit Overlay	401-03575	Bituminous Surface 11, HV	TON	7	50.50	30.63	149.07	43.70
J213	Mill Surface & Bit Overlay	401-03620	Bituminous Surface 9, HV	TON	2	39.33	39.15	39.52	0.26
J213	Mill Surface & Bit Overlay	401-04274	Bituminous Mixture for Wedge & Level	TON	2	38.15	32.45	43.85	8.06
J213	Mill Surface & Bit Overlay	401-04290	Bituminous Mixture for Wedge & Level,	TON	1	49.52	49.52	49.52	
J213	Mill Surface & Bit Overlay	401-04531	Bituminous Binder 0.75 in., MV	TON	1	31.27	31.27	31.27	
J213	Mill Surface & Bit Overlay	401-04533	Bituminous Surface 0.375 in., MV	TON	1	40.42	40.42	40.42	
J213	Mill Surface & Bit Overlay	401-04817	HMA Base 25.0 mm, Mainline	TON	2	36.31	33.49	39.13	3.98
J213	Mill Surface & Bit Overlay	401-04819	HMA Intermediate 12.5 mm, Mainline	TON	5	36.76	30.81	44.82	6.32
J213	Mill Surface & Bit Overlay	401-04820	HMA Intermediate 19.0 mm, Mainline	TON	3	35.24	26.83	39.75	7.28
J213	Mill Surface & Bit Overlay	401-04823	HMA Surface 9.5 mm, HV, Mainline	TON	9	40.13	36.31	48.70	3.75
J213	Mill Surface & Bit Overlay	401-04824	HMA Base 25.0 mm, Shoulder	TON	1	44.02	44.02	44.02	
J213	Mill Surface & Bit Overlay	401-04826	HMA Intermediate 12.5 mm, Shoulder	TON	1	45.72	45.72	45.72	
J213	Mill Surface & Bit Overlay	401-04827	HMA Intermediate 19.0 mm, Shoulder	TON	1	44.23	44.23	44.23	
J213	Mill Surface & Bit Overlay	401-04828	HMA Surface 9.5 mm, LV, Shoulder	TON	2	52.18	44.72	59.63	10.54
J213	Mill Surface & Bit Overlay	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	30.56	30.56	30.56	

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J213	Mill Surface & Bit Overlay	401-05454	QC/QA HMA Intermediate 12.5 mm, Mainline	TON	7	28.95	21.15	31.75	3.58
J213	Mill Surface & Bit Overlay	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	9	32.65	22.50	43.22	6.41
J213	Mill Surface & Bit Overlay	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	27	39.21	27.39	52.81	6.50
J213	Mill Surface & Bit Overlay	401-05457	QC/QA HMA Surface 12.5 mm, Mainline	TON	8	38.32	33.19	44.82	4.42
J213	Mill Surface & Bit Overlay	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	4	35.00	31.49	37.77	2.70
J213	Mill Surface & Bit Overlay	401-05462	QC/QA HMA Intermediate 12.5 mm, Shoulder	TON	1	27.79	27.79	27.79	
J213	Mill Surface & Bit Overlay	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	3	35.50	31.08	37.77	3.82
J213	Mill Surface & Bit Overlay	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	6	37.01	30.56	45.12	6.46
J213	Mill Surface & Bit Overlay	401-05465	QC/QA HMA Surface 12.5 mm, Shoulder	TON	2	31.47	29.67	33.26	2.53
J213	Mill Surface & Bit Overlay	401-05467	Milled HMA Corrugations	LFT	6	6.19	0.07	21.36	9.60
J213	Mill Surface & Bit Overlay	401-93821	Bituminous Surface 11, HV, with Fibers	TON	1	39.13	39.13	39.13	
J213	Mill Surface & Bit Overlay	401-96377	Bituminous Mixture for Wedge & Level,	TON	1	44.72	44.72	44.72	
J213	Mill Surface & Bit Overlay	402-05468	HMA Base 25.0 mm, Mainline	TON	4	80.86	62.17	107.59	20.30
J213	Mill Surface & Bit Overlay	402-05473	HMA Intermediate 12.5 mm, Mainline	TON	3	29.64	23.06	40.67	9.61
J213	Mill Surface & Bit Overlay	402-05477	HMA Surface 9.5 mm, Mainline	TON	12	44.57	29.03	86.18	15.31
J213	Mill Surface & Bit Overlay	402-05479	HMA Surface 12.5 mm, Mainline	TON	2	29.54	26.50	32.59	4.31
J213	Mill Surface & Bit Overlay	402-05481	HMA Base 25.0 mm, Shoulder	TON	1	46.83	46.83	46.83	
J213	Mill Surface & Bit Overlay	402-05485	HMA Intermediate 9.5 mm, Shoulder	TON	1	29.34	29.34	29.34	
J213	Mill Surface & Bit Overlay	402-05490	HMA Surface 9.5 mm, Shoulder	TON	2	39.59	33.26	45.93	8.96
J213	Mill Surface & Bit Overlay	402-05495	HMA for Wedge & Level	TON	6	41.38	23.06	59.63	13.76
J213	Mill Surface & Bit Overlay	402-05495	HMA Wedge & Level	TON	20	42.95	26.06	81.68	14.52
J213	Mill Surface & Bit Overlay	406-05520	Asphalt for Tack Coat	TON	11	202.84	29.89	593.32	143.97
J213	Mill Surface & Bit Overlay	406-05520	Asphalt Material for Tack Coat	TON	1	994.74	994.74	994.74	
J213	Mill Surface & Bit Overlay	501-04010	Cement Concrete Pavement for Patching	SYS	2	140.44	109.92	170.97	43.17
J213	Mill Surface & Bit Overlay	501-04011	Cement Concrete Pavement for Patching	SYS	2	154.34	143.81	164.88	14.90
J213	Mill Surface & Bit Overlay	501-04842	Cement Concrete Pavement, Reinf., 260mm	SYS	1	45.34	45.34	45.34	
J213	Mill Surface & Bit Overlay	501-05090	Cement Concrete Pavement, Reinforced, 250	SYS	1	45.11	45.11	45.11	
J213	Mill Surface & Bit Overlay	501-05092	Cement Concrete Pavement, Reinforced, 30	SYS	1	71.30	71.30	71.30	
J213	Mill Surface & Bit Overlay	501-05094	Cement Concrete Pavement, Reinforced, 35	SYS	2	58.28	47.26	69.31	15.60
J213	Mill Surface & Bit Overlay	501-05191	Cement Concrete Pavement, Plain, 350 mm	SYS	1	46.72	46.72	46.72	
J213	Mill Surface & Bit Overlay	501-05240	Contraction Joint, D1	LFT	4	10.55	5.17	20.97	7.16
J213	Mill Surface & Bit Overlay	501-05310	Terminal Joint	LFT	4	46.51	13.15	81.07	27.75
J213	Mill Surface & Bit Overlay	501-90283	Contraction Joint, D-1, Modified	LFT	1	24.91	24.91	24.91	
J213	Mill Surface & Bit Overlay	501-98614	Cement Concrete Pavement for Driveways,	SYS	1	47.78	47.78	47.78	
J213	Mill Surface & Bit Overlay	610-04291	Bituminous Mixture for Approaches, LV	TON	2	60.29	54.66	65.92	7.96
J213	Mill Surface & Bit Overlay	610-04292	Bituminous Mixture for Approaches, MV	TON	6	53.12	42.60	65.86	9.30
J213	Mill Surface & Bit Overlay	610-04293	Bituminous Mixture for Approaches, HV	TON	1	49.30	49.30	49.30	

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J213	Mill Surface & Bit Overlay	610-05527	HMA for Approaches	TON	27	57.97	35.09	88.03	17.74
J214	Mill Full Depth & Bit Overlay	310-04013	Patching, Full Depth, Plain Concrete Pav	SYS	2	109.44	86.26	132.63	32.79
J214	Mill Full Depth & Bit Overlay	401-04817	HMA Base 25.0 mm, Mainline	TON	1	35.41	35.41	35.41	
J214	Mill Full Depth & Bit Overlay	401-04820	HMA Intermediate 19.0 mm, Mainline	TON	1	30.56	30.56	30.56	
J214	Mill Full Depth & Bit Overlay	401-04824	HMA Base 25.0 mm, Shoulder	TON	1	28.12	28.12	28.12	
J214	Mill Full Depth & Bit Overlay	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	2	36.29	35.92	36.66	0.52
J214	Mill Full Depth & Bit Overlay	401-05454	QC/QA HMA Intermediate 12.5 mm, Mainline	TON	3	31.79	28.12	38.13	5.52
J214	Mill Full Depth & Bit Overlay	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	2	35.87	34.72	37.03	1.63
J214	Mill Full Depth & Bit Overlay	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	4	39.26	38.13	39.89	0.82
J214	Mill Full Depth & Bit Overlay	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	3	30.94	27.79	36.47	4.81
J214	Mill Full Depth & Bit Overlay	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	3	30.77	25.53	33.42	4.53
J214	Mill Full Depth & Bit Overlay	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	4	34.62	30.81	40.75	4.63
J214	Mill Full Depth & Bit Overlay	401-05467	Milled HMA Corrugations	LFT	3	0.31	0.15	0.62	0.27
J214	Mill Full Depth & Bit Overlay	401-05467	Milled Shoulder Corrugations	LFT	1	0.83	0.83	0.83	
J214	Mill Full Depth & Bit Overlay	402-05468	HMA Base 25.0 mm, Mainline	TON	2	37.73	32.42	43.04	7.51
J214	Mill Full Depth & Bit Overlay	402-05470	HMA Base C25.0 mm, Mainline	TON	3	41.19	35.58	44.21	4.86
J214	Mill Full Depth & Bit Overlay	402-05475	HMA Intermediate C19.0 mm, Mainline	TON	3	29.96	26.21	35.64	5.00
J214	Mill Full Depth & Bit Overlay	402-05477	HMA Surface 9.5 mm, Mainline	TON	1	58.69	58.69	58.69	
J214	Mill Full Depth & Bit Overlay	402-05483	HMA Base C25.0 mm, Shoulder	TON	2	46.36	44.21	48.52	3.05
J214	Mill Full Depth & Bit Overlay	402-05486	HMA Intermediate 12.5 mm, Shoulder	TON	1	44.02	44.02	44.02	
J214	Mill Full Depth & Bit Overlay	402-05488	HMA Intermediate C19.0 mm, Shoulder	TON	2	33.36	28.03	38.68	7.53
J214	Mill Full Depth & Bit Overlay	406-05520	Asphalt for Tack Coat	TON	2	200.44	185.24	215.64	21.50
J214	Mill Full Depth & Bit Overlay	406-05520	Asphalt Material for Tack Coat	TON	1	187.89	187.89	187.89	
J214	Mill Full Depth & Bit Overlay	501-04010	Cement Concrete Pavement for Patching	SYS	1	110.44	110.44	110.44	
J214	Mill Full Depth & Bit Overlay	501-05092	Cement Concrete Pavement, Reinforced, 12	SYS	1	57.58	57.58	57.58	
J214	Mill Full Depth & Bit Overlay	501-05160	Cement Concrete Pavement, Plain, 8 in.	SYS	1	48.52	48.52	48.52	
J214	Mill Full Depth & Bit Overlay	501-05182	Cement Concrete Pavement, Plain, 12 in.	SYS	1	38.19	38.19	38.19	
J214	Mill Full Depth & Bit Overlay	501-05182	Cement Concrete Pavement, Plain, 300 mm	SYS	1	35.38	35.38	35.38	
J214	Mill Full Depth & Bit Overlay	501-05191	Cement Concrete Pavement, Plain, 350 mm	SYS	1	66.71	66.71	66.71	
J214	Mill Full Depth & Bit Overlay	501-05240	Contraction Joint, D1	LFT	4	10.80	4.31	19.72	6.45
J214	Mill Full Depth & Bit Overlay	501-05310	Terminal Joint	LFT	1	107.82	107.82	107.82	
J214	Mill Full Depth & Bit Overlay	502-06329	PCCP, 12 in.	SYS	1	48.52	48.52	48.52	
J214	Mill Full Depth & Bit Overlay	502-06331	PCCP, 350 mm	SYS	1	37.56	37.56	37.56	
J214	Mill Full Depth & Bit Overlay	610-05527	HMA for Approaches	TON	3	73.32	53.91	83.14	16.81
J214	Mill Full Depth & Bit Overlay	610-06257	Reinforced Concrete Bridge Approach,	SYS	1	64.69	64.69	64.69	
J215	Microsurface (Microtexture)	402-03720	Micro-Surfacing, Surface Course	SYS	1	1.16	1.16	1.16	
J215	Microsurface (Microtexture)	402-03721	Micro-Surfacing, Leveling Course	SYS	1	0.69	0.69	0.69	

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J216	Widen Pvmnt & Bit Overlay	401-02832	Bituminous Binder 8C, MV	TON	1	24.34	24.34	24.34	
J216	Widen Pvmnt & Bit Overlay	401-03201	Bituminous Base 5, MV	TON	1	25.35	25.35	25.35	
J216	Widen Pvmnt & Bit Overlay	401-03220	Bituminous Binder 8, MV	TON	1	25.35	25.35	25.35	
J216	Widen Pvmnt & Bit Overlay	401-03303	Bituminous Base 5D, LV	TON	2	26.37	26.37	26.37	0.00
J216	Widen Pvmnt & Bit Overlay	401-03304	Bituminous Base 5D, MV	TON	1	26.37	26.37	26.37	
J216	Widen Pvmnt & Bit Overlay	401-03560	Bituminous Surface 11, MV	TON	1	31.44	31.44	31.44	
J216	Widen Pvmnt & Bit Overlay	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	1	25.40	25.40	25.40	
J216	Widen Pvmnt & Bit Overlay	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	1	28.12	28.12	28.12	
J216	Widen Pvmnt & Bit Overlay	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	1	26.31	26.31	26.31	
J216	Widen Pvmnt & Bit Overlay	402-05495	HMA for Wedge & Level	TON	1	31.75	31.75	31.75	
J216	Widen Pvmnt & Bit Overlay	501-05090	Cement Concrete Pavement, Reinforced, 250	SYS	1	37.39	37.39	37.39	
J216	Widen Pvmnt & Bit Overlay	610-04291	Bituminous Mixture for Approaches, LV	TON	1	36.51	36.51	36.51	
J216	Widen Pvmnt & Bit Overlay	610-04292	Bituminous Mixture for Approaches, MV	TON	1	36.51	36.51	36.51	
J216	Widen Pvmnt & Bit Overlay	610-05527	HMA for Approaches	TON	1	50.80	50.80	50.80	
J220	Resurface Conc. Pvmnt	402-05473	HMA Intermediate 12.5 mm, Mainline	TON	1	27.39	27.39	27.39	
J220	Resurface Conc. Pvmnt	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	1	26.90	26.90	26.90	
J220	Resurface Conc. Pvmnt	402-05477	HMA Surface 9.5 mm, Mainline	TON	2	29.98	28.37	31.59	2.28
J220	Resurface Conc. Pvmnt	402-05492	HMA Surface 12.5 mm, Shoulder	TON	1	26.90	26.90	26.90	
J220	Resurface Conc. Pvmnt	402-05493	HMA Surface 19.0 mm, Shoulder	TON	1	23.72	23.72	23.72	
J220	Resurface Conc. Pvmnt	610-05527	HMA for Approaches	TON	2	48.42	43.04	53.80	7.61
J221	Crack & Seat & Bit Overlay	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	1	31.08	31.08	31.08	
J221	Crack & Seat & Bit Overlay	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	1	38.10	38.10	38.10	
J221	Crack & Seat & Bit Overlay	402-05495	HMA for Wedge & Level	TON	1	70.19	70.19	70.19	
J221	Crack & Seat & Bit Overlay	610-05527	HMA for Approaches	TON	1	62.17	62.17	62.17	
J222	Rubblize Existing Pvmnt & Bit Overlay	401-04605	HMA Pavement Mixtures, Warranted	TON	1	37.05	37.05	37.05	
J222	Rubblize Existing Pvmnt & Bit Overlay	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	2	29.30	28.02	30.57	1.80
J222	Rubblize Existing Pvmnt & Bit Overlay	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	2	30.56	29.83	31.30	1.04
J222	Rubblize Existing Pvmnt & Bit Overlay	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	2	38.49	37.06	39.92	2.02
J222	Rubblize Existing Pvmnt & Bit Overlay	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	2	29.78	26.21	33.34	5.04
J222	Rubblize Existing Pvmnt & Bit Overlay	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	2	32.05	29.83	34.27	3.14
J222	Rubblize Existing Pvmnt & Bit Overlay	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	2	35.69	35.25	36.12	0.62
J222	Rubblize Existing Pvmnt & Bit Overlay	401-05467	Milled HMA Corrugations	LFT	2	0.14	0.09	0.20	0.08
J222	Rubblize Existing Pvmnt & Bit Overlay	402-05488	HMA Intermediate C19.0 mm, Shoulder	TON	1	29.64	29.64	29.64	
J222	Rubblize Existing Pvmnt & Bit Overlay	406-05520	Asphalt for Tack Coat	TON	2	171.71	158.18	185.24	19.13
J222	Rubblize Existing Pvmnt & Bit Overlay	610-05527	HMA for Approaches	TON	2	35.14	6.78	63.50	40.11
J222	Rubblize Existing Pvmnt & Bit Overlay	610-06259	Reinforced Concrete Bridge Approach, 300	SYS	1	45.82	45.82	45.82	
J300	Pvmnt Rehab. (3r/4r St&ard)	305-04020	Bituminous Mixture for Patching	TON	2	123.25	117.38	129.12	8.30

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J300	Pvmnt Rehab. (3r/4r St&ard)	310-04013	Patching, Full Depth, Plain Concrete Pav	SYS	2	106.20	83.85	128.56	31.62
J300	Pvmnt Rehab. (3r/4r St&ard)	310-04014	Patching, Full Depth, Reinforced Concret	SYS	1	62.00	62.00	62.00	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-02222	Bituminous Binder 8, HV, with Fibers	TON	2	37.19	34.77	39.62	3.44
J300	Pvmnt Rehab. (3r/4r St&ard)	401-02434	Bituminous Binder 8C, LV	TON	7	40.24	26.84	76.06	17.80
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03102	Bituminous Base 5C, HV	TON	2	32.37	27.95	36.79	6.25
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03150	Bituminous Base 8C, LV	TON	1	29.85	29.85	29.85	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03200	Bituminous Base 5, LV	TON	1	19.01	19.01	19.01	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03201	Bituminous Base 5, MV	TON	4	34.74	28.40	45.50	7.71
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03202	Bituminous Base 5, HV	TON	5	31.08	26.27	36.51	4.42
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03220	Bituminous Binder 8, MV	TON	1	30.34	30.34	30.34	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03229	Bituminous Binder 8 or 9, LV	TON	4	32.07	23.67	50.71	12.53
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03230	Bituminous Binder 8 or 9, MV	TON	5	40.19	29.41	57.84	13.22
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03231	Bituminous Binder 8 or 9, HV	TON	4	36.22	30.18	41.29	4.57
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03239	Bituminous Binder 9, MV	TON	1	40.57	40.57	40.57	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03240	Bituminous Binder 9, HV	TON	1	33.47	33.47	33.47	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03247	Bituminous Binder 11, LV	TON	3	40.91	30.67	58.53	15.32
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03263	Bituminous Mixture for Widening, LV	TON	4	35.02	25.99	41.88	7.25
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03264	Bituminous Mixture for Widening, MV	TON	2	40.08	34.28	45.88	8.21
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03265	Bituminous Mixture for Widening, HV	TON	1	29.62	29.62	29.62	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03301	Bituminous Base, MV	TON	1	30.01	30.01	30.01	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03302	Bituminous Base, HV	TON	1	95.02	95.02	95.02	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03303	Bituminous Base 5D, LV	TON	11	34.31	25.34	63.89	11.27
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03304	Bituminous Base 5D, MV	TON	4	35.85	27.38	42.18	6.73
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03305	Bituminous Base 5D, HV	TON	3	30.51	26.83	35.91	4.78
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03545	Bituminous Surface 11, LV	TON	9	35.98	25.77	65.92	12.52
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03560	Bituminous Surface 11, MV	TON	9	40.99	28.17	56.35	7.70
J300	Pvmnt Rehab. (3r/4r St&ard)	401-03575	Bituminous Surface 11, HV	TON	5	43.06	41.58	44.12	1.05
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04273	Bituminous Mixture for Wedge & Level,	TON	2	51.06	42.48	59.63	12.13
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04274	Bituminous Mixture for Wedge & Level	TON	2	45.85	38.87	52.82	9.87
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04290	Bituminous Mixture for Wedge & Level,	TON	1	28.23	28.23	28.23	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04525	Bituminous Base 25.0 mm, HV	TON	3	30.51	25.71	35.50	4.90
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04526	Bituminous Binder 0.75 in., HV	TON	1	33.54	33.54	33.54	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04526	Bituminous Binder 19.0 mm, HV	TON	3	29.37	26.60	30.83	2.40
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04527	Bituminous Binder 0.50 in., HV	TON	1	32.14	32.14	32.14	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04527	Bituminous Binder 12.5 mm, HV	TON	1	31.44	31.44	31.44	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04528	Bituminous Surface 0.375 in., HV	TON	2	41.78	36.05	47.51	8.10
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04528	Bituminous Surface 9.5 mm, HV	TON	4	38.99	34.48	45.64	4.91

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04530	Bituminous Base 1.0 in., MV	TON	1	32.36	32.36	32.36	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04531	Bituminous Binder 0.75 in., MV	TON	1	32.41	32.41	32.41	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04533	Bituminous Surface 0.375 in., MV	TON	2	46.63	38.76	54.50	11.13
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04533	Bituminous Surface 9.5 mm, MV	TON	1	38.54	38.54	38.54	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04536	Bituminous Binder 0.75 in., LV	TON	1	39.13	39.13	39.13	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04536	Bituminous Binder 19.0 mm, LV	TON	2	28.90	26.37	31.44	3.59
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04538	Bituminous Surface 0.375 in., LV	TON	2	34.66	27.95	41.36	9.49
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04538	Bituminous Surface 9.5 mm, LV	TON	2	31.95	29.41	34.48	3.59
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04605	Asphalt Pavement Mixtures, Warranted	TON	4	33.47	32.45	34.74	1.13
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04817	HMA Base 25.0 mm, Mainline	TON	2	34.54	33.59	35.48	1.34
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04819	HMA Intermediate 12.5 mm, Mainline	TON	1	33.64	33.64	33.64	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04820	HMA Intermediate 19.0 mm, Mainline	TON	2	31.11	31.10	31.13	0.02
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04822	HMA Surface 9.5 mm, MV, Mainline	TON	2	36.55	33.35	39.75	4.53
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04823	HMA Surface 9.5 mm, HV, Mainline	TON	3	44.33	39.75	48.25	4.29
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04824	HMA Base 25.0 mm, Shoulder	TON	3	30.15	29.41	30.81	0.70
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04826	HMA Intermediate 12.5 mm, Shoulder	TON	2	32.62	32.45	32.80	0.24
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04827	HMA Intermediate 19.0 mm, Shoulder	TON	2	29.88	28.40	31.37	2.10
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04828	HMA Surface 9.5 mm, LV, Shoulder	TON	2	34.38	34.29	34.48	0.14
J300	Pvmnt Rehab. (3r/4r St&ard)	401-04829	HMA Surface 9.5 mm, MV, Shoulder	TON	2	40.07	38.54	41.60	2.17
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	26	31.17	23.96	40.82	5.28
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05453	QC/QA HMA Intermediate 9.5 mm, Mainline	TON	1	30.08	30.08	30.08	
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05454	QC/QA HMA Intermediate 12.5 mm, Mainline	TON	6	27.92	25.40	32.43	2.69
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	46	31.44	22.46	45.94	5.65
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	52	40.53	23.48	63.30	8.43
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	16	28.97	22.68	42.11	5.38
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05462	QC/QA HMA Intermediate 12.5 mm, Shoulder	TON	2	34.23	27.63	40.84	9.34
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	22	28.78	23.59	41.68	5.18
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	27	33.89	24.95	50.00	6.04
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05467	Milled HMA Corrugations	LFT	23	0.17	0.06	0.67	0.14
J300	Pvmnt Rehab. (3r/4r St&ard)	401-05467	Milled Shoulder Corrugations	LFT	2	0.26	0.23	0.28	0.04
J300	Pvmnt Rehab. (3r/4r St&ard)	401-93821	Bituminous Surface 11, HV, with Fibers	TON	2	51.02	45.01	57.04	8.50
J300	Pvmnt Rehab. (3r/4r St&ard)	401-94960	Bituminous Binder 8C, HV	TON	4	28.89	26.88	33.47	3.08
J300	Pvmnt Rehab. (3r/4r St&ard)	401-96012	Bituminous Binder, 8 or 9, HV, with Fibe	TON	1	48.94	48.94	48.94	
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05468	HMA Base 25.0 mm, Mainline	TON	4	42.33	29.58	68.15	17.47
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05470	HMA Base C25.0 mm, Mainline	TON	12	33.22	27.07	41.73	4.21

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05471	HMA Base C50.0 mm, Mainline	TON	1	35.09	35.09	35.09	
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	5	34.58	31.49	38.34	2.69
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05475	HMA Intermediate C19.0 mm, Mainline	TON	4	30.67	24.50	39.01	6.18
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05477	HMA Surface 9.5 mm, Mainline	TON	5	43.74	33.09	53.68	7.47
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05481	HMA Base 25.0 mm, Shoulder	TON	9	37.42	19.39	64.45	12.85
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05483	HMA Base C25.0 mm, Shoulder	TON	1	32.65	32.65	32.65	
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05485	HMA Intermediate 9.5 mm, Shoulder	TON	1	36.10	36.10	36.10	
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	5	33.25	19.80	39.14	8.41
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05488	HMA Intermediate C19.0 mm, Shoulder	TON	3	30.47	28.07	33.26	2.61
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05490	HMA Surface 9.5 mm, Shoulder	TON	6	41.04	27.79	59.16	12.27
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05495	HMA for Wedge & Level	TON	2	38.10	36.10	40.11	2.84
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05495	HMA Wedge & Level	TON	13	37.79	19.76	61.26	12.51
J300	Pvmnt Rehab. (3r/4r St&ard)	402-05542	Special HMA Surface C9.5 mm, Mainline	TON	1	36.10	36.10	36.10	
J300	Pvmnt Rehab. (3r/4r St&ard)	406-05520	Asphalt for Tack Coat	TON	21	194.54	39.85	408.38	77.77
J300	Pvmnt Rehab. (3r/4r St&ard)	406-05520	Asphalt Material for Tack Coat	TON	2	216.36	191.71	241.01	34.86
J300	Pvmnt Rehab. (3r/4r St&ard)	501-04010	Cement Concrete Pavement for Patching	SYS	2	99.96	86.87	113.05	18.51
J300	Pvmnt Rehab. (3r/4r St&ard)	501-04011	Cement Concrete Pavement for Patching	SYS	1	112.17	112.17	112.17	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-04014	Patching, Full Depth, Reinforced Concret	SYS	1	93.47	93.47	93.47	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-04842	Cement Concrete Pavement, Reinf., 260mm	SYS	1	51.84	51.84	51.84	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05090	Cement Concrete Pavement, Reinforced, 10	SYS	3	53.69	45.00	63.54	9.32
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05090	Cement Concrete Pavement, Reinforced, 250	SYS	5	51.60	42.06	67.61	10.80
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05092	Cement Concrete Pavement, Reinforced, 12	SYS	2	57.57	57.01	58.13	0.79
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05092	Cement Concrete Pavement, Reinforced, 30	SYS	3	57.30	45.80	68.39	11.30
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05093	Cement Concrete Pavement, Reinforced, 32	SYS	2	42.93	39.13	46.74	5.38
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05094	Cement Concrete Pavement, Reinforced, 35	SYS	2	56.18	46.74	65.61	13.35
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05179	Cement Concrete Pavement, Plain, 325 mm	SYS	4	35.69	33.45	37.39	1.67
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05182	Cement Concrete Pavement, Plain, 12 in.	SYS	1	38.57	38.57	38.57	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05182	Cement Concrete Pavement, Plain, 300 mm	SYS	6	39.09	29.35	52.29	7.64
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05191	Cement Concrete Pavement, Plain, 14 in.	SYS	1	44.55	44.55	44.55	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05191	Cement Concrete Pavement, Plain, 350 mm	SYS	1	33.82	33.82	33.82	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05240	Contraction Joint, D1	LFT	15	7.17	4.92	11.29	1.90
J300	Pvmnt Rehab. (3r/4r St&ard)	501-05310	Terminal Joint	LFT	10	94.40	19.47	142.84	35.25
J300	Pvmnt Rehab. (3r/4r St&ard)	501-95573	Longitudinal Joint	LFT	1	2.75	2.75	2.75	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-95901	Cement Conc, Pavmnt Shldr, Plain, Fd, 350	SYS	1	28.85	28.85	28.85	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-97067	Cement Concrete Pavement, Plain, for Bas	SYS	1	27.50	27.50	27.50	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-97879	Contraction Joint, D1, Joint Seal	LFT	1	1.19	1.19	1.19	
J300	Pvmnt Rehab. (3r/4r St&ard)	501-97983	Cement Concrete Pavement, Reinforced, 37	SYS	1	74.78	74.78	74.78	
J300	Pvmnt Rehab. (3r/4r St&ard)	502-03516	QA Cement Concrete Pavement, Plain, 275	SYS	2	24.39	21.65	27.12	3.87
J300	Pvmnt Rehab. (3r/4r St&ard)	502-04777	QA Cement Conc. Pavement, Plain, 325 mm	SYS	1	27.81	27.81	27.81	

APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J300	Pvmnt Rehab. (3r/4r St&ard)	502-04797	QA Cement Concrete Pavement, Plain, 375mm	SYS	1	18.53	18.53	18.53	
J300	Pvmnt Rehab. (3r/4r St&ard)	502-06327	PCCP, 250 mm	SYS	1	68.29	68.29	68.29	
J300	Pvmnt Rehab. (3r/4r St&ard)	610-04291	Bituminous Mixture for Approaches, LV	TON	6	43.61	30.89	61.10	10.91
J300	Pvmnt Rehab. (3r/4r St&ard)	610-04292	Bituminous Mixture for Approaches, MV	TON	3	63.23	55.59	67.48	6.63
J300	Pvmnt Rehab. (3r/4r St&ard)	610-04293	Bituminous Mixture for Approaches, HV	TON	7	37.19	28.40	55.90	10.60
J300	Pvmnt Rehab. (3r/4r St&ard)	610-05527	HMA for Approaches	TON	35	58.93	32.59	254.01	36.12
J300	Pvmnt Rehab. (3r/4r St&ard)	610-06257	Reinforced Concrete Bridge Approach,	SYS	1	57.75	57.75	57.75	
J300	Pvmnt Rehab. (3r/4r St&ard)	610-06257	Reinforced Concrete Bridge Approach, 250	SYS	1	50.17	50.17	50.17	
J310	Road ReConstr.	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	25.07	25.07	25.07	
J310	Road ReConstr.	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	2	32.16	25.17	39.15	9.89
J310	Road ReConstr.	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	2	39.23	28.07	50.38	15.77
J310	Road ReConstr.	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	1	24.06	24.06	24.06	
J310	Road ReConstr.	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	1	24.16	24.16	24.16	
J310	Road ReConstr.	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	1	26.07	26.07	26.07	
J310	Road ReConstr.	402-05488	HMA Intermediate C19.0 mm, Shoulder	TON	1	24.87	24.87	24.87	
J310	Road ReConstr.	406-05520	Asphalt for Tack Coat	TON	1	241.20	241.20	241.20	
J310	Road ReConstr.	502-06999	PCCP, 8 in.	SYS	1	25.13	25.13	25.13	
J310	Road ReConstr.	610-05527	HMA for Approaches	TON	1	36.10	36.10	36.10	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-02222	Bituminous Binder 8, HV, with Fibers	TON	1	22.08	22.08	22.08	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-02434	Bituminous Binder 8C, LV	TON	3	27.01	26.05	27.61	0.84
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03101	Bituminous Base 5C, MV	TON	1	53.00	53.00	53.00	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03102	Bituminous Base 5C, HV	TON	1	33.12	33.12	33.12	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03201	Bituminous Base 5, MV	TON	1	53.00	53.00	53.00	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03202	Bituminous Base 5, HV	TON	2	29.31	25.49	33.12	5.40
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03229	Bituminous Binder 8 or 9, LV	TON	1	44.17	44.17	44.17	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03231	Bituminous Binder 8 or 9, HV	TON	1	24.10	24.10	24.10	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03303	Bituminous Base 5D, LV	TON	1	33.12	33.12	33.12	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03304	Bituminous Base 5D, MV	TON	1	44.17	44.17	44.17	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03305	Bituminous Base 5D, HV	TON	2	28.61	24.10	33.12	6.38
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03545	Bituminous Surface 11, LV	TON	1	53.00	53.00	53.00	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-03560	Bituminous Surface 11, MV	TON	1	29.58	29.58	29.58	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-04605	Asphalt Pavement Mixtures, Warranted	TON	1	35.05	35.05	35.05	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-04817	HMA Base 25.0 mm, Mainline	TON	2	30.21	26.95	33.47	4.61
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-04819	HMA Intermediate 12.5 mm, Mainline	TON	1	29.58	29.58	29.58	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-04820	HMA Intermediate 19.0 mm, Mainline	TON	3	28.29	26.30	29.31	1.72
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-04823	HMA Surface 9.5 mm, HV, Mainline	TON	3	40.44	37.25	44.32	3.59
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-04824	HMA Base 25.0 mm, Shoulder	TON	3	26.77	25.86	28.16	1.22

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-04826	HMA Intermediate 12.5 mm, Shoulder	TON	3	26.56	23.28	29.36	3.07
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-04828	HMA Surface 9.5 mm, LV, Shoulder	TON	3	30.83	26.62	35.50	4.45
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-04829	HMA Surface 9.5 mm, MV, Shoulder	TON	3	32.52	27.28	39.91	6.58
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	2	26.36	26.03	26.68	0.46
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	2	40.06	36.75	43.38	4.69
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	2	32.73	28.72	36.75	5.68
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-05461	QC/QA HMA Intermediate 9.5 mm, Shoulder	TON	1	28.30	28.30	28.30	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-05462	QC/QA HMA Intermediate 12.5 mm, Shoulder	TON	1	33.04	33.04	33.04	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	1	24.26	24.26	24.26	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	2	30.57	25.86	35.28	6.66
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-05467	Milled Shoulder Corrugations	LFT	2	0.48	0.28	0.67	0.28
J311	Mill Bit, Crack & Seat W/Mod. & Safety	401-93821	Bituminous Surface 11, HV, with Fibers	TON	1	38.65	38.65	38.65	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	402-05468	HMA Base 25.0 mm, Mainline	TON	2	41.25	32.11	50.39	12.93
J311	Mill Bit, Crack & Seat W/Mod. & Safety	402-05473	HMA Intermediate 12.5 mm, Mainline	TON	1	45.62	45.62	45.62	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	402-05483	HMA Base C25.0 mm, Shoulder	TON	1	42.98	42.98	42.98	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	1	41.69	41.69	41.69	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	402-05488	HMA Intermediate C19.0 mm, Shoulder	TON	2	34.67	32.60	36.75	2.93
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-04010	Cement Concrete Pavement for Patching	SYS	3	89.20	52.68	120.51	34.21
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-04014	Patching, Full Depth, Reinforced Concret	SYS	1	55.45	55.45	55.45	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05090	Cement Concrete Pavement, Reinforced, 250	SYS	2	58.93	43.93	73.93	21.21
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05092	Cement Concrete Pavement, Reinforced, 30	SYS	1	54.96	54.96	54.96	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05094	Cement Concrete Pavement, Reinforced, 35	SYS	3	66.61	66.41	67.00	0.34
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05179	Cement Concrete Pavement, Plain, 325 mm	SYS	1	42.06	42.06	42.06	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05180	Cement Concrete Pavement, Plain, 250 mm	SYS	1	67.00	67.00	67.00	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05181	Cement Concrete Pavement, Plain, 275 mm	SYS	1	0.92	0.92	0.92	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05182	Cement Concrete Pavement, Plain, 300 mm	SYS	1	41.22	41.22	41.22	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05191	Cement Concrete Pavement, Plain, 350 mm	SYS	3	35.03	32.39	37.43	2.53
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05240	Contraction Joint, D1	LFT	5	7.26	5.01	9.54	1.74
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-05310	Terminal Joint	LFT	5	99.20	83.48	117.98	14.17
J311	Mill Bit, Crack & Seat W/Mod. & Safety	501-95901	Cement Conc, Pavmnt Shldr, Plain, Fd, 350	SYS	1	36.64	36.64	36.64	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	610-04291	Bituminous Mixture for Approaches, LV	TON	1	42.33	42.33	42.33	
J311	Mill Bit, Crack & Seat W/Mod. & Safety	610-05527	HMA for Approaches	TON	2	33.08	30.39	35.78	3.81
J312	Crack & Seat Conc. Pvmt. W/Mod & Safty	401-03102	Bituminous Base 5C, HV	TON	1	39.16	39.16	39.16	
J312	Crack & Seat Conc. Pvmt. W/Mod & Safty	401-04273	Bituminous Mixture for Wedge & Level,	TON	1	45.91	45.91	45.91	
J312	Crack & Seat Conc. Pvmt. W/Mod & Safty	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	2	31.78	30.07	33.49	2.42
J312	Crack & Seat Conc. Pvmt. W/Mod & Safty	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	3	30.51	26.76	34.39	3.82
J312	Crack & Seat Conc. Pvmt. W/Mod & Safty	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	3	35.31	29.94	40.61	5.34

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	1	30.07	30.07	30.07	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	2	33.24	30.39	36.10	4.03
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	2	36.89	35.38	38.40	2.14
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	401-05467	Milled HMA Corrugations	LFT	1	1.04	1.04	1.04	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	402-05470	HMA Base C25.0 mm, Mainline	TON	1	29.03	29.03	29.03	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	402-05483	HMA Base C25.0 mm, Shoulder	TON	1	36.90	36.90	36.90	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	402-05495	HMA Wedge & Level	TON	1	28.12	28.12	28.12	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	501-05094	Cement Concrete Pavement, Reinforced, 35	SYS	1	54.35	54.35	54.35	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	501-05240	Contraction Joint, D1	LFT	1	14.55	14.55	14.55	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	501-05310	Terminal Joint	LFT	1	99.06	99.06	99.06	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	502-06331	PCCP, 350 mm	SYS	1	38.96	38.96	38.96	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	610-04293	Bituminous Mixture for Approaches, HV	TON	1	54.26	54.26	54.26	
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	610-05527	HMA for Approaches	TON	3	40.68	31.75	45.36	7.73
J312	Crack & Seat Conc. Pvmnt. W/Mod & Safty	610-06257	Reinforced Concrete Bridge Approach, 250	SYS	1	40.97	40.97	40.97	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-02832	Bituminous Binder 8C, MV	TON	1	35.29	35.29	35.29	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-03201	Bituminous Base 5, MV	TON	1	25.66	25.66	25.66	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-03202	Bituminous Base 5, HV	TON	1	28.95	28.95	28.95	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-03230	Bituminous Binder 8 or 9, MV	TON	1	26.47	26.47	26.47	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-03231	Bituminous Binder 8 or 9, HV	TON	1	28.95	28.95	28.95	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-03304	Bituminous Base 5D, MV	TON	1	26.67	26.67	26.67	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-03560	Bituminous Surface 11, MV	TON	1	39.96	39.96	39.96	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-03575	Bituminous Surface 11, HV	TON	1	43.46	43.46	43.46	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	30.66	30.66	30.66	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	2	26.32	25.07	27.58	1.78
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	2	37.87	35.09	40.64	3.92
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	1	31.21	31.21	31.21	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	2	27.09	25.07	29.12	2.87
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	2	31.55	28.07	35.02	4.91
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	401-05467	Milled HMA Corrugations	LFT	1	0.16	0.16	0.16	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	402-05495	HMA Wedge & Level	TON	2	30.78	29.48	32.09	1.84
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	501-04635	Milled Concrete Shoulder Corrugations	LFT	1	0.16	0.16	0.16	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	501-05090	Cement Concrete Pavement, Reinforced, 250	SYS	1	43.42	43.42	43.42	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	501-05092	Cement Concrete Pavement, Reinforced, 30	SYS	1	40.66	40.66	40.66	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	501-05180	Cement Concrete Pavement, Plain, 250 mm	SYS	1	48.09	48.09	48.09	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	501-05181	Cement Concrete Pavement, Plain, 275 mm	SYS	1	32.34	32.34	32.34	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	501-05182	Cement Concrete Pavement, Plain, 300 mm	SYS	1	35.12	35.12	35.12	
J313	Repair Conc Pvmnt & Bit Overlay W/Mod & Sf	501-05191	Cement Concrete Pavement, Plain, 350 mm	SYS	1	51.36	51.36	51.36	

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J313	Repair Conc Pvmt & Bit Overlay W/Mod & Sf	501-05240	Contraction Joint, D1	LFT	2	6.60	6.13	7.07	0.67
J313	Repair Conc Pvmt & Bit Overlay W/Mod & Sf	501-05310	Terminal Joint	LFT	2	100.58	94.33	106.82	8.84
J313	Repair Conc Pvmt & Bit Overlay W/Mod & Sf	610-04292	Bituminous Mixture for Approaches, MV	TON	1	94.17	94.17	94.17	
J313	Repair Conc Pvmt & Bit Overlay W/Mod & Sf	610-05527	HMA for Approaches	TON	2	41.74	41.37	42.11	0.53
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	4	29.81	28.35	30.73	1.13
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	4	31.63	30.73	32.50	0.97
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	4	40.88	37.81	45.36	3.43
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	3	30.50	28.35	34.13	3.16
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	401-05462	QC/QA HMA Intermediate 12.5 mm, Shoulder	TON	1	33.51	33.51	33.51	
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	3	33.03	30.84	37.18	3.59
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	3	35.62	32.89	37.70	2.48
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	401-05467	Milled HMA Corrugations	LFT	2	1.32	0.15	2.48	1.65
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	401-05467	Milled Shoulder Corrugations	LFT	1	0.18	0.18	0.18	
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	402-05470	HMA Base C25.0 mm, Mainline	TON	2	35.16	30.39	39.93	6.75
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	406-05520	Asphalt for Tack Coat	TON	1	184.12	184.12	184.12	
J314	Rubblize & Asph. Overlay, W/Mod. & Sfty	610-05527	HMA for Approaches	TON	3	75.29	54.43	99.24	22.56
J315	Conc. Overlay W/Mod. & Safety	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	36.10	36.10	36.10	
J315	Conc. Overlay W/Mod. & Safety	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	1	35.09	35.09	35.09	
J315	Conc. Overlay W/Mod. & Safety	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	1	50.13	50.13	50.13	
J315	Conc. Overlay W/Mod. & Safety	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	1	35.09	35.09	35.09	
J315	Conc. Overlay W/Mod. & Safety	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	1	38.10	38.10	38.10	
J315	Conc. Overlay W/Mod. & Safety	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	1	43.12	43.12	43.12	
J315	Conc. Overlay W/Mod. & Safety	401-05467	Milled HMA Corrugations	LFT	1	0.20	0.20	0.20	
J315	Conc. Overlay W/Mod. & Safety	402-05477	HMA Surface 9.5 mm, Mainline	TON	1	45.12	45.12	45.12	
J315	Conc. Overlay W/Mod. & Safety	402-05488	HMA Intermediate C19.0 mm, Shoulder	TON	1	36.10	36.10	36.10	
J315	Conc. Overlay W/Mod. & Safety	501-04842	Cement Concrete Pavement, Reinf., 260mm	SYS	1	69.31	69.31	69.31	
J315	Conc. Overlay W/Mod. & Safety	501-04870	Cement Concrete Pavement, Plain,	SYS	1	60.07	60.07	60.07	
J315	Conc. Overlay W/Mod. & Safety	501-05092	Cement Concrete Pavement, Reinforced, 30	SYS	1	75.59	75.59	75.59	
J315	Conc. Overlay W/Mod. & Safety	501-05180	Cement Concrete Pavement, Plain, 250 mm	SYS	1	18.94	18.94	18.94	
J315	Conc. Overlay W/Mod. & Safety	501-05182	Cement Concrete Pavement, Plain, 300 mm	SYS	1	24.03	24.03	24.03	
J315	Conc. Overlay W/Mod. & Safety	501-05240	Contraction Joint, D1	LFT	1	3.20	3.20	3.20	
J315	Conc. Overlay W/Mod. & Safety	501-05310	Terminal Joint	LFT	1	117.91	117.91	117.91	
J315	Conc. Overlay W/Mod. & Safety	610-05527	HMA for Approaches	TON	1	50.13	50.13	50.13	
J316	Other Methods Of Rehabing Pvmnt	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	31.49	31.49	31.49	
J316	Other Methods Of Rehabing Pvmnt	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	3	27.93	25.99	29.45	1.77
J316	Other Methods Of Rehabing Pvmnt	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	3	37.82	34.35	42.06	3.91
J316	Other Methods Of Rehabing Pvmnt	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	2	25.85	25.76	25.93	0.12

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
J316	Other Methods Of Rehabling Pvmnt	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	3	33.84	28.02	41.08	6.65
J316	Other Methods Of Rehabling Pvmnt	401-05467	Milled HMA Corrugations	LFT	3	0.10	0.05	0.13	0.04
J316	Other Methods Of Rehabling Pvmnt	402-05468	HMA Base 25.0 mm, Mainline	TON	1	39.13	39.13	39.13	
J316	Other Methods Of Rehabling Pvmnt	402-05470	HMA Base C25.0 mm, Mainline	TON	1	19.56	19.56	19.56	
J316	Other Methods Of Rehabling Pvmnt	402-05481	HMA Base 25.0 mm, Shoulder	TON	1	29.34	29.34	29.34	
J316	Other Methods Of Rehabling Pvmnt	402-05483	HMA Base C25.0 mm, Shoulder	TON	2	25.07	21.77	28.37	4.67
J316	Other Methods Of Rehabling Pvmnt	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	1	35.21	35.21	35.21	
J316	Other Methods Of Rehabling Pvmnt	402-05495	HMA Wedge & Level	TON	2	37.98	35.21	40.75	3.92
J316	Other Methods Of Rehabling Pvmnt	406-05520	Asphalt for Tack Coat	TON	2	162.28	152.82	171.74	13.38
J316	Other Methods Of Rehabling Pvmnt	610-05527	HMA for Approaches	TON	2	32.65	32.54	32.77	0.16
J410	Wedge & Level Only	305-04020	Bituminous Mixture for Patching	TON	3	96.69	89.43	109.51	11.14
J410	Wedge & Level Only	401-02465	Bituminous Mixture for Wedge & Level,M	TON	1	43.32	43.32	43.32	
J410	Wedge & Level Only	401-03056	Bituminous Mix for Wedg+Levl LV,11,Surfa	TON	3	57.44	55.90	59.63	1.95
J410	Wedge & Level Only	401-03263	Bituminous Mixture for Widening, LV	TON	1	55.90	55.90	55.90	
J410	Wedge & Level Only	401-03545	Bituminous Surface 11, LV	TON	1	36.27	36.27	36.27	
J410	Wedge & Level Only	401-03560	Bituminous Surface 11, MV	TON	1	29.63	29.63	29.63	
J410	Wedge & Level Only	401-04273	Bituminous Mixture for Wedge & Level,	TON	1	42.60	42.60	42.60	
J410	Wedge & Level Only	401-04274	Bituminous Mixture for Wedge & Level	TON	1	29.47	29.47	29.47	
J410	Wedge & Level Only	401-04290	Bituminous Mixture for Wedge & Level,	TON	4	58.25	27.38	135.27	51.53
J410	Wedge & Level Only	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	1	31.42	31.42	31.42	
J410	Wedge & Level Only	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	1	31.42	31.42	31.42	
J410	Wedge & Level Only	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	2	38.38	34.21	42.55	5.90
J410	Wedge & Level Only	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	1	32.62	32.62	32.62	
J410	Wedge & Level Only	401-97738	Bituminous Mixture for Wedge & Level,	TON	4	28.52	26.37	29.63	1.46
J410	Wedge & Level Only	402-05477	HMA Surface 9.5 mm, Mainline	TON	2	38.95	35.83	42.06	4.40
J410	Wedge & Level Only	402-05483	HMA Base C25.0 mm, Shoulder	TON	1	39.30	39.30	39.30	
J410	Wedge & Level Only	402-05495	HMA Wedge & Level	TON	6	46.88	29.34	70.43	18.52
J410	Wedge & Level Only	406-05520	Asphalt for Tack Coat	TON	1	813.33	813.33	813.33	
J410	Wedge & Level Only	501-04014	Patching, Full Depth, Reinforced Concret	SYS	1	96.18	96.18	96.18	
J410	Wedge & Level Only	501-05090	Cement Concrete Pavement, Reinforced, 10	SYS	1	116.23	116.23	116.23	
J410	Wedge & Level Only	610-04291	Bituminous Mixture for Approaches, LV	TON	6	88.70	35.77	212.39	68.19
J410	Wedge & Level Only	610-04293	Bituminous Mixture for Approaches, HV	TON	1	86.20	86.20	86.20	
J410	Wedge & Level Only	610-05527	HMA for Approaches	TON	2	62.23	54.38	70.08	11.10
L000	Pvmnt Replacement	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	4	32.33	30.73	34.92	1.93
L000	Pvmnt Replacement	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	4	34.30	31.64	38.00	2.67
L000	Pvmnt Replacement	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	4	47.15	42.00	51.71	4.39
L000	Pvmnt Replacement	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	2	41.90	40.67	43.14	1.74

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
L000	Pvmnt Replacement	401-05463	QC/QA HMA Intermediate 19.0 mm, Shoulder	TON	1	73.70	73.70	73.70	
L000	Pvmnt Replacement	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	2	73.75	63.27	84.22	14.82
L000	Pvmnt Replacement	402-05468	HMA Base 25.0 mm, Mainline	TON	1	33.09	33.09	33.09	
L000	Pvmnt Replacement	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	1	37.60	37.60	37.60	
L000	Pvmnt Replacement	402-05475	HMA Intermediate C19.0 mm, Mainline	TON	1	30.81	30.81	30.81	
L000	Pvmnt Replacement	402-05477	HMA Surface 9.5 mm, Mainline	TON	1	63.17	63.17	63.17	
L000	Pvmnt Replacement	402-05481	HMA Base 25.0 mm, Shoulder	TON	2	33.88	31.75	36.00	3.00
L000	Pvmnt Replacement	402-05490	HMA Surface 9.5 mm, Shoulder	TON	2	48.18	45.36	51.00	3.99
L000	Pvmnt Replacement	402-05495	HMA Wedge & Level	TON	1	54.43	54.43	54.43	
L000	Pvmnt Replacement	406-05520	Asphalt for Tack Coat	TON	2	176.35	162.70	190.00	19.31
L000	Pvmnt Replacement	501-05094	Cement Concrete Pavement, Reinforced, 35	SYS	1	59.79	59.79	59.79	
L000	Pvmnt Replacement	501-05240	Contraction Joint, D1	LFT	3	5.53	4.83	6.34	0.76
L000	Pvmnt Replacement	501-05310	Terminal Joint	LFT	1	83.21	83.21	83.21	
L000	Pvmnt Replacement	501-06323	QC/QA PCCP, 300 mm	SYS	1	27.17	27.17	27.17	
L000	Pvmnt Replacement	501-06325	QC/QA PCCP, 350 mm	SYS	2	27.66	27.24	28.07	0.59
L000	Pvmnt Replacement	501-06664	QC/QA PCCP, 300 mm for Shoulder	SYS	1	27.17	27.17	27.17	
L000	Pvmnt Replacement	501-06665	QC/QA PCCP, 350 mm for Shoulder	SYS	2	27.66	27.24	28.07	0.59
L000	Pvmnt Replacement	501-06697	QC/QA PCCP, Rein., 300 mm for Shoulder	SYS	1	53.93	53.93	53.93	
L000	Pvmnt Replacement	501-06698	QC/QA PCCP, Rein., 350 mm for Shoulder	SYS	2	63.19	55.56	70.81	10.78
L000	Pvmnt Replacement	502-03532	QA Cement Concrete Pavement, Plain, 350	SYS	1	30.22	30.22	30.22	
L000	Pvmnt Replacement	502-04540	QA Cement Concrete Pavmnt,Shoulder,350mm	SYS	1	30.22	30.22	30.22	
L000	Pvmnt Replacement	502-04777	QA Cement Conc. Pavement, Plain, 325 mm	SYS	1	28.98	28.98	28.98	
L000	Pvmnt Replacement	502-04778	QA Cement Conc. Pvmnt for Shoul,Plai,325	SYS	1	28.98	28.98	28.98	
L000	Pvmnt Replacement	610-05527	HMA for Approaches	TON	4	60.20	31.18	97.57	27.58
L000	Pvmnt Replacement	610-06259	Reinforced Concrete Bridge Approach, 300	SYS	1	64.30	64.30	64.30	
L000	Pvmnt Replacement	610-06262	Reinforced Concrete Bridge Approach	SYS	4	63.88	58.32	71.08	6.57
L111	Pvmnt Replacement, New Conc.	401-05459	QC/QA HMA Base 25.0 mm, Shoulder	TON	1	35.58	35.58	35.58	
L111	Pvmnt Replacement, New Conc.	401-05464	QC/QA HMA Surface 9.5 mm, Shoulder	TON	1	35.58	35.58	35.58	
L111	Pvmnt Replacement, New Conc.	401-05467	Milled HMA Corrugations	LFT	1	0.12	0.12	0.12	
L111	Pvmnt Replacement, New Conc.	402-05468	HMA Base 25.0 mm, Mainline	TON	3	33.63	31.00	38.15	3.93
L111	Pvmnt Replacement, New Conc.	402-05470	HMA Base C25.0 mm, Mainline	TON	1	36.19	36.19	36.19	
L111	Pvmnt Replacement, New Conc.	402-05473	HMA Intermediate 12.5 mm, Mainline	TON	2	42.77	41.08	44.45	2.38
L111	Pvmnt Replacement, New Conc.	402-05474	HMA Intermediate 19.0 mm, Mainline	TON	1	26.15	26.15	26.15	
L111	Pvmnt Replacement, New Conc.	402-05477	HMA Surface 9.5 mm, Mainline	TON	3	40.25	31.38	45.36	7.71
L111	Pvmnt Replacement, New Conc.	402-05481	HMA Base 25.0 mm, Shoulder	TON	1	38.10	38.10	38.10	
L111	Pvmnt Replacement, New Conc.	402-05487	HMA Intermediate 19.0 mm, Shoulder	TON	1	54.43	54.43	54.43	
L111	Pvmnt Replacement, New Conc.	402-05490	HMA Surface 9.5 mm, Shoulder	TON	1	81.65	81.65	81.65	

**APPENDIX 3: Unit Costs for Pavement Repair, by Work Types
of INDOT Contract Bidding Documents (continued)**

Work Code	Work Designation	Item Code	Item Description	Unit	Nr. of Cntrcts ¹	Unit Cost Statistics (\$ Y2000)			
						Mean	Min.	Max.	Std Dev
L111	Pvmnt Replacement, New Conc.	402-05495	HMA Wedge & Level	TON	1	36.29	36.29	36.29	
L111	Pvmnt Replacement, New Conc.	501-05093	Cement Concrete Pavement, Reinforced, 32	SYS	1	68.05	68.05	68.05	
L111	Pvmnt Replacement, New Conc.	501-05191	Cement Concrete Pavement, Plain, 350 mm	SYS	1	41.74	41.74	41.74	
L111	Pvmnt Replacement, New Conc.	501-05240	Contraction Joint, D1	LFT	2	6.98	6.47	7.48	0.71
L111	Pvmnt Replacement, New Conc.	501-05290	Reinforcing Steel, Pavement	kg	1	1.56	1.56	1.56	
L111	Pvmnt Replacement, New Conc.	501-05310	Terminal Joint	LFT	1	121.13	121.13	121.13	
L111	Pvmnt Replacement, New Conc.	501-06324	QC/QA PCCP, 325 mm	SYS	1	28.19	28.19	28.19	
L111	Pvmnt Replacement, New Conc.	501-06325	QC/QA PCCP, 350 mm	SYS	1	28.18	28.18	28.18	
L111	Pvmnt Replacement, New Conc.	502-04777	QA Cement Conc. Pavement, Plain, 325 mm	SYS	1	25.46	25.46	25.46	
L111	Pvmnt Replacement, New Conc.	502-04959	QA Cement Concrete Pavement, Plain, 300mm	SYS	1	25.95	25.95	25.95	
L111	Pvmnt Replacement, New Conc.	502-06331	PCCP, 350 mm	SYS	1	50.17	50.17	50.17	
L111	Pvmnt Replacement, New Conc.	610-05527	HMA for Approaches	TON	4	57.24	31.75	99.77	29.76
L111	Pvmnt Replacement, New Conc.	610-06259	Reinforced Concrete Bridge Approach, 300	SYS	1	66.61	66.61	66.61	
L210	Pvmnt Replacement, Asphalt	401-05437	QC/QA HMA Base 25.0 mm, Mainline	TON	2	35.20	29.06	41.34	8.69
L210	Pvmnt Replacement, Asphalt	401-05455	QC/QA HMA Intermediate 19.0 mm, Mainline	TON	2	35.82	29.32	42.33	9.20
L210	Pvmnt Replacement, Asphalt	401-05456	QC/QA HMA Surface 9.5 mm, Mainline	TON	2	43.16	34.63	51.68	12.06
L210	Pvmnt Replacement, Asphalt	402-05470	HMA Base C25.0 mm, Mainline	TON	1	29.78	29.78	29.78	
L210	Pvmnt Replacement, Asphalt	402-05481	HMA Base 25.0 mm, Shoulder	TON	1	30.00	30.00	30.00	
L210	Pvmnt Replacement, Asphalt	402-05490	HMA Surface 9.5 mm, Shoulder	TON	1	35.00	35.00	35.00	
L210	Pvmnt Replacement, Asphalt	406-05520	Asphalt for Tack Coat	TON	1	196.87	196.87	196.87	
L210	Pvmnt Replacement, Asphalt	610-05527	HMA for Approaches	TON	2	53.86	35.37	72.36	26.15
L210	Pvmnt Replacement, Asphalt	610-06257	Reinforced Concrete Bridge Approach, 250	SYS	1	40.90	40.90	40.90	

APPENDIX 4 A Sample of Nationwide State of Practice of M&R Scheduling

Figure A.1. Preliminary Pavement Rehabilitation Decision Tree Selected for Incorporation into the Prototype Performance-Related Specification for HMA Pavement Construction Being Developed Under NCHRP Project 9-20 [NCHRP, 1998]

APPENDIX 4 (Continued)

Figure A.2. Preventive Maintenance Strategy Provided to Pavement [NYDOT, 1993]

APPENDIX 4 (Continued)

Figure A.3. Network Level Decision Tree for Bituminous Pavements – Minnesota DOT [Hicks et al., 2000]

APPENDIX 4 (Continued)

Figure A.4. Network Level Decision Tree for CRCP – Minnesota DOT

APPENDIX 4 (Continued)

Table A.2. General Guidelines for Effective Maintenance Treatments – Caltrans [Hicks et al., 2000]

Treatment	Pavement Condition										Parameters														
	Raveling	Oxidation	Bleeding	Rutting		Cracking				Desert	Climate		Traffic Volumes			Night/Cold	Stop Points	Urban	Rural	High Snow Plow Use	Cost Per Lane Mile	Life Expectancy (years)	Life Cycle Cost (\$/year)		
				< 1/2"	> 1/2"	Alligator B	Longitudinal	Transverse	Valley		Coastal	Mountains	adt < 5000	adt < 5000 < 30,000	adt > 30,000										
																								0 to 10%	10 to 20%
Crack/Joint Seal																									
Emulsion	N	N	N	N	N	F	P	N	F	F	G	G	G	G	G	G	N	G	G	G	G	2,500	1 to 2	1,700	
Modified (Rubber)	N	N	N	N	N	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	2,500	2 to 3	1,000	
Low Modulus (Polymer & Asphalt)																									
Fog Seal (See note 1)	F	G	N	N	N	F	P	N	P	P	G	G	G	G	F	N	N	P	F	G	G	F	4,500	1	4,500
Rejuvenator (See note 1)	G	G	N	N	N	F	N	N	N	N	G	G	G	G	G	F	N	N	N	G	G	F	4,500	2 to 4	1,500
Slurry Seals																									
Type II (See note 2)	F	G	N	N	N	F	N	N	N	N	G	G	G	F	G	G	G	P	G	G	G	P	13,000	3 to 4	3,700
Type III	G	G	N	F	N	F	P	N	N	N	G	G	G	F	G	G	G	N	G	G	G	P	13,000	3 to 4	3,700
Microsurfacing																									
Type II (See note 2)	F	G	N	G	N	F	N	N	N	N	G	G	G	G	G	G	G	F	G	G	G	F	16,000	3 to 4	4,500
Type III	G	G	N	G	G	F	P	N	N	N	G	G	G	G	G	G	G	F	G	G	G	F	16,000	3 to 4	4,500
Chip Seal																									
PME – Med. Fine	G	G	N	F	N	G	F	N	P	P	G	G	F	F	G	G	N	N	P	P	G	P	6,500	3 to 5	1,600
PME – Medium	G	G	N	F	N	G	F	N	P	P	G	G	F	F	G	N	N	N	P	P	G	F	6,500	3 to 5	1,600
PMA – Medium	G	G	N	F	N	G	F	P	P	P	G	G	G	G	G	N	N	G	P	P	G	F	12,500	4 to 5	2,800
PMA – Coarse	G	G	N	F	N	G	F	P	P	P	G	G	G	G	G	N	N	G	P	P	G	G	12,500	4 to 5	2,800
AR – Medium	G	G	N	F	N	G	G	F	P	P	G	G	G	G	G	N	G	P	P	G	F	20,000	4 to 6	4,000	
AR – Coarse	G	G	N	F	N	G	G	F	P	P	G	G	G	G	G	N	N	G	P	P	G	G	20,000	4 to 6	4,000
PM Alternative																									
Conventional OGAC	G	G	P	P	N	G	F	N	P	P	G	G	G	G	G	G	G	P	G	G	G	O	19,500	3 to 4	5,600
PBA OGAC	G	G	P	P	N	G	F	N	P	P	G	G	G	G	G	G	G	F	G	G	G	P	25,000	4 to 5	5,600
AR (Type O)	G	G	P	F	N	G	G	F	P	P	G	G	G	G	G	G	G	P	G	G	G	P	28,000	4 to 6	5,600
Thin Blanket ACOL																									
Conventional	G	G	P	G	G	G	G	F	P	P	G	G	G	G	G	G	G	G	G	G	G	G	20,000	3 to 5	5,000
PBA	G	G	P	G	G	G	G	G	F	F	G	G	G	G	G	G	G	G	G	G	G	G	25,000	3 to 6	5,600
R (Type G)	G	G	P	G	F	G	G	G	G	G	G	G	G	G	G	G	G	F	G	G	G	G	30,000	5 to 8	4,600
Digouts	P	P	G	N	G	N	N	G	P	P	G	G	G	G	G	G	G	G	G	G	G	G	19,000	5 to 8	2,900

G – Good Performance
F – Fair Performance
P – Poor Performance
N – Not Recommended

Note: 1. Generally used on shoulders, low volume roads, and parking areas. Should not be placed on traveled way by contract until further notice.
2. Generally used on shoulders, parking areas, and locations where a less aggressive surface texture is desired.

APPENDIX 4 (Continued)

Table A.3. Pavement Preventive Maintenance Techniques – Asphalt Pavement Surfaces Ohio DOT
[Hicks et al., 2000]

Preventive Maintenance Technique	Reasons for Use						Traffic Volume		Average Thickness	Application Rate			Average Life (Years)	Average Cost ¹	
	Friction	Raveling	Rutting	Seal Minor Cracks	Aging & Oxidation	Keep Out Water	Low	High		Asphalt	Aggregate	Mix		Weight or Area	Lane Mile
Crack Sealing						✓	X	X					1-4	\$0.60-\$1.00 per lb	\$1,000-\$4,000
Fog Seal		✓		✓	✓		X			0.10-0.15 Gal/sy			1-2	\$0.20-\$0.25 per sy	\$1,400-\$1,700
Slurry Seal		✓		✓	✓		X		1/8"-1/4"	0.15-0.20 Gal/sy		6-15 #/sy	2-5	\$0.70-\$0.95 per sy	\$5,000-\$7,000
Microsurfacing	✓	✓	✓	✓	✓			X	1/2"-1 1/2" Ruts & 1/4 Surface			22-26 #/sy to 50 #/sy	3-8	\$1.25-\$2.00 per sy	\$8,500-\$14,000
Sand Seal				✓	✓	✓	X		3/4"-1"				2-5	\$30-\$35 per ton	\$8,500-\$13,500
Rubber Sand Seal				✓	✓	✓	X	X	3/4"-1"				4-8	\$35-\$45 per ton	\$10,000-\$15,000
Chip Seal	✓	✓		✓	✓	✓	X		1/4"	0.30-0.35 Gal/sy	#8/#9 LS 15-25#/sy		3-5	\$0.80-\$1.10 per sy	\$5,500-\$7,500
Double Chip Seal	✓	✓		✓	✓	✓	X		1/2"	0.35 Gal/sy	#8/#9 LS 25-40#/sy		4-8	\$1.25-\$1.75 per sy	\$8,500-\$12,000
Open Graded Friction Course	✓						X	X	3/4"				5-9	\$30-\$40 per ton	\$8,500-\$11,500
Rubber OGFC	✓							X	3/4"				6-12	\$35-\$45 per ton	\$10,000-\$13,000
Thin Hot Mix Asphalt Overlay	✓	✓	✓	✓	✓	✓	X	X	1"-1 1/2"				7-10	\$30-\$35 per ton	\$7,000-\$15,000
Cold in Place Recycling		✓	✓	✓	✓		X		Scarify 1"-4"				5-10	\$15-\$25 per ton	\$6,000-\$8,000
Hot in Place Recycling			✓	✓	✓			X	Scarify 1"-1 1/2"	0.10 Gal/sy			5-10	\$2.00-\$2.20 per sy	\$14,000-\$15,500

¹1997 Statewide average unit bid prices ODOT projects

Note: These treatments should only be used on structurally sound pavements.

APPENDIX 4 (Continued)

Table A.4. NHS (High Traffic) Years Functional Life (YFL) - Colorado DOT [Brakey, 2000]

REHABILITATION STRATEGIES		10-YR DESIGN YFL ⁽¹⁾ WHEN EXISTING DISTRESSES BELOW ARE TREATED BY THE INDICATED REHABILITATION STRATEGIES												
WEARING SURFACE HBP overlay YFLs are for neat asphalt, 50% reliability.	SUBSIDIARY TREATMENTS ⁽²⁾ May be used with selected wearing surface. Basic is included in Major-Minor.	YFL by Cracking Index ⁽³⁾ if existing Transverse or Crack Index has an:		YFL expected by OPI plot for the identified predominate existing distress. ⁽⁴⁾ End parentheses are Design Manual pgs. The two degrees of severity include the subjective extent. Low level not included as it is unlikely to be treated.										
				Transv (Temp/ Refl) Cracking (B9, 12)		Long. or Block Cracking (B6, 11)		Load Assoc (Align or Long) Cracking (B4)		NP Rutting (B17) If plastic, see note 5		Raveling or Weathering (B16)		Bleeding (B5)
		RSL 3-0	RSL <0	Med	High	Med	High	Med	High	Med	High	Med	High	No Degree
MAJOR OVERLAY >4 to 6", 5" used. If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	12	12	14	14	14	14	14	14	14	14	14	14	NA
	Moderate	11	10	13	12	14	13	14	13	13	12	14	13	NA
	Minor	10	9	12	11	13	12	13	12	12	11	13	12	NA
	Basic Only	9	8	11	10	12	11	12	11	11	10	NA	NA	NA
MEDIUM OVERLAY >2 to 4", 3" used. If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	10	10	12	12	12	12	12	12	12	12	12	12	NA
	Moderate	9	8	11	10	12	11	12	11	11	10	12	11	NA
	Minor	8	7	10	9	11	10	11	10	10	9	11	10	NA
	Basic Only	7	6	9	8	10	9	10	9	9	8	10	NA	NA
THIN OVERLAY (2" HBP) If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	8	8	10	10	10	10	10	10	10	10	10	10	NA
	Moderate	7	6	9	8	10	9	10	9	9	8	10	9	NA
	Minor	6	5	8	7	9	8	9	8	8	7	9	NA	8
	Basic Only	5	4	7	6	8	7	8	7	7	6	NA	NA	NA
SMA (1.5 - 2") If over CIPR, must be ≥2"	Major	10	10	12	12	12	12	12	12	12	12	12	12	NA
	Moderate	9	8	11	10	12	11	12	11	11	10	12	11	NA
	Minor	8	7	10	9	11	10	11	10	10	9	11	10	10
	Basic Only	7	6	9	8	10	9	10	9	9	8	NA	NA	NA
MICRO SURFACING	Basic/Minor	4	3	5	4	5	4	5	4	5	4	6	5	NA
	Micro Surf in filled ruts	4	3	5	4	5	4	5	4	5	4	NA	NA	NA
GRIND/MICRO-MILL	Basic (applicable)	1	1	5	5	NA	NA	NA	NA	5	5	NA	NA	NA

Table Notes: (Columns are alternately shaded for easier reading)

Hatched cells represent 1999 PMS survey consensus values, +/- 1 year.

- Years Functional Life (YFL) is defined as the life predicted by the CDOT Network PMS at time of construction, at this time it is synonymous with RSL.
- Defined as any applicable treatment (see Conditions for Use) to the existing pavement prior to placing new HBP or other wearing surfaces. The four categories (the first three include Basic) are defined as follows:
 - Major: (1) Cold-in-place recycle, 4" or greater or (2) Cold mill >3" (and replace lost SN). (In this table, the SN replacement thickness is to be added to original Wearing Surface thickness)
 - Moderate: (1) Cold mill >1.5" to 3" (& replace lost SN), (2) hot-in-place recycling >1.5", or (3) fill non-plastic ruts (>0.5" to 1.5") with micro surfacing.
 - Minor: (1) Cold mill >0.75" - 1.5" (& replace lost SN), (2) hot-in-place recycle 0.75" - 1.5", (3) fabric interlayer (4) or fill non-plastic ruts (<0.5") with micro surf.

- Basic: Includes, but is not limited to, patching isolated weak areas, leveling up to 0.75" average by milling or HBP, or crack filling, as appropriate for the subsidiary treatment selected.

- The YFL by Cracking index is listed first as it is critical to performance and affects Ride and OPI. If by the PMS condition plot, either the Transverse or Cracking RSL at time of design are as indicated, YFL by Cracking Index is as shown. Use these YFLs for Cracking regardless of whether Transverse cracking is predominate, or not.

- The degrees of distress in the five categories below are to be arrived at subjectively by PMS data and/or project evaluation and include extent. The YFLs shown are those predicted from OPI by PMS.

- For medium to severe plastic rutting, it is presumed that little cracking and no raveling is present. For these conditions, repair by milling and replacing in accordance with CDOT guidelines shall be done. The pavement is then presumed to be restored to its original design life.

APPENDIX 4 (Continued)

Table A.5. Non-NHS (Low to Medium Traffic) Years Functional Life (YFL) - Colorado DOT [Brakey, 2000]

REHABILITATION STRATEGIES		10-YR DESIGN YFL ⁽¹⁾ WHEN EXISTING DISTRESSES BELOW ARE TREATED BY THE INDICATED REHABILITATION STRATEGIES												
WEARING SURFACE HBP overlay YFLs are for neat asphalts, 50% reliability.	SUBSIDIARY TREATMENTS ⁽²⁾ May be used with selected wearing surface. Basic is included in Major-Minor.	YFL by Cracking Index ⁽³⁾ if existing Transverse or Crack Index has an:		YFL by OPI plot for the identified predominate existing distress ⁽⁴⁾ . End parentheses are Design Manual pgs. The two degrees of severity include the subjective extent. Low level not included as it is unlikely to be treated.										
				Transv (Temp/ Refl) Cracking (B9, 12)		Long. or Block Cracking (B6, 11)		Load Assoc (Align or Long) Cracking (B4)		NP Rutting (B17) If plastic, see note 5		Raveling or Weathering (B16)		Bleeding (B5)
		RSL 3-0	RSL <0	Med	High	Med	High	Med	High	Med	High	Med	High	No Degree
MAJOR OVERLAY >4 to 6", 5" used. If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	#	#	#	#	#	#	#	#	#	#	#	#	NA
	Moderate	13	12	#	#	#	#	#	#	#	#	#	#	NA
	Minor	12	11	#	#	#	#	#	#	#	#	#	#	NA
	Basic Only	11	10	#	13	#	#	#	#	#	13	NA	NA	NA
MEDIUM OVERLAY >2 to 4", 3" used. If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	12	12	#	#	#	#	#	#	#	#	#	#	NA
	Moderate	11	10	#	13	#	#	#	#	#	13	#	#	NA
	Minor	10	9	13	12	#	13	#	13	13	12	#	13	NA
	Basic Only	9	8	12	11	13	12	13	12	12	11	13	NA	NA
THIN OVERLAY (2" HBP) If top layer is made from (98%reliability) modified AC, add 1 yr.	Major	10	10	#	#	#	#	#	#	#	#	#	#	NA
	Moderate	9	8	13	12	13	12	#	13	13	12	#	13	NA
	Minor	8	7	11	10	12	11	13	12	12	11	13	12	8
	Basic Only	7	6	10	9	11	10	12	11	11	10	12	NA	NA
SMA (1.5 - 2") If over CIPR, must be ≥2"	Major	12	12	#	#	#	#	#	#	#	#	#	#	NA
	Moderate	11	10	#	13	#	#	#	#	#	13	#	#	NA
	Minor	10	9	13	12	#	13	#	13	13	12	#	13	10
	Basic Only	9	8	12	11	13	12	13	12	12	11	13	NA	NA
MICRO SURFACING	Basic/Minor	8	4	6	5	6	5	6	5	6	5	7	6	NA
	Micro Surf in filled ruts	5	4	6	5	6	5	6	5	6	5	NA	NA	NA
GRIND/MICRO-MILL	Minor	2	2	6	6	NA	NA	NA	NA	6	6	NA	NA	NA

YFLs for these cells were 14, or higher, removed as unlikely combinations for 10-yr design.

Table Notes: (Columns are alternately shaded for easier reading)

1. Years Functional Life (YFL) is defined as the life predicted by the CDOT Network PMS at time of construction, at this time it is synonymous with RSL.

2. Defined as any applicable treatment (see Conditions for Use) to the existing pavement prior to placing new HBP or other wearing surfaces. The four categories (the first three include Basic) are defined as follows:

- **Major:** (1) Cold-in-place recycle, 4" or greater or (2) Cold mill >3" (and replace lost SN). (In this table, the SN replacement thickness is to be added to original Wearing Surface thickness)
- **Moderate:** (1) Cold mill >1.5" to 3" (& replace lost SN), (2) hot-in-place recycling >1.5", or (3) fill non-plastic ruts (>0.5" to 1.5") with micro surfacing.
- **Minor:** (1) Cold mill >0.75" - 1.5" (& replace lost SN), (2) hot-in-place recycle 0.75" - 1.5", (3) fabric interlayer (4) or fill non-plastic ruts (<0.5") with micro surf.

- **Basic:** Includes, but is not limited to, patching isolated weak areas, leveling up to 0.75" average by milling or HBP, or crack filling, as appropriate for the subsidiary treatment selected.

3. The YFL by Cracking index is listed first as it is critical to performance and affects Ride and OPI. If by the PMS condition plot, either the Transverse or Cracking RSL at time of design are as indicated, YFL by Cracking Index is as shown. Use these YFLs for Cracking regardless of whether Transverse cracking is predominate, or not.

4. The degrees of distress in the five categories below are to be arrived at subjectively by PMS data and/or project evaluation and include extent. The YFLs shown are those predicted from OPI by PMS.

5. For medium to severe plastic rutting, it is presumed that little cracking and no raveling is present. For these conditions, repair by milling and replacing in accordance with CDOT guidelines shall be done. The pavement is then presumed to be restored to its original design life.

APPENDIX 4 (Continued)

Table A.6. Pavement Distress Types and Their Alternative Treatments and Service Lives, Wisconsin DOT [Shober et al., 1997]

Distress Type	Distress Severity	Treatment Number and Type ⁽¹⁾												
		0	1	2	3	4	5	6	7	8	9	10	11	12
		Do Nothing	Spot Repair	Seal Coat	Crack Filling	Cold Recycle	Rut Fill	Surface Mill	Thin Overlay	Thick Overlay	Partial Mill and Overlay	Full Depth Mill/Overlay	Reconstruct	Micro Surface
Flushing/ Bleeding	Moderate	N/A	RL ⁽²⁾	RL ⁽³⁾										
	Severe							RL	RL		10-12			RL
Non-Structural Cracking	Minor	N/A	3-5		3-5									
	Moderate		3-5		3-5				6-9		8-10			
	Severe									8-12	8-10	12-15	FL	
Insufficient Structure	Minor		RL ⁽²⁾			5-8 ⁽⁴⁾	2-6		4-8					2-6 ⁽⁵⁾
	Moderate						2-6		4-8	8-12		12-15	FL	2-6 ⁽⁵⁾
	Severe									8-12		12-15	FL	
Bad Ride	Minor	N/A	RL ⁽⁶⁾					RL						
	Moderate							RL	8-10		10-12			
	Severe							RL		12-15	10-12			
Unstable Base and Subgrade	Minor		RL ⁽²⁾				2-6		4-8					2-6
	Moderate					5-8 ⁽⁴⁾	2-6		4-8	8-12		12-15		
	Severe									8-12	10-12	12-15	FL	
Unstable Mix	Minor						2-6				6-10	8-12		5-8
	Moderate											8-12	FL	
	Severe											8-12	FL	
Aged Pavement	Minor		4-8 ⁽⁷⁾	3-6			2-6							
	Moderate					5-10 ⁽⁸⁾	2-6		6-10	8-12	8-12			
	Severe									8-12	8-12	12-15	FL	
Surface Raveling	Minor	N/A												
	Moderate			3-6										
	Severe								8-12					

Notes: ⁽¹⁾ Numbers in cells indicate the expected range in life (in years) of an alternative treatment; RL = remaining life and FL = full life.

⁽²⁾ Executed on pavement lengths of 50 ft or less. Consists of light sanding, seal coat, milling or thin overlay.

⁽³⁾ Use reduced oil content in seal coat.

⁽⁴⁾ Only on low emphasis routes; usually followed by a seal coat.

⁽⁵⁾ Use multiple passes to build up surface.

⁽⁶⁾ Spot repairs may include skip grinding.

⁽⁷⁾ Spot repairs may include edge wedging, thin overlay and thick overlay.

⁽⁸⁾ With or without mixing grade emulsion added.

APPENDIX 4 (Continued)

Table A.7. Alternative Preventive Maintenance Treatments and Their Conditions for Use by New York State DOT [NYDOT, 1999]

Pavement Maintenance Treatment	Conditions for Use					
	Traffic Criteria		Maximum Pavement Distress Criteria*			
	AADT	Trucks	Cracking Severity	Raveling Severity	Rutting Severity	Drop-Off Severity
Single Course Surface Treatment	Less Than 2000	Low - Moderate	Low	Low	Low	---
Quick-Set Slurry	Low Volume	Low - Moderate	Low	Low	Low	---
Micro-Surfacing	No Restriction	No Restriction	Low	Low	Medium	---
Paver Placed Surface Treatment	No Restriction	No Restriction	Low	Low	Medium	---
Hot-Mix Asphalt Overlay (40 mm)	No Restriction	No Restriction	Low	Infrequent	Medium	Medium
Cold Milling with Non-Structural HMA Inlay	No Restriction	No Restriction	Low to Medium	Medium	Medium	Medium
CIPR with Non-Structural HMA Inlay	Less Than 4000	Less Than 10%	Medium	High	High	High

*Note: All treatments (with the exception of CIPR with Non-Structural HMA Inlay) assume infrequent corrugations, settlements, heaves or slippage cracks.

APPENDIX 4 (Continued)

Table A.8. Decision Table for Maintenance Treatments on Interstate and Primary Highways from Montana Department of Transportation – PMS [Hicks et al., 2000]

Ride	SCI	Maintenance Treatment
> 73		Do Nothing
60 - 73	> 60	Thin Overlay
	≤ 60	Thin Overlay_SR
< 60		Reactive Maintenance

ACI	AGE	SCI	Maintenance Treatment
> 90			Do Nothing
81 - 90	> 6		Crack Seal and Seal & Cover
	≤ 6		Crack Seal
66 - 80		> 60	Thin Overlay
		≤ 60	Thin Overlay_SR
< 66			Reactive Maintenance

MCI	AGE	SCI	Maintenance Treatment
> 94	> 12		Do Nothing
	7 - 12		Crack Seal and Seal & Cover
	< 7		Do Nothing
71 - 94	> 6		Crack Seal and Seal & Cover
	≤ 6		Crack Seal
56 - 70		> 60	Thin Overlay
		≤ 60	Thin Overlay_SR
< 56			Reactive Maintenance

Rut	Ride	SCI	Maintenance Treatment
> 52			Do Nothing
41 - 52	> 60	> 60	Maintenance Rut Fill
		≤ 60	Reactive Maintenance
	≤ 60		Reactive Maintenance
< 41			Reactive Maintenance