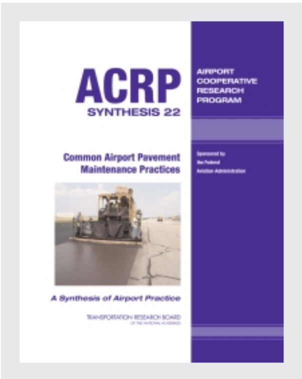

Common Airport Pavement Maintenance Practices

DETAILS

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP SYNTHESIS 22

Common Airport Pavement Maintenance Practices

A Synthesis of Airport Practice

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TRANSPORTATION RESEARCH BOARD

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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Cover figure: Construction of microsurfacing layer on runway.
Credit: The Miller Group.

FOREWORD

Airport administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the airport industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire airport community, the Airport Cooperative Research Program authorized the Transportation Research Board to undertake a continuing project. This project, ACRP Project 11-03, "Synthesis of Information Related to Airport Practices," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an ACRP report series, *Synthesis of Airport Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Gail R. Staba
Senior Program Officer
Transportation Research Board

This synthesis study is intended to inform airport pavement engineers and airport maintenance managers and personnel about how airports implement a pavement maintenance management program, including inspection and tracking pavement condition, scheduling maintenance, identifying necessary funds, and treating distresses in asphalt and concrete pavements.

Information used in this study was acquired through a review of the literature and interviews with airport operators and industry experts.

Jerry Hajek, Jim W. Hall, and David K. Hein, Applied Research Associates, Inc., collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

COMMON AIRPORT PAVEMENT MAINTENANCE PRACTICES

SUMMARY

Every airport operator is faced with the need to maintain airside pavements in good order for safe and efficient aircraft operation using the available budget. This synthesis describes how airports of all sizes currently practice pavement maintenance.

Decision making for maintenance and rehabilitation (M&R) of airport pavements typically consists of two stages of sequential decisions. The first stage involves identifying and prioritizing future pavement preservation needs, treatments, and projects, considering the needs and priorities of all airport pavements together. The objective of this stage is to decide at a given time which pavement sections are prioritized to receive M&R treatments. The second stage consists of determining, using site-specific engineering considerations, what type(s) of M&R treatment is to be carried out on the previously selected sections.

Although both stages are described in the synthesis, the emphasis was placed on the first stage, identifying and prioritizing future pavement preservation needs. The main challenge facing airport authorities is not which M&R treatment to use, but how to justify that M&R treatments are necessary, using a judicious and objective process, and to obtain funding for their implementation. In other words, the first priority is to select the right pavement sections for treatment.

The synthesis describes pavement preservation practices and treatments for asphalt concrete (AC) and portland cement concrete (PCC) pavements. Pavement preservation treatments for surface-treated and aggregate-surfaced pavements are not included. The technology of pavement preservation treatments is summarized in the *Catalog of Airport Pavement Preservation Treatments* in Appendix B. The *Catalog* contains a description of 24 common pavement preservation treatments for AC and PCC airport pavements

The synthesis addresses both M&R treatments because these two treatment types overlap, have a common goal, and work together to provide a cost-efficient pavement preservation program. Special attention was paid to describing the role of preventive maintenance in pavement preservation. Preventive maintenance is carried out to prevent premature pavement deterioration. Routine pavement maintenance that does not substantially improve the pavement surface is not included in the synthesis.

The main sources of information were an extensive literature review and a survey of airport pavement professionals representing individual airports or small groups of airports serving one small geographical area. The survey was a four-page questionnaire and is included in Appendix A. The survey focused on the use and operation of airport pavement management systems (APMSs), evaluation of pavement conditions, procedures used to select M&R treatments, use of preventive maintenance, identification of pavement preservation needs, funding sources, and the usage and field performance of common airport pavement preservation treatments. Survey responses were obtained from 50 pavement maintenance professionals, an 80% response rate for airports with daily aircraft operations ranging from a few to several thousand flights.

The role of an APMS is to support the technical, engineering, and management activities of airport personnel responsible for providing pavement infrastructure for safe and efficient operation of aircraft. The pavement management process provides systematic and objective procedures for maintaining the inventory of pavement infrastructure, monitoring pavement performance, selecting the right treatment for the right pavement at the right time, planning and budgeting of pavement preservation activities, and evaluating the cost-effectiveness of past pavement preservation actions. Based on the survey, more than 80% of airports have a functional APMS or are in the process of developing one. Approximately 30% of respondents rated their APMS as excellent and essential, and about 34% rated their system as functional but in need of improvement. The rest of the respondents were generally satisfied with their system.

The inventory of pavement infrastructure is the basic building block of an APMS. Because pavements deteriorate with time, the inventory includes the past and the current condition of pavements and the anticipated future pavement conditions. The predominant pavement performance modeling technique for airport pavements uses a set of characteristic pavement performance curves developed for groups (or "families") of similar pavement sections. Pavement condition evaluation includes the review of pavement surface distresses, roughness, friction, presence of foreign debris, and the evaluation of pavement surface deflections. With the exceptions of a few small airports, all airports surveyed carry out periodic pavement condition evaluation of runways using the Pavement Condition Index, with the average frequency of 3.4 years. Additional pavement evaluation cycles are utilized for timely selection and implementation of preventive maintenance treatments. The pavement evaluation results are used to assess trends in the overall condition (the health) of the pavement network, document the funding needs and the benefits of the APMS, identify major causes of pavement deterioration, and determine the performance of specific pavement structures and M&R treatments.

For purposes of the survey, 38 separate M&R treatments were identified; 19 for AC pavements and 19 for PCC pavements, and airport officials were asked to provide information on the use and performance of these 38 treatments. For AC pavements, the most frequently used treatment was crack sealing using hot-poured bituminous sealant, which was used by 90% of all airport agencies that had such pavements on at least one facility. The next four most frequently used treatments were pothole patching with hot mix, hot-mix overlay, milling and overlay, and pothole patching with cold mix. For PCC pavements, the most frequently used treatments were full-depth slab repairs and replacement using PCC or AC materials, joint resealing using silicone sealants, and shallow patching repairs using AC material. Based on the survey results, the average performance of the 19 M&R treatments for AC pavements was considered to be slightly better than the average performance for the 19 M&R treatments for PCC pavements.

Pavement preservation needs depend on the level of service the airport pavements are expected to provide. For the same pavement structure, a higher level of service results in higher M&R costs. The levels of service that can be used to guide the needs for M&R treatments include target or desirable level of service, minimum acceptable level of service, and minimum safety-related level of service. Trigger values can be used to provide guidance on timing for M&R treatments. The identification of needs is discussed for two time horizons: short-term planning for the time horizon of about 5 years or less, and long-term planning for the time horizon exceeding 5 years. Approximately 56% of respondents systematically identify pavement sections that would benefit from pavement maintenance.

Prioritization of M&R projects is typically based on priority levels that are related to the levels of service used to identify pavement preservation needs. Prioritization can be based on a single characteristic, such as the Pavement Condition Index, or on a composite indicator that combines several characteristics.

Budgeting takes into account not only pavement preservation needs but also other airfield needs affecting airport pavements, such as projects involving safety and functional improvements, underground utilities, and in-pavement lighting. Budgetary issues involve financial considerations related to the available funding and the time when the funding is available and operational considerations that include the impact on airport operations and safety during construction. Based on the survey, all airport agencies that have an APMS use a software application to facilitate the identification of needs, prioritization, and budgeting. About 53% of survey respondents reported using MicroPAVER, 13% used other commercial software, and 34% used in-house software.

With a few exceptions, all airport authorities surveyed already operate or are developing an APMS. The average age of the existing systems at the time of this survey was 9 years. The reported challenge for most of the agencies is not to develop an APMS, but to sustain and enhance its operation. Approximately 27% of airports that have an APMS characterized their systems as operational, but in need of improvement. The attributes that contribute to the successful operation and sustainability of an APMS include long-term commitment and support from decision makers, data integrity and timeliness, periodic reporting of results, meeting user needs through ongoing improvements, and a provision for training and succession planning.

In addition to ongoing system enhancements, a structured comprehensive review and enhancement of the APMS operations can be done using gap analysis and benchmarking.

CHAPTER ONE

INTRODUCTION

This report describes the results of ACRP Project 11-03, S09-02, Common Airport Pavement Maintenance Practices. The objective of the synthesis is to provide information for airport managers and engineers on how airports implement airport pavement maintenance systems (APMSs), including inspection and tracking pavement condition, scheduling maintenance and rehabilitation (M&R), identifying necessary funds and treating distresses in asphalt concrete (AC) and portland cement concrete (PCC).

PURPOSE

There is a large amount of information available on pavement maintenance; however, the information is dispersed and not always current. The specific objectives of the synthesis include:

- Documenting current pavement maintenance practices;
- Synthesizing relevant information by comparing, evaluating, and prioritizing it; and
- Identifying ongoing and recently completed research in the area of airport pavement maintenance programs and treatments.

Pavement maintenance as discussed in this synthesis includes both maintenance treatments such as crack sealing and rehabilitation treatments such as overlays. All types of M&R treatments are needed for cost-effective preservation of airport pavements. The synthesis describes pavement M&R practices for AC and PCC pavements; however, such practices for surface-treated and aggregate-surfaced pavements are not included.

BACKGROUND

Airport pavement maintenance practices generally follow the objectives, principles, and methodology of highway pavement management and asset management. There are several publications that provide useful information on pavement management procedures, including pavement condition evaluation, selection of maintenance and rehabilitation treatments, priority analysis, and other pavement management topics. For example, *FAA Advisory Circular on Guidelines and Procedures for Maintenance of Airport Pavements* (2007); *FAA Advisory Circular on Airport Pavement Management Program* (2006); *Transportation Research Circular E-C127: Implementation of an Airport Pavement Management System* (Tighe and Covalt 2008); *Unified Facilities Criteria on Pavement Maintenance Management* (2008); *Modern Pavement Management* (Hass et al. 1994); *Pavement Management for Airports, Roads, and Parking Lots* (Shahin 1994); and the AASHTO *Pavement Management Guide* (2001). The FHWA *Pavement Preservation Compendium II* (2006) describes many practical aspects of preventive maintenance applied to highway pavements.

The activities included for cost-effective preservation of airport pavements can be divided into two broad stages. The first stage includes identification and selection of future M&R treatments and projects considering the needs of all airport pavements. The objective of the first stage is to develop a budget for a Capital Improvement Program (CIP) or for a similar infrastructure preservation program. The second stage involves the design and construction of the M&R treatments for specific pavement sections identified during the first stage.

In the context of pavement management, the first stage activities represent the network-level management and the second stage activities the project-level management. Although both pavement management stages are described in the synthesis, the emphasis is on the network-level activities (how to select the right M&R treatments for the right pavements) rather than on materials and construction methods used for pavement preservation (how to design and build the right treatment). The reasons for emphasizing network-level activities rather than project-level activities include:

- Activities carried out at the network level, such as a systematic and objective assessment of pavement network condition, have universal applicability, whereas project-level activities often depend on airport-specific and site-specific conditions.
- Some maintenance treatments, such as microsurfacing and slurry seals, are constructed according to industry- or region-wide specifications with little input by local airport authorities.
- Pavement maintenance management practices on the network level are the cornerstone of pavement preservation. The main challenge facing airport authorities is not which pavement preservation treatment to use on a particular section, but to justify that M&R treatments are necessary and to obtain funding for their implementation.
- Information on airport pavement maintenance practices on the network level needs to be documented.

Combining Maintenance and Rehabilitation

This synthesis is concerned with both pavement maintenance and rehabilitation treatments, because these treatments overlap and are an integral part of a pavement preservation program. Guidelines and manuals on pavement preservation typically combine M&R treatments. For example, *FAA Advisory Circular on Guidelines and Procedures for Maintenance of Airport Pavements* (2007) describes M&R treatments together using the term "maintenance and repair." MicroPAVER (2003), a predominant pavement management software application, recommends pavement preservation strategies using several M&R treatments.

Pavement maintenance may also include routine maintenance that does not substantially improve the pavement surface, such as removal of debris, snow and ice control, repainting of pavement markings, maintenance of in-pavement lights, and removal of rubber deposits. These routine maintenance activities are not included in the synthesis.

Role of Preventive Maintenance (Preservation)

Preventive maintenance is carried out to prevent premature pavement deterioration or to slow the rate of deterioration. It is accomplished when the treatment is most effective, typically when the pavement is fairly new. Preventive maintenance may include, for example, crack sealing or machine patching of AC pavements, or resealing of PCC pavements. Preventive maintenance is an integral part of a pavement preservation program—of applying the right treatment to the right pavement at the right time.

Preventive maintenance has a special standing in the area of pavement preservation for several reasons:

- Preventive maintenance embodies the age-old experience that a stitch in time saves nine.
- The term preventive maintenance, and the concept of preventive maintenance, have become widely accepted and are well-liked by many practitioners.
- The successful application of preventive maintenance programs depends on the timeliness of the application that includes:
  - Detailed pavement surveys that can pinpoint when the treatment produces best results. For example, routing and sealing of longitudinal and transverse cracks in AC pavements produces favorable results after the cracks are well-defined, but before single cracks develop into multiple cracks.
  - Dedicated funding so that the treatment can be carried out at the right time without funding delays.

Consequently, the emphasis on preventive maintenance highlights the need for timely pavement preservation actions and contributes to judicious monitoring of pavement condition and to the establishment of dedicated maintenance budgets.

METHODOLOGY

The synthesis is based on information obtained by an extensive literature review, a targeted survey of airport pavement maintenance professionals, follow-up telephone interviews, and interviews and discussions with pavement experts, including technical staff representing airports of different sizes located in different regions of the country.

Literature Review

Airport pavement maintenance technology is documented in many publications such as books, guidelines, manuals of practice, specifications, circulars, and field performance and research reports. The primary information sources included the following:

- U.S.DOT—The FAA has issued several applicable advisory circulars referenced previously. The FHWA and its Office of Asset Management has produced several useful publications, notably the *Pavement Preservation Toolbox* (2006).
- U.S. Department of Defense (DOD). The Air Force has issued eight applicable Engineering Technical Letters that provide practical guidance for M&R of airfield pavements; for example, *Maintenance and Repair of Rigid Airfield Pavement Surfaces, Joints, and Cracks* (2004). The DOD also issues Unified Facilities Criteria (UFC) publications. The UFC series contains more than a dozen relevant reports and technical manuals; for example, *Pavement Maintenance Management* (2004).
- Reports produced by the Strategic Highway Research Program (SHRP), such as *Asphalt Pavement Repair Manuals of Practice* (1993) and *Concrete Pavement Repair Manuals of Practice* (1993), and reports produced by SHRP Long Term Pavement Performance Program, such as *Comparison of Rehabilitation Strategies for AC Pavements* (2000).
- National and international industry associations such as International Slurry Surfacing Association, National Asphalt Paving Association, American Concrete Pavement Association, and The Asphalt Institute.
- Technical associations and foundations such as TRB, American Society of Civil Engineers, Association of Asphalt Paving Technologists, Foundation for Pavement Preservation, National Centre for Pavement Preservation, Airfield Asphalt Technical Program, and Innovative Pavement Research Foundation.
- State sources. Several state transportation agencies developed comprehensive pavement maintenance guides, notably California (2008), Michigan (1999), Minnesota (2001), and Ohio (2001).

This synthesis contains only a small selection from the available information, with the objective to provide an overview of common airport pavement maintenance practices and their current application.

Many information sources, such as pavement management guides, specifications, manuals, and field performance reports, used for the preparation of the synthesis, were written for roadway pavements. There are differences between airfield and roadway pavements. Airfield pavements are subjected to a greater range of wheel loads, and wheel load applications are relatively infrequent and more spatially distributed (less channelized) as compared with roadway pavements. However, both airfield and roadway pavements are built and maintained using the same construction technology (materials, construction equipment, and construction methods), are supported by similar subgrade soils, and are exposed to a similar environment.

There are also differences between pavement management procedures used for airport pavement networks and roadway pavement networks. These differences are caused primarily by the differences in the size of airport and roadway networks. The large size of roadway networks, particularly networks managed by state transportation agencies, leads to the development of customized pavement management software and pavement management procedures. For example, the customized software may incorporate an interface with other corporate databases and management systems, and include a customized approach to generating project priorities. Large roadway networks are also built on a variety of subgrades and in different environmental zones, necessitating more sophisticated prediction of pavement performance and the selection of M&R treatments. Nevertheless, the management of both airport and roadway networks is based on the same management principles, and uses similar management procedures and frequently the same pavement management software.

There is also a degree of similarity in the mechanism for funding of pavement preservation for roadway pavements and for airport pavements by external agencies, and in the consequent requirement to justify funding requests. Airfield pavement preservation is primarily funded by the FAA with some contribution by the states; roadway pavement preservation, for Interstate and primary highways, receives funding from the FHWA. Both federal funding agencies require recipients to report periodically on the condition and utilization of pavement networks receiving funding. However, unlike airfield pavements, many roadway pavements are primarily funded by their owner: the state, county, or a municipality.

Survey of Pavement Maintenance Professionals

The first systematic assessment of airport pavement management practices in the United States was carried out by Broten and Wade (2004) in 2003, and included a survey of all 50 state aviation agencies. The survey focused on how the state aviation agencies were using their APMSs. The survey documented widespread use of APMSs and the positive impact the APMS had on the overall condition of airport pavements.

Unlike the previous survey, the synthesis survey did not target state aviation agencies, but individual pavement maintenance professionals representing individual airports or small groups of airports serving one small geographical area.

The survey of airport pavement maintenance practitioners representing individual airports was the main tool for gathering information on current maintenance practices. The survey questionnaire is included in Appendix A. Key survey results are presented in subsequent chapters of this synthesis, with additional results presented in Appendix B.

The survey and subsequent interviews focused on the following topics:

- Use of an APMS and experience with its operation. The topics included the age of the APMS, type of software used, and the involvement of consultants in the operation of the APMS.
- Evaluation of pavement condition, including periodic evaluation of pavement surface distresses, roughness, friction, and pavement surface deflections.
- Procedures used to select best pavement rehabilitation treatments.
- Use of preventive maintenance, including the existence of a dedicated budget for preventive maintenance.
- Sources of funding and procedures used to obtain funding for pavement preservation activities.
- Use and performance of common pavement M&R treatments, including new and innovative pavement preservation treatments.

The survey questionnaire was sent to 62 airports in 34 states to obtain information on current practices in airport pavement maintenance and the application of pavement management systems (PMSs) to track pavement performance and aid in planning and budgeting. Survey respondents were selected to represent different geographic and climatic regions, airports of different sizes, and airports with different pavement types. Figure 1 shows the locations of the airports that responded to the survey.

In total, 50 completed surveys were received, representing approximately an 80% response rate. Figure 2 shows the average daily aircraft operations for the airports included in the survey, and indicates that the responses were representative of airports of all sizes. The average number of daily aircraft operations ranged from one to about three thousand and was obtained from AirNav.com.

REPORT ORGANIZATION

The next seven chapters are arranged in the technological order of developing, operating, and sustaining an APMS, as shown in Figure 3. The names of the seven technological

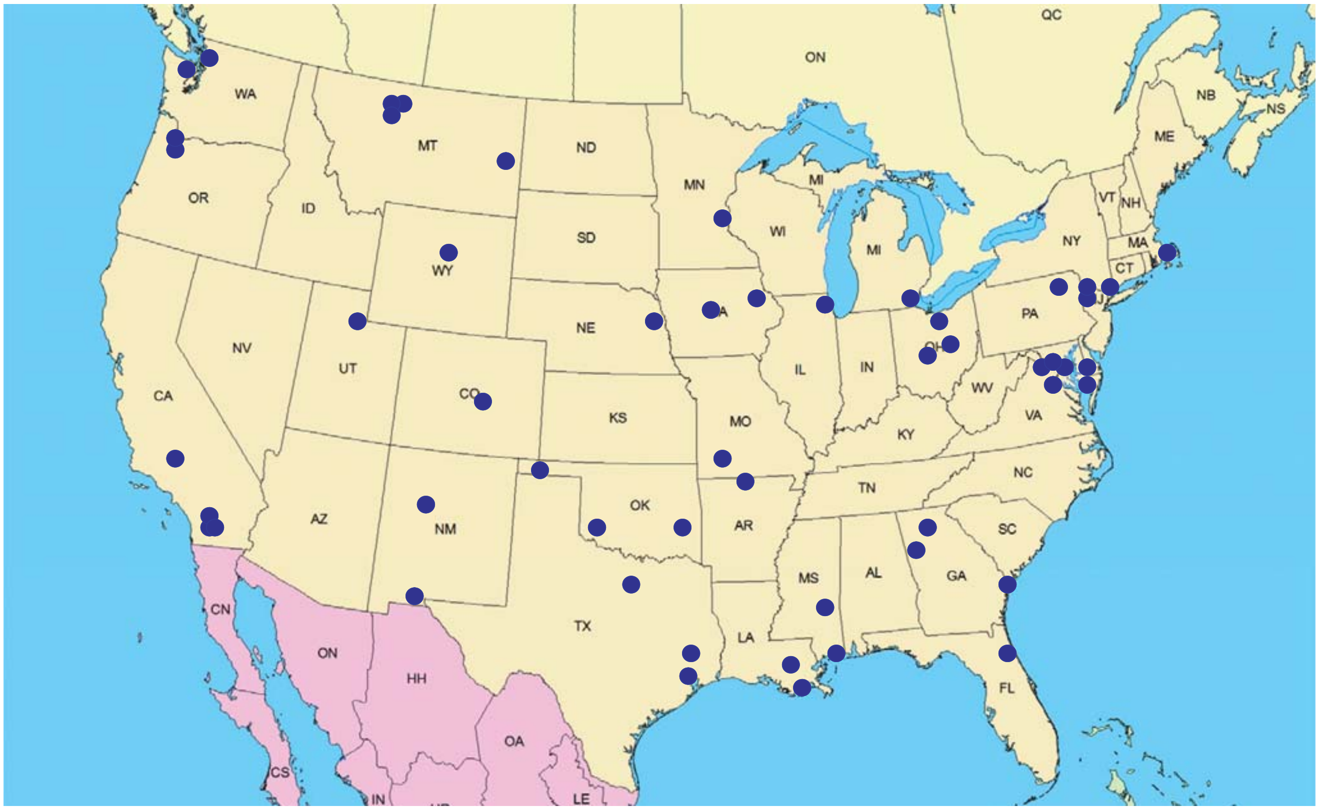

FIGURE 1 Locations of airports that responded to the survey.

steps given in Figure 3 are also the titles of the next seven chapters (chapters two through eight). Chapter nine contains conclusions and suggestions for further research. The report also includes References and a Glossary of Terms.

Appendix A presents the survey questionnaire and the survey results that are not included in the body of the report, and Appendix B presents a *Catalog of Airport Pavement Preservation Treatments.*

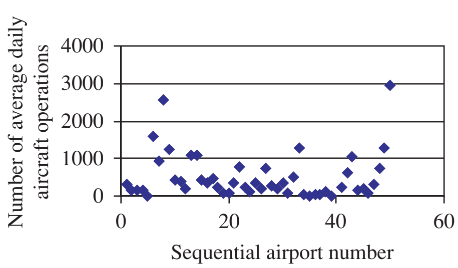

FIGURE 2 Number of average daily aircraft operations for airports included in the survey.

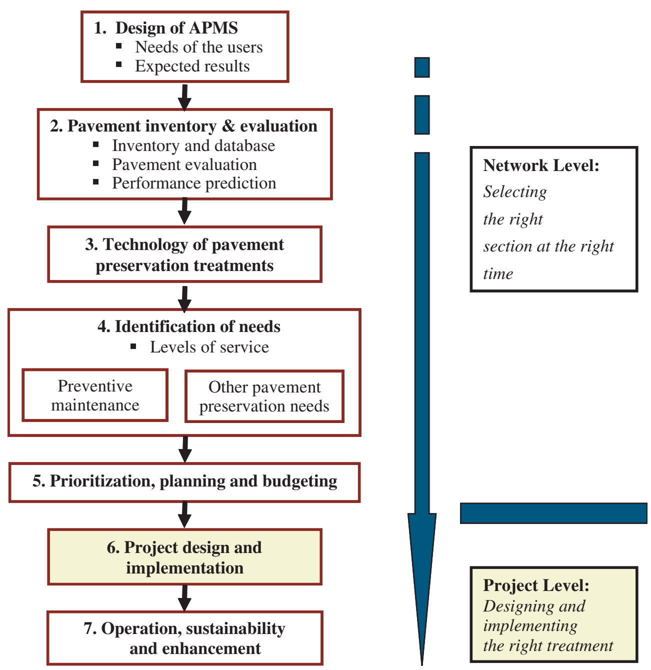

FIGURE 3 Main components of an APMS.

CHAPTER TWO

DESIGN OF AIRPORT PAVEMENT MANAGEMENT SYSTEMS

This chapter describes the main features of an APMS and its use by airport agencies. It also describes the potential benefits of the APMS, and basic steps necessary for the successful design of an APMS. More than 80% of airports that responded to the survey reported that they have a functional APMS or are in the process of developing one. The primary technical resource for this chapter is the FAA AC 150/5380-7A, *Advisory Circular on Airport Pavement Management Program.*

AIRPORT PAVEMENT MANAGEMENT PROCESS

An APMS includes all activities connected with pavement infrastructure, including the initial pavement design and construction, and the subsequent pavement maintenance and rehabilitation activities. The APMS is part of airport asset management that includes the management of all core airport assets including pavements, buildings, and guidance systems.

The role of an APMS is to support technical, engineering, and management activities of airport personnel responsible for providing pavement infrastructure for safe and efficient operation of aircraft. The pavement management process provides systematic and objective procedures for maintaining the inventory of pavement infrastructure, monitoring pavement performance, planning and budgeting of pavement preservation activities, and evaluating the cost-effectiveness of past pavement preservation actions. The main components of an APMS, grouped into seven main activities, are shown in Figure 3 in chapter one.

Current Use of Airport Pavement Management Systems

The 2003 survey of state aviation agencies indicated that 84% of the state agencies used a PMS, and that agencies using an APMS reported improvements in pavement condition over time (Broten and Wade 2004). The widespread use of APMSs by state aviation agencies was attributed partially, in the *Transportation Research Circular E-C127: Implementation of an Airport Pavement Management System* (Tighe and Covalt 2008), to the passage of Public Law 103-305 in 1994. This law requires a public airport to implement an effective airport pavement maintenance management system to be eligible for federal funding for pavement preservation.

Synthesis survey results indicated that 60% of all airports operate an APMS, 23% of airports are developing an APMS, and that about 17% of airports do not have an APMS. Several airports that are developing or do not have an APMS reported that they already carry out periodic pavement condition surveys or that periodic pavement condition surveys are carried out by their state aviation agency. Pavement condition surveys are an important component of an APMS.

Of those airports that responded to the survey, the average age of the APMS being used is approximately 9 years. For comparison, Broten and Wade (2004) reported that the average age of the APMS used by state aviation agencies was 10.7 years. The distribution of the age of APMSs is shown in Figure 4. Considering the usage of the APMS and their age, airport pavement management technology can be considered to be mature.

Approximately 30% of the airport authorities who already have a functional APMS characterized their system as excellent and essential, and about 27% characterized their APMS as functional, but in need of improvement (Figure 5). Approximately 34% of the agencies characterized their APMS as accepted and used. None of the agencies reported that their APMS is not useful.

MANAGEMENT AND TECHNICAL ASPECTS

An APMS design includes the establishment of its management and technical aspects. Management aspects include decisions regarding the overall system operation (e.g., in-house or using outside staff or consultants), securing the budget for the operation of the system, appointing staff, and establishing reporting relationships between the APMS staff and other airport agency staff. The successful operation of an APMS requires that it be well-integrated into the decision-making process of the agency and that it be supported by the airport management.

Technical aspects are concerned with the establishment of a database for the storage and retrieval of pavement-related data, selecting APMS software, choosing the methodology for pavement condition evaluation, establishing procedures for estimating pavement deterioration, and selecting the most cost-effective M&R treatments.

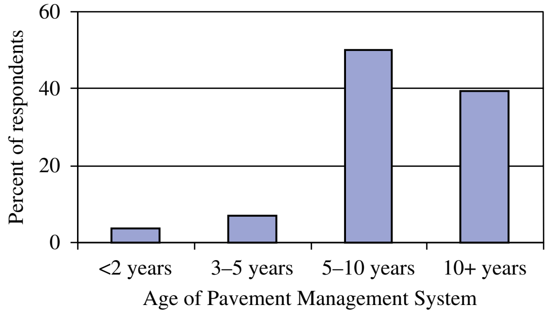

FIGURE 4 Age distribution of airport pavement management systems.

Pavement Management on the Network and Project Levels

Brief definitions of the network and project pavement management are provided in the Glossary of Terms. The division of APMS activities between the network and project levels is also shown in Figure 2 (see chapter one). For smaller airports, consisting of only one or two runways and a few taxiways and aprons, the network-level pavement management may include only a handful of pavement sections, whereas large airports may have hundreds of sections. Consequently, network-level management needs and procedures depend on airport size. Pavement preservation at large airports typically uses specialized pavement management software.

Project-level management activities, which concern the design and construction of M&R treatments for a specific pavement section, tend to be similar for all airports. The main difference is in the scale and importance of specific M&R projects. For large M&R projects, or for projects with high demand on the reliability of pavement design, advanced engineering design and quality control procedures are typically used to minimize costs and achieve product quality and reliability.

Benefits and Costs of an Airport Pavement Management System

APMS literature confirms that considerable benefits can be obtained by agencies through the following capabilities of the APMS:

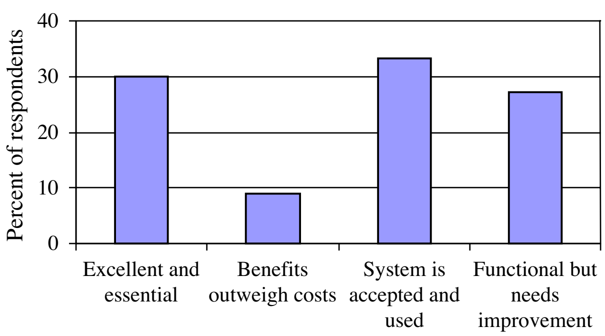

FIGURE 5 Experience with airport pavement management systems.

- **Computerized database**—An APMS promotes the development of a computerized database that facilitates the organization and storage of all pavement-related data (such as pavement structural and condition data) in one place and with easy retrieval.
- **Objective monitoring of pavement condition**—The operation of an APMS requires periodic, systematic, and objective monitoring of pavement conditions. This leads to the objective identification of pavement preservation needs and enables funding agencies to allocate M&R funds to different airports based on reliable data.
- **Establishment of pavement deterioration rates**—The deterioration rates are used to estimate when maintenance and rehabilitation treatment will be needed. They can be also used to determine the service lives of specific M&R treatments and to identify pavement sections and pavement treatments that are deteriorating at abnormally high rates. The life spans, together with costs, are used to calculate cost-effectiveness of pavement M&R treatments.
- **Planning and budgeting**—An APMS allows the user to logically select, or even optimize, the list of pavement M&R treatments for a given budget.
- **Obtaining funding**—An APMS facilitates the systematic identification and documentation of pavement preservation needs. The APMS is a prerequisite for obtaining federal and/or state funding for M&R of airport pavements, and aids in the justification of M&R funding from upper management.
- **Flexibility of operation**—An APMS fosters the need for thorough documentation of the pavement management process. The existence of a documented pavement management process enables agencies to adjust to changes, particularly to changes concerning agency personnel and consultants operating the system or providing system support.

Figure 6 shows how airports use different features of an APMS. For example, approximately 90% of airports use their APMS system to track the pavement condition and prepare budgets. Only about 45% of respondents use the system to determine the performance of past M&R treatments.

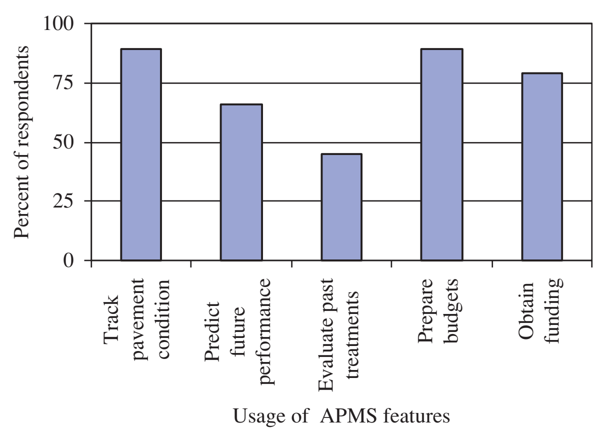

FIGURE 6 Use of the features and results provided by airport pavement management systems.

The costs associated with APMS include the initial costs to develop the system, establish a pavement management database, and train the personnel. Subsequent ongoing costs of operating the system include periodic pavement condition surveys, system maintenance, and modifications and improvements to the system.

Initial Design of Airport Pavement Management Systems

The initial design of an APMS is important for ensuring the future use and sustainability of the APMS operation. A comprehensive summary of design activities for successful implementation and operation of an APMS is provided in *Transportation Research Circular E-C127* (Tighe and Covalt 2008). Briefly, the design and implementation of an APMS includes the following activities:

- Obtain a commitment to establish and operate an APMS and appropriate funding to do so from airport management.
- Identify potential users of the system and determine their needs.
- Decide who will develop and operate the system (internal staff, consultant, or a combination of the two).
- Select APMS software.
- Develop a database including sectioning of the network and initial pavement condition evaluation.
- Customize software to reflect local input values such as pavement deterioration rates, M&R policies, typical unit costs of M&R treatments, and agency-specific preferences and priorities concerning the selection of M&R treatments.
- Customize software to incorporate agency preferences regarding data analysis and reporting, such as network condition analysis and the incorporation of geographic information systems (GIS).
- Provide initial and ongoing staff training.
- Construct a follow-up plan to ensure that data are updated (e.g., periodic pavement condition evaluation and updating the database to record new M&R activities) and that the software keeps pace with new developments.

CHAPTER THREE

PAVEMENT INVENTORY AND EVALUATION

The inventory of pavement infrastructure is the basic building block of an APMS. Because pavements deteriorate with time, the inventory includes past and current condition of pavements and anticipates future condition. This chapter provides a brief description of the main features of pavement inventory and procedures used for the assessment of pavement condition. Evaluation procedures are described for pavement surface distresses, roughness, friction, and pavement deflection testing. With the exception of a few small airports, all airports surveyed carry out periodic pavement condition surveys of runways using the Pavement Condition Index (PCI), with an average survey frequency of 3.4 years.

PAVEMENT INVENTORY

The documentation of pavement inventory is a prerequisite for a systematic pavement condition evaluation and the selection of M&R treatments on the network level. On the project level, pavement inventory data are essential for the design of M&R treatments. The inventory includes the size and main characteristics of pavement assets and their condition. Preferably, pavement inventory is viewed and organized as part of an airport asset inventory. The U.S.DOT developed the *Data Integration Primer* (2001), which explains principles and options for developing integrated asset management databases. There is also the ASTM Standard E177-96, Standard Guide for Prioritization of Data Needs for Pavement Management (ASTM 2002).

A pavement inventory divides the airport pavement network into homogeneous pavement sections with the same pavement structure and a similar pavement condition throughout. A pavement section is the basic building block for pavement inventory. It is also a basic unit for pavement preservation decision making. An M&R project can be carried out on a single pavement section. In other words, a section is established as a "repair unit"—a portion of the network that can be managed and repaired independently from other sections (Tighe and Covalt 2008).

The pavement network is typically divided into four levels according to specifications given in ASTM Standard D 5340 (2003) or in *FAA Advisory Circular on Guidelines and Procedures for Maintenance of Airport Pavements* (2007):

1. **Network**—represents the entire pavement infrastructure managed by the airport authority.
2. **Branch**—a part of the network that serves a specific purpose. Typical branches are runways, taxiways, aprons or ramps, and airside pavements; for example, each airport runway is considered to be a branch.
3. **Section**—a part of a branch that has a uniform pavement structure (and construction and maintenance history), traffic loads, and pavement condition. It is the basic repair unit.
4. **Sample units**—a part of a section created to carry out pavement condition surveys based on the ASTM standard. The maximum size of the sampling unit for AC and PCC pavements is specified in the standard.

Data storage and retrieval is facilitated by APMS software such as MicroPAVER (2003). As a minimum, the pavement inventory data for each section includes the following:

- **Section identification**—functional class (branch) and dimensions of the pavement section.
- **Location of the section**—for example, within the branch, keel, or outer wings.
- **Pavement structure**—date of the original construction and the description of pavement structure. The description includes thickness and basic material properties of all layers, both the original layers and the subsequent changes.
- **Subgrade and drainage characteristics**—subgrade type and the presence of subdrains and edge drains.
- **Maintenance history**—types and dates of subsequent pavement M&R treatments, including the age of a current pavement surface.
- **Pavement condition data**—includes past and current data.
- **Traffic data**—number of aircraft operations and type of aircraft.

Pavement inventory data are stored in an APMS database, such as MicroPAVER, that has the capability to graphically display archived data.

PAVEMENT EVALUATION PRINCIPLES

APMS pavement evaluation includes field measurements of the current state of pavement characteristics and recording them for future use. It encompasses the evaluation of pavement surface distresses, roughness, friction, and pavement strength. The main principles of airport pavement evaluation include:

- **Objectivity and consistency**—Objective and consistent pavement evaluation produces true trends and provides reliable data for pavement investment decisions. Objectivity and consistency of repeated evaluations enables airport owners to see how the pavement conditions change over the years. They also enable funding agencies to compare pavement conditions of different airports within and outside their jurisdiction.
- **Timelines and relevancy**—Pavement evaluations support planning and budgeting cycles and provide data for timely implementation of pavement preservation treatments, particularly preventive maintenance treatments.
- **Long-term monitoring**—Historical pavement performance data from repeated evaluations are vital for the development of pavement performance models used to estimate when M&R treatments will be needed. Long-term monitoring data also enables evaluation of past performance of pavement preservation treatments.
- **Cost-effectiveness**—Collection of pavement evaluation data in the field can be expensive. The type, amount, and the frequency of data collection are affected by cost-effectiveness considerations.
- **Frequency of evaluation**—Public Law 103-305 (1994) states that if an airport is conducting a PCI assessment as part of pavement management activities, a 3-year inspection cycle is sufficient. However, the 3-year cycle may be too long for selecting and implementing preventive maintenance treatments in a timely manner.
- **Network- and project-level evaluation**—There is a difference between pavement evaluation data at network and project levels. Network-level management entails periodic surveys of pavement surface distresses and pavement friction on sample units. Project-level pavement management typically involves detailed evaluation of pavement surface conditions over the entire project area and the evaluation of pavement load capacity through nondestructive testing (e.g., deflection, cone penetrometer, and ground penetrating radar) and destructive testing (e.g., coring and boring and subsequent material testing).

EVALUATION OF PAVEMENT CONDITION

The following pavement characteristics are evaluated for in-service airfield pavements

- Pavement surface distress
- Pavement roughness
- Pavement friction
- Presence of foreign object debris
- Pavement structural strength or capacity.

Pavement Surface Distress

Surface distresses of airport pavements are typically evaluated using the PCI. The PCI evaluation methodology was developed by the U.S. Army Corps of Engineers and is described in *FAA Advisory Circular on Guidelines and Procedures for Maintenance of Airport Pavements* (2007) and in ASTM Standard D5340 (2003). It is noteworthy that ASTM adopted the PCI as a pavement condition rating standard for airfield pavements. The PCI values can range from 0 to 100 and be interpreted as shown in Table 1.

PCI distress data are obtained by a visual survey carried out by trained pavement evaluators who walk on the pavement. Alternatively, the evaluation can be done by taking high-quality pavement images and interpreting them using pavement evaluators or specialized software. The PCI is based on the evaluation of distress type, severity, and quantity.

- **Distress type**—There are 16 pavement surface distress types for AC pavements and 15 for PCC pavements. Considering pavement preservation needs, prominent distresses for AC pavements include longitudinal and transverse cracking, rutting, weathering and raveling, and block cracking. Also included are two distresses specifically related to airport operations—jet blast and oil spillage. For PCC pavements, prominent distresses include joint seal damage, joint spalling, faulting, corner break, and linear cracking.

TABLE 1
PAVEMENT CONDITION INDEX FOR AIRPORT PAVEMENTS

PCI Rating	Description	Applicable Pavement Preservation Treatments
86–100	Good—only minor distresses	Routine maintenance only
71–85	Satisfactory—low and medium distresses	Preventive maintenance
56–70	Fair, some distresses are severe	Corrective maintenance and rehabilitation
41–55	Poor—severity of some of the distresses can cause operational problems	Rehabilitation or reconstruction
26–40	Very poor—severe distresses cause operational problems.	Rehabilitation and reconstruction
11–25	Serious—many severe distresses cause operational restrictions	Immediate repairs and reconstruction
0–10	Failed—pavement deterioration prevents safe aircraft operations	Reconstruction

- **Severity of pavement surface distress**—There are four severity levels defined for most of the pavement distress types—none, low, medium, and high. The severity rating is facilitated by a systematic description of the severity levels and by photographs illustrating the differences between the levels.
- **Quantity of pavement distress**—Quantities are measured in feet or in square feet of the affected area.

Evaluation Methodology

The distress assessment is done only on selected sample units. The results for sample units are averaged and the average result is reported for the entire section. The sample units are of a uniform size and selected by statistical sampling. The number of sampling units is chosen to achieve the desired accuracy and reliability.

The major advantages of the PCI procedure are its wide use, objectivity, and acceptance. A PCI rating provides a good indication of the functional serviceability of the pavement and basic information about its structural integrity. A PCI rating alone can be used to estimate M&R needs for planning purposes. The advantages as well as potential misconceptions and pitfalls of using the PCI procedure for airfield pavements have been described by Broten and De Sombre (2001).

As described in Table 2, 78% of all airports surveyed carry out periodic PCI surveys on the runways, with an average frequency of every 3.4 years. The PCI surveys are done even by airports that do not have a formal PMS, and are sometimes done by state aviation administrations on behalf of the individual airports. Only one airport used an internal method to evaluate pavement surface distresses, and 10% of airports did not carry out any periodic pavement evaluation. Table 2 also notes that 54% of survey respondents use the PCI for taxiways and other facilities, with average frequencies of every 3.3 years. Information on the use of other types of pavement characteristics is also described. In addition, several airport agencies reported using digital images to document pavement surface distresses.

Most state aviation agencies, such as those in Ohio, Michigan, Washington, Montana, and Oregon, carry out periodic distress surveys for all airports under their jurisdiction using the PCI procedure. For example, all 50 public airports in Michigan are evaluated using the PCI methodology (Michigan Airports Division 2007).

For project-level analysis, the evaluation of surface distresses typically uses the same rating as that used for the network level. However, the entire section is evaluated instead of only sample units.

Roughness

The FAA defines profile roughness as surface profile deviations over a portion of the runway that may increase fatigue on airplane components, reduce braking action, impair cockpit operations, and/or cause discomfort to passengers. The interaction between aircraft responses and runway pavement roughness is complex and depends on the type, weight, and speed of aircraft, and on the position of the observer in the aircraft (Woods and Papagiannakis 2009). Traditionally, M&R actions designed to improve pavement smoothness have been based on pilot observations and complaints (Larkin and Hayhoe 2009).

For newly constructed airport pavements, procedures for measuring and specifying pavement roughness have been developed and accepted. For in-service pavements, a first step toward defining and implementing pavement roughness criteria is provided by *FAA Advisory Circular on Guidelines and Procedures for Measuring Airfield Pavement Roughness* (2009). The roughness criteria presented in the current version of the *Circular* are intended to address isolated bump events and do not address cyclic or harmonic events that can have a substantial impact on airplane occupants, components, and operations.

The FAA also developed an inertial profiling system for measuring runway and taxiway longitudinal elevation profiles and a computer program, Profile Federal Aviation Administration (ProFAA), to analyze the measured profiles. The ProFAA can be used to compute a variety of airport pavement roughness indices from the measured profiles, including the Boeing Bump Index and the International Roughness Index.

TABLE 2
EVALUATION OF PAVEMENT CHARACTERISTICS

Pavement Characteristic	Runways		Taxiways and Other Facilities	
	Usage (%)	Average Frequency, years	Usage (%)	Average Frequency, years
PCI	78	3.4	54	3.3
Roughness	12	N/A	4	N/A
Friction	22	N/A	8	N/A
FWD testing	18	3.7	12	N/A

Based on the survey.
Notes: FWD = Falling Weight Deflectometer; N/A = Data are not available or are insufficient.

Based on the survey results, approximately 12% of agencies reported using roughness surveys on runways and 4% of agencies on taxiways and other facilities (see Table 2).

Pavement Friction

Pavement friction is the force that resists the motion between a vehicle tire and a pavement surface. Pavement friction is a significant safety concern for aircraft with greater weight and landing speeds, such as turbojet aircraft, particularly when the pavement is wet. The *Guide for Pavement Friction* (Hall at al. 2009) provides general technical information on pavement friction.

FAA Advisory Circular on Measurement, Construction, and Maintenance of Skid-resistant Airport Pavement Surfaces (2004) provides guidelines for designing skid-resistant airport pavement surfaces and for on-going monitoring and evaluation of pavement friction. The *Circular* also describes recommended procedures to measure pavement friction and provides specific friction levels required for safe aircraft operations. These friction levels can be used to plan and carry out appropriate M&R actions.

For airfield pavements, friction is typically evaluated on runways only. Twenty-two percent of responding agencies reported that they evaluate pavement friction on runways. In addition, 8% of airport agencies reported measuring friction on taxiways (see Table 2).

Presence of Foreign Object Debris

The presence of foreign object debris is evaluated using the Foreign Object Damage/Debris (FOD) Index. The FOD Index is determined from the PCI calculated by considering only the distresses/severity levels capable of producing FOD (*Pavement Engineering Assessment Standards* 2004). The FOD index is generally not used at major airports.

Structural Evaluation

The overall structural strength of airport pavements is evaluated using the Aircraft Classification Number–Pavement Classification Number (ACN-PCN) method outlined in the draft *FAA Advisory Circular on Standardized Method of Reporting Airport Pavement Strength—PCN* (2009). The PCN captures the relative strength of the pavement structure (considering a standard subgrade) and the ACN provides guidance to airport operators regarding the relative effect of an aircraft on the pavement structure. The PCN evaluation is not routinely used for the planning of pavement M&R treatments and was not included in the survey.

According to the survey (see Table 2), 18% of airports, typically large airports, carry out periodic network-level surveys using a Falling Weight Deflectometer (FWD) on runways and 12% of surveyed airports reported FWD surveys of taxiways and other facilities. The average frequency of the FWD surveys on runways was 3.7 years.

Procedures for FWD testing are outlined in *FAA Advisory Circular on Use of Nondestructive Testing Devices in the Evaluation of Airport Pavements* (2004). For project-level analysis, structural evaluation is discussed in chapter seven.

CONDITION ANALYSIS

Pavement condition analysis utilizes pavement condition data in pursuit of the following outcomes:

- Assessment of the overall condition of the pavement network. For example, Figure 7 shows the results of a PCI survey for a small Michigan airport (Michigan Airports Division 2007). The objective assessment of the condition of the asset is also useful in meeting the accounting recommendations of the Governmental Accounting Standards Board (1999).

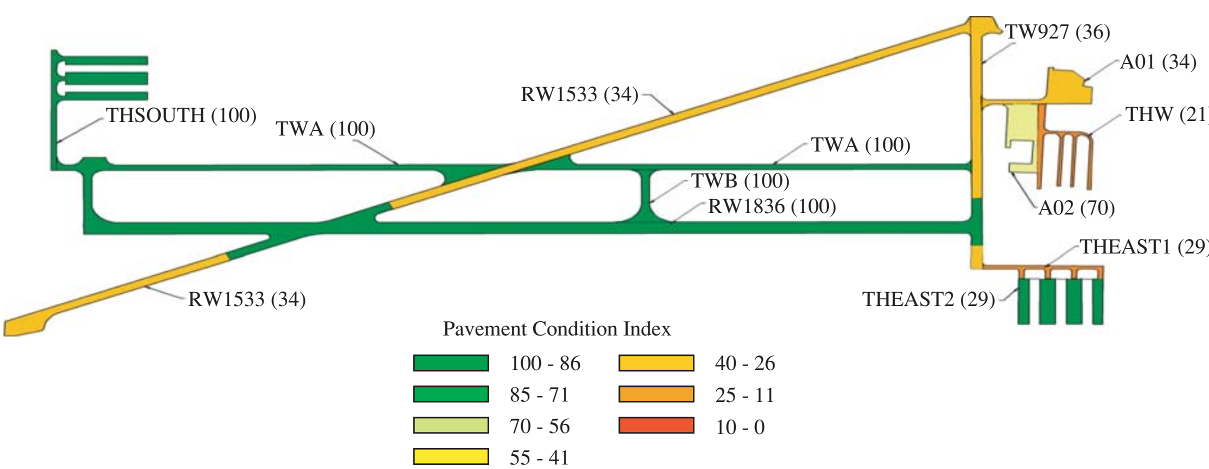

FIGURE 7 Example of a graphical display of Pavement Condition Index.

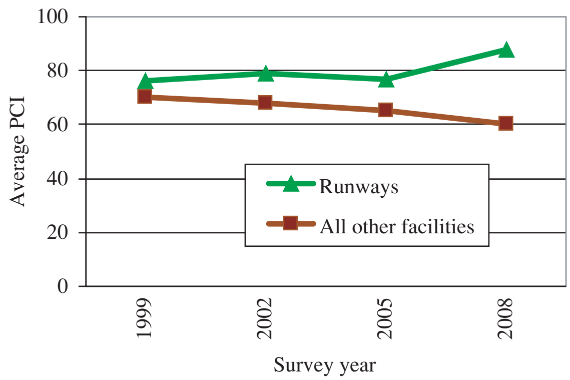

FIGURE 8 Illustration of trends in average PCI for runway pavements and all other pavements.

- Trends in pavement condition. Historical trends in the health of the network provide linkage between pavement preservation investments and the outcomes. For example, Figure 8 shows an improvement in the condition of the runway pavements, but no improvement in the condition of pavements on other facilities. The PCI results in Figure 8 are based on a 3-year evaluation period.
- Documentation of system benefits. Systematic analyses of pavement conditions play a vital role in the documentation of APMS benefits necessary to secure continued financial support for the program.
- Documentation of funding needs. Condition analysis provides basic data for the determination of funding needs, as described in chapter five.
- Technical analysis of pavement performance. Systematic pavement condition evaluation can identify:
  - Major causes of pavement deterioration such as poor drainage and inappropriate pavement materials.
  - Well or poorly performing initial pavement structures, or the subsequent M&R treatments.
  - Rates of pavement deterioration for different pavement types, facilities, and M&R treatments. The deterioration rates are used to develop pavement performance models discussed in chapter five.
  - Pavement sections with inadequate structural capacity.

PAVEMENT EVALUATION FOR PREVENTIVE MAINTENANCE

Pavement condition surveys that evaluate the type, severity, and extent of pavement surface distresses are also used in preventive maintenance programs. However, for selection and application of preventive maintenance treatments it is also desirable to identify specific pavement conditions and early indicators that trigger the need for preventive maintenance treatments.

Preventive maintenance treatments are best applied when they are most cost-effective, typically before distresses progress and more expensive corrective treatments are needed. For example, treatments to route and seal cracks in asphalt concrete pavements are carried out when the cracks are already well-formed, but before cracks become raveled, have developed into multiple cracks, or before the crack width exceeds about three-eighths of an inch. Most effectively, condition surveys of pavement surface distresses for the selection and timing of preventive maintenance treatments are annually carried out on candidate pavement sections. The first pavement preservation treatments are typically carried out when the pavement surface layer is between 3 and 5 years old. The results of the synthesis survey show that the average frequency of PCI surveys on runways was 3.4 years (see Table 2) with the range of from 1 to 10 years.

PAVEMENT PERFORMANCE PREDICTION

For planning purposes, airport pavement maintenance managers estimate future pavement preservation needs. A typical planning period is 5 years; however, some large airports may prepare pavement preservation plans for major runways for up to 15 years. Predicting pavement performance and storing the results in the APMS database assists managers in identifying future pavement performance.

Use of Pavement Performance Prediction

Future pavement performance, or pavement deterioration, is estimated using pavement performance models. The survey revealed that 66% of responding airport agencies use an APMS to predict future pavement deterioration (see Figure 6). Pavement performance prediction serves the following:

- Estimation of when the pavement will require M&R treatment. The need for performance prediction is illustrated in Figure 9, which shows pavement performance curves for two pavements. Both pavements have the same present PCI, but pavement B deteriorates, and is expected to deteriorate, faster than pavement A. Consequently, pavement B will require an earlier pavement preservation treatment.
- Estimation of treatment type. As shown in Figure 9, when pavement condition reaches a minimum acceptable service level it should be rehabilitated. To identify

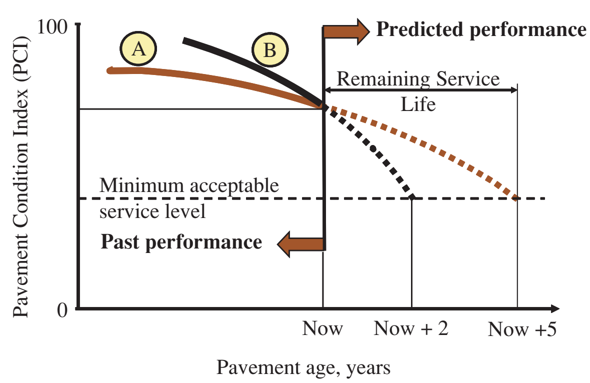

FIGURE 9 Pavement performance prediction.

future funding needs, the type of the M&R treatment, and its cost and timing, need to be estimated.

- Estimation of the life span of M&R treatments. To select cost-effective treatments, it is necessary to estimate the cost of the treatment and its life span. The subsequent monitoring of the treatment performance provides feedback on the choices made.
- Deterioration rate. The predicted rate of pavement deterioration can also be used as one of the factors to select candidate sections for M&R. In Figure 9, pavement B is expected continue to deteriorate at a higher rate than pavement A, and the timing of the M&R treatment for pavement B is now.
- Estimation of the remaining service life. Figure 9 also defines the remaining service life of the pavement. When known for all sections of the network, the remaining service life can be used to characterize the overall condition of the network. It is also useful in planning and programming pavement M&R activities (Wade at al. 2007a).
- Timing of preventive maintenance treatments. Pavement conditions that exist at the time of the pavement evaluation survey may need to be extrapolated to the time when an M&R treatment will be applied. In some cases, the lead time may be 3 or more years. Preventive maintenance treatments are typically planned only from 2 to 18 months in advance.

Pavement Performance Modeling Techniques

Pavement performance depends on many local factors such as the type and frequency of traffic loads, environmental exposure, subgrade characteristics including drainage, and pavement structure. Consequently, pavement performance models are not easily transferable from airport to airport. The selection of performance models depends on available data, agency requirements for estimating future pavement preservation needs, and on the APMS software used.

Typical methods used for pavement performance modeling include:

- Expert modeling. Expert modeling can be used when historical pavement performance data are not available. Performance models, such as a relationship between pavement condition and pavement age for different pavement types (e.g., AC or PCC) and airport pavement facilities (e.g., runways and taxiways) are based on the expert opinion of pavement professionals (Zimmerman 2000).
- Modeling using families of performance curves. The concept of "family" modeling is based on the expectation that similar airport pavements exposed to similar traffic will perform in a similar way. For example, all pavement sections on runways that have AC overlays are expected to have the same pattern of pavement deterioration. The deterioration pattern is established using a few sections with known performances and applied to all other sections. Family modeling is a default modeling approach in MicroPAVER (Shahin 2001).
- Extrapolation of existing trends. This approach is a variation on family modeling. If the condition of the pavement was evaluated on only one previous occasion, the family pattern is extrapolated taking into account the condition observed in the past. If the condition of the pavement was evaluated in the past on more than one occasion, the extrapolation using a family curve can take into account the past observation points using regression analysis.

  The extrapolation using one observation point is illustrated in Figure 10. The observed PCI value in year 10 is above the family prediction curve. Following the trend established by the family prediction curve it is expected that the section will reach the minimum recommended PCI level in year 20, compared with year 18 expected for the pavement family prediction.
- Markov probability models. Markov models have been used for pavement performance prediction of highway pavements. However, it appears that they have not been used for airfield pavements (Tighe and Covalt 2008).

Artificial neural networks. Artificial neural networks (ANN), or neural networks, are computing procedures or systems that can link a large set of data (e.g., a data set describing the pavement and its exposure to the traffic and environment) to an outcome (e.g., expected life span of the pavement) without using traditional statistical analysis. However, pavement performance models, whether they are developed using ANN or conventional modeling techniques, have to be calibrated to local conditions. Although the calibration process can be facilitated using ANN, the calibration of ANN requires specialized computational techniques that are still experimental. The applicable technology of ANN is reviewed in *Transportation Research Circular E-C012: Use of Artificial Neural Networks in Geomechanical and Pavement Systems* (1999).

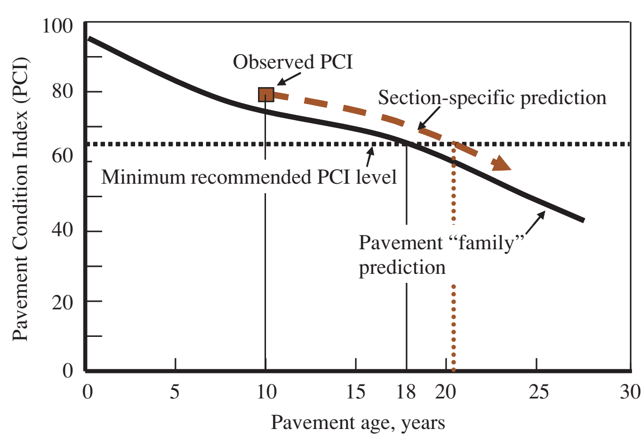

FIGURE 10 Pavement performance prediction using a pavement family prediction.

CHAPTER FOUR

TECHNOLOGY OF PAVEMENT PRESERVATION TREATMENTS

This chapter describes the technology of pavement M&R treatments for AC and PCC pavements. It also describes the survey results concerning the use and performance of M&R treatments reported by airport agencies.

SURVEY RESULTS

Survey results for AC and PCC pavements are summarized in Tables 3 and 4, respectively. The tables contain information on the usage and performance of common M&R treatments as reported by 50 representatives of airport agencies. There were 19 M&R treatments included in the survey for AC pavements (Table 3) and 19 M&R treatments for PCC pavements (Table 4). The treatments traditionally considered to be preventive maintenance treatments are shown in Tables 3 and 4 in italic font.

Data presented in Tables 3 and 4 are the percentages of usage or performance of M&R treatments reported by survey respondents. For example, referring to the first row of data in Table 3, 84% of airports that responded to the survey routinely use crack sealing with hot-poured sealant and 11% of airports have tried using this treatment. Consequently, 95% of the airports routinely use or have tried using this treatment and the remaining 5% have not. Continuing with the example data in the first row, 19% of the airports that routinely use or have tried using crack sealing with hot-poured sealant reported very good performance with this treatment, 71% of the airports reported good performance, and 10% of the airports reported poor performance. The number of reporting airports, corresponding to the percentages of airports given in Tables 3 and 4, are presented in Appendix A as part of the Survey Questionnaire.

Approximately 70% of the responding airports had both AC and PCC pavements on at least some airfield facilities, and about 30% of airports had both AC and PCC pavements on runways (Figure 11). Approximately 50% of airports had only AC pavements on runways and 20% of airports had only PCC pavements on runways. Considering the distribution of pavement types, a large segment of airports need to have staff familiar with the technology of both AC and PCC pavements.

Use of Maintenance and Rehabilitation Treatments

Information on the use of M&R treatments obtained from the survey provides a good indication of what types of such treatments are used across the country. For example, 84% of airports (that have AC pavements) reported that they routinely use crack sealing with hot-poured sealant (Table 3). Similarly, 61% of agencies (that have PCC pavements) reported that they are routinely using, or have tried using, joint sealing with silicone sealant (Table 4).

The use of some M&R treatments depends on the size and volume of traffic of the airport, such as the treatments aimed at increasing pavement friction. Consequently, although about 39% of the responding airports reported using diamond grinding (routinely or on a trial basis), the percentage for small airports would probably be considerably lower, and for large airports most likely considerably higher.

For AC pavements, the following six M&R treatments were used by less than 15% of agencies that had AC pavements on at least one facility: spray patching, texturization using fine milling, microsurfacing, hot and cold in-place recycling, and PCC overlay.

For PCC pavements, the following four M&R treatments were used by less than 15% of the agencies: load transfer restoration treatments using sub-sealing and slab stitching, full-depth repairs using precast panels, and microsurfacing.

Performance of Maintenance and Rehabilitation Treatments

Survey results concerning the performance of M&R treatments reported in Tables 3 and 4 are not reliable because of sample size limitations and the lack of objective guidelines for the evaluation of treatment performance. A very large sample size would be needed to obtain a statistically significant number of performance reports for the M&R treatments that are not frequently used, even if all survey responses were grouped in one sample. However, the treatment performance may depend on the environmental zone (e.g., wet-freeze, dry-freeze, dry-no freeze, and wet-no freeze) and on the airport facility (runway, taxiway, and apron) further increasing the sample size.

To obtain an objective rating of the treatment performance shown in Tables 3 and 4 would also require the development of performance evaluation guidelines for all M&R treatments and adherence to such guidelines by the respon-

TABLE 3
PAVEMENT PRESERVATION TREATMENTS FOR ASPHALT CONCRETE PAVEMENTS

Treatment Type		Survey Result, %					
		Usage			Performance		
		Routine	Have Tried	Total	Very Good	Good	Poor
Crack sealing with	hot-poured sealant	84	11	95	19	71	10
	cold-applied sealant	9	7	16	17	66	17
Small area (pothole) patching using	hot mix	52	16	68	42	58	0
	cold mix	43	18	61	13	50	37
	proprietary mix	9	11	20	25	50	25
Spray patching (includes manual chip seal)		5	7	11	0	100	0
Machine patching with AC		27	14	41	39	55	6
Milling and machine patching with AC		34	18	52	39	61	0
Texturization using	fine milling	7	5	11	20	80	0
	controlled shot blasting	0	16	16	0	71	29
Rejuvenators, fog seals, etc.		30	23	52	23	59	18
Surface treatment		15	18	43	6	81	13
Slurry seal		23	25	48	10	75	15
Microsurfacing		2	9	11	25	75	0
Hot-mix overlay		45	23	68	48	48	4
Milling and hot-mix overlay		45	18	64	58	42	0
Hot in-place recycling		5	2	7	N/A	N/A	N/A
Cold in-place recycling		2	0	2	N/A	N/A	N/A
Whitetopping (PCC overlay)		7	7	14	60	20	20

Notes: Treatments traditionally considered preventive maintenance treatments are in italics.
N/A: sample size is too small.

dents. For example, evaluation guidelines would need to be prepared to explain what conditions need be met to rank the performance of an overlay as very good. Several respondents did not provide performance ranking for treatments that they do not use routinely, and some respondents were reluctant to provide any ranking at all. Nevertheless, the performance information obtained from the survey provides information on overall trends.

Average performance data from the survey respondents for both AC and PCC pavements are presented in Table 5. There is only a very small, statistically insignificant difference between the average performance of M&R treatments for AC pavements and those for PCC pavements. For example, on the average, the performance of approximately 60% of M&R treatments for AC pavements was rated as good, whereas the corresponding number of M&R treatments for PCC pavements was about 58%. On average, only about 11% of M&R treatments for AC pavements received a poor performance, whereas the corresponding percentage for PCC pavements was 12.

For frequently used treatments, it is possible to identify some expected trends in the performance of M&R treatments. For example, approximately 50% of airport agencies routinely use or tried making shallow repairs of PCC slabs using PCC material or AC material. It is generally recommended that PCC material be used to repair PCC slabs. This recommendation is supported by the performance data given in Figure 12. As expected, the survey data show somewhat better performance of PCC material.

Innovative and Additional Treatments

In addition to the common M&R treatments listed in Tables 3 and 4, airport agencies reported the use, and in some cases commented on the performance, of the following innovative M&R treatments:

- Stress-relieving membranes to retard reflective cracking in AC overlays.
- Proprietary materials for AC overlays.
- Portland cement with high proportions of fly ash and blast furnace slag.
- Rejuvenators (asphalt emulsions) to stabilize granular shoulders.
- Over-band method of sealing cracks in AC pavements with sealing material containing fibers.
- Slurry seals containing thermoplastic coal-tar (fuel-resistant) emulsion.

TABLE 4
PAVEMENT PRESERVATION TREATMENTS FOR PORTLAND CEMENT CONCRETE PAVEMENTS

Treatment Type		Survey Result, %					
		Usage			Performance		
		Routine	Have Tried	Total	Very Good	Good	Poor
Joint/crack sealing with	bituminous sealant	29	15	44	13	80	7
	silicone sealant	39	22	61	29	71	0
	neoprene seal	7	22	29	36	36	27
Load transfer restoration	sub-sealing and slab jacking	2	5	7	N/A	N/A	N/A
	slab stitching	2	5	7	N/A	N/A	N/A
	dowel retrofit	12	5	17	60	40	0
Shallow patch repair using	PCC	34	15	49	28	67	6
	AC	29	20	49	18	65	18
	proprietary mix	17	17	34	42	42	17
Full and partial depth repairs or slab replacement using	PCC	46	15	61	47	47	6
	AC	20	39	59	31	54	15
	proprietary mix	7	17	24	30	50	20
	precast panels	2	2	5	N/A	N/A	N/A
Machine patching with AC		5	12	17	33	50	17
Diamond grinding		5	34	39	21	79	0
Controlled shot blasting		0	15	15	0	80	20
Microsurfacing		0	5	5	N/A	N/A	N/A
AC overlay		10	27	37	36	64	0
Bonded PCC overlay (whitetopping)		7	7	15	40	40	20

Notes: Treatments traditionally considered preventive maintenance treatments are in italics.
N/A: sample size is too small.

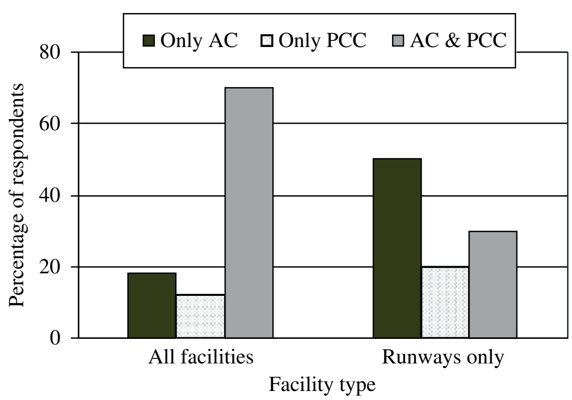

FIGURE 11 Distribution of pavement types.

- Fuel-resistant AC containing resin-modified asphalt cement.
- Warm-mix AC (rather than the traditional hot mix).
- Transverse grooving of AC pavement surfaces to improve pavement friction.
- Specific repairs of wide or deteriorated pavement cracks in AC pavements.
- Various types of fog seals.
- Crack filling AC mixes (mastic) for repairs of large cracks in AC pavements.
- Proprietary AC and PCC mixes for patching repairs.

All of these M&R treatments and materials require continuing evaluation to document cost-effectiveness.

TABLE 5
AVERAGE PERFORMANCE OF M&R TREATMENTS FOR DIFFERENT PAVEMENT TYPES

Pavement Type	No. of Airports	No. of Treatments	Average Performance for all Treatments and Airports (%)		
			Very Good	Good	Poor
AC Pavements	44	19	30.2	59.1	10.7
PCC Pavements	41	19	29.6	58.1	12.3

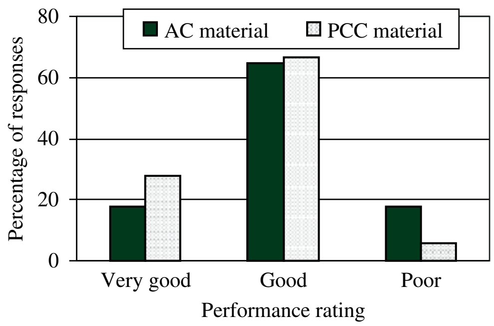

FIGURE 12 Performance of materials used for shallow patch repairs of PCC slabs.

CATALOG OF AIRPORT PAVEMENT PRESERVATION TREATMENTS

There is a large amount of information available concerning the technology of pavement preservation treatments. For example, there are literally dozens and in some cases even hundreds of reports on each of the 38 M&R treatments listed in Tables 3 and 4. To present information in a concise and systematic way, each of the 38 M&R treatments was described using the same structure in less than three pages. The result is a *Catalog of Airport Pavement Preservation Treatments* provided in Appendix B.

Some of the treatments listed in Tables 3 and 4 can be applied, with only very small modifications, to both AC and PCC pavements; for example, microsurfacing, and controlled shot blasting. Other treatments listed in the tables are just a variation of the same treatment using different materials. An example for AC pavements would be the crack sealing of such pavements with hot-poured sealant versus cold-applied sealant. An example for PCC pavements would be the shallow patch repair using PCC material versus using AC material or proprietary material.

For survey purposes, treatments common to both pavement types, as well as treatments that differ only by the material used, were considered separately because the usage and performance of these treatments may differ. For the description in the *Catalog* the treatments used in the survey were combined into generic categories based primarily on the construction technology of the treatments. As a result, the 38 treatments listed in Tables 3 and 4 were combined into the 24 treatments listed in Table 6 and are described in the *Catalog of Airport Pavement Preservation Treatments* (Appendix B).

TABLE 6
AIRPORT PAVEMENT PRESERVATION TREATMENTS INCLUDED IN THE CATALOG

Both Pavement Types	Asphalt Concrete	Portland Cement Concrete
• Texturization using controlled shot blasting • Diamond grinding • Microsurfacing	• Sealing and filling of cracks (with hot- or cold-applied sealants) • Small area patching (using hot mix, cold mix, or proprietary material) • Spray patching (manual chip seal or mechanized spray patching) • Machine patching with AC material • Rejuvenators and seals • Texturization using fine milling • Surface treatment (chip seal, chip seal coat) • Slurry seal • Hot-mix overlay (includes milling of AC pavements) • Hot in-place recycling • Cold in-place recycling • Ultra-thin whitetopping	• Joint and crack sealing (with bituminous, silicone, or compression sealants) • Partial-depth repairs (using AC, PCC, or proprietary materials) • Full-depth repairs (using AC, PCC, or proprietary materials) • Machine patching using hot mix • Slab stabilization and slab-jacking • Load transfer • Crack and joint stitching • Hot-mix overlays • Bonded PCC overlay
3 treatments	12 treatments	9 treatments

CHAPTER FIVE

IDENTIFICATION OF NEEDS

The identification of pavement preservation needs described in this chapter is based on the results of pavement condition surveys, the prediction of pavement deterioration, and the desirable level of service for airfield pavements (*Unified Facilities Criteria on Pavement Maintenance Management* 2004). The concept is simple: pavement preservation needs arise when the predicted pavement condition is lower than the recommended or mandated level-of-service criteria. The key for the successful operation of this model is the objective assessment of pavement condition and the establishment of the levels of service that are accepted or mandated by decision makers.

LEVELS OF SERVICE AND TRIGGER LEVELS

Pavement preservation needs depend on the level of service the airport pavements are expected to provide. A higher level of service, for the same pavement structure, results in higher M&R needs and thus in higher agency costs. Levels of service for airport pavements are typically expressed in terms of PCI values. They are seldom expressed in terms of pavement roughness because of the unavailability of recognized roughness criteria for in-service airport pavements (Larkin and Hayhoe 2009). However, the FAA is developing new guidelines on roughness of in-service airport pavements as discussed in chapter three.

Level of Service

There are several types of level of service that may be used to establish the amount of maintenance and rehabilitation airport pavements may require.

Target Level of Service

The target or the desirable level of service can be expressed only as an average condition of all pavement sections for a given airport facility. The target level of service is specified for different facility types because all facilities do not require the same target level of service. An example is provided in Table 7. For comparison purposes, this table also includes the minimum acceptable level of service, which is discussed subsequently. If the target level of service is approved and mandated by the airport management it can be used to determine the pavement preservation strategy to provide the mandated level of service. In other words, the pavement preservation needs become justified and mandated on the basis of approved criteria.

The levels of service given in Table 7 are *example* levels and are included herein for a medium-sized general aviation airport for illustrative purposes only. It is noted that levels of service in terms of PCI depend on several factors:

- Airport type and size—General aviation airports may have lower target levels of service than carrier airports, particularly large carrier airports.
- Facility type—Higher target levels of service are typically required for runway pavements than for pavements on taxiways or aprons. Also, some airports may use higher target levels of service for primary facilities (e.g., primary runways) than for secondary or tertiary facilities.
- Number of aircraft operations and aircraft size—Higher target levels of service are typically required for facilities serving a larger number of aircraft operations or larger and heavier aircraft.
- Pavement type—Some agencies use different levels of service for different pavement types (*Utah Continuous Airport System Plan* 2007).

Minimum Acceptable Level of Service

The minimum acceptable level of service can be expressed as the average condition for all sections for a given facility type or as the minimum acceptable level of service for individual pavement sections (see Table 7). The sections at or below this minimum acceptable level of service are slated for M&R at the first opportunity. The establishment of the minimum acceptable levels of service also provides rational justification for pavement maintenance and rehabilitation needs. The minimum acceptable levels of service are also called critical levels or critical PCI values.

Safety-related Level of Service

The safety-related level of service is typically defined in terms of minimum recommended friction levels for runway pavement surfaces given in *FAA Advisory Circular on Measurement, Construction, and Maintenance of Skid-resistant Airport Pavement Surfaces* (2004). The safety-related level

TABLE 7
EXAMPLE LEVELS OF SERVICE FOR A MEDIUM-SIZE GENERAL AVIATION AIRPORT WITH AC PAVEMENTS

Facility Type	Level of Service Average PCI for all Sections: Target or desirable	Level of Service Average PCI for all Sections: Minimum acceptable	Minimum Acceptable Level of Service PCI for Individual Sections
Runway	80	65	55
Taxiway	70	60	45
Apron	70	60	40

of service can also be defined in terms of other pavement surface defects such as rutting depth.

Trigger Levels

In addition to using levels of service to estimate the need for pavement M&R, trigger levels provide timing guidance for pavement M&R treatments. An example of levels of service and trigger values is provided in Figure 13. Trigger values may be general or treatment specific.

General Trigger Levels General trigger levels provide guidance on what types of M&R treatments are considered for a given pavement condition. For example, MicroPAVER enables the user to specify the PCI levels that trigger a rehabilitation treatment.

Treatment-Specific Trigger Levels These trigger levels are related to the need to apply a preservation treatment at the right time to be effective, before the pavement reaches a condition where a different, more expensive treatment would be needed. For example, sealing of cracks in AC pavements is most effective when the pavement is still in very good condition. An example of a trigger level for crack sealing and for an overlay is shown in Figure 13.

Closely related to the concept of trigger levels is the linkage between specific pavement surface distresses and the recommended pavement M&R treatments. An example of the linkage between pavement cracking and recommended pavement M&R treatments is shown in Table 8. The relationship shown in this table, developed for all key pavement distresses, is called a maintenance policy in MicroPAVER.

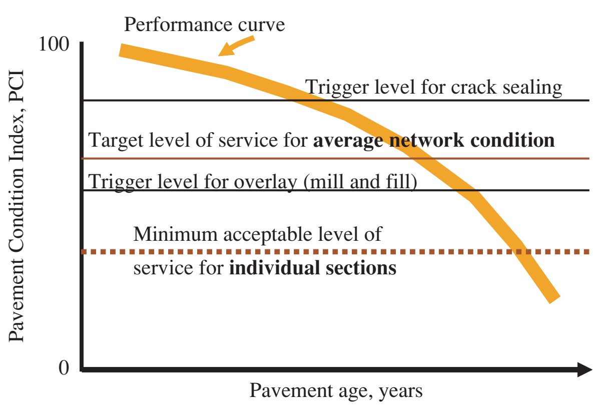

FIGURE 13 Example of levels of service and trigger levels.

IDENTIFICATION OF NEEDS

Identification of needs on the network level consists of the following four steps:

1. Identification of pavement sections that require M&R treatments because of the level-of-service requirements or because of trigger levels.
2. Selection of M&R treatments for the sections identified in step 1.
3. Estimation of the costs for the implementation of M&R treatments selected in step 2.
4. Prioritization of projects if the cost of the treatments, estimated in step 3, exceeds the available budget. The selection and prioritization of projects is done systematically and objectively using the procedures described in the next chapter.

Identification of needs is discussed separately for two time horizons:

- Short-term planning for time horizons of about 5 years or less. For simplicity, it is also assumed that the analytical procedures used for short-term planning do not include the generation and evaluation of alternative treatments in future years.
- Long-term planning for time horizons of more than 5 years. In this case, analytical procedures can include the generation and evaluation of alternative treatments in future years.

Short-Term Planning

Many airports use short-term planning to identify and prioritize pavement M&R needs. The typical procedure consists of the following steps:

a) Updating Pavement Inventory—Pavement inventory, including pavement condition, is updated. The update includes results of all recent pavement-related projects and other changes to the pavement infrastructure.

TABLE 8
EXAMPLE OF MAINTENANCE POLICY FOR CRACKING

Severity of Pavement Cracking	Recommended Maintenance Treatment	
	AC pavements	PCC pavements
Low	None—continue to monitor	None—continue to monitor
Medium	Crack routing and sealing	Crack sealing
High	Crack repairs	Full-depth repairs

b) Defining Scope of Work—Pavement preservation treatments that can be planned at least a year in advance are included, whether corrective maintenance, preventive maintenance, or rehabilitation treatments. The treatments may include, for example, sealing of cracks and joints, AC overlays, full-depth repairs of PCC pavements, and installation of subdrains.

c) Reviewing Pavement Preservation Needs for Each Airport Pavement Section—One of the reasons for dividing a pavement network into sections is to create future pavement repair units. Each section is considered in turn to decide if the section is expected to require any M&R work during the next 5 years, or during the given planning horizon. Many sections may not require any treatment during the planning horizon, whereas other sections may require preventive maintenance or other types of treatments. The decisions are based on the mandated levels of service (Table 7) and trigger values such as those shown in Figure 13. The needs take into account expected pavement deterioration during the planning period. The identification of needs is documentation of the needs that are necessary on the basis of the levels of service.

   An example of pavement preservation needs for a small airport (shown in Figure 7) is given in Table 9. Table 9 was generated by MicroPAVER. In this example, the costs of the major M&R treatments depend on the PCI levels. The actual type of M&R treatments is not defined.

d) Selecting Treatment Types—To refine the cost estimates, airport pavement maintenance managers select the M&R treatment. Figure 14 provides a summary of survey responses regarding the methods used for the selection of M&R treatments. For example, about 85% of respondents use engineering judgment and 30% of the respondents use computer-based tools. Decision trees were used by about 6% of the respondents. However, engineering judgment often includes reasoning that has the structure of decision trees.

The need for maintenance treatments, particularly preventive maintenance treatments, is determined using trigger values for individual pavement surface distresses. For example, using the PCI pavement distress evaluation terminology, the occurrence of joint seal damage at the medium or high severity triggers the need for joint sealing, and the occurrence of corner break at the medium or high severity levels triggers the need for full-depth patching with PCC. An example of the network-level maintenance plan generated by MicroPAVER for the small airport shown in Figure 7 is shown in Table 10. The exact extent of maintenance work is determined on the project level. For example, the existence of the 11 corner breaks was estimated by sampling (and not by an actual field count) and verified by a detailed survey on the project level. Similarly, the size of the full-depth patches to repair the cracks needs to be determined individually for each crack repair.

For localized M&R treatments, MicroPAVER uses maintenance polices that match the distresses with M&R treatments (Table 8). Major M&R treatments are identified as a function of the PCI level in terms of costs only (Table 9). Other software packages identify generic

TABLE 9
EXAMPLE OF 2009 5-YEAR MAJOR M&R PLAN FOR UNLIMITED BUDGET

Plan Year	Branch Name	Section Number	Section Area, ft^2	Maintenance, $	Major M&R, $	Cost, $
2009	A01	10	48,000	0	238,000	238,000
		20	46,000	49,400	0	49,400
	THEAST	10	17,800	0	97,100	97,000
	RW1533	10	205,600	0	945,900	945,900
2010	No work identified					
2010	No work identified					
	etc.					
5-year plan total				49,400	1,794,700	1,844,100

Source: Michigan Airports Division (2007).

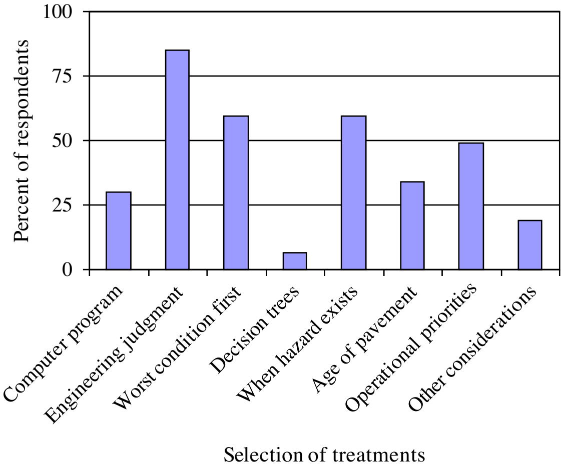

FIGURE 14 Methods used to select M&R treatments on the network level.

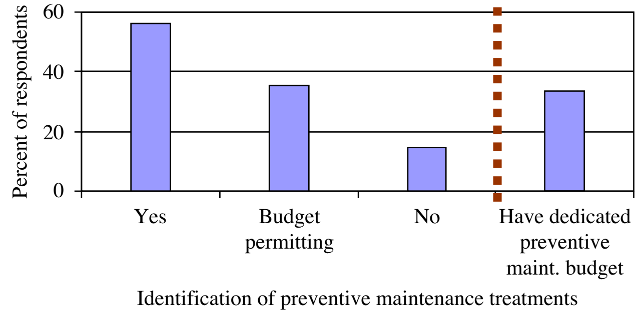

FIGURE 15 Systematic identification of preventive maintenance needs.

treatment types; for example, an AC overlay, and the corresponding cost of the generic treatment types. The actual treatment design, including the design of pre-overlay improvements, overlay thickness, and material properties, is done on the project level.

e) Selection of Preventive Maintenance Treatments—About 56% of airports systematically identify pavements that would benefit from preventive maintenance and 35% of airports do so when budget permits (Figure 14). For comparison purposes, Figure 15 also shows that 33% of airports have dedicated budgets for preventive maintenance. The existence of a dedicated budget for preventive maintenance is considered to be one of the prerequisites for timely, successful, and sustainable operation of preventive pavement maintenance programs.

Long-Term Planning

Long-term planning for airport pavement maintenance needs can improve engineering and economic decision making by helping answer the following example questions:

- What will be the condition of the pavement network 10 years from now given the existing budget?
- What is the future funding to achieve a specified level of service?
- How much additional funding will be needed in the future to compensate for reduced funding now?
- What would be the impact on the network condition of diverting funds to preventive maintenance or lower-cost treatments?
- What would be the impact of constructing new runways or taxiways on the pavement preservation budget?

The accuracy of future funding requirements for airport pavement maintenance depends on the reliability of long-term prediction of pavement performance and the generation of feasible alternatives. Long-term planning and prioritization can consider, for each section, several treatment options in each analysis year. This results in a large number of possible combinations of program years and treatments for one section alone.

The concept of generating alternative M&R treatments for different years is illustrated for one pavement section in Figure 16. For clarity, only two treatments (microsurfacing and overlay) and two analysis years (now-plus-3 years and now-plus-9 years) are considered. Alternative 1 is microsur-

TABLE 10
EXAMPLE MAINTENANCE PLAN

Branch Name	Section No.	Pavement Surface Distress: Type	Severity	Quantity	Unit	Maintenance Treatment	Cost
A01	20	Corner break	High	11	Slab	Full-depth patching with PCC	$9,500
		Linear cracking	Medium	150	Feet	Crack sealing	$400
		Joint seal damage	High	460	Slab	Joint sealing	$34,000
		Shattered slab	High	4	Slab	Full-depth patching with PCC	$4,700
		Corner spalling	High	12	Slab	Partial-depth patching with PCC	$800
Total							$49,400

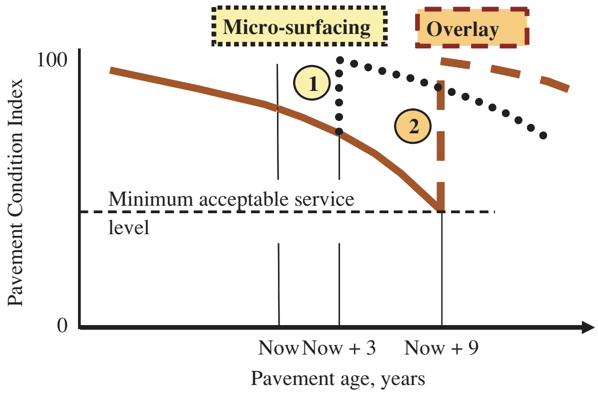

FIGURE 16 Pavement performance prediction for multi-year identification of needs.

facing to be constructed 3 years from now. Alternative 2 is an overlay to be constructed in year now plus 9 years, when the existing pavement will reach the minimum acceptable level of service.

Sophisticated software generates and evaluates multiple treatment options. For the example shown in Figure 16 it means generating the two alternative treatments (microsurfacing and overlay) at two different years, and estimating their life spans. The life spans of the alternatives and their costs are used subsequently to select the most cost-effective alternative. This type of analysis has been carried out by many highway agencies, but is not routinely done by airport agencies.

CHAPTER SIX

PRIORITIZATION, PLANNING, AND BUDGETING

This section outlines how M&R needs are prioritized, scheduled for implementation through programming, and then molded into a budget for a CIP (Wade et al. 2007b). Also described is the computer software that facilitates the identification of M&R needs and prioritization.

The listing of all M&R needs, such as those shown in Tables 9 and 10 in chapter five, represent an unlimited budget. The unlimited budget will change for the following reasons:

- Economic considerations. Not all M&R treatments can be carried out to the extent and at the time recommended by the unlimited budget because of financial constraints.
- Operational considerations. Scheduling of the projects avoids interfering with airport operation. It is particularly important for scheduling work on runways and taxiways that provide service that cannot be picked up by alternative facilities. Other operational concerns include safety issues, airlines' operations, and allowable closures.
- Other construction work. Pavement preservation work is typically coordinated with other airfield maintenance and construction activities. For example, during the replacement of an in-pavement lighting system on a runway, pavement preservation work can be carried out on a parallel taxiway.
- Construction capacity. The schedule may need to take into account capabilities of the local construction industry and the capability of the airport agency to manage construction work.

PRIORITIZATION

The prioritization of needs is described for the same two scenarios used for the identification of needs—short-term planning and long-term planning.

Prioritization for Short-Term Planning

Short-term planning supports only limited prediction of future network conditions without considering alternative future pavement conditions resulting from M&R treatments. The historical and predicted condition of the pavement network can be used to evaluate the adequacy of different pavement preservation budgets. It is also possible to use the backlog of projects as an indication of desirable funding levels.

The first step in the prioritization is the assignment of a priority level to each M&R treatment on the list of treatments representing the unlimited budget. The priority level reflects the main reason why the treatment is recommended for implementation. The priority levels are related to the levels of service used to identify M&R needs and include safety, critical, cost-effectiveness, and target-priority levels.

a) Safety Level Prioritization—The safety priority level is the highest priority for airport pavement maintenance and includes M&R treatments that are needed to maintain safe operation of aircraft. In general, this level includes projects to meet safety and regulatory requirements mandated by the FAA and environmental agencies. In the pavement area, the safety priority level may include, for example, M&R treatments for an AC section with raveling surface resulting in FOD or a runway with inadequate pavement friction. Because treatments in this category are obligatory, it can also include carryover projects (already approved projects and projects that are in progress and need additional funding).
b) Critical Level Prioritization—The critical priority level includes M&R treatments that are necessary to provide or maintain a minimum acceptable level of service.
c) Cost-effectiveness Level Prioritization—This level includes projects where implementation timing is important to achieve cost-effectiveness. Typically, this level includes preventive maintenance projects, such as joint resealing, carried out before more significant damage occurs. Approximately 29% of the responding airports indicated that they implement preventive maintenance treatments at the right time, and about 57% of airports noted that they sometimes implement preventive maintenance treatments at the right time (Figure 17).
d) Target Level Prioritization—Target level includes projects to maintain or achieve the target level of service.

Projects that belong to the critical level and apply to runways would have higher priority than projects that belong to the cost-effectiveness level and apply to taxiways.

It is easier and preferable to prioritize projects that belong to the same priority level and functional class than to prioritize projects across priority levels and functional classes. Prioritization across functional classes, for the same priority

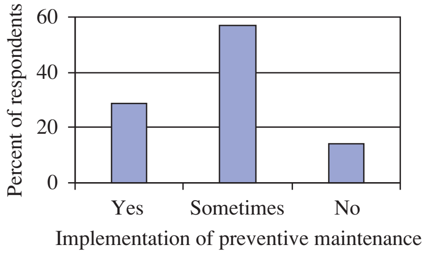

FIGURE 17 Implementation of preventive maintenance treatments at the right time.

level, can be facilitated by developing priority rankings of the type shown in Table 11. The highest ranking, in this simplified example, is assigned to runways serving a high number of aircraft operations.

Prioritization can be based on a single characteristic such as PCI or on a composite indicator that combines the influence of several characteristics.

An example of prioritization of M&R treatments for 271 pavement sections using a composite priority indicator was provided by Tighe et al. (2004). The composite priority indicator combines the influence of four factors:

1. PCI of the section. This factor represents pavement characteristics and was assigned the highest weighting. In general, other pavement characteristics that can be used include a friction index and FOD potential.
2. Number of annual aircraft departures taking off from the section. This factor represents volume of aircraft movements and can be alternatively represented by, for example, the total number of aircraft operations.
3. Functional class of the section (runway, taxiway, apron).
4. Operational importance of the section (primary, secondary, or tertiary). For example, a runway may be primary or secondary; an apron may be primary, secondary, or tertiary.

Another factor that can be incorporated into a composite priority indicator is cost-effectiveness—the ratio of effectiveness and the net present value—defined in the section on *Prioritization for Long-Term Planning.*

Inclusion of Preventive Maintenance

Preventive maintenance reinforces the concept of the right treatment on the right pavement at the right time. According to the survey, about 29% of agencies reported that they implement preventive maintenance treatments at the right time (see Figure 17). For comparison, a 1999 survey of state transportation agencies, carried out by the AASHTO Pavement Preservation Lead State Team (2000), reported that 85% of the 41 agencies that responded to the survey have established a preventive pavement maintenance program. Systematic implementation of preventive maintenance treatments may represent a shift in the way the pavement preservation is done. The selection of sections for M&R is not done using a worst-condition-first approach, but by selecting sections where an M&R treatment would be most cost-effective. Often, the most cost-effective treatment is a preventive maintenance treatment. At the same time, agencies still have to maintain pavements to provide safe operation of the aircraft and provide a minimum level of service.

A systematic application of a preventive maintenance program for airport pavements has not been well-documented. Most of the experience has been reported by state highway agencies as it applies to highway pavements (Geoffroy 1996; Zimmerman and Wolters 2003). The Foundation for Pavement Preservation (2001) developed useful guidelines for launching a preventive maintenance program and outlined the need to establish the overall strategies and goals of the program.

Prioritization for Long-Term Planning

Multi-year prioritization of alternative treatments is typically based on cost-effectiveness. Cost-effectiveness is the ratio of the effectiveness (benefits) and costs for individual M&R treatments. The cost of the treatment is based on life-cycle costs as much as possible (Zimmerman et al. 2000). The effectiveness for an airport pavement section can be calculated by multiplying (1) the area under the pavement performance curve, (2) the number of aircraft departures, and (3) the area of the pavement section (Tighe et al. 2004).

TABLE 11
PRIORITY RANKING BY FUNCTIONAL CLASS AND TRAFFIC

	Aircraft Operations or Usage Priority Rank		
Functional Class	High	Medium	Low
Runways	1	2	4
Taxiways	3	5	7
Aprons	6	8	9

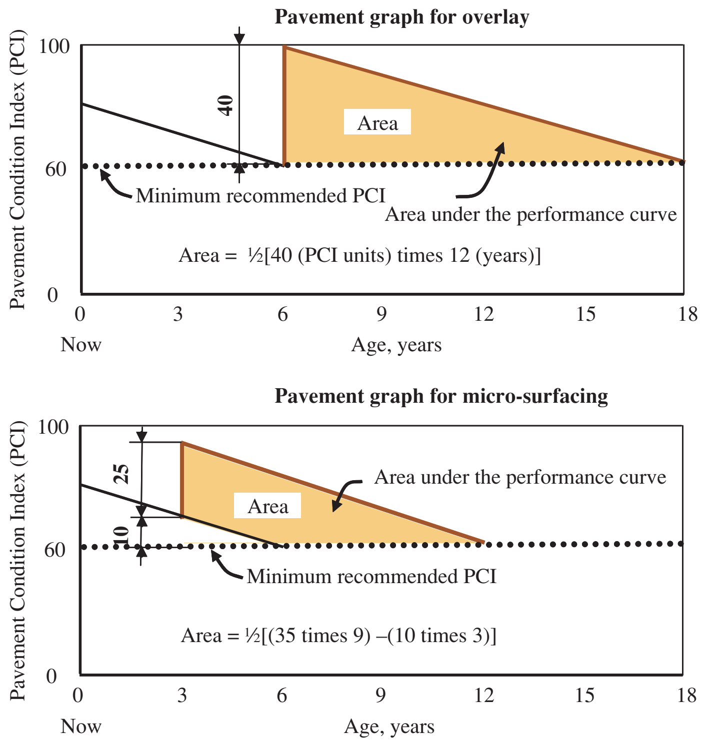

FIGURE 18 Example calculation of treatment effectiveness.

The area under the pavement performance curve represents the beneficial effect of the pavement condition that is above the minimum recommended pavement condition as shown in Figure 18. Figure 18 illustrates the difference in the area under the performance curve for two alternatives: an overlay and microsurfacing. For simplicity, it is assumed that the change of PCI with pavement age is linear.

The number of aircraft departures is used as the measure of aircraft operations that benefit from the improved pavement condition. The use of aircraft departures instead of the total number of aircraft operations accounts for higher pavement loads during departures.

The area of the pavement section is used to account for the differences in the length and width of airport pavement sections. The dimensions of the pavement section are thus included in the calculation of both the cost and the effectiveness.

Multi-year prioritization analysis need not include projects addressing the safety and critical priority levels, because these projects are obligatory. Projects addressing the cost-effectiveness priority level and the target priority level are analyzed simultaneously because both are prioritized on the cost-effectiveness basis. The analysis has the potential to yield the most cost-effective combination of preventive maintenance projects and other pavement preservation projects.

Projects are selected for implementation using incremental cost-effectiveness analysis. This facilitates a multi-year projection of impacts of the selected M&R treatment on the health of the pavement network. The result of multi-year prioritization analysis is a prioritized list of pavement preservation projects for different years that meet specific budget requirements.

Long-term planning and prioritization of needs, incorporating incremental cost-effectiveness analysis, has been successfully implemented by many transportation agencies on large highway networks (Federal Highway Administration 1996). The implementation for airport networks is still in initial phases. A clear example of prioritization using cost-effectiveness analysis for an airport pavement network is provided by Tighe et al. (2004). The reasons for slower implementation include smaller airport pavement networks, greater importance of operational constraints, and the limitations of existing software.

PROGRAMMING AND BUDGETING

Programming activities move projects from the initiation, prioritization, and budget stages to the design stage and to implementation. Budgeting builds on the results of planning and programming activities and produces a budget—a financial document that specifies how the money will be invested in airport infrastructure.

The type of projects included in the airport capital budget depend on local circumstances. Whereas large airports may have a budget dedicated solely to pavement preservation, capital budgets for smaller airports combine all projects concerning airfield infrastructure, and not just pavement preservation projects, to establish CIP. For example, the budget may also include projects related to the expansion of the airfield pavements, operational improvements, and M&R of other airfield infrastructure, such as buildings and guidance systems. Some authorities prepare a combined budget for a group of airports they manage. The budgeting process is part of asset management, the process that strives to manage all airport infrastructure assets together to achieve the efficient allocation of resources.

Funding Sources

According to the survey results, the majority of airport agencies establish a pavement preservation budget by considering pavement preservation needs and PCI (Figure 19). The main source of funding for pavement preservation, as reported by airport operators, was the FAA (Figure 20). Funding can also come from state aviation offices and other sources.

The main source of federal funding for airport pavement preservation is the Airport Improvement Program (AIP) administered by the FAA. The AIP provides grants for the planning and development of public-use airports that are included in the National Plan for Integrated Airport Systems. For large and medium primary hub airports, the grant covers 75% of eligible costs. For small primary, reliever, and general aviation airports, the grant covers 95% of eligible costs. Eligible costs include costs of runway, taxiway, and apron construction and rehabilitation, and costs associated with airfield drainage improvements. The projects must involve more than $25,000 in AIP funds.

In accordance with Public Law 103-305, section 107, amended Title 49, section 47105, of the United States Code, the FAA requires that airport owners receiving any grants for pavement construction or rehabilitation provide assurances that the airport has implemented an effective Airport Pavement Maintenance Management Program (APMMP). The features of an effective APMMP are described in FAA Engineering Policy 99-01. This policy, as well as other documents associated with AIP, is available on the FAA website (www.faa.gov/airports/aip).

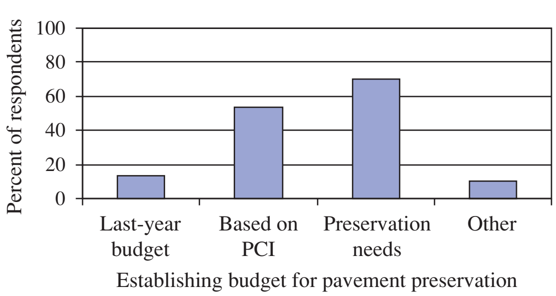

FIGURE 19 Methods used to establish pavement preservation budgets.

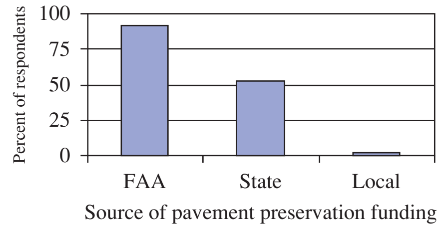

FIGURE 20 Sources of pavement preservation funding.

There is a variety of state funding programs that support airport pavement preservation. In addition, several states, under the FAA State Block Grant Program, assume the responsibility of administering AIP grants at smaller airports.

Budget Development

Budgeting takes in account engineering and financial concerns, mandatory safety and regulatory requirements, and airport operational concerns. The process of establishing a budget is schematically illustrated in Figure 21. As shown in this figure, budget development takes into account a number of needs and considerations, including the following:

- Pavement preservation needs such as mandatory projects based on the safety priority level and prioritized M&R treatments established through APMS.
- Other airfield needs affecting airport pavements such as the expansion of the airfield pavement network, safety and functional improvements, in-pavement lighting, drainage improvements, and projects involving underground utilities.

Budgetary considerations include the following:

- Financial considerations such as budget constraints in terms of available funding and the time frame when the funding is available. Financial considerations may also dictate staging the project to meet specific completion dates. It is often advantageous to combine construction projects to achieve economies of scale. According to Stroup-Gardiner and Shatnawi (2008), significant cost savings can be achieved by organizing pavement preservation work into larger contracts. This activity can be feasible for large airports or for airport agencies that manage several airports in one geographical area.
- Operational considerations include the impact on airport operations experienced by carriers and other airport users, safety concerns during construction, and the importance of the facility to overall operations (Wade et al. 2007b).

Budget Evaluation

Budget evaluation, within the framework of pavement preservation, examines the relationship between the investment in

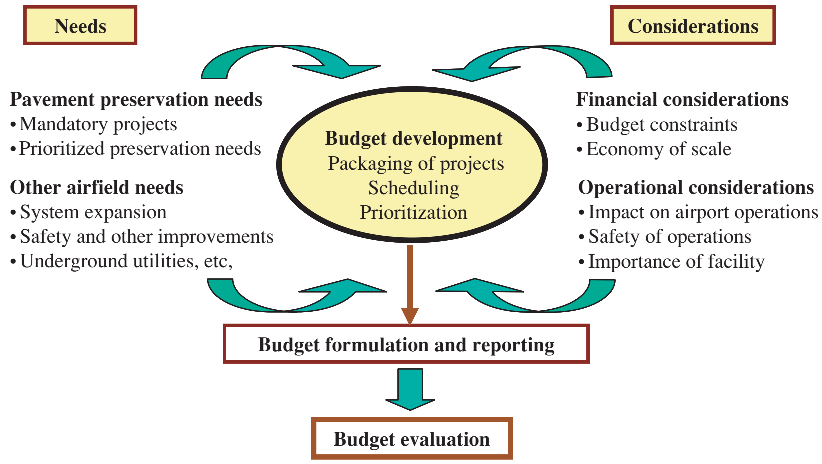

FIGURE 21 Programming and budgeting activities.

pavement preservation and the resulting condition of the pavement network. It also attempts to quantify the adequacy of the budget in meeting pavement preservation needs. Budget evaluation tools include the following:

- Monitoring pavement performance trends. An example of monitoring pavement condition in terms of PCI is shown in Figure 8 in chapter three.
- Monitoring of expenditures. For example, some road agencies monitor yearly expenditures on pavement preservation in terms of dollars per square yard of pavement.
- Tracking the dollar value of unfunded pavement preservation needs, if any, and yearly changes in unfunded needs.
- Evaluation of the consequences of different budget levels on the future condition of the pavement network. The future pavement condition is typically measured in terms of PCI.

COMPUTATIONAL SUPPORT

Software

Management of the pavement database and the identification and prioritization of M&R projects requires extensive data processing using specialized computer software. Many practitioners view APMS as computer-based decision support systems. There are several pavement management software products that can be purchased and customized by airport agencies.

According to the survey, all airport agencies that have an operational APMS use a software application. About 53% of airports reported using MicroPAVER, whereas 13% of airports used other commercial software (Figure 22). MicroPAVER is a public use PMS application.

Pavement administrators and engineers select the APMS software based on individual needs, as each PMS package has different strengths and weaknesses. Because MicroPAVER was publicly developed and is publicly supported, the following list of advantages and disadvantages of MicroPAVER is provided only as an example and guidance to the characteristics that can be used to evaluate and select APMS software. Advantages of MicroPAVER include:

- Long-term support by the FAA and other agencies, and ongoing enhancements.
- Relatively inexpensive.
- Incorporates ASTM PCI evaluation methodology.
- Highly scalable; used by small and large airports.
- Integrated with GIS platform; for example, enables graphical representation of pavement condition.
- Dependable pavement performance prediction based on "family" curves.
- Enables generation of customized reports and exporting data to other software applications.
- Customized maintenance policy (for stop-gap, preventive, and global).
- Estimates pavement life extension resulting from maintenance treatments.
- Evaluation of different budget alternatives (unlimited budget, maintain current condition, constrained annual budget, eliminate backlog).

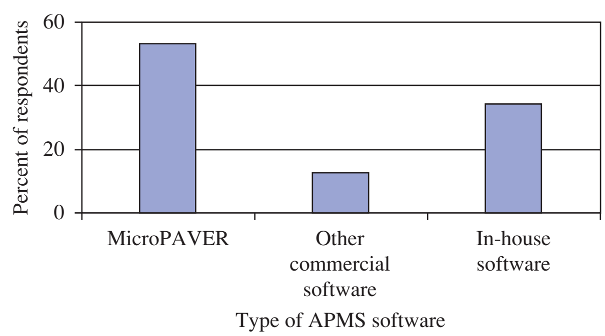

FIGURE 22 Use of APMS software.

Disadvantages of MicroPAVER include:

- Cost of M&R treatments on the network level is based on PCI range and not on specific M&R treatments that address root causes of pavement distress.
- Limited optimization features on network level; optimization is based on PCI value and facility types without considering costs and benefits of the individual M&R treatments.
- Lack of user customization may require longer implementation.

Based on the survey, 47% of APMS software was operated by in-house staff with outside support (Figure 23). Thirty-three percent of APMS software was operated by in-house staff, and 20% of agencies use outside consultants to operate their APMS.

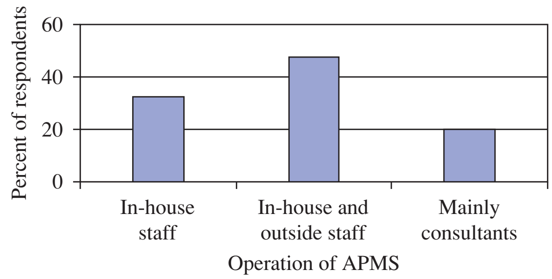

FIGURE 23 Operation of APMS.

New FAA Software

The FAA is developing airport pavement management software called PAVEAIR to be distributed to airports and airport engineers for implementation on commercial and general aviation airports. PAVEAIR will be a web-based application for easy dissemination of information and will allow data for multiple airports to be made available on a single server connected to the web. The FAA server installed at the FAA William J. Hughes Technical Center is intended to be a repository for PMS data from PAVEAIR on airport projects funded under AIP; this will allow the FAA to monitor the performance of AIP projects and gain needed information on variables and materials that impact pavement performance.

PAVEAIR software will be available to users as a free download and the software will initially be similar to MicroPAVER in application and operational features. Existing MicroPAVER databases (Micro Paver e60 files and Micro Paver MDB files) can be imported into PAVEAIR so that current MicroPAVER users will not lose any existing data. The first release of PAVEAIR will have the functionality of MicroPAVER Version 5.3. The release of PAVEAIR is planned for late 2010.

CHAPTER SEVEN

PROJECT DESIGN AND IMPLEMENTATION

The final treatment type and associated technical details and costs are determined at the project level. The project-level activities discussed in this chapter include project design, project implementation, and the monitoring of completed projects. The project design and implementation is an integral part of the airport pavement management process (Haas et al. 1994).

PROJECT DESIGN

Project design determines the specific treatment type and design details for the construction of the project, such as layer types, material properties, and construction details. The selected M&R treatments address the primary cause of pavement deterioration and not just the distresses seen on the pavement surface during a PCI survey. Compared with the network-level identification of needs and prioritization, the project-level design requires additional data and data with greater detail. For large or complicated projects, the design process consists of a preliminary design stage and the final design stage. The preliminary design stage includes: (1) identification of alternatives, (2) design of alternatives, and (3) selection of a recommended alternative. The final design stage includes detailed design of the selected alternative.

Identification of Alternative Maintenance and Rehabilitation Treatments

Common M&R treatments for airfield pavements are listed in Tables 3 and 4 in chapter four, and are described in the *Catalog of Airport Pavement Preservation Treatments.* Treatments can be used alone or in combination. For example, sealing of longitudinal and transverse cracks in AC pavements and machine patching with hot mix can be carried out together with a microsurfacing treatment or an AC overlay. The objective of the identification of alternatives is to ensure that no viable alternative is overlooked. Alternatives that are not realistic or practical need not be evaluated. There are also situations where there are no alternatives and only one practical M&R treatment exists.

The generation of M&R alternatives uses similar considerations as those used for the design of M&R treatments. For brevity, these considerations were combined and are listed here.

- Facility type and the associated requirements for performance reliability of the M&R treatments.
- Pavement surface quality in terms of surface friction, roughness, and the potential for FOD.
- Existing pavement condition, surface distresses, and pavement performance history.
- Construction history and previous experience with a particular treatment under similar circumstances.
- Physical properties of the existing pavement structure. For the design of M&R treatments, this may require coring and boring of the existing pavement structure to obtain dimensions and material samples, and the use of a dynamic cone penetrometer.
- Structural pavement strength. For the design of M&R treatments, the determination of pavement strength (structural support) can be done with pavement deflection testing. A good reference is *FAA Advisory Circular on Use of Nondestructive Testing Devices in the Evaluation of Airport Pavements* (2004).
- Anticipated traffic loads in terms of the number of operations, particularly departures, and the type of aircraft.
- Environmental exposure, such as pavement temperature extremes, number of freeze–thaw cycles, and exposure to fuel spills.
- Life-cycle costs.
- Benefits; for example, estimated life span of the treatment and frictional properties of the pavement surface.
- Time of year available for construction.
- Availability of funds, qualified or suitable contractors, agency staff, and availability of materials.
- Facility downtime (for the current pavement M&R treatment and for subsequent treatments) and associated user costs.
- Operational constraints and construction phasing requirements.

Over time, many agencies have developed various technical aides for the selection of pavement preservation treatments on the network and project levels. Some of the procedures used on the network level were discussed in chapter five. Good sources of information are comprehensive pavement maintenance guides developed by state highway agencies mentioned previously—California (2008), Michigan (1999), Minnesota (2001), and Ohio (2001). Other notable references include an FHWA report, *Selecting a Preventive Maintenance Treatment for Flexible Pavements* (Hicks et al. 2000; Wade et al. 2007b).

Design of Alternative Maintenance and Rehabilitation Treatments

The M&R treatment design enables the analyst to estimate the project-specific costs and benefits, and other attributes of the competing treatments. Design considerations were listed in the previous section. Basic information on the design of M&R treatments is given in the *Catalog of Airport Pavement Preservation Treatments* in Appendix B.

Selection of the Recommended Maintenance and Rehabilitation Treatments

Candidate M&R treatments are typically ranked by airport pavement maintenance managers according to their estimated benefits and costs. Estimation of benefits for maintenance treatments are in terms of the extension of pavement life of the original pavement. This concept is illustrated in Figure 24.

Maintenance treatments, particularly preventive maintenance treatments, do not substantially increase the longevity of the existing pavement condition as shown in the top part of Figure 24. The main benefit of a maintenance treatment is the difference between the life span of the original pavement with and without the maintenance treatment. For example, full-depth repairs of PCC pavements may last 15 years or more, but may extend the life of a specific pavement section by only 12 years, because the section may fail owing to the presence and progression of other distresses.

Treatment costs include life-cycle costs defined in the Glossary of Terms. Because construction costs depend on location, time, quantities, and the capacity of the local industry, and other factors, project-specific construction costs are typically used in the evaluation of the M&R treatments.

The methods used to select the recommended M&R alternative include life-cycle cost analysis, cost-effectiveness evaluation, and ranking analysis. The ranking analysis method is the most comprehensive and is typically used for important projects.

Life-Cycle Cost Analysis

Life-cycle cost analysis (LCCA) facilitates the selection of the least expensive alternative. LCCA can incorporate the costs of not only the initial M&R treatments, but also the subsequent treatments. For example, the installation of retrofitted subdrains may have a beneficial effect on more than one rehabilitation cycle.

Maintenance treatments, particularly preventive maintenance treatments, postpone more expensive rehabilitation treatments. However, the cost of maintenance treatments is paid much sooner than the cost of any future rehabilitation treatment. The need to pay now rather than later is explicitly recognized in the LCCA by discounting all costs to their present value. It is important that the analysis period, the period for which the costs are included in the analysis, be sufficiently long to take into account all relevant consequences of alternative treatments. The FHWA publication *Life-Cycle Cost Analysis in Pavement Design* (Walls and Smith 1998) provides a detailed description of the LCCA procedures. The LCCA methodology has been also used to recommend opti-

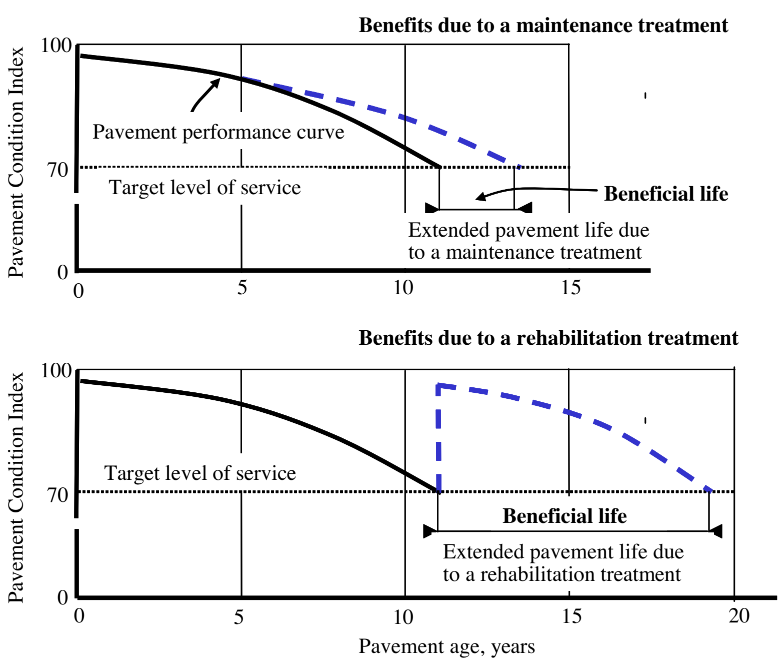

FIGURE 24 Benefits for M&R treatments in terms of beneficial life.

mal timing of preventive maintenance treatments by Peshkin et al. (2004). A new LCCA guide and software package is also being developed under Airfield Asphalt Pavement Technology Program Project 06-06.

The methodology of LCCA consists of the following steps:

- Inclusion of all viable and practical alternative M&R treatments.
- Determination of agency costs for each alternative. The agency costs include the initial construction costs and subsequent M&R costs throughout the analysis period.
- Determination of user costs. Many agencies do not include user costs in LCCA on the project level, because user costs are often similar for all alternatives and do not affect agency budget. However, when construction of M&R alternatives may have a different impact on airport operations and revenues, for example because of the differences in the length of construction, user costs are included.
- Selection of economic parameters for LCCA in terms of the discount rate and analysis period.
- Calculation of the net present value of agency costs and user costs.
- Selection of the alternative. The alternative with the lowest agency and user costs is the best from the economical point of view.

Cost-effectiveness Evaluation

Cost-effectiveness is the ratio and effectiveness (benefits) to life-cycle costs. The effectiveness is calculated using a similar procedure as that used on the network level described in the section on *Prioritization for Long-term Planning,* with the additional benefit of using more reliable project-specific data. On the network level, the effectiveness is calculated by multiplying the area under the PCI performance curve by the number of aircraft operations and the surface area of the section. The area under the performance curve, considered to be a measure of pavement serviceability, is illustrated in Figure 18 in chapter six. On the project level, the number of aircraft operations and the surface area are the same for all alternatives and need not be considered. The cost-effectiveness method provides an improvement over the LCCA method by taking into account differences in pavement serviceability provided by different alternatives.

Ranking Evaluation

Some of the attributes of M&R treatments, such as disruption of airport operations, previous agency experience with the treatment, sustainability, or improved pavement friction, cannot be readily quantified in monetary terms. M&R treatments may also create additional benefits in the form of improved pavement surface or impose operational constraints during construction. For this reason, in addition to the LCCA that takes into account monetary aspects of cost and benefits, a systematic assessment of other treatment attributes may also be carried out.

For example, consider two alternative rehabilitation treatments for an AC pavement on a runway of a small airport: a traditional overlay and in-place recycling. In addition to the LCCA that may favor in-place recycling, it is advisable to also consider other attributes:

- Effectiveness of the two alternatives. Effectiveness is defined as the area under the pavement performance curve (see Figure 18).
- Agency experience with the performance of the alternatives.
- Availability of qualified contractors.
- Reliability of cost estimates, particularly if local contractors are not available to carry out a specific alternative M&R treatment.
- Environmental and sustainability benefits owing to recycling of AC pavement material in-place.
- Potential for future cost savings if a new, less expensive rehabilitation method becomes available.
- Compatibility with phased or off-peak construction requirements.

A step-by-step example of this approach is provided in *Selecting a Preventive Maintenance Treatment for Flexible Pavements* (Hicks et al. 2000). Briefly, the procedure consists of four steps:

1. Selection of relevant attributes that are important to the customer and the agency. The list of attributes given in the earlier example is only illustrative and does not include many other attributes that may be important for specific alternatives, such as pavement friction, sensitivity to weather during construction, and availability of quality materials.
2. Assigning relative importance to the attributes using a *rating factor.* The total score of 100 is distributed to all relevant attributes.
3. Scoring each attribute in terms of its importance for the selection of the preferred treatment. This is accomplished using *scoring factors* on a 5-point scale, 5 being very important, and 1 not important.
4. Calculating total scores for all alternative treatments by summing the product of *rating and scoring factors* obtained for all attributes.

PROJECT IMPLEMENTATION AND MONITORING

The application of M&R treatments currently considers the use of appropriate materials, construction methods, and quality control and assurance procedures. Following the trends of the highway construction industry, many airports use end-result specifications for construction quality control. In addition to quality control and quality assurance procedures, airport operators also use construction warranties. Warranties provide a catch-all provision to ensure basic construction quality. Warranties are particularly important for pavement maintenance treatments where the construction materials and procedures are difficult to specify and enforce.

In addition to the periodic condition evaluation of the entire pavement network, discussed in chapter four, airports evaluate periodically specific pavement M&R treatments, particularly treatments that are not routinely used. This enables the airport pavement manager to expand, modify, or discontinue specific treatments based on their documented field effectiveness. According to data presented in Figure 6 (in chapter two), only 45% of agencies reported using an APMS to determine the performance of the past M&R treatments.

CHAPTER EIGHT

OPERATION, SUSTAINABILITY, AND ENHANCEMENT

More than 80% of airport agencies surveyed already operate or are developing an APMS. The average age of the existing APMS for those airports responding to the questionnaire was approximately 9 years. The challenge for most of the agencies is not to establish an APMS, but to sustain and enhance its operation. The focus of this chapter is on sustainability and enhancements of APMS operations rather than on procedures for establishing APMS.

AIRPORT PAVEMENT MANAGEMENT SYSTEMS OPERATION AND SUSTAINABILITY

The existing APMS operations and the sustainability of the APMS are closely linked; a successful operation of the system is one of the best guarantees of its sustainability. Long-term sustainability of the APMS is an on-going process that should be considered during the initial implementation (Broten and Wade 2004). The following factors contribute to the successful operation and sustainability of the APMS:

- **Long-term commitment.** Long-term commitment to the operation of the APMS and adequate financial support by the decision makers are essential. Benefits obtained from the APMS increase with the length of time the system is in operation. For example, it takes several years of pavement condition monitoring to ascertain which pavement M&R treatments work best on the local level, and to establish pavement deterioration rates. An acceptance of the APMS across the organization also requires time.
- **Data integrity and timeliness.** The APMS database is the source for obtaining pavement-related data. Current and objective pavement condition data are catalogued here for the preparation and updating of CIPs.
- **Periodic reporting.** The manager of an APMS typically provides periodic reports to decision makers on the condition of airport pavements and on the anticipated pavement preservation needs. Different versions of the reports, with different levels of detail and presentation styles, may be desirable for each audience. In addition to periodic reporting, special reports addressing pavement-related issues such as experience with new M&R treatments are developed and made available. Regular reporting is essential for documenting the benefits of operating an APMS.
- **Documentation of the APMS process.** A user manual documents the APMS process. Documentation ensures sustainability and continuity of operation during unexpected staff changes and facilitates the transfer of responsibilities between staff members and/or between consultants. Based on the survey, 20% of all APMSs are operated primarily by outside staff, and 48% of these systems are operated jointly by in-house and outside staff (see Figure 22).
- **Meeting user needs.** Universal user needs are monitored and include user-friendly software and the provision for sharing of data and results.
- **Permanent APMS committee.** Operation of a permanent APMS committee, with representation from all user groups, can be instrumental in the sustainability and enhancement of the system (Broten and Wade 2004). One of the tasks of the committee is to monitor user needs.
- **Ongoing improvements.** The monitoring of user needs and follow-up to implement improvements enhances the system over time. Recent enhancements of APMS developed to meet user needs discovered during proactive monitoring include:
  - Graphical presentation and mapping of data and results using computer-assisted drafting and GIS,
  - Automating pavement condition surveys and using digital images to document pavement distresses,
  - Improving the linkage between an APMS and the preparation of CIPs,
  - Incorporating preventive pavement maintenance programs,
  - Addition of pavement structural analysis to APMS software, and.
  - Providing access to APMS database and software through the Internet.
- **Providing training.** Initial APMS implementation includes staff training. However, staff training, together with succession planning is part of the ongoing operations. Training, including proficiency testing, is particularly critical for personnel who carry out periodic PCI surveys.

SYSTEM ENHANCEMENT

In addition to ongoing system enhancements there are situations where a structured comprehensive review of the APMS operation is beneficial for improving the current practice and ensuring sustainability. The objectives of the review are twofold:

1. To determine enhancements based on identified user needs.
2. To determine enhancements that may be beneficial based on the best appropriate practice (BAP). The BAP is the desired state of practice that meets the particular agency's needs in the most appropriate and efficient way.

The common methodology used for the systematic assessment of the APMS is the gap analysis. As the name suggests the analysis is concerned with identifying the difference between the existing management process and the future desirable process defined as the BAP. The gap analysis consists of three basic steps:

1. Assessment of the existing APMS activities against the BAP.
2. Identification of activities where the agency has already achieved the BAP.
3. Identification of activities and an implementation guide to improvements to reach the BAP.

The APMS activities that are the subject of the gap analysis can encompass all the main areas of a PMS shown in as Figure 3 or they may focus on specific "weak" areas of the APMS operation. Formal reviews of PMS operation for highway networks, done by either an outside agency or in-house, are quite common. For example, Zimmerman (2004) developed a self-assessment tool that helps highway agency personnel to systematically evaluate PMS operations and identify areas for improvement. The process includes a self-assessment questionnaire, interviews with the stakeholders, and a technical review. Smith at al. (2004) used gap analysis to carry out a number of structured reviews of pavement and highway management systems in several countries. The systematic review of APMS operations is less common than the reviews of roadway PMS; however, its potential to improve the operations, introduce needed changes, and sustain the operation is similar to the roadway PMS.

Another method that can help airports to improve their pavement management practices is benchmarking. Benchmarking is similar to gap analysis in the sense that it provides a method for agencies to move from an internal focus to an external focus in the search for best management practices. However, as the name suggests, benchmarking seeks to compare the operation of different organizations using objective, agreed-upon measures. In the airport context, the benchmarking measures include outcomes (e.g., average PCI for runways) and recourses (e.g., annualized pavement preservation cost per square yard of pavements). A primer and a guide on benchmarking for highway maintenance were developed by Booz Allen Hamilton (2003). The application of benchmarking as the means to improve airport pavement maintenance practices can be used as part of the gap analysis. In the context of airport pavement management, the information on the use of gap analysis and benchmarking is lacking.

It is expected that the new FAA APMS software, AIRPAVE, now under development, will enhance APMS technology in two significant ways: (1) it will make the PMS data readily available to users through the Internet, and (2) it will be a linchpin linking all main FAA pavement software applications.

CHAPTER NINE

CONCLUSIONS

There is extensive literature on the subject of airport pavement maintenance and rehabilitation (M&R) technology, including the technology of pavement preservation treatments. However, the information is dispersed and not always current. Airport pavement maintenance practices generally follow the objectives, management principles, and methodology of roadway pavement management practices. Airfield and roadway pavements are built and maintained using the same construction technology, materials, and methods. Also, airport and roadway pavement management systems frequently use similar pavement management software.

All types of pavement preservation treatments, including maintenance treatments, preventive maintenance treatments, and rehabilitation treatments, are considered together when developing pavement preservation strategies for individual pavement sections and for Capital Improvement Programs.

Preventive maintenance has a special standing in the area of pavement preservation. The preventive maintenance program has the potential to improve cost-effectiveness of pavement preservation activities, promote the use of frequent detailed pavement condition surveys, and facilitate the establishment of a dedicated budget for pavement maintenance. The need for preventive pavement maintenance is well-recognized. About 56% of all respondents systematically identify pavements that would benefit most from preventive maintenance and approximately 35% of respondents implement preventive maintenance treatments at the right time. Approximately 33% of airport agencies have a dedicated budget for pavement maintenance.

The main challenge facing airport authorities is not the type of M&R treatment, but is to justify that M&R treatments are necessary using a judicious and objective process, and to obtain funding for their implementation.

Pavement management technology is mature. More than 80% of all airport authorities surveyed operate an Airport Pavement Management System (APMS) or are in the process of developing one. All airport agencies surveyed that have an APMS use a pavement management software application, primarily MicroPAVER. It is expected that the new web-based FAA pavement management software now under development, called AIRPAVE, will further enhance the technology of the APMS.

Based on the survey, the average frequency of Pavement Condition Index surveys was 3.3 years. Annual condition surveys of pavement surface distresses on the candidate pavement sections, such as sections with newly constructed and rehabilitated pavements aids in the selection and timing of preventive pavement maintenance treatments.

There is no recognized single pavement roughness standard for in-service airport pavements that could be used to identify M&R needs based on pavement roughness. However, the FAA has recently proposed roughness criteria for runways addressing isolated bump events. Establishing practical roughness standards for the scheduling of M&R treatments on in-service airport pavements continues.

The performance of specific M&R treatments, particularly treatments that are not routinely used, are typically tracked by pavement managers. This enables the airport authority to expand, modify, or discontinue M&R treatments based on their documented field performance. Pavement management software applications, such as MicroPaver or AIRPAVE, currently do or will include features to facilitate the evaluation of past pavement M&R treatments.

About 35% of responding airports have recently (during the past 10 years or so) evaluated the performance of new and innovative M&R treatments. The data on the cost-effectiveness of new and innovative treatments, as well as the treatments that utilize proprietary products, are lacking.

Seventy percent of airports surveyed had both asphalt concrete (AC) and portland cement concrete (PCC) pavements on at least some types of airport facilities, and 30% of airports had both AC and PCC pavements on runways. Consequently, many airports need to have staff that has expertise in the technology of both AC and PCC pavements. To present information in a concise structured way, 24 common M&R treatments were systematically described in the *Catalog of Airport Pavement Preservation Treatments* in Appendix B.

The 50 airport survey sample size did not permit desegregation of results by geographical or environmental regions, or by airport size.

Multi-year prioritization using incremental cost-effectiveness analysis, the most advanced method for optimizing the allocation of available funding used by transportation agencies administering large highway networks, is seldom used for airport pavement networks. The reasons for slower implementation include smaller airport pavement networks, greater importance of operational issues at airports, and limitations of existing airport pavement management software.

Life-cycle cost analysis, a systematic assessment of other treatment attributes important to an airport, can aid in the selection of alternative M&R treatments. These attributes may include, for example, agency experience with the performance of the alternatives, impact on airport operations, and environmental and sustainability considerations.

A comprehensive review of an APMS could use gap analysis that identifies differences between the existing management procedures and those based on the best appropriate practice. The comparison between the results achieved by different APMSs can be assessed through benchmarking.

Further research includes making pavement preservation knowledge available to practitioners by organizing and synthesizing information and data in an interactive electronic format.

GLOSSARY OF TERMS

This section contains the definitions of 26 key terms used in the airport pavement management area. The objective of the glossary of terms is to facilitate communication between all concerned parties. It is not intended to override the established usage of terms by various agencies. The terms are listed in an alphabetical order.

Airport Pavement Maintenance Management Program—The main characteristics of this program are defined by Public Law 103-305 (2004). Briefly, the program specifies how airport agencies should monitor and report the condition of airport pavements to be eligible for federal funding for pavement preservation.

Airport Pavement Maintenance Management System—Application of management principles to the maintenance of airport pavements. The terms *airport pavement maintenance management system* and *airport pavement management system* are sometimes use interchangeably depending on the understanding of what constitutes *pavement maintenance.*

Airport Pavement Management System (APMS)—A pavement management system (defined subsequently) applied to airfield pavements.

Asset management—A systematic process of maintaining, upgrading, and operating physical assets cost-effectively. Pavement maintenance is part of the management of airport assets. It is typically assumed that an asset management process can provide a logical approach to the management of assets by combining engineering science with sound business and accounting practices. The other desired feature of asset management is that it can facilitate coordination of planning and funding actions across all types of physical assets, such as pavements, buildings, and guidance and lighting installations.

Budgeting—A process of developing, securing, and administering a budget.

Corrective maintenance—Also called reactive maintenance, is defined as a maintenance activity performed after pavement defects occur; that is, loss of pavement friction, rutting, or cracking. Corrective maintenance treatments are generally less desirable than preventive maintenance treatments. However, preventive maintenance treatments, such as crack sealing, also correct pavement defects. It is also possible that a specific corrective maintenance treatment is the right treatment at the right time. Other differences between corrective and maintenance are discussed under *preventive maintenance.*

Emergency maintenance—Maintenance treatments performed during an emergency situation, such as filling in a large pothole or removing foreign object debris, for both old and new pavements.

Life-cycle cost analysis—An economic analysis procedure used to compare alternative pavement structures or pavement preservation strategies and treatments over an extended period of time (often 20 years or more) taking into account life-cycle costs. The life-cycle costs include agency costs (initial construction costs and all subsequent maintenance and rehabilitation costs), as well as user costs (such as the cost of operational delays or restrictions during construction). The quantification of user costs in monetary terms is not always used and is not always possible.

Multi-year planning—A process that plans future pavement preservation activities on the network level over a period of 5 years or more.

Network-level management—Management activities carried out at the network level concern all or a substantial part of airport pavements. Decisions made at the network level are typically planning, budgeting, or policy decisions.

Pavement condition—A measure of the way the pavement serves the intended purpose. Pavement condition can be described using the characteristics of individual defects such as roughness or the lack of pavement friction, or using characteristics that combine the influence of several defects such as a Pavement Condition Index (PCI). Pavement condition assessment also includes pavement structural evaluation and testing.

Pavement maintenance—A strategy to maintain pavements in the desired condition. Traditionally, for roadway pavements, pavement maintenance treatments are those that do not substantially improve pavement condition or add to pavement strength, such as crack and joint sealing. For airport pavements, the term pavement maintenance often encompasses both maintenance and rehabilitation treatments. The possible reason for using "maintenance" as a synonym for "maintenance and rehabilitation" is Public Law 103-305 (1994). This law requires that a public airport must implement an "effective airport pavement maintenance-management program as a precondition for being considered for funding of replacement or reconstruction of airport pavements." This phraseology links a maintenance management program with replacement and reconstruction. The Government Accounting Standards Board, which influences how expenses appear on financial statements, defines maintenance as the act of keeping fixed assets in an acceptable condition; that is, keeping conditions at satisfactory rather than at initial design levels (Lemer 2004). In this report, the term pavement maintenance means the traditional definition of maintenance as a treatment that does not substantially modify the existing pavement surface layers.

Pavement maintenance treatment—A specific maintenance action; a part of a pavement maintenance strategy.

Pavement management—A process that assists the custodians of pavement networks in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a period of time.

Pavement Management System—An application of pavement management principles that encompasses a wide spectrum of activities including periodic evaluation of pavement condition, planning and programming of pavement preservation activities, pavement design, and construction. For airport pavements, a pavement management system is also called an airport pavement maintenance system. Some airports may operate two complementary systems, one for airfield pavements and one for roads and parking lots.

Pavement performance—Pavement condition recorded over a period of time. Pavement performance describes how the pavement condition changes over time.

Pavement preservation—Also known as airport pavement preservation, this is a program of activities designed to preserve the investment in the nation's airport pavements. Pavement preservation is a sum of all activities undertaken to keep pavements in good repair and to meet the users' needs. Pavement preservation includes routine maintenance, emergency maintenance, preventive maintenance, corrective maintenance, and rehabilitation. Pavement preservation treatments include treatments ranging from crack sealing to asphalt overlays and a full-depth slab replacement. The FHWA Pavement Preservation Expert Task Group defined pavement preservation as "a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations" (*Pavement Preservation Compendium II* 2006).

Pavement rehabilitation—A strategy undertaken to restore pavement to its original condition using rehabilitation treatments such as pavement overlays and the replacement of failed portland cement concrete slabs.

Pavement rehabilitation treatment—Treatments undertaken to substantially improve the pavement condition. The boundary between maintenance and rehabilitation treatments is not well defined. A thin overlay may be considered to be either a maintenance or a rehabilitation treatment. The same treatment (such as a full-depth slab repair) may be called a maintenance treatment, if only a very few slabs are repaired, or a rehabilitation treatment, if multiple slabs are repaired. Typically, rehabilitation treatments add or replace one or more pavement surface layers. Some agencies also distinguish between minor rehabilitation and major rehabilitation. Pavements may receive several rehabilitation treatments (or undergo several rehabilitation cycles) before they are reconstructed.

Planning—A process used to identify pavement preservation needs. Planning includes elements of inventory, condition evaluation, identification of needs, and prioritization.

Preventive maintenance—The definition of the preventive maintenance has evolved. Originally, preventive maintenance was defined in 1997 by the AASHTO Standing Committee on Highways as ". . . a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity)." It typically includes low-cost pavement treatments applied when the pavement is in very good or good condition. Recently, preventive maintenance has been defined in broader terms as a program of applying the right pavement preservation treatment to the right pavement at the right time. The preventive and corrective maintenance treatments are not defined by the type of treatment, but by the reason why (or when) the treatment is performed. For example, a microsurfacing treatment applied to seal an open asphalt concrete pavement surface that starts to ravel can be considered a preventive maintenance treatment, whereas a microsurfacing applied to an asphalt concrete pavement surface that is raveling (or to counteract moderate rutting) is a corrective maintenance treatment. Consequently, the distinction between preventive maintenance and corrective maintenance is blurred.

Programming—The process of developing implementation plans (for pavement preservation) and acquiring the means and resources necessary for implementation.

Project-level management—Activities at the project level concern a specific pavement section. After deciding which sections are selected to receive generic pavement preservation treatments at the network level, the project-level decisions result in the selection of project-specific pavement preservation treatments, including the selection of construction materials and procedures for implementation. Project-level activities also include construction and subsequent monitoring of the treatment performance.

Routine maintenance—Also called operational maintenance, this includes activities that do not substantially improve the pavement surface, such as removal of debris representing foreign object debris, snow and ice control, repainting of pavement markings, maintenance of in-pavement runway lights, and removal of rubber deposits. Routine maintenance is not discussed in detail in the Synthesis.

Temporary maintenance treatment—Treatments designed to hold the pavement surface together until more permanent or substantial rehabilitation takes place. Temporary maintenance is also called holding maintenance or stopgap maintenance. Temporary maintenance treatments may be necessitated by the timing of future rehabilitation or reconstruction activities or by a lack of funds.

The right treatment to the right pavement at the right time—The application of the right treatment to the right pavement at the right time is the essence of a cost-effective pavement preservation program. There is the ever-present need to implement the right treatment at the right time. All candidate pavement preservation treatments compete for the same pavement preservation budget, with the "winner" representing the best cost-effective method of providing pavement infrastructure. The winner may be a single treatment or a combination of treatments.

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APPENDIX A

Survey Questionnaire and Survey Responses

INTRODUCTION

The main source of information on current airport pavement maintenance practices was a survey of airport pavement maintenance professionals. The survey consisted of a four-page questionnaire which is reproduced herein in Tables 1A to 4A. The first two pages of the questionnaire contain, in addition to the introductory material, 11 questions concerning airport pavement management practices. Tables 3A and 4A (pages 3 and 4 of the survey questionnaire) contain questions regarding the use and performance of common airport pavement maintenance and rehabilitation (M&R) treatments. Table 3A concerns M&R treatments applicable to asphalt concrete (AC) pavements, and Table 4A is for M&R treatments applicable to Portland cement concrete (PCC) pavements.

The objectives of the survey, the survey procedures, survey response rate, and the key results of the survey are described in the main part of the synthesis. Additional survey results, that are not included in the main part of the report, are summarized in this appendix.

In order to present the survey results efficiently, Tables 3A and 4A also contain the entries that represent the number of survey responses obtained. For example, referring to the first numerical entry in Table 3A, 37 airports reported routinely sealing cracks in AC pavements using hot-poured sealant. The corresponding percentages are presented in Tables 3 and 4 of the main report. For example, according to Table 3, 95 percent of airports (that have AC pavements on at least some of the facilities) routinely seal cracks in AC pavements using hot poured sealant.

TABLE 1A
SURVEY QUESTIONNAIRE, PAGE 1 OF 4

Survey Questionnaire
Synthesis of Common Airport Pavement Maintenance Practices

This survey questionnaire is distributed to practitioners engaged in the maintenance and preservation of airfield pavements. The results of the survey will be used to develop Synthesis of Common Airport Pavement Maintenance Practices. The survey is sponsored by Airport Cooperative Research Program. Details about the Program are available at **http://www.trb.org/news/blurb_browse.asp?id=138**.

Thank you for your participation in this survey. Please send the completed survey to Dr. Jim Hall by email: jhall@ara.com or by fax: (601) 629-6169 before June 30, 2009. If you prefer to respond by a telephone interview instead, please contact Dr. Jim Hall at (601) 629-6165

Respondent Information

Name: ______________________ Position: ____________________

Agency: ______________________ Address: ____

Phone: ____________________ Fax: _________________

Email:_________________________

General Facility Information Facility Name or Code**:** ___________________________

What is the largest aircraft using your facility? ____________________________

What is the predominant aircraft? ____________________________

What pavement surface types do you have at your facility? (*Please check all appropriate boxes*)

Facility	Asphalt Concrete (AC)	Portland Cement Concrete (PCC)	Composite (AC over PCC)	Surface Treated	Gravel
Runways					
Taxiways					
Aprons					

Pavement Management

1. Does your agency operate a pavement management system (or a pavement maintenance system)?
   Yes ☐ Under development ☐ No ☐
   If yes, for how long has the system been in use?
   Less than 2 years ☐ 3 to 5 years ☐ 5 to 10 years ☐ More than 10 years ☐

2. What is your experience with a pavement management system (or a pavement maintenance system)?
   Please check all applicable boxes
   Excellent, couldn't do without it ☐ The system is accepted and used ☐ Not applicable ☐
   Benefits outweigh costs ☐ Functional, but needs improvement ☐ Not useful ☐
3. Which pavement management (or pavement maintenance) software do you use or plan to adopt or develop?
4. Who is involved in operating your pavement (or pavement maintenance) management system?
   In-house staff ☐ In-house staff with outside support ☐ Mainly outside staff/consultant ☐

TABLE 2A
SURVEY QUESTIONNAIRE, PAGE 2 OF 4

5. How do you use the results of pavement management (or pavement maintenance) system?
Please check all applicable boxes
- To keep track of the pavement condition ☐ To predict future pavement deterioration ☐
- To determine the performance of the past pavement maintenance and rehabilitation treatments ☐
- To prepare Capital Improvement Programs or annual budgets ☐
- To obtain funding from FAA or other agencies ☐

6. How do you evaluate the condition of your pavements?

Pavement evaluation procedure	If yes, frequency of evaluation, years:	
	Runways	Other facilities
Pavement Condition Index (PCI)	Yes ☐	Yes ☐
Other types of surface distress surveys, but not PCI *If yes, what type of distress survey?*	Yes ☐	Yes ☐
Pavement smoothness (or roughness) surveys *If yes, which roughness measure do you use?*	Yes ☐	Yes ☐
Periodic pavement friction surveys	Yes ☐	Yes ☐
Periodic Falling Weight Deflectometer (FWD) surveys	Yes ☐	Yes ☐
Other surveys? Please specify (e.g., digital imaging of the pavement surface)		

7. How do you select pavement sections that require pavement maintenance or rehabilitation treatments?
Please check all applicable boxes
- With the help of a computer program ☐ Engineering judgement ☐
- Worst pavement condition first ☐ Decision trees or guidelines ☐
- When a perceived hazard exist ☐ Pavement age ☐
- Operational priorities ☐ Other considerations ☐

Preventive pavement maintenance is carried out to prevent premature pavement deterioration and is done at the right time (when the treatment is most cost-effective). Preventive maintenance treatments may include, for example, crack sealing or thin asphalt concrete overlays.

8. Do you systematically identify pavements that would benefit most from preventive maintenance?
Yes ☐ When budget permits ☐ No ☐

9. Do you implement preventive maintenance treatment at the right time?
Yes ☐ Sometimes ☐ No ☐

10. Has your agency recently (during last 10 years or so) evaluated the performance of specific pavement maintenance or rehabilitation treatments? *We are particularly interested in new and innovative pavement preservation treatments and technologies.*
Yes ☐ No ☐
If yes, please elaborate or tell us where we can get additional information.______________________

11. How do you obtain funding for pavement maintenance and rehab.? *Please check all applicable boxes.*
- Through FAA funding ☐ Through state funding ☐
- Have dedicated funding for preventive maintenance ☐ Based on the last-year budget ☐
- Based on pavement needs such as PCI level ☐ Based on needs to preserve pavement ☐

TABLE 3A
SURVEY QUESTIONNAIRE, PAGE 3 OF 4

Maintenance and Rehabilitation of Asphalt Concrete Pavements

- Which of the following maintenance treatments do you use, or have tried, during the past 10 years?
- What is your experience in using them?

Maintenance of Asphalt Concrete Pavements

Treatment		**Current Practice**			**Performance**				**Comments, questions, experience** *Please comment on your experience with specific treatments*
		Routine	**Have Tried**	**Never Tried**	**V. Good**	**Good**	**Poor**	**Unknown**	
Crack sealing with sealant	Hot- poured	37	5		8	30	4		Do you recommend routing of cracks before sealing? Yes ☐ No ☐ Sometimes ☐
	Cold-applied	4	3		1	4	1		
Small area (pothole) patching using:	Hot mix	23	7		11	15			
	Cold mix	19	8		3	12	9		
	Proprietary mix	4	5		2	4	2		Do you recommend the use of proprietary materials? Yes ☐ No ☐
Spray patching (Includes manual chip seal)		2	3			5			
Machine patching with AC		12	6		7	10	1		
Milling and machine patching		15	8		7	11			
Surface treatment		11	8		1	13	2		
Texturization	Fine milling	3	2		1	4			
	Shot blasting		7		5	2			
Surry seal		10	11		2	15	3		
Micro-Surfacing		1	4		1	3			
Hot mix overlay		20	10		12	12	1		Do you use hot mix overlays less than 1½" thick? Yes ☐ No ☐
Milling and overlay		20	8		14	10			
Hot in-place recycling		2	1		1	1			
Cold in-place recycling		1			1				
Whitetopping (PCC overlay)		3	3		3	1	1		
Rejuvenators, fog seals, etc.		13	10		5	13	4		
Other techniques/materials that you are using? (Please add)									

TABLE 4A
SURVEY QUESTIONNAIRE, PAGE 3 OF 4

Maintenance and Rehabilitation of Portland Cement Concrete Pavements

- Which of the following maintenance treatments do you use, or have tried, during the past 10 years?
- What is your experience in using them?

Maintenance of Exposed PCC Pavements

Treatment		Current Practice			Performance				Comments, questions, experience
		Routine	Have Tried	Never Tried	V. Good	Good	Poor	Unknown	*Please comment on your experience with specific treatments*
Joint/Crack sealing	Bituminous sealant	12	6		2	12	1		
	Silicone sealant	16	9		5	12			
	Neoprene seal	3	9		4	4	3		
Load transfer restoration	Sub-sealing	1	2		1	2			*(under slab grouting)*
	Slab stitching	1	2		1	2			
	Dowel retrofit	5	2		3	2			
Shallow patch repair using	PCC	14	6		5	12	1		
	AC	12	8		3	11	3		
	Proprietary mix	7	7		5	5	2		Do you recommend the use of proprietary materials? Yes ☐ No ☐
Full and partial depth repairs or replacement using	PCC	19	6		8	8	1		
	AC	8	16		4	7	2		
	Proprietary mix	3	7		3	5	2		Do you recommend the use of proprietary materials? Yes ☐ No ☐
	Precast panels	1	1		1	1			
Diamond grinding		2	14		3	11			
Controlled shot blasting			6			4	1		
Micro-surfacing			2			1	1		
Machine patching with AC		2	5		2	3	1		
AC overlay		4	11		4	7			
PCC overlay (white topping)		3	3		2	2	1		
Other techniques/materials? (Please add)									

Thank you for completing the survey. Please send the completed survey to Dr. Jim Hall by email: jhall@ara.com or by fax: (601) 629-6169 before June 30, 2009.
Applied Research Associates Inc. 112 Monument Place, Suite A, Vicksburg, Mississippi 39180-5156

ADDITIONAL SURVEY RESULTS

The key survey results are presented and discussed in the main part of the synthesis and are not reproduced herein. The following contains additional survey results.

The survey questions are in an italic font; survey response data are in regular font.

What pavement surface type do you have at your facility?

Facility	Asphalt Concrete (AC)	Portland Cement Concrete (PCC)	Composite (AC over PCC)	Surface Treated	Gravel
Runways	37	23	13	3	1
Taxiways	37	24	8	1	0
Aprons	30	32	7	1	0

See Figure 11 in the main part of the synthesis. Figure 11 is based on 30 responses.

1. *Does your agency operate a pavement management system* (*or a pavement maintenance system*)?

	No.	Percent
Yes	29	60
Under development	11	23
No	8	17

If yes, for how long has the system been in use?
See Figure 4, which is based on 28 responses.

2. *What is your experience with a pavement management system* (*or a pavement maintenance system*)?

See Figure 5. Figure 5 is based on 33 responses of agencies that operate an airport pavement management system. None of the respondents checked "not useful."

3. *Which pavement management* (*or pavement maintenance*) *software do you use or plan to adopt or develop?*

See Figure 22, which is based on 33 responses. An additional 17 respondents checked "not applicable."

4. *Who is involved in operating your pavement* (*or pavement maintenance*) *management system?*

See Figure 23, which is based on 39 responses.

5. *How do you use the results of pavement management* (*or pavement maintenance*) *system?*

See Figure 6, which is based on 38 responses.

6. *How do you evaluate the condition of your pavements?*

See Table 2, which is based on 38 responses.

7. *How do you select pavement sections that require pavement maintenance or rehabilitation treatments?*

See Figure 14, which is based on 47 responses.

8. *Do you systematically identify pavements that would benefit most from preventive maintenance?*

See Figure 15, which is based on 48 responses

9. *Do you implement preventive maintenance treatment at the right time?*

See Figure 17, which is based on 30 responses.

10. *Has your agency recently* (*during last 10 years or so*) *evaluated the performance of specific pavement maintenance or rehabilitation treatments?*

	Number	Percent
Yes	17	36
No	27	58
No response	3	6

See section "Survey Results" in chapter four for the list of innovative and additional treatments.

11. How do you obtain funding for pavement maintenance and rehabilitation?
See Figures 19 and 20, each based on 48 responses. Regarding the dedicated funding for preventive maintenance, see Figure 15.

Additional information regarding maintenance and rehabilitation treatments of asphalt concrete pavements.

Do you recommend routing of cracks in AC pavements before sealing?

	Number	Percent
Yes	15	34
No	2	4
Sometimes	20	23
No response	23	39

Do you recommend the use of proprietary materials for small area patching of AC pavements?

	Number	Percent
Yes	14	32
No	9	20
Sometimes	10	23
No response	17	25

Additional information regarding maintenance and rehabilitation treatments of portland cement concrete pavements.

Do you recommend the use of proprietary materials for shallow patch repairs?

	Number	Percent
Yes	3	5
No	10	12
No response	16	83

Do you recommend the use of proprietary materials for full depth repairs?

	Number	Percent
Yes	4	10
No	4	10
No response	33	80

RESPONDING AIRPORTS

Table 5A lists all 50 airports and airport agencies that completed the survey questionnaire. Also listed in Table 5A are the airport location, the average number of daily aircraft operations, and pavement type of airfield pavements. Geographical location of the airports is illustrated in Figure 1 of the main report.

TABLE 5A
LIST OF AIRPORTS

State	Airport Name	Location	Average No. of Daily Operations	Pavement Type
Arkansas	Ozark Regional Airport	Mountain Home	136	AC
California	Eight small airports, the largest is Gillespie Field	County of San Diego	1 to 669	AC
	Meadows Field Airport	Bakersfield	344	Both
Colorado	Colorado Springs Municipal Airport	Colorado Springs	420	Both
Delaware	Sussex County Airport	Georgetown	57	Both
Florida	St. Augustine/St. Johns County Airport	St. Augustine	347	AC
Georgia	LaGrange Callaway Airport	LaGrange	47	AC
	Savannah/Hilton Head International Airport	Savannah	267	Both
	Hartsfield–Jackson Atlanta Int. Airport	Atlanta	2,939	PCC
Illinois	Chicago O'Hare International Airport	Chicago	2,563	Both
	Chicago Midway International Airport	Chicago	730	Both
Iowa	Dubuque Regional Airport	Dubuque	155	Both
	Des Moines International Airport	Des Moines	333	Both
Louisiana	Hammond Northshore Regional Airport	Hammond	210	Both
	Houma–Terrebonne Airport	Houma	243	Both
Maryland	Baltimore Washington International Airport	Baltimore	760	Both
	Easton Airport	Easton	137	AC
Massachusetts	Boston Logan International Airport	Boston	1,094	Both
Michigan	Detroit Metro. Wayne County Air.	Romulus	1,266	Both
Mississippi	Gulfport–Biloxi International Airport	Gulfport	153	Both
	Hesler–Noble Field	Laurel	63	Both
Missouri	Springfield–Branson Regional Airport	Springfield	181	Both
Minnesota	Saint Paul Downtown Airport	St. Paul	435	AC
	Minneapolis–St. Paul International Airport	St. Paul	1,240	PCC
Montana	Dawson Community Airport	Glendive	16	AC
	Great Falls International Airport	Great Falls	115	Both
Nebraska	Omaha Epply Airfield	Omaha	366	Both
New Jersey	Essex County Airport	Caldwell	245	AC
	Morristown Municipal Airport	Morristown	403	AC
New Mexico	Albuquerque International Airport	Albuquerque	522	AC
	Dona Ana County Airport	Santa Teresa	89	AC
New York	JFK International Airport	Queens	1,291	Both
Ohio	Port Columbus International Airport	Columbus	449	Both
	Mansfield Lahm Airport		77	Both
	Dayton International Airport	Vandalia	300	Both
	Altus/Quartz Mountain Reg. Air.	Altus	38	PCC

TABLE 5A
(*continued*)

State	Airport Name	Location	Average No. of Daily Operations	Pavement Type
Oklahoma	Arrowhead Airport	Canadian	1	AC
	Boise City Municipal Airport	Boise City	10	AC
Oregon	Portland International Airport	Portland	630	Both
	28 airports throughout Oregon	Oregon	N/A	Both
Pennsylvania	Wilkes–Barre/ Scranton Int. Air.	Avoca	178	Both
	Lone Star Executive Airport	Conroe	219	Both
Texas	Mineral Wells Airport	Mineral Wells	62	AC
	George Bush Intercontinental Air.	Houston	1,577	Both
Utah	Salt Lake City International Airport	Salt Lake City	1,071	Both
Virginia	Washington Dulles International Airport	Chantilly	1,048	PCC
	Winchester Regional Airport	Winchester	100	Both
Washington	Seattle Tacoma International Airport	Seatac	946	PCC
	Snohomish County Airport	Everett	311	Both
Washington DC	Ronald Regan National Airport	Washington, D.C.	754	PCC
Wyoming	Airports throughout Wyoming	Wyoming	N/A	Both

N/A = not available.

APPENDIX B

Catalog of Airport Pavement Preservation Treatments

CONTENTS

INTRODUCTION

The objective of the *Catalog of Airport Pavement Preservation Treatments* is to describe common airport pavement preservation treatments for both asphalt concrete (AC) and portland cement concrete (PCC) airfield pavements, and to include materials, methods, and applications. The information is organized in the form of Fact Sheets. Each pavement preservation treatment is described on a separate Fact Sheet using a set format.

Selection of Treatments Included in the Catalog

This appendix includes 24 Fact Sheets, each describing pavement preservation treatments as listed in Table B1. These 24 treatments were compiled from responses to the questionnaire sent to airport managers and engineers that identified 38 separate treatments as part of this synthesis project. Additional information was obtained from the 35 referenced documents listed in the Resource sections of this appendix. The survey is described in chapter one, the survey questionnaire in Appendix A, the key survey results are described throughout the report, and additional survey results are summarized in Appendix A.

Briefly, 50 survey responses were obtained from a geographically diverse set of airports ranging in size from one to approximately 3,000 daily aircraft operations. Thirty-eight pavement preservation treatments were included on the survey form for respondents to review; these encompassed commonly used pavement preservation treatments for AC and PCC pavements. The 24 treatments included in the catalog were taken from the 50 responses and each of these has been used routinely by at least one of the airports surveyed, or they have been tried by at least 10% of the airports. All treatments included in the survey satisfied these inclusion criteria with the exception of microsurfacing used for PCC pavements.

The 38 treatments included in the survey were reduced to 24 treatments included in the catalog by combining treatments that differed primarily by the material used or by the pavement type to which the treatment is applied. An example of combining treatments that differ only by the material used is the combination of two types of crack sealing of AC pavements (using hot-poured sealant or using cold-applied sealant) into one treatment (sealing and filling of cracks of AC pavement). An example of combining treatments that differ primarily by the pavement type is microsurfacing of AC pavements and microsurfacing of PCC pavements, which became one treatment—microsurfacing. As a result, the *Catalog* includes 3 pavement preservation treatments applicable to both AC and PCC pavements, 12 treatments applicable to AC pavements, and 9 treatments applicable to PCC pavements (see Table B1).

TABLE B1
AIRPORT PAVEMENT PRESERVATION TREATMENTS INCLUDED IN THE CATALOG

Both Pavement Types 3 treatments	Asphalt Concrete 12 treatments	Portland Cement Concrete 9 treatments
1) Texturization using shot blasting	4) Sealing and filling of cracks (with hot or cold applied sealants)	16) Joint and crack sealing (with bituminous, silicone, or compression sealants)
2) Diamond grinding	5) Small area patching (using hot mix, cold mix, or proprietary material)	17) Partial depth repairs (using AC, PCC, and proprietary materials
3) Microsurfacing	6) Spray patching (manual chip seal and mechanized spray patching)	18) Full-depth repairs (using AC, PCC, and proprietary materials
	7) Machine patching with AC material	19) Machine patching using hot mix
	8) Rejuvenators and seals	20) Slab stabilization and slab-jacking
	9) Texturization using fine milling	21) Load transfer
	10) Surface treatment (chip seal, chip seal coat)	22) Crack and joint stitching
	11) Slurry seal	23) Hot-mix overlays
	12) Hot-mix overlay (includes milling of AC pavements)	24) Bonded PCC overlay
	13) Hot in-place recycling	
	14) Cold in-place recycling	
	15) Ultra-thin whitetopping	

Sources of Information

Information sources used for the preparation of the catalog were similar to those used for the report and are described in the Methodology section in chapter one of the synthesis report. In addition, each Fact Sheet contains a section titled "Resources," which typically contains two or three source references and additional information. The main purpose of these references is to direct the reader to key publications containing general and specific information on the treatment. The number of references listed on the Fact Sheets was restricted for brevity.

References used in development of the fact sheets included:

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, Apr. 2010.

Ohio Department of Transportation, *Pavement Preventive Maintenance Guidelines,* Office of Pavement Engineering, Columbus, May 2001.

Minnesota Department of Transportation, *Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements,* Report MN/RC-2009-18, Office of Materials and Road Research, Maplewood, May 2009.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Wu, Z., J.L. Groeger, A.L. Simpson, and G.R. Hicks, *Performance Evaluation of Various Rehabilitation and Preservation Treatments,* Office of Asset Management, Federal Highway Administration, Washington, D.C., Jan. 2010.

Organization of the Catalog

The *Catalog* consists of 24 Fact Sheets, each describing a separate pavement preservation treatment. Although the pavement preservation treatments are described separately, several treatments can be used on the same pavement section at the same time, or at different times, as part of a single pavement rehabilitation project or strategy. For example, a single PCC pavement rehabilitation project may include four maintenance and rehabilitation (M&R) treatments: shallow patch repair, full-depth repair, diamond grinding, and joint/crack resealing.

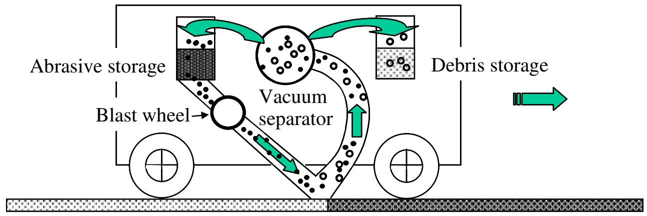
The order in which the M&R treatments are described in the *Catalog* was set up according to the following rules:

1. Treatments that can be applied to both AC and PCC pavements without any substantial modification are described first, followed by the description of treatments applicable to AC pavements and PCC pavements.
2. For each pavement type, the treatments are arranged in an approximate order of their increasing contribution to restoring pavement serviceability.

The Fact Sheets describe treatments using a uniform format. Each Fact Sheet starts with a sketch showing a sequence of operations, and a short definition of the treatment.

Service lives and unit costs of the pavement preservation treatments given in the Fact Sheets provide relative information that can be used for orientation and comparison purposes only. The service lives and costs are based on a literature review and apply to typical situations only. The synthesis survey included questions on the usage and performance of pavement preservation treatments, but not on their life spans and costs.

Fact Sheet 1—Texturization Using Shot Blasting



Schematic of Shot Blasting Operation

Shot blasting is a texturization technique that uses a self-propelled machine that blasts abrasive particles onto the pavement surface as shown in the above schematic. The objective is to remove contaminants, such as rubber deposits and excess asphalt cement (AC), and to abrade deteriorated surface material to restore both micro- and macrotexture. Surface retexturing with shot blasting can be used for both AC and PCC (portland cement concrete) pavements to improve pavement friction.

Sources of Information and Additional Resources

The source document and additional general information is from Gransberg, "Life-Cycle Cost Analysis of Surface Retexturing with Shotblasting as an Asphalt Pavement Preservation Tool," *Transportation Research Record: Journal of the Transportation Research Board, No. 2108,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 46–52.

Purpose and Selection Criteria

Unlike fine milling and diamond grinding, shot blasting does not improve pavement smoothness. It can be used to improve pavement friction by removing materials from the pavement surface, to clean pavement surface before the application of sealants, and to remove traffic control lines and signs. The best improvement in pavement surface friction by shot blasting is achieved when abrasion-resisting aggregate particles are embedded in a mortar that can be abraded by shot blasting.

Typical Service Life and Costs

When used to restore pavement friction by removing softer or deteriorated material, the treatment effectiveness may last 1 to 6 years. When used to remove rubber deposits on runways, the effectiveness depends on the formation of new rubber deposits. The cost is typically lower than for diamond grinding and is in the range of approximately $2 to $10 per square yd.

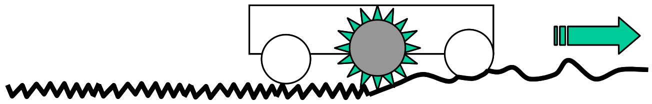
Materials and Construction

There are several types of proprietary equipment that can produce a pattern width ranging from approximately 6 in. to 6 ft. The equipment includes a system that propels abrasive particles, such as small round steel pellets, onto the pavement surface, vacuums up the resulting pavement material debris and abrasive particles, separates the abrasive particles from debris for re-use, and stores the debris for disposal. The technique is commonly applied to PCC pavements, but has also been successfully used on both AC and surface-treated surfaces.

Airport Experience

Just over 20% of airports surveyed reported that they have tried using shot blasting for PCC or for AC pavements. None of the airports reported routine use of shot blasting for either pavement type. Typically, the performance of shot blasting was reported as good.

Fact Sheet 2—Diamond Grinding



Schematic of Diamond Grinding Operation

Diamond grinding is a rehabilitation technique that removes a shallow depth of pavement surface material by saw cutting closely spaced grooves into the pavement surface using diamond-tipped blades. The above illustration shows a self-propelled diamond grinding machine.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, Apr. 2010.

Ohio Department of Transportation, *Pavement Preventive Maintenance Guidelines,* Office of Pavement Engineering, Columbus, May 2001.

Additional resources include a comprehensive manual of practice; the *Concrete Pavement Repair Manual* was issued by American Concrete Pavement Association (ACPA) in 2003 and is available from www.pavement.com.

American Concrete Pavement Association, *Diamond Grinding and Concrete Pavement Restoration,* Report TB008P, Skokie, Ill., 2000.

Purpose and Selection Criteria

The purpose of diamond grinding is to improve pavement smoothness and/or improve pavement surface friction. When used to improve pavement smoothness, diamond grinding is applied only to selected areas of the pavement. For example, to remove slab stepping (faulting), grinding can be applied to selected transverse joints. When used to improve pavement surface friction, diamond grinding is typically used over the entire pavement area.

Diamond grinding can remove up to ¾ in. from the pavement surface and can remove surface defects and irregularities such as polished or scaling surface and faulting, and improve pavement surface smoothness. When used to correct faulting, the faulting is expected to be relatively stable in terms of progression and typically does not exceed approximately ¼ in. Diamond grinding is often used as the penultimate treatment in a PCC rehabilitation project, done after load transfer restoration, and partial and full-depth repairs. The last treatment is for joint and crack resealing.

Diamond grinding will not address the underlying cause of pavement structural problems and is inappropriate for surfaces with material problems such as durability (D)-cracking or alkali-reactive aggregate.

Typical Service Life and Costs

The restoration of pavement surface friction by diamond grinding may last 5 to 12 years. Grinding to improve pavement smoothness on faulted slabs may last only a few years, particularly if the original faulting was progressing and the underlying reasons for the faulting were not addressed.

Typical cost of diamond grinding is in the range of $4 to $12 per square yard, depending on quantities and the hardness of the aggregate.

Materials and Construction

Diamond grinding employs a large drum, equipped with closely spaced diamond-tipped teeth, mounted on a moving heavy-set framework. The best results are achieved with continuous operation employing wide grinding drums. When several grinding passes are required to cover one traffic lane, the passes typically overlap by less than 2 in. The diamond grinding operation is carried out in the longitudinal direction, and preferably against the predominant direction of aircraft operations.

The spacing between the diamond-tipped saw blades is such that the ridges (or fins) left between the blades break readily, approximately 2 or 3 mm, depending on the strength of the concrete (Figure B1). If the ridges do not break off readily, the spacing between the blades can be reduced. Diamond grinding results in a characteristic corduroy texture with high pavement surface friction produced by the combination of smoothly cut channels and rough surface where the ridges have broken off.

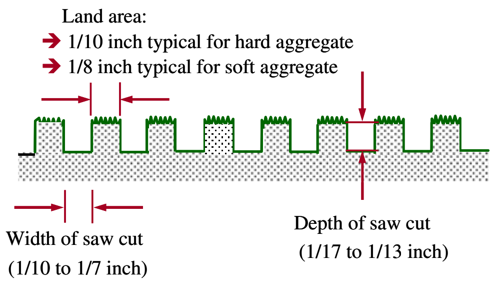


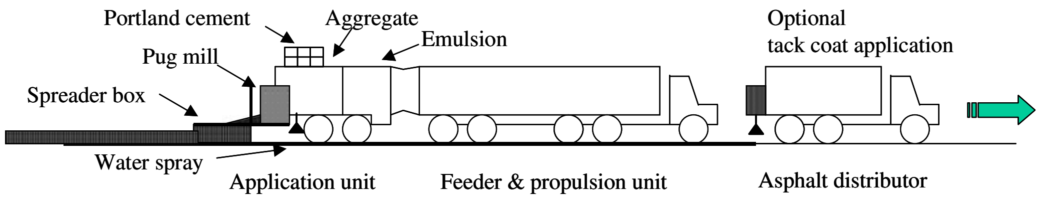
FIGURE B1 Profile of diamond-grooved surface. Improved pavement surface friction is provided by the land area created by the broken-off ridges.

Slurry resulting from the grinding operation (water is used to cool diamond-tipped blades and suppress dust) is continuously vacuumed and collected. Diamond grinding done only to improve pavement surface friction on relatively new pavements may not require resealing of joints. Grinding done to correct faulting on older pavements is typically followed up by joint resealing.

Airport Use

About 8% of airports surveyed use diamond grinding routinely, and approximately 46% of airports surveyed have tried using it. All airports that routinely use or have tried using diamond grinding rated its performance as very good or good.

Fact Sheet 3—Microsurfacing



Schematic of Microsurfacing Operation

Microsurfacing is an unheated mixture of polymer-modified asphalt emulsion, high-quality frictional aggregate, mineral filler, water, and other additives, mixed and spread over the pavement surface as a slurry. The construction of microsurfacing using a self-propelled truck-mounted continuous-feed mixing machine is illustrated by the schematic above.

The aggregate skeleton used for microsurfacing consists of high-quality interlocking crushed aggregate particles. Consequently, it is possible to place microsurfacing in layers thicker than the largest aggregate size, or in multiple layers, without the risk of permanent deformation.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, Apr. 2010.

Ohio Department of Transportation, *Pavement Preventive Maintenance Guidelines,* Office of Pavement Engineering, Columbus, May 2001.

Minnesota Department of Transportation, *Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements,* Report MN/RC–2009-18, Office of Materials and Road Research, Maplewood, May 2009.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

The International Slurry Surfacing Association (ISSA) maintains a website at www.slurry.org, which contains recommended specifications and useful guidance for microsurfacing (*Recommended Performance Guidelines for Micro-Surfacing,* A143).

Purpose and Selection Criteria

Microsurfacing is used to correct surficial distresses such as slight block cracking, raveling and segregation, flushing, and loss of pavement friction. Because microsurfacing contains high-quality crushed aggregate it is also used to fill in ruts and surface deformation to the depth of up to 1¾ in. Microsurfacing can also be used to extend the service life of the pavement until a more permanent restoration can be completed.

As a preventive maintenance treatment it can be used to seal the surface of the pavement, protecting the pavement from water infiltration and greatly reducing the rate at which the existing AC surface oxidizes. Microsurfacing is also used on PCC pavements to improve or maintain frictional resistance and smoothness.

Typical Service Life and Costs

When used to protect the existing pavement structure as a preventive maintenance treatment, microsurfacing can prolong pavement life span by 4 to 6 years. When used to restore or improve pavement surface; for example, to restore pavement friction or to repair wheel track rutting, microsurfacing can last 5 to 8 years.

The cost of one application of microsurfacing is approximately \$3 to \$6 per square yard, typically approximately 75% of the cost of a single hot-mix overlay.

Materials and Construction

Microsurfacing mix is always designed by a contractor or an emulsion supplier. Figure B2 shows a finished product a year after construction. The ISSA recommends two types of gradations, Type II and Type III. The Type II gradation is finer, with 90% to 100%

FIGURE B2 Microsurfacing texture one year after construction; diameter of the coin is 1 in.

passing a 4.75 mm sieve. The Type III gradation is coarser with 70% to 90% of aggregate passing the No. 4 sieve size, and can be used on runways. A minimum thickness of microsurfacing mix using Type III gradation is 0.4 in. for a single course.

The surface on which microsurfacing is applied is expected to have uniform pavement condition. Areas that exhibit significantly more severe defects than the remainder of the section (e.g., raveling, cracking, or rutting) are repaired. The repairs can by made using an additional course of microsurfacing or by other means depending on the type, extent, and severity of the defects. On high traffic volume facilities, and/or when the surface of the pavement has minor distortions and/or has ruts exceeding approximately ¼ in., two courses of microsurfacing are used. The first (scratch) course is intended to improve the profile of the pavement and the second course provides the wearing surface. Ruts exceeding ½ in. are typically filled with microsurfacing material using a rut-filling spreader box.

After the microsurfacing application, traffic can use the pavement without restrictions in about 45 to 120 minutes, depending on setting time of the asphalt emulsion, weather, and traffic conditions. Microsurfacing is typically carried out only during the warmer, dryer months. Cooler temperatures and wetter conditions can result in longer curing times during which the microsurfacing can be damaged by traffic.

Airport Experience

Microsurfacing can be used for both AC and PCC pavements. For AC pavements, only one airport surveyed used microsurfacing routinely, and two airports surveyed have tried using it. For PCC pavements, only one of the surveyed airports indicated use of microsurfacing.

Fact Sheet 4—Sealing and Filling Cracks in AC Pavement

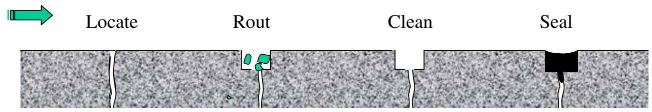


Illustration of Crack Routing, Cleaning, and Sealing

Crack sealing is a maintenance technique that cleans cracks and seals them with a rubberized bituminous compound. The crack sealing typically includes routing of the crack to create a reservoir for the sealant at the top of the crack, as shown in the illustration above. Crack sealing without routing is called crack filling. Crack filling is not as cost-effective as crack sealing and is easily damaged by snow plows. For this reason, this Fact Sheet concentrates only on crack sealing.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, April 2010.

Ohio Department of Transportation, *Pavement Preventive Maintenance Guidelines,* Office of Pavement Engineering, Columbus, May 2001.

Minnesota Department of Transportation, *Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements,* Report MN/RC–2009-18, Office of Materials and Road Research, Maplewood, May 2009.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

Michigan Department of Transportation produced a manual, *Sealing and Filling of Cracks for Bituminous Concrete Pavements, Selection and Installation Procedures,* which is available on CD and distributed by Foundation for Pavement Preservation, Austin, Tex. [Online]. Available: www.fp2.org.

A useful summary of information is available from *Crack Seal Application, Pavement Preservation Checklist Series,* Publication FHWA-IF-02-005, produced by the Foundation for Pavement Preservation, Austin, Tex. [Online]. Available: www.fp2.org.

UFC 3-250-08FA, *Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements.*

Purpose and Selection Criteria

The purpose of crack sealing is to prevent water from entering the pavement structure and damaging it. Crack sealing is most effective in a wet-freeze environment. It is applied to “working or active” cracks. These cracks change in width during the year because of temperature changes, and include both transverse cracks and longitudinal cracks. Figure B3 shows how water from melting snow enters the pavement through unsealed cracks. Infiltrated water, together with the effect of freeze–thaw cycles and pavement loads,

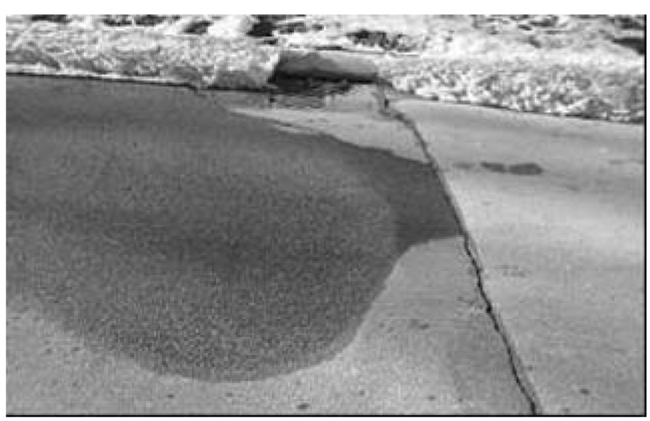


FIGURE B3 Water from melting snow readily enters pavement structure through a transverse crack.

FIGURE B4 Transverse crack heaving caused by water that saturated pavement structure and froze.

leads to heaving of the cracks (Figure B4) and to the deterioration of the pavement structure beneath the crack. The additional benefit of sealing is the prevention of spalling and raveling of unsealed crack edges.

Crack sealing is typically done soon after transverse and longitudinal cracks develop, often when the pavement is 2 to 5 years old. At that time, the crack pattern would be well-developed and the crack would reach the width of 0.1 to 0.4 in. at moderate temperatures. The initial crack sealing is typically followed by a second sealing carried out when new cracks appear or when the original sealant no longer works, often after another 3 to 5 years.

Crack sealing is most cost-effective for thick AC pavements. It is typically not cost-effective for thin AC pavements with the total thickness of the AC layer less than 3 in. Thin pavements tend to develop many secondary cracks that cannot be effectively sealed or filled.

Typical Service Life and Costs

The expected life of crack sealing is about 2 to 7 years. The crack sealing performance depends on the crack and pavement condition, sealant material, rout configuration, and construction procedures. Typical cost of rout-and-seal treatment is approximately $2 to $3 per linear yard.

Materials and Construction

There are many AC sealants on the market and their performance can differ significantly. Hot-poured rubberized bituminous sealants are most often used. Some agencies are not satisfied with the existing specifications for sealants (e.g., ASTM D6690 or AASHTO T187-60) and have modified them.

The reservoir for the sealant at the top of the crack is created by a router. The opinions regarding the size and shape of the most effective reservoir differ. It is generally agreed that routs with greater width than depth and a rectangular shape are preferable. The routed crack is typically cleaned before sealing.

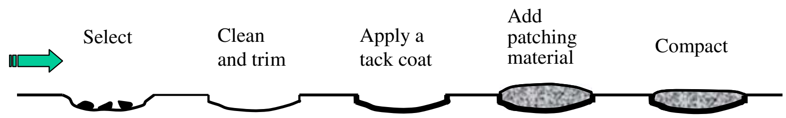
The sealant is heated in a double-jacketed kettle to avoid exposure of the sealant to direct heat. It is important to avoid overheating or re-heating the sealant, and dispersing the sealant into the crack by a device (a pump wand) that maintains the sealant at a desired temperature. Because the sealant shrinks after the installation and cooling, the hot sealant is installed “proud” of the surface.

Until the sealant hardens and there is no danger that it will be picked up by passing tires, it is covered by a bond-breaking material such as sawdust or flour. The use of cement or mineral dust is typically avoided. Occasionally, it is necessary to seal cracks wider than 30 mm. These cracks can be temporarily repaired by fine aggregate hot mix or liquefied patching materials similar to a slurry material.

Airport Use

Based on the survey, a majority of all airports routinely perform crack sealing using a hot-poured bituminous sealant. The majority of the airports surveyed reported good performance of crack sealing. Only a small minority of airports surveyed use cold-applied sealants routinely. The majority of airports surveyed rout cracks prior to sealing.

Fact Sheet 5—Small-Area Patching



The Sequence of Operations for Small Patching Repairs

Small-area patching is a maintenance treatment that includes placing and spreading of bituminous mixtures, hot or cold, to repair potholes and other pavement distresses without the use of mechanical pavers or graders. The illustration shows the sequence of operations. The patching with hot mix or cold mix can be used for both bituminous pavements and PCC pavements; however, permanent repairs of PCC pavements are typically done using PCC material. If pavers or graders are used, the treatment is called machine patching and is described on a separate Fact Sheet.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Additional resources include:

A useful manual of practice was issued by the Federal Highway Administration as Report FHWA-RD-99-168, *Materials and Procedures for Repair of Potholes in Asphalt-Surfaced Pavements: Manual of Practice,* and is available at www.tfhc.gov/pavement/ltpp/pdf/99168.pdf.

Several highway agencies have developed manuals for patching of AC pavements. One of the most comprehensive has been published by the Minnesota Technology Transfer Center, *Best Practices Handbook on Asphalt Pavement Maintenance,* Manual No. 2000-04, Minneapolis, 2000.

Purpose and Selection Criteria

Small-area patching is used to repair localized defects such as potholes, distortion resulting from utility cuts, and small areas with severe ravelling and/or alligator cracking. The repair of potholes such as the one shown in Figure B5 reduces pavement roughness and the rate of pavement deterioration by improving drainage and reducing dynamic traffic loads. The repairs may be permanent, semi-permanent, or temporary.

Permanent repairs—Permanent repairs are used on pavements that are in good condition to bring the life span of the repaired area in line with that of the rest of the pavement. Permanent repairs require the use of appropriate patching materials and techniques, with the goal of addressing the underlying cause of the defects being repaired. Unless the original cause for the pavement defects is corrected, the repairs are susceptible to early failure.

Semi-permanent repairs—Semi-permanent repairs have a typical life expectancy of one or two years. Usually, the area is not saw cut and may be repaired with cold mix.

Temporary repair—Temporary repairs are used to hold the pavement until it can be resurfaced or permanently repaired. They are also used as emergency repairs when the pavement condition may pose a hazard to airplane operations.

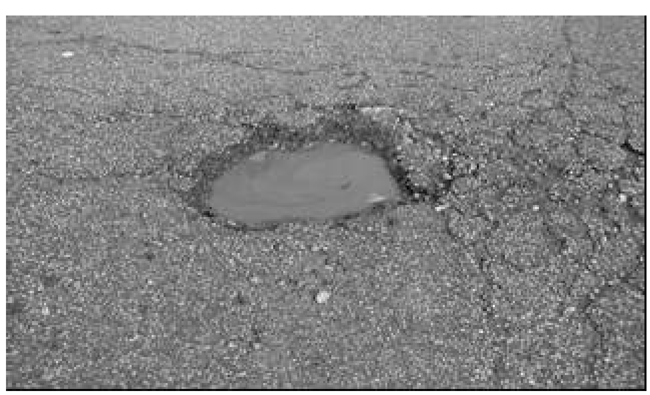


FIGURE B5 Untreated pothole collects water and accelerates pavement deterioration.

Typical Service Life and Costs

Temporary patching repairs may last one year or less; permanent repairs may last 10 years or more. The cost of small-area patching is highly dependent on the extent of the repairs and on the selection of patching material. A typical unit cost for small-area patching is $20 to $40 per square yard.

Materials and Construction

The main types of patching materials include hot mix, local or agency-specified cold mix, and proprietary cold mix. A tack coat, if used, is typically an emulsion diluted with additional water. Hot-mix AC patching material provides the most durable treatment. Some suppliers of proprietary cold patching mixes suggest that their products can achieve similar performance and that their products can be successfully applied to potholes containing water. Cold mixes with single-size aggregate may not perform well in relatively large repairs. The single-size aggregate mix has low stability and is susceptible to rutting and ravelling.

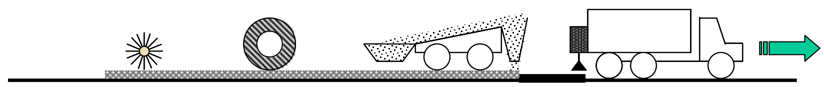
Typically, small-area *permanent* patching repair includes the following steps:

- Removal of broken pavement material in the patch area by jack hammering, cold milling, and/or pavement sawing.
- Cleaning out loose material from the patch area by blowing or brushing.
- Applying a tack coat to provide a bond between the existing pavement and the patching material.
- Placing the bituminous mix into the patch area. If the patch area is deeper than 2 in., the mix is placed and compacted in lifts until the level of the surrounding pavement is reached.
- Compacting the mix with a steel or rubber-tire roller, a vibratory plate compactor, or a hand tamper. Depending on the size and depth of the repair, and the material used, the finished repair will have crown of 0.1 to 0.4 in.
- Sealing the joint between the patch and the original pavement with hot-poured crack sealant. Sealing is typically done for larger and deeper repair areas.

Airport Experience

Patching is one of the most common pavement maintenance treatments. According to survey respondents, the majority of airports (that have AC pavements) routinely use small-area patching using hot mix and a minority of airports routinely use cold mix. None of the agencies surveyed reported poor performance of repairs using hot mix, whereas approximately 20% of agencies surveyed reported poor results using cold mix. A small minority of agencies surveyed routinely used a proprietary mix.

Fact Sheet 6—Spray Patching (Manual Chip Seal and Mechanized Spray Patching)



Schematic of Chip Seal Operation

Spray patching is a maintenance treatment that includes the application of bituminous material followed by spreading of cover aggregate. The technological sequence is shown in the above schematic. Spray patching can be done manually or by specialized self-propelled equipment that sprays an emulsion, applies the cover aggregate, and provides the initial compaction—all in one pass. Mechanized spray patching applied on the full-width of a facility, such as a taxiway, and that is longer than 100 ft, is called surface treatment. The *Catalog* contains a separate Fact Sheet for surface treatments.

Sources of Information and Additional Resources

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.
Asphalt Recycling and Reclaiming Association, *Basic Asphalt Recycling Manual,* Annapolis, Md., 2001.

Additional information includes:

U.S. Department of Transportation, *Pavement Preservation Compendium II,* Publication FHWA-IF-06-049, Sep. 2006.
InfraGuide 2005: Preservation of Bituminous Pavement Using Thin Surface Restoration Techniques, 2005 [Online]. Available: http://gmf.fcm.ca/Infraguide/Roads_and_Sidewalks.asp.

Purpose and Selection Criteria

Spray patching is used to slow down pavement deterioration of vulnerable localized areas or to repair localized pavement distresses such as ravelling, flushing, and block cracking. A properly applied spray patching produces an all-weather surface that seals the pavement surface, prevents or retards propagation of surficial distresses, and can provide improved surface friction. The use of spray patching to repair or slow down the progression of transverse or longitudinal cracks is not considered to be cost-effective.

Manual spray patching is suitable for localized repairs. Machine patching is typically used to repair large areas that do not require full-width coverage.

Typical Service Life and Costs

The typical life span of spray patching is 2 to 5 years. A typical cost of spray patching is in the range of $3 to $8 per square yard, depending primarily on the quantity of work.

Materials and Construction

Manual spray patching employs a variety of bituminous products (applied hot or cold) and aggregates (chips, graded aggregate, or sand). Typically, bituminous products used for spray patching are emulsions heated to less than 185°F.

Aggregate used for mechanized spray patching is typically open-graded (chips). Aggregate used for manual patching can be dense or open-graded with a typical maximum aggregate size of approximately ½ in. Sand is also used.

Manual application of emulsion is done with a hand wand or a spray bar. Cover aggregate is applied immediately after spraying emulsion. Compaction with truck tires or rubber-tired rollers follows. Generally, after compaction, 75% of the height of the aggregate particles is imbedded in the emulsion.

The procedure for manual spray patching typically consists of the following steps:

- Removal of all loose material and debris.
- Spraying of an emulsion in a uniform manner.
- Application of aggregate to obtain even coverage.

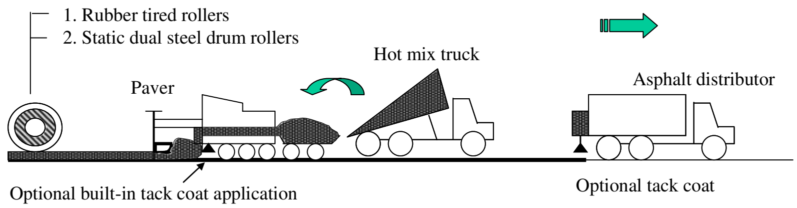
- Compaction; wheels of the truck used to supply the cover aggregate can be used for compaction.
- Sweeping off loose aggregate around and over the patch.

Spray patching is generally carried out only during the warmer, dryer months. Cooler temperatures and wetter conditions prolong setting (hardening) of the emulsion and the time the repairs are susceptible to damage by traffic.

Airport Experience

Spray patching used to be one of the key maintenance treatments for AC pavements. However, the usage of manual spray patching has been declining. Only a few airports surveyed routinely use spray patching or have tried it.

Fact Sheet 7—Machine Patching of AC Pavement Using Bituminous Materials



Schematic of Machine Patching Operation

Machine patching of AC pavements is a maintenance technique that involves placing and spreading of premixed bituminous materials (hot or cold mix) using a mechanical paver or a grader on parts of a pavement section. As shown in the illustration, machine patching includes the application of tack coat, placement of the patching material, and compaction.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Additional resources includes:

SHRP H 348: Asphalt Pavement Repair Manuals of Practice, Materials, and Procedures for the Repair of Potholes in Asphalt-Surfaced Pavements, Strategic Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., 1993.

Purpose and Selection Criteria

Typical applications of machine patching include repairs of localized areas of ravelling and segregation, alligator cracking, potholing, rutting, frost heaving, and subgrade settlement. The areas selected for patching are expected to be well-defined and separated by areas that are in good condition. If the areas requiring patching are closely spaced, it may be more cost-effective to resurface the entire section.

Machine patching repairs can be divided into permanent and semi-permanent repairs:

Permanent repairs—Permanent patching repairs can be used on pavements that are in good condition to bring the life span of the repaired area in line with that of the rest of the pavement. For example, if it is expected that the pavement being repaired will require resurfacing in 8 years, the patching repair could be done to also last approximately 8 years.

Semi-permanent repairs—Semi-permanent repairs have a limited life expectancy and are used typically when it is anticipated that the entire pavement will be resurfaced within a few years. To save costs, the extent of patching is limited and the patched area may not receive a tack coat.

Typical Service Life and Costs

Permanent repairs may last 5 to 12 years or more; semi-permanent repairs may last approximately 5 years or less. A typical cost of machine patching is $10 to $25 per square yard.

Materials and Construction

For permanent repairs, the same type of hot mix may be used for patching as that used for the surface of the existing asphalt pavement. Typically, permanent machine patching includes the following steps:

- *Structural repairs*—If the patch is over an area exhibiting structural weakness (e.g., alligator cracking, rutting, or depression and settlement) it may be necessary to remove some or all of the underlying base and subbase material. The granular base is restored and re-compacted. The additional pavement strength, if required, is achieved by replacing some part of the granular material with AC to avoid increasing the overall thickness of the pavement structure.
- *Removal of the deteriorated AC layer by milling*—Milling may be required to maintain pavement elevation or to provide a smooth transition between the original pavement and the patch. Figure B6 shows a construction detail for the start of a long patch.

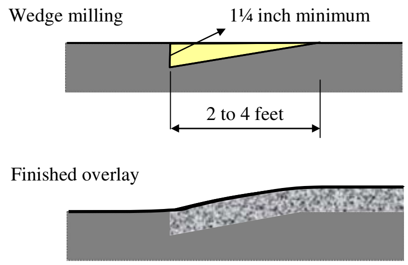


FIGURE B6 Wedge milling to key in a 1¼-in.-thick AC patch.

- Application of a tack coat at the sides of the patch and over the entire patched area to improve the bond between the original pavement and the patch, and to minimize water infiltration.
- Placing of the mix. The placement is done by a paver. The material is placed in layers not exceeding 3 in. The minimum thickness of a permanent machine-placed patch is typically 1¼ in.
- Compaction of the patch area using rollers.
- Application of a sealant at the joint of the patch and the existing pavement. Resealing the joint if it opens in a few years.

Airport Experience

About one-half of all survey respondents routinely use or have tried using machine patching. A large majority of respondents reported very good or good performance.

Fact Sheet 8—Restorative Seals

Schematic of Restorative Sealing Operation

Restorative seals consist of an application of a bituminous or coal-tar material, typically emulsion-based, to the surface of AC pavement as illustrated by the schematic. Restorative seals are also called rejuvenators or fog seals. Some agencies or suppliers recommend light sanding of fog seals (approximately 1 lb of sand per square yard).

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Minnesota Department of Transportation, *Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements,* Report MN/RC-2009-18, Office of Materials and Road Research, Maplewood, May 2009.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

Shoenberger, J.E., "Skid Resistance of Rejuvenated Airfield Pavements," *Proceedings of the 27th International Air Transportation Conference, Advancing Airfield Pavements,* American Society of Civil Engineers, Reston, Va., 2007.

Engineering Technical Letter 03-8, *Rejuvenation of Hot-Mix Asphalt* (*HMA*) *Pavements,* Dec. 2003.

Boyer, R. and D.I. Hanson, *Non-Coal-Tar Fuel Resistant Sealers and HMA Systems: State-of-the-Practice,* prepared for Airfield Asphalt Technology Program Project 05-02, May 2008.

Purpose and Selection Criteria

Restorative seals can serve one or more of following three purposes:

To seal the surface—Restorative seals can reduce penetration of water by sealing small cracks and porous pavement surfaces. Restorative seals can slow the progression of raveling and coarse aggregate loss, and have been used shortly after paving to seal areas with low to moderate segregation. The sealing can also slow down oxidation and hardening of AC.

To rejuvenate oxidized and hardened asphalt binder—Restorative seals used primarily to revitalize the surface of the AC pavement are called rejuvenators. Rejuvenators are intended to penetrate the surface of the AC pavement and reverse the oxidation and hardening process in the AC. The depth of penetration is usually only 0.1 to 0.2 in. Rejuvenators do not leave much residual material on the surface and can be re-applied.

To provide protection against fuel spills and oil leak—Aircraft fuels and lubricants are chemically compatible with AC, can dissolve it, and degrade the surface of AC pavements. Restorative seals that are not compatible with AC can provide protection from the damaging effects of fuel spills and oil leaks.

Typical Service Life and Costs

A restorative seal is a temporary fix generally lasting 1 to 3 years. The cost can range from \$0.5 to \$2 per square yard.

Materials and Constructions

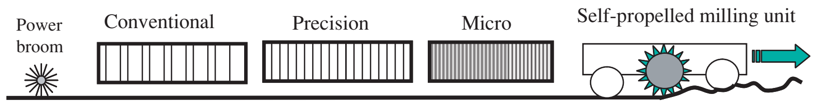
Restorative seals designed to seal the pavement surface use slow or medium setting asphalt emulsion further diluted with water. Aggregate, if applied to provide better pavement friction, is typically medium to fine sand with the particle size of less than 0.05 in. Restorative seals designed to function as rejuvenators or as rejuvenators/sealers contain proprietary materials that may contain solvents. Restorative seals for the protection against fuel spills and oil leaks are typically coal-tar sealers—an emulsion of coal tar stabilized with clay. Acrylic-modified bituminous emulsions can also increase protection against fuel spills.

Restorative seals are sprayed on the pavement surface by distributors. Asphalt emulsion is typically heated to about 175°F before the application to pavement that is in good condition and has been broomed before the restorative seals are applied. With correct application rates, and in some instances the use of sand, restorative seals can generally provide satisfactory levels of pavement friction.

Airport Experience

About one-half of the airports surveyed routinely use or have used restorative seals, and a large majority of the users reported very good or good performance.

Fact Sheet 9—Texturization Using Fine Milling



Schematic of Milling Operation

Texturization techniques using milling include conventional milling, precision milling, and fine milling. Milling is done by a cylindrical milling drum with closely spaced carbide-tipped tools (teeth). The techniques differ by the spacing of the cutting teeth, as shown on the above illustration, and by the degree of control over the profile of the milled surface. Fine milling, also called micromilling, removes unevenness from the pavement surface or improves its texture, and leaves an abraded surface that can be used as a driving surface.

Sources of Information and Additional Resources

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

The *Basic Asphalt Recycling Manual* by the Asphalt Recycling and Reclaiming Association provides guidelines for milling and other texturization techniques.

Hall, K.L., J.W. Smith, and P. Littleton, *NCHRP Report 634: Texturing of Concrete Pavements,* Final Report, Nov. 2008, Transportation Research Board of the National Academies, Washington, D.C., Nov. 2008, 97 pp.

Purpose and Selection Criteria

Fine milling can improve pavement smoothness and pavement friction. Smoothness is improved by milling of protruding pavement features such as bumps, stepping (faulting) at transverse cracks, and rutting. If the pavement has sufficient structural capacity, the reduction in thickness is not of concern.

Figure B7 shows an example of pavement surface where micromilling was used to reduce rutting and roughness.

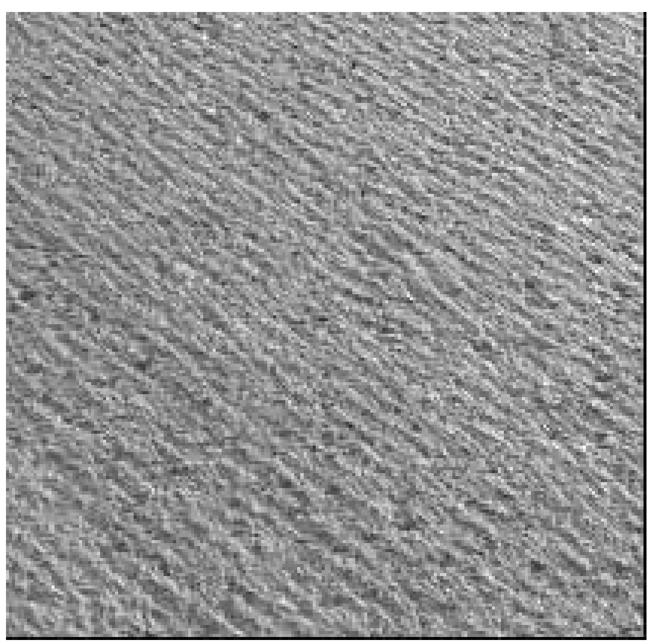


FIGURE B7 The milled surface has grooves with the peak-to-peak distance of approximately 0.6 in.

Typical Service Life and Costs

The expected service life of texturization using fine milling is 1 to 7 years. A typical cost is approximately $4 to $12 per square yard.

Materials and Construction

Milling is a general term used to describe the removal of the surface of AC or PCC materials from pavements by a self-propelled unit having a cutting drum equipped with closely spaced carbide-tipped tools. Micromilling and precision-milling are types of milling that strive to provide a more even platform for an overlay and/or a finished pavement surface. Micromilling and precision-milling operations are also called fine milling. The following definitions of micromilling and precision milling are not universally accepted and are provided for orientation purposes only.

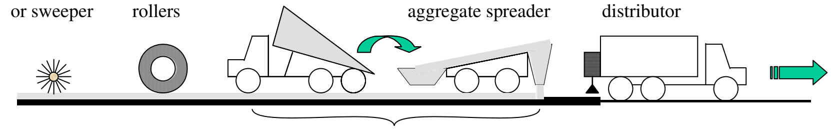
Micromilling—Typically, the depth of micromilling is up to 0.6 in. and results in a surface texture depth of about 0.04 in. with the groove-to-groove spacing of 0.2 in. Such surface does not need an overlay.

Precision milling—Typically, the depth of precision milling is up to 1 in. and results in a surface texture depth of approximately 0.2 in. A precision-milled surface is usually overlaid.

Airport Use

A small minority of airports surveyed routinely use or have used fine milling. In addition, one responding airport reported using transverse grooving of the AC surface to improve pavement friction.

Fact Sheet 10—Surface Treatment (Chip Seal, Chip Seal Coat)



Schematic of Surface Treatment Construction Process

Surface treatment (also known as surface seal, seal, and chip seal) is the application of asphalt binder, immediately followed by an application of cover aggregate, to any type of pavement surface. A typical construction process is shown in the schematic. If the aggregate is of uniform size, the treatment is usually called chip seal. Typically, surface treatments are applied on top of a granular base producing surface-treated pavement. Surface treatments can be also applied to AC pavements as a preventive or corrective maintenance treatment.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, Apr. 2010.

Ohio Department of Transportation, *Pavement Preventive Maintenance Guidelines,* Office of Pavement Engineering, Columbus, May 2001.

Minnesota Department of Transportation, *Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements,* Report MN/RC-2009-18, Office of Materials and Road Research, Maplewood, May 2009.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

Several agencies have published guidelines for the design and construction of surface treatments including the Minnesota Department of Transportation (Janish, D.W. and F.S. Gaillard, *Minnesota Seal Coat Handbook,* Office of Research Services, St. Paul, 1998).

A recent NCHRP Synthesis of Highway Practice provides practical guidelines for the construction of surface treatments (Gransberg, D. and D.M.B. James, *NCHRP Synthesis of Highway Practice 342: Chip Seal Best Practices,* Transportation Research Board of the National Academies, Washington, D.C., 2005).

Purpose and Selection Criteria

Surface treatments applied on top of AC pavements can be used as preventive or corrective treatments. As a preventive measure, surface treatment is primarily used to seal the surface showing non-traffic-load associated cracks and ravelling. As a corrective measure, surface treatment is used to restore frictional resistance and to maintain wearing surface on AC pavements. Surface treatments using polymer-modified emulsions have been used as crack relief layers between the existing AC surface and an AC overlay, or as stress relief layers between the existing PCC surface and an overlay.

Typical Service Life and Costs

When used to protect the existing pavement structure as a preventive maintenance treatment, surface treatment can prolong pavement life span by 4 to 6 years. When used to restore or improve pavement surface; for example, to restore pavement friction, surface treatment can last 5 to 8 years. The cost of a single surface treatment is approximately \$2 to \$4 per square yard.

Materials and Construction

The surface on which surface treatment is applied is expected to have a uniform capacity to absorb emulsion. Active cracks, such as transverse and longitudinal cracks, can be sealed prior to application of the surface treatment.

Typically, the asphalt binder used for surface treatment is asphalt emulsion applied at an elevated temperature (120°F to 180°F) using an asphalt distributor. The cover aggregate can be either chips (open-graded aggregate) or dense-graded as shown in Figure B8.

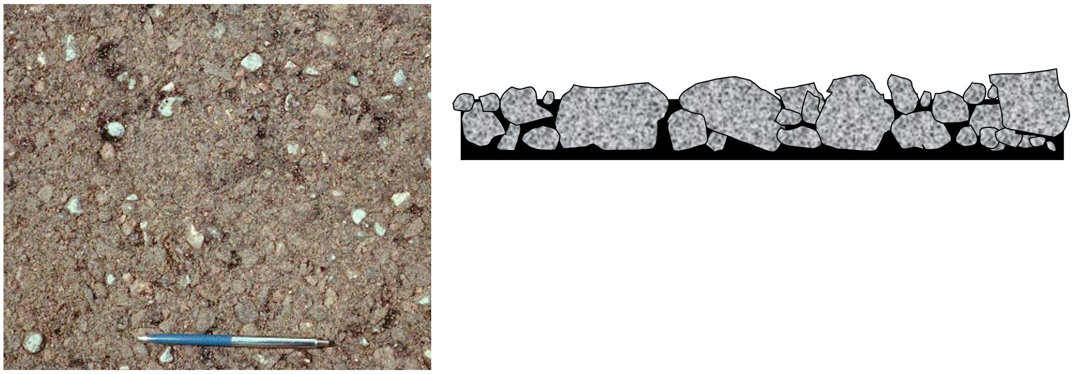


FIGURE B8 Surface of a newly constructed surface treatment using 5/8-in.-dense-graded aggregate and high-float emulsion.

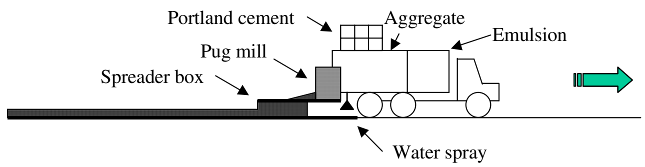
About 70% of the aggregate is typically imbedded or surrounded by the binder. The need for accurate application of the binder and aggregate cover is facilitated by modern asphalt distributors, which can automatically maintain selected application rates regardless of the distributor speed. Newly constructed surface treatments need to be protected from traffic for several hours after construction.

Emulsion application rates for seal coats typically range from 0.2 to 0.4 gallon per square yard depending on the existing surface (granular, seal coat, or AC) and aircraft operations, and are further adjusted during construction according to weather conditions and other factors.

Airport Use

A small number of the surveyed airports indicated routine use of surface treatments, or have tried them. However, the majority of responding airports that routinely use or have used surface treatment rated its performance as good. Some of the reasons reported for low usage of surface treatments by airports are probably concerns about loose aggregate, dust, and rougher surface texture.

Fact Sheet 11—Slurry Seal



Schematic of Slurry Seal Construction

Slurry seal is an unheated mixture of asphalt emulsion, graded fine aggregate, mineral filler, water, and other additives, mixed and uniformly spread over the pavement surface as slurry. The construction of slurry seal using a self-propelled truck-mounted mixing machine is illustrated by the above schematic. Slurry seal systems are formulated with the objective of creating a bitumen-rich mortar. They are similar to microsurfacing, but the mineral skeleton is typically not very strong and has limited interlocking of the aggregate particles. Consequently, slurry seals are applied in thin lifts to avoid permanent deformation by traffic.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication No. FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

The ISSA maintains a website, www.slurry.org, that contains recommended specifications for slurry seal [International Slurry Surfacing Association, *Recommended Performance Guidelines for Microsurfacing,* Document ISSA A143 (revised), 2005].

Engineering Brief No. 35A, SEP 27 1994, *Thermoplastic Coal-Tar Emulsion Slurry Seal,* Amended Interim Specification, Federal Aviation Administration, Washington, D.C.

Purpose and Selection Criteria

Slurry seals are used to correct surficial distresses such as raveling and coarse aggregate loss, seal slight cracking, and improve pavement friction. They are also used as a preventive maintenance treatment to seal pavement surfaces from intrusion of water and slow surface oxidation and ravelling. Slurry seals are best placed on structurally sound pavements that are in good condition with little or no cracking or rutting.

Slurry seals perform best on surfaces with uniform characteristics. If defects such as moderate or severe ravelling, cracking, or rutting occur frequently, the section is probably not a good candidate for slurry sealing. Working cracks, such as transverse cracks, can be sealed either before or after the slurry seal application.

Typical Service Life and Costs

When used as a preventive maintenance treatment, slurry seal can prolong pavement life span by 3 to 6 years. When used to restore or improve pavement surface characteristics, for example to restore pavement friction, slurry seals can last 3 to 7 years. The cost of slurry seal is approximately $2 to $4 per square yard, typically less than half of the cost of a hot-mix overlay.

Materials and Construction

Asphalt emulsion used in slurry seals is typically cationic and contains about 60% to 65% of residual AC. The slurry mix contains 9% to 10% of AC. Coal tar-based emulsions that provide protection against fuel spills and oil leaks are also available in some markets.

Aggregate used for slurry seals is crushed high-quality dense-graded aggregate. Its gradation generally follows one of the three gradation types, Type I, II, or III, recommended by the ISSA. Type II gradation can be used for aprons and low-volume taxiways and Type III gradation for runways. Type III gradation has 70% to 90% of aggregate passing No. 4 sieve.

Mineral filler, typically portland cement or hydrated lime, is used to control curing time of the mix (break time of the emulsion). The amount of mineral filler is typically less than 1% of the total dry mix weight. The thickness of a slurry seal application is slightly more than the thickness of the largest aggregate particle in the mix, typically approximately 0.4 in.

Some proprietary slurry seal mixes contain crushed aggregate particles and polymer-modified emulsion and may have strength and durability characteristics that are closer to a microsurfacing than to a traditional slurry seal.

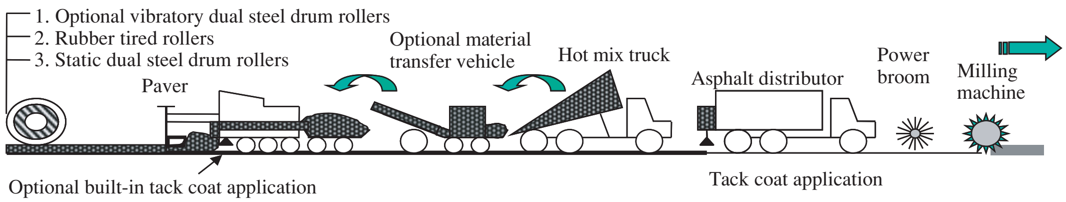
The slurry seal mixture is supplied using a specialized equipment that carries all of the components of the mixture, accurately measures and mixes them in a pug mill, and spreads the mixture (by means of a spreader box linked to the mixing unit) in a strip 10 to 12 ft wide as a thin, homogeneous coat of slurry mix.

Slurry seals are typically carried out only during the warmer, dryer months. After the slurry seal application, traffic can use the pavement without restrictions (except 360 degree turns by aircraft) in approximately 45 to 120 min, depending on setting time of the asphalt emulsion, weather condition, and traffic conditions. Cooler temperatures and wetter conditions can result in long curing times during which the slurry seal can be damaged by traffic.

Airport Experience

A small number of surveyed airports reported the use of slurry seals routinely, or have tried using them. The majority of responding airports that use slurry seals reported very good or good performance.

Fact Sheet 12—Hot-mix Overlay of AC Pavement



Schematic of Hot-Mix Overlay Construction Process

Hot-mix overlay of AC pavement consists of placing a layer or layers of hot mix over the existing AC surface. The above illustration shows the construction of an overlay including milling of the pavement surface, application of a tack coat, and the use of a material transfer vehicle.

Conventional AC overlays are usually constructed with a minimum thickness of 1½ in. Overlays that are less than 1½ in. thick are called thin overlays and typically require special construction provisions.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, Apr. 2010.

Ohio Department of Transportation, *Pavement Preventive Maintenance Guidelines,* Office of Pavement Engineering, May 2001.

Minnesota Department of Transportation, *Preventive Maintenance Best Management Practices of Hot Mix Asphalt Pavements,* Report MN/RC-2009-18, Office of Materials and Road Research, Maplewood, May 2009.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication No. FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Another useful manual on the construction of asphalt overlays is from the Asphalt Institute (*Asphalt Overlays for Highway and Street Rehabilitation,* Manual Series No. 17, Lexington, Ky., 1998).

Purpose and Selection Criteria

Overlays are used to restore pavement serviceability by improving ride quality and providing a new waterproof surface that covers cracking, ravelling, rutting, polished pavement surface, and other pavement defects. Overlays are also used as a preventive maintenance treatment to seal pavement surfaces from intrusion of water, slow surface ravelling, seal small cracks, and improve surface friction.

Overlays can be used to strengthen the pavement structure to accommodate increased pavement loads. In this case, overlay thickness is determined by appropriate pavement design procedures.

Single overlays are typically constructed over structurally sound pavements. Areas that exhibit weakness (e.g., settlement, alligator cracking, and rutting) can be strengthened by patching or even by full-depth repairs. Some agencies rout and seal cracks in the existing AC pavement before placing an overlay, and carry out full-depth repairs of deteriorated transverse cracks.

Typical Service Life and Costs

Hot-mix overlays have an expected service life of 7 to 12 years depending on overlay thickness, traffic loads, existing pavement condition, environment, and material and construction quality. A typical cost of constructing an AC overlay is in the range of \$60 to \$90 per ton of material placed. For a 2-in.-thick single overlay, the corresponding cost is approximately \$6 to \$9 per square yard.

Materials and Construction

There are many variations in the material of hot mix. Some of the common variations are outlined in the following.

Dense-graded and open-graded mixes—The two main types of hot mix used for overlays are dense-graded and open-graded mixes. Dense-graded mixes have aggregate particles that are fairly uniformly distributed. Open-graded mixes contain a large percentage of one-size coarse aggregate resulting in a mix with interconnected voids and high permeability. Open-graded mixes provide good pavement friction and reduce the potential for hydroplaning (Figure B9).

FIGURE B9 (*Left*) Thin open-graded hot-mix overlay surface; (*Right*) Dense-graded overlay surface. Diameter of the coins is 0.7 in.

Virgin or recycled mixes—The use of recycled material in hot mix is common, particularly for a binder course. For surface courses on runways, the use of virgin materials is usually specified.

Superpave—Introduced in 1992 to the highway industry, the Superpave system represented a new system for designing AC mixes. The Superpave system includes the use of performance-graded asphalt binder specifications and Superpave mix design procedures.

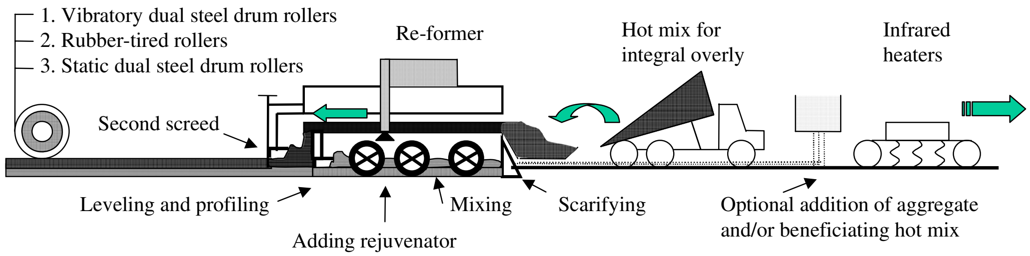
Fuel resistant mixes—There are currently two proprietary hot mixes on the U.S. market that are designed to resist degradation caused by aircraft fuel spills and leaks of lubricants and hydraulic oils. In general, lower air voids and stiffer AC increase the fuel resistance of the mix.

The existence of distresses such as ravelling, segregation, and cracking may dictate partial-depth removal (cold milling) of the AC prior to resurfacing. Partial-depth removal is normally accomplished using cold milling equipment. Grade-controlled precision milling may also be used to restore longitudinal and cross-sectional pavement profile and to improve smoothness of the subsequent overlay. The reclaimed asphalt pavement material may be reused as hot or cold mix or mixed with granular material. A tack coat is typically used before placing an overlay. A tack coat is a typically slow or medium setting asphalt emulsion diluted with water.

Airport Experience

A majority of surveyed airports routinely use or have tried using hot-mix overlays with or without prior milling, and nearly all surveyed airports reported very good or good performance. No responding airports reported using thin overlay (with thickness of less than 1½ in.).

Fact Sheet 13—Hot In-Place Recycling of AC Pavement



Schematic of Hot In-Place Recycling Process

Hot in-place recycling (HIR) is a pavement rehabilitation method that involves reprocessing of the existing AC material in-place at temperatures normally associated with hot-mix AC paving. The illustration above shows the construction of HIR with an integral overlay using a reformer.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

The 1997 FHWA publication *Pavement Recycling Guidelines for State and Local Governments* (Report FHWA-SA-98-042, National Technical Information Service, Springfield, Va.) describes all aspects of recycling of asphalt pavement materials to produce new pavement materials.

Button, J.W., D.N. Little, and C.K. Estakhri, *Synthesis of Highway Practice 193: Hot In-Place Recycling of Asphalt Concrete,* Transportation Research Board, National Research Council, Washington, D.C., 1994.

Taylor, M. and E. Dillman, "Airport Saves with Hot-in-place Recycling," *Public Works,* Vol. 19, No. 10, 1999.

Purpose and Selection Criteria

HIR is suitable for structurally sound pavements with surface defects, such as raveling and segregation, cracking, and rutting that affect mainly the top pavement surface layer. An additional requirement is that the AC surface layer is suitable for recycling, has a uniform composition (aggregate gradation, asphalt content, and thickness), and materials of good quality (aggregate and asphalt binder). Material properties of pavements considered for HIR are thoroughly evaluated. Because of the size of a recycling train, HIR is suitable for large projects with room to maneuver.

Typical Service Life and Costs

The success of HIR depends on the properties of the existing materials, quality and quantity of new materials added, quality of construction, and the thickness and type of the surface layer placed on top of the HIR mix. Consequently, the expected service life can range from about 5 to 12 years. Overall, HIR pavements can perform comparably to conventional asphalt surfaces.

A typical cost of a hot-in-place recycling layer is in the range of $5 to $10 per square yard.

Materials and Construction

There are other types of HIR processes and equipment in addition to the process illustrated above. Typical HIR construction consists of the following steps:

- *Heating of the existing AC surface*—Several methods are available including infrared heating panels, flame burners, and microwave heating.
- *Pavement scarification*—The depth of scarification is usually limited (by the capacity of the heaters) to the top 2¼ in. of the AC surface.

- *Adding new materials and mixing*—Depending on the properties of the existing AC material, the added new materials may include a combination of rejuvenating agents and (hot) aggregate, or the addition of a beneficiating hot mix. The objective is to compensate for deficiencies in the asphalt material to be recycled.
- *Levelling and reprofiling of the recycled mix*—Some improvement can be made to the pavement profile. Addition of new AC overlay is necessary to make significant corrections to profile.
- *Placement of a thin hot-mix layer* (*optional*)—Some HIR recycling equipment can add new hot-mix material on top of the recycled mix as an integral overlay. The thickness of the integral overlay is typically 1¼ in. The total thickness of the recycled and new mix is typically up to 3 in.
- *Compaction*—Standard compaction procedures utilizing vibratory steel drum rollers, rubber tired rollers, and static steel drum rollers are employed.

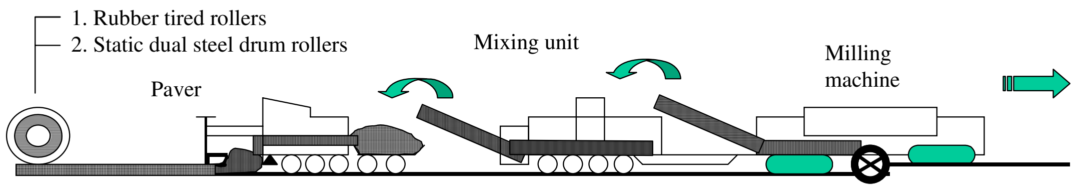
The resulting recycled layer can be used as a wearing surface or can be protected by a slurry seal, surface treatment, or a hot-mix overlay. If an integral overlay is used, the overlay serves as the wearing surface.

HIR is typically carried out only during the warmer, dryer months. Cooler temperatures and wetter conditions can result in longer heating times leading to the overheating and burning of the pavement surface, and creating smoke and vapors. Cooler ambient temperatures can also result in lower mix temperatures leading to an insufficient depth of scarification, fracturing aggregate during scarification, and poor compaction of the mix.

Airport Experience

None of the airports surveyed used hot-in-place recycling. However, hot-in-place recycling has been used for the rehabilitation of runways.

Fact Sheet 14—Cold In-Place Recycling of AC Pavement



Schematic of Cold Recycling Process

Cold in-place recycling (CIR) is a pavement rehabilitation method that involves reprocessing of an existing hot-mix asphalt pavement at ambient temperatures, either in-place or in an off-site processing plant, and laying it back down. The illustration above shows the construction of CIR. The recycled AC layer is typically covered by a hot-mix overlay.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

The 1997 FHWA publication *Pavement Recycling Guidelines for State and Local Governments* (Report FHWA-SA-98-042, National Technical Information Service, Springfield, Va.) describes all aspects of recycling of asphalt pavement materials.

The FHWA also maintains a web page on "Cold In-place Recycling State of Practice Review" at: http://www.fhwa.dot.gov/Pavement/recycling/cir/.

Purpose and Selection Criteria

CIR is a suitable pavement rehabilitation treatment for thick AC pavements in poor condition exhibiting extensive severe cracking, rutting, or other distresses. CIR mix helps to retard reflection cracking. CIR can also be used for pavements that require increased structural strength. In this case, the additional strength is achieved primarily by an overlay atop the CIR layer.

Candidate pavements for cold-in place recycling are thoroughly evaluated and the properties of the existing AC determined. Because of the size of a recycling train, CIR is suitable for large projects with room to maneuver.

Typical Service Life and Costs

CIR with an appropriate hot-mix overlay provides a service life of 10 years or more. In situations where the surface layer atop the CIR mix is a surface treatment, the expected service life is lower. A typical cost of a 4-in.-thick cold recycled AC pavement is about $9 to $16 per square yard.

Materials and Construction

Cold recycling can be classified by the location where the recycling takes place as:

- *Cold in-place recycling* (*CIR*)—All asphalt pavement material processing is completed in situ. CIR is faster and environmentally preferable because of the reduced need to transport materials.
- *Cold central plant recycling* (*CCPR*)—Reclaimed asphalt pavement is hauled to a plant site and stockpiled. Subsequently, it is processed (crushed, screened, and mixed with additives), transported to the job site, and placed and compacted.

CIR can also be classified by the type of the asphalt added to the recycled mix:

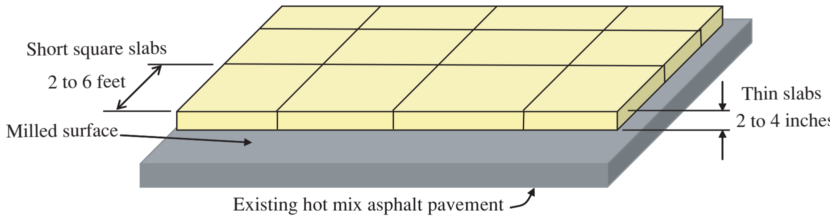
- *Addition of emulsified asphalt*—Traditionally, asphalt emulsion is used to bind the mix. Polymer-modified asphalt emulsions or polymer-modified high-float emulsions are also used. The total amount of emulsion and water is approximately 4%, the emulsion alone being approximately 1.5%. Because of the added water, the resulting mix requires a minimum 14 days of curing before the mix can be sealed (overlaid). During this time, the exposed CIR mix can be damaged by traffic. CIR using emulsi-

fied asphalt is typically carried out only during the warmer, dryer months. Cooler temperatures and wetter conditions can result in long curing time during which the cold mix is susceptible to moisture intrusion and abrasion by traffic.
- *Addition of expanded* (*foamed*) *asphalt*—Although the addition of expanded asphalt can be done in-place or off-site, it is typically done in-place. The resulting material is called cold in-place recycled expanded asphalt mix (CIREAM). CIREAM allows a hot-mix surface course to be placed after only two days of curing. Expanded asphalt mix is less susceptible to environmental conditions than emulsion mix.

Airport Experience

Only one surveyed airport reported a routine use of cold-in-place recycling. However, the use of CIR is relatively frequent for the rehabilitation of runways and taxiways on small airports.

Fact Sheet 15—Ultra-thin Whitetopping of AC Pavement



Ultra-thin Whitetopping Pavement Rehabilitation Method

Ultra-thin whitetopping (UTW) of AC pavements is a rehabilitation method where a thin layer of PCC (2 to 4 in. thick) is bonded to the milled AC pavement to form a composite pavement structure with a new wearing surface. UTW uses short square slabs, typically from 2 and 6 ft, as shown in the above illustration.

If the thickness of the PCC overlay is more than 4 and less than 8 in., whitetopping is usually called thin whitetopping; if the thickness exceeds 8 in., it is called conventional whitetopping.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Additional resources include:

ACPA-issued, comprehensive *Construction Specification Guidelines for Ultra-thin Whitetopping* (IS120).

Rasmussen, R.O. and D.K. Rozycki, *NCHRP Synthesis of Highway Practice 338: Thin and Ultra-Thin Whitetopping,* Transportation Research Board of the National Academies, Washington, D.C., 2004.

Saeed, A., M.I. Hammons, and J.W. Hall, "Design, Construction, and Performance Monitoring of Ultra-Thin Whitetopping at a General Aviation Airport," *Proceedings of the 27th International Air Transportation Conference,* 2007.

Purpose and Selection Criteria

UTW can be used to rehabilitate AC runways, taxiways, and aprons. It has also been successfully used to mitigate rutting of AC pavements, block cracking, and fuel spill damage, and to increase structural capacity of pavements.

The surface of the existing pavement is cold milled to remove the deteriorated AC pavement. The milled surface also enhances the bond between the new PCC overlay and the existing AC pavement. The objective is to provide a sound platform for the PCC slab with a minimum thickness of AC pavement after milling of at least 4 in. A thorough engineering analysis is performed to ensure the suitability of a UTW overlay. Severe distresses (such as frost heaving and subgrade settlement) are repaired full depth prior to the placement of UTW. UTW placed on a thick cracked AC layer may result in reflection cracking of PCC slabs.

Typical Service Life and Costs

Preliminary results suggest life spans of 10 years or more. The typical cost of a UTW is estimated to be in the range of $12 to $18 per square yard.

Materials and Construction

PCC mixes used in UTW overlays are typically high early-strength mixes and generally contain fibers such as polyolefin and polypropylene. Fibers are expected to increase tensile strength of the mix and improve its resistance to shrinkage and fatigue cracking.

The construction of UTW consists of the following steps:

Pre-overlay repair—Localized repairs may be required to obtain uniform support for UTW.

Surface preparation—Milling of the existing AC is essential for the good performance of the UTW overlay. Milling removes deteriorated AC and provides a roughened surface that enhances the bond between the remaining AC and the new PCC surface, thereby creating an integrated pavement layer. Milling is followed by cleaning to remove all debris and any slurry resulting from milling. The typical predominant defect of UTW overlays is corner cracking attributed to the loss of bond between the PCC slab and the underlying hot-mix asphalt.

PCC placement—Conventional paving practices are used. Ambient temperatures are considered to ensure that UTW concrete is not placed on an overly hot AC surface. The hot surface could cause the PCC slab to crack when it cools down at night. It could also reduce the available water (for the chemical hardening process) at the interface of the two materials, thereby reducing the strength of the PCC at the interface. The AC surface is moistened before the PCC placement to minimize absorption of water from the PCC mix by AC and to promote bonding.

Texturing—Conventional texturing methods, such as tining, are used.

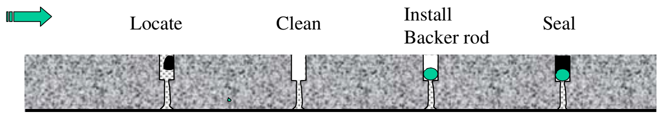
Curing—Curing is important for all PCC pavements. It is especially important for UTW overlays because of their small thickness (and large exposure area relative to the volume). Curing compound is placed on all exposed surfaces immediately after texturing and at twice the normal rate.

Joint sawing and sealing—Joint sawing starts as soon as it can be done without significant chipping of the joint edges. Typical joints are 1 in. deep and ⅛ in. wide, and are spaced 2 to 6 ft apart depending on thickness. Joints are not sealed.

Airport Experience

Only a few surveyed airports reported routine use of whitetopping. The Spirit of Saint Louis Airport in Missouri was the first general aviation airport in the United States to receive an ultra-thin whitetopping in 1995. Since then, whitetopping has been used on both small and large airports, including the George Bush Intercontinental Airport in Huston.

Fact Sheet 16—Joint/Crack Sealing of PCC Pavement



Sequence of Sealing Joints and Cracks in PCC Pavements

Sealing of joints and cracks in PCC pavements is a maintenance treatment that re-seals joints that have missing or poorly performing sealants, and seals major cracks. The sequence of the operation is shown on the above illustration.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.
Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, Apr. 2010.
Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

Evans, L.D., K.L. Smith, and A.R. Romine, *Materials and Procedures for the Repair of Joint Seals in Portland Cement Concrete Pavements—Manual of Practice,* FHWA-RD-99-146, Federal Highway Administration, McLean, Va., 1999.
A comprehensive *Concrete Pavement Repair Manual* issued by the ACPA in 2003 is available from www.pavement.com.
Engineering Technical Letter 02-8, *Silicone Joint Sealant Specification for Airfield Pavements,* 2002.

Purpose and Selection Criteria

The purpose of joint and crack sealing is to prevent incompressible materials from getting into joints, and to prevent infiltration of water and de-icing chemicals into the pavement structure. The presence of incompressible material in the joints can cause spalling and raveling when the joints close in the summer months. Excess water in the pavement structure can lead to erosion of the base support, and de-icing chemicals can corrode dowels and tie bars.

The objective of resealing is to keep all joints sealed. Typically, only working cracks with the opening (at moderate temperatures) between ¼ and ½ in. are sealed. Working cracks are typically transverse and longitudinal cracks. Re-sealing operations are carried out as scheduled maintenance when more than 50% of transverse joints start to show adhesion failures. Typically, pavements requiring joint resealing and crack sealing also require other maintenance treatments, such as partial-depth repairs.

Typical Service Life and Costs

There are three main categories of sealants for PCC pavements on the market: hot-poured bituminous sealants, silicone sealants, and compression seals (preformed or neoprene). Hot-pour sealants have a service life of 8 or more years, silicone sealants 10 years, and compression seals 12 or more years. The performance of sealants can differ significantly depending on the material and workmanship.

The typical cost of resealing operation is in the range of $3 to $4 per yard for hot-poured rubberized sealant, $4 to $5 per yard for silicone sealant, and $6 to $7 per yard for compression seals.

Materials and Construction

Typical joint and crack resealing operation consists of the following steps.

Removal of existing sealant—Damaged and underperforming sealant is removed. This may be accomplished by a mechanical device mounted on a garden-type tractor.
Preparation of sealant reservoir—Typical as-constructed transverse joints have sufficient reservoir at the top of the joint for hot-poured sealant. If the slab faces at the top of the joint do not have sufficient reservoir, the joint may be refaced by diamond saw cutting. Preformed compression seals require that joint sidewalls are perpendicular and without spalling. In the case of cracks, the reservoir is created by using a saw equipped with a special crack-sawing blade, rather than by using impact or rotary routers (e.g., those used for routing AC pavements) that can chip away at the crack face.

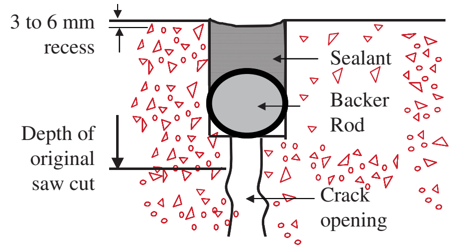


FIGURE B10 Resealed transverse contraction joint with bituminous sealant and a backer road.

Cleaning—All debris are cleaned by sand blasting or water blasting to remove all loose and weakened material, and to remove slurry residue from saw cutting. If sand blasting is used it is followed by air blasting to clean the joint. Joints must be dry before installing sealant.

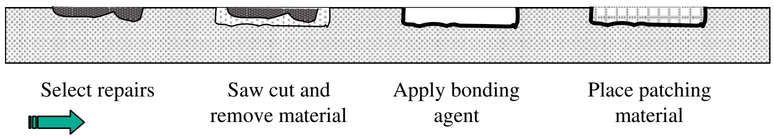
Insertion of backer rod—Bituminous sealants may require a device that would prevent a liquid sealant from seeping deep inside the joint. One such device is a backer rod (Figure B10). The backer rod keeps the sealant in place near the surface of the pavement and prevents bituminous sealant from seeping into the widened crack opening.

Sealant application—The application of hot-poured sealant is similar to the application used for sealing AC pavements. Sealing operation with compression seals requires the application of a lubricant/adhesive to the joint sidewalls before the insertion of the seal. Compression seals are typically applied by a specialized machine and primarily used on new pavements. High-modulus silicone sealants are leveled (tooled) to force the sealant into a full contact with the joint sidewalls and to produce the correct shape of the sealant on top.

Airport Experience

A majority of surveyed airports reported routine use of silicone sealants, half of the responding airports have used bituminous sealants, and a minority of responding airports has used neoprene sealants. The silicone sealants as reported by survey respondents performed best, with all airports reporting very good or good performance. A majority of surveyed airports reported very good or good performance using bituminous sealants or compression sealants.

Fact Sheet 17—Partial-depth (Patch) Repairs of PCC Pavement



Construction Steps of Partial-depth Repair of PCC Pavement

Partial-depth patch repair of PCC pavements is a maintenance activity that includes removal of damaged material from shallow areas and replacing it with new PCC material or AC material. The key construction steps involved are shown in the above illustration.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, Apr. 2010.

Ohio Department of Transportation, *Pavement Preventive Maintenance Guidelines,* Office of Pavement Engineering, Columbus, May 2001.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

A comprehensive manual of practice, *Concrete Pavement Repair Manual,* issued by the ACPA in 2003, is available from www.pavement.com.

Fowler, D., D. Zollinger, and D. Whitney, *Implementing Best Concrete Pavement Spall Repairs,* FHWA/TX-08/5-5110-01-1, National Technical Information Service, Springfield, Va. [Online]. Available: www.ntis.gov.

UFC 3-270-03, *Concrete Crack and Partial-Depth Spall Repair,* U.S. Department of Defense, Washington, D.C., 2006, 68 pp.

Purpose and Selection Criteria

The purpose of partial-depth repairs is to repair localized shallow areas of damaged pavement, such as joint and corner spalling (joint chipping, cracking, and breaking), and any loss of material caused by weak concrete. The objective is to prevent further deterioration, restore pavement smoothness, remove the potential for loose material coming off the pavement, and facilitate joint resealing.

Partial-depth repairs are typically done only for surface distresses that affect up to one-half of the slab thickness. Partial-depth repairs are not suitable for slabs with poor load transfer and areas where reinforcing steel or load transfer devices are exposed. Partial-depth repairs cannot effectively address spalls caused by durability (D) cracking or alkali silica reaction (ASR) damage. If there are several moderate or severe spalls present along one joint, it may be necessary and more economical to repair the joint using a full-depth repair.

Partial-depth repairs are often done in combination with full-depth repairs, joint re-sealing and diamond grinding as part of a pavement rehabilitation project.

Typical Service Life and Costs

A partial-depth repair can last as long as the slab itself, typically 10 years or more. A typical cost of a partial-depth repair operation is in the range of $160 to $220 per square yard.

Materials and Construction

The selection of repair material depends on a number of factors including time constraints, climate, repair size and configuration, experience with local materials, and future maintenance and rehabilitation plans. Ideal repair materials have similar physical properties, such as elastic modulus, strength, and thermal expansion, as the original concrete. PCC repair materials can be general-use hydraulic cement or high early-strength hydraulic cement. There are also rapid-set proprietary patching materials on the market. Bonding agents, if used, are typically sand–cement slurries or epoxy-modified cement slurries. AC material is typically used for temporary repairs only.

FIGURE B11 Prepared repair area; the insert, separating the repair area from the joint, extends beyond the saw cut into the existing longitudinal joint.

The patching procedure using PCC materials consists of the following steps:

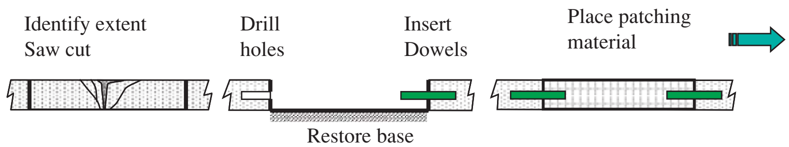
1. Marking the boundaries of deteriorated and/or delaminated concrete.
2. Removal of existing concrete by saw cutting and chipping, or by milling, to create vertical surfaces of the sides of the excavated area.
3. Cleaning of the excavated area by sand blasting or water blasting.
4. Installation of a joint breaker, if the repairs are adjacent to joints, as shown in Figure B11.
5. Application of bonding agent (if used).
6. Placement of the patch material and its consolidation.
7. Finishing and texturing to match surrounding surface.
8. Application of a curing compound to retain moisture.
9. Joint resealing if the patch is adjacent to a joint.

The use of AC material for patching of PCC pavements is considered to be a temporary repair. For this reason, the excavated area is typically not saw cut and a joint breaker is not installed.

Airport Experience

About one-half of the airports surveyed routinely used or have tried partial-depth repairs with PCC material, a majority of surveyed airports have used AC material, and a large minority of surveyed airports has used proprietary materials. Overall, the performance of PCC materials was reported to be better than the performance of AC or proprietary materials.

Fact Sheet 18—Full-depth (Patch) Repairs of PCC Pavements



Sequence of Operation of Full-depth Repair of PCC Pavements

Full-depth patch repair of PCC pavements is a rehabilitation method that involves the full-depth removal of an entire slab or a substantial portion of the entire slab, the installation of load transfer devices (and other reinforcement if applicable), and the replacement of PCC material. The sequence of the operation is shown on the above illustration.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, Apr. 2010.

Ohio Department of Transportation, *Pavement Preventive Maintenance Guidelines,* Office of Pavement Engineering, Columbus, May 2001.

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

A comprehensive manual of practice, *Concrete Pavement Repair Manual,* was issued by the ACPA in 2003 and is available from www.pavement.com.

Concrete Pavement Rehabilitation—Guide for Full-depth Repairs, Report FHWA-RC Atlanta 1/10-03, Resource Center, Federal Highway Administration, Atlanta, Ga.

Purpose and Selection Criteria

The purpose of full-depth repairs is to repair slabs that can no longer be repaired using partial-depth repairs. This includes slabs with deteriorated concrete (particularly near joints), corner breaks, mid-slab cracking, slabs damaged by frost heaving and subgrade settlement, slabs with poor load transfer, and slabs where dowels are exposed. The objective of the repair is to restore the smoothness and structural integrity of the pavement, and to arrest further deterioration.

Full-depth repairs are often done together with other maintenance treatments, such as partial-depth repairs, load transfer restoration, and crack and joint sealing, as part of a pavement rehabilitation project. Full-depth repairs using PCC are also done before overlays.

Typical Service Life and Costs

The full-depth repairs are designed to last as long as the adjacent un-repaired slabs, typically 10 years or more. The typical cost of a full-depth repair using PCC material is in the range of $160 to $240 per square yard.

Materials and Construction

Full-depth repairs can be done using PCC or AC materials. Patching with AC materials is not considered a permanent repair. When using PCC materials, depending on the need to open the area to traffic, PCC repair materials can be a conventional PCC paving concrete or a "fast-track" high early-strength mix. Cement mixes modified with the addition of accelerating admixtures, polymers, or proprietary cement materials are also used. If timing is critical, the use of pre-cast slabs can be considered.

Typical full-depth cast-in-place repair of jointed PCC pavement with dowels consists of the following steps:

Selection of repair boundaries—Full-depth repairs are typically done on the full width of the lane and have the minimum length of approximately 6 ft. Detailed engineering investigation is required to properly identify the areas requiring full-depth repairs. Visual examination is not sufficient (Figure B12).

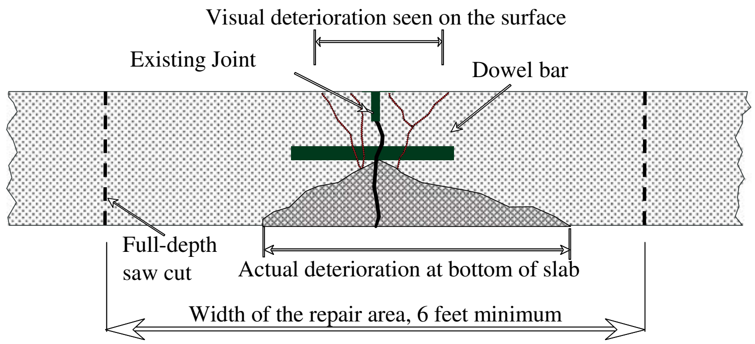


FIGURE B12 Cross section of deteriorated transverse joint.

Base preparation—After the removal of the deteriorated concrete, the base course, subgrade, and subdrains are restored. Any disturbed base material is re-compacted.

Dowel and tie bar placement—Load transfer across the transverse repair joints is re-established. The illustration at the beginning of this Fact Sheet shows the sequence of operations for installing dowels. Tie bars may be installed into the side of the PCC repair area using epoxy; these tie bars will hold the patch to the existing concrete.

Placement of concrete—Before placing concrete, the exposed portion of the dowel bars is coated with a bond breaker. Tie bars are not coated as it is important for the concrete to bond to the tie bar to prevent separation at the interface between the patch and the existing concrete.

Finishing and texturing—Unless a grinding operation or an overlay placement is to follow, the patch is textured to resemble the finish on the rest of the pavement.

Curing—Curing compound is placed as soon as the texturing is completed.

Joint cutting and sealing—All longitudinal and transverse joints are cut and sealed, or resealed.

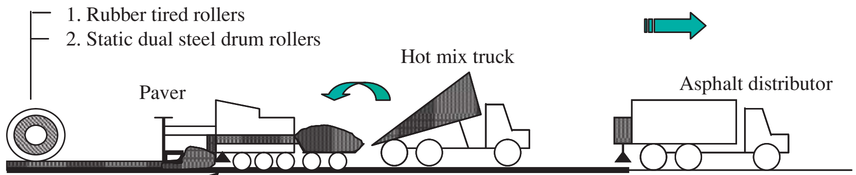
Pre-Cast Repairs

Pre-cast repairs can provide a good alternative to cast-in-place repairs when it is necessary to minimize the duration of repairs. A new pre-fabricated concrete slab is placed into the prepared repair area in one piece. The restoration of the load transfer is accomplished by installing the dowels before or after the slab placement.

Airport Experience

A majority of surveyed airports routinely used or have tried full-depth repairs using PCC or AC materials. A large minority of surveyed airports used proprietary materials. The frequent use of AC materials is surprising and may be the result of the temporary nature of the repairs and to the low priority for restoring load transfer between PCC slabs on aprons and taxiways. Performance of both AC and PCC materials was similar, with the majority of surveyed airports reporting very good or good performance. None of the surveyed airports reported using precast panels.

Fact Sheet 19—Machine Patching of PCC Pavement with AC Material



Schematic of Machine Patching Operation of PCC Pavement

Machine patching of PCC pavements is a maintenance technique that involves placing and spreading of AC mix using a paver on parts of a pavement section. Machine patching includes the preparation of the patching area, addition of the patching material, and compaction as shown on the illustration above.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Additional resources include:

A comprehensive manual of practice, *Concrete Pavement Repair Manual,* was issued by the ACPA in 2003 and is available from www.pavement.com.

Purpose and Selection Criteria

Hot-mix patching of PCC pavements does not substantially improve their structural capacity. Machine patching is most suitable for repairing surface defects such as map cracking, scaling, loss of pavement friction, and durability cracking. The areas selected for patching are expected to be well-defined and separated by areas that are in good condition. If the areas requiring patching are closely spaced, it may be more cost-effective to resurface the entire section.

Machine patching repairs can be divided into permanent and semi-permanent repairs:

Permanent repairs—Permanent patching repairs are used on pavements that are in good condition to improve surface characteristics and extend the life span. For example, if it is expected that the pavement being repaired will require resurfacing in 6 years, the patching repair lasting approximately 6 years will be appropriate.

Semi-permanent repairs—Semi-permanent repairs have a limited life expectancy and are typically used when it is anticipated that the entire pavement will be resurfaced/reconstructed within a few years.

Typical Service Life and Costs

Permanent repairs may last 6 to 10 years or more; semi-permanent repairs may last about 3 to 5 years. A typical cost of machine patching repairs is in the range of $10 to $30 per square yard.

Materials and Construction

Typically, permanent machine patching includes the following steps:

- Removal of the deteriorated PCC material by milling or chipping. Milling may be required to provide a smooth transition between the original pavement and the patch. Figure B13 shows a construction detail for the start of a long patch applied over a full width of a facility.
- Application of a tack coat at the sides of the patch and over the entire patched area to improve the bond between the original pavement and the patch, and to minimize water infiltration.
- Placing of the mix. The placement is done by a paver, and typically in layers not exceeding 3 in. The minimum thickness of a permanent machine-placed patch is approximately 2 in.
- Compaction of the patch area using rollers.

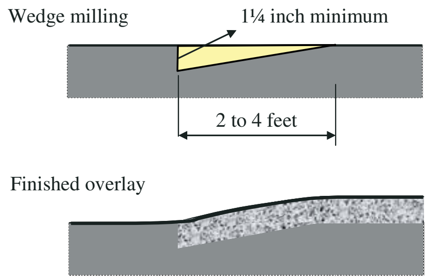


FIGURE B13 Wedge milling to key-in a 2-in.-thick AC patch.

Airport Experience

A few surveyed airports reported on the use of machine patching of PCC pavements with AC routinely; other surveyed airports reported that they have tried it. Performance data from the survey are incomplete.

Fact Sheet 20—Slab Stabilization and Slabjacking

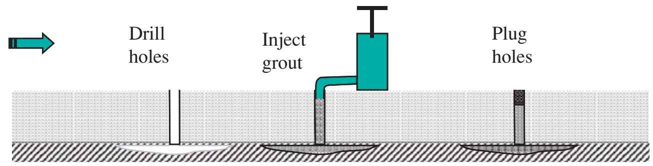


Illustration of Slab Stabilization Procedure

Slab stabilization is a rehabilitation technique that fills voids underneath PCC slabs with grout, but does not raise slabs. Slab stabilization is also called slab subsealing and under-slab grouting. Slabjacking fills voids underneath PCC slabs *and* raises the grade of the slabs. The construction sequence is shown on the above illustration

Sources of Information and Additional Resources

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

A comprehensive manual of practice, *Concrete Pavement Repair Manual,* was issued by the ACPA in 2003 and is available from www.pavement.com.

Purpose and Selection Criteria

The purpose of *slab stabilization* is to stabilize a pavement slab by pressurized injection of grout underneath the slab. The objective is to fill existing voids and restore full slab support, particularly at transverse joints and cracks. The main benefit of subsealing is slowing down the erosion of base and subgrade materials caused by excessive pavement deflections. Slab stabilization is typically carried out at the first signs of pumping (wetness and discoloration at transverse cracks during wet weather) and before the onset of visible signs of pavement damage such as corner cracks. Slab stabilization is typically done only for joints and working cracks that exhibit loss of support.

The purpose of *slabjacking* is to raise pavement slabs, which have settled over time, back to their original grade by pressurized injection of grout underneath the slab. At the same time, slabjacking will also stabilize the slab. The objective is to improve pavement smoothness and to fill voids underneath the pavement. Slabjacking can raise PCC slabs by over 2 in.

Slab stabilization and slabjacking are typically carried out concurrently with other rehabilitation techniques such as partial- and full-depth repairs, diamond grinding, and joint resealing. Slab stabilization is also used to achieve uniform foundation for overlays and as part of the installation of precast PCC panels.

Typical Service Life and Costs

The expected service life of slab stabilization and slabjacking is 5 to 10 years. The typical cost of slab stabilization is in the range of $80 to $180 per square yard.

Materials and Construction

Grouting materials used for slab stabilization include portland cement, fly ash-cement, polyurethane, and proprietary products. Typical slab stabilization material consists of a mixture of three parts fly ash and one part Type 10 cement, and water. Important properties of the grout material include the ability to flow into small voids, sufficient strength to support the slab and the load, and long-term resistance to erosion and deterioration.

Typical slab stabilization operation consists of the following steps:

Location of injection and observation holes—The number of holes depends on the size of the slab. Figure B14 shows an example pattern of injection and observation holes for the stabilization of transverse joints of a small slab (approximately 15 ft by 20 ft).
Drilling holes—Holes are typically 2 in. in diameter or smaller, and penetrate 2 to 6 in. below the concrete slab. Injection holes are grouted the same day.

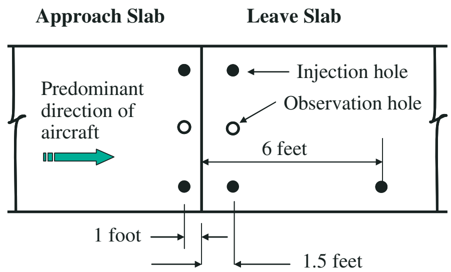


FIGURE B14 Typical location of injection and observation holes for the stabilization of a transverse joint; altogether there are five injection holes and two observation holes per slab.

Grout injection—During the grout injection process, vertical movement of the slabs is continuously monitored. The injection process is complete when grout undiluted with water appears in the observation holes, when the slab begins to rise, or when no grout material is injected at the maximum allowable pressure (typically 100 psi).

Plugging and cleanup—After injecting one hole, the hole is immediately temporarily plugged. After all holes are injected, the temporary plugs are removed and the holes are filled flush with cement grout.

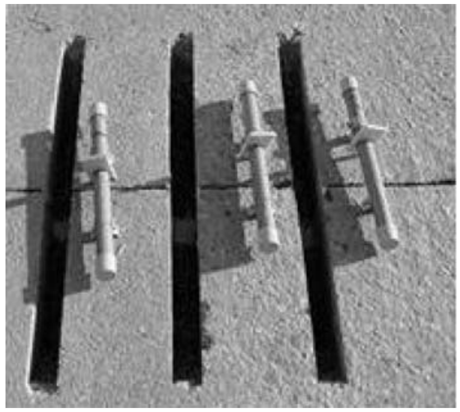
Verification testing—After a minimum of 24 h, slabs are retested for the presence of voids and load transfer efficiency. It is possible to repeat the slab stabilization operation if the first attempt is insufficient. In this case, a new set of injection and observation holes is used.

Slabjacking process is similar to the slab stabilization process. However, the injection of grout continues until the slab reaches the desired grade.

Airport Experience

One surveyed airport reported routine use of slab sub-sealing. A small minority of surveyed airports has tried slab sub-sealing. Performance data from the survey are insufficient.

Fact Sheet 21—Load Transfer Restoration



Slots with Dowel Bars for Load Transfer Restoration

Load transfer restoration is a rehabilitation method that restores the ability of the concrete slabs to transfer wheel loads across transverse joints. The illustration above shows three slots with dowel bars prior to grouting (*Source:* Pierce et al. 2009).

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Michigan Department of Transportation, *Capital Preventive Maintenance,* 2003 ed., Construction and Technology Division, Lansing, Apr. 2010.

Additional resources include:

The FHWA in conjunction with the ACPA has issued a useful publication entitled *Guide for Load Transfer Restoration.* ACPA also issued as a useful guide *Stitching Concrete Pavement Cracks and Joints,* Special Report SR903P [Online]. Available: www.pavement.com.

Pierce, L.M., J. Weston, and J.S. Uhlmeyer, *Dowel Bar Retrofit—Do's and Don'ts,* Report No. WA-RD 576.2, Washington State Department of Transportation, Olympia, Mar. 2009.

Purpose and Selection Criteria

Load transfer restoration (also called dowel bar retrofit) is achieved by inserting tie bars across the transverse joints of jointed PCC pavements. The objective is to increase load transfer across joints.

Load transfer restoration is suitable for pavements with the load transfer efficiency of 60% or less, early signs of faulting (typically more than 0.1 inch but less than 0.4 inch), and with adequate slab thickness. To ensure proper selection of transverse joints that would benefit from load transfer restoration, evaluation of the load transfer efficiency is typically carried out using Falling Weight Deflectometer (FWD) testing. Load transfer restoration is typically done concurrently with other rehabilitation treatments such as full-depth repairs and resealing of joints. It is also used prior to overlays.

Typical Service Life and Costs

The estimated service life for load transfer restoration is between 5 and 15 years. The typical cost of a load transfer restoration or crack stitching is on the order of $50 to $100 per dowel bar or tie bar.

Materials and Construction

The procedure of load transfer restoration includes the following steps:

Selecting joints—The selection is normally based on FWD testing. Some joints may not require any repairs, and some joints may require full-depth repair rather than load transfer restoration.

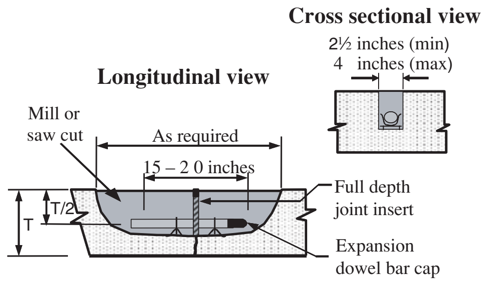


FIGURE B15 Placement of a dowel in the slots. Dowel is placed on a support chair and is approximately ½ in. above the bottom of the slot.

Slot cutting—A diamond-tipped slot cutting saw has become the most common equipment for slot cutting, although modified milling machines have been also used. It is important that the slots are perpendicular to the transverse joint, are large enough to place the dowel at mid-depth of the slab and allow for the backfill material to flow under and around the dowel, and are properly cleaned by sand blasting followed by air blasting.

Insertion of dowels—The most common type of load transfer device is a smooth epoxy-coated dowel bar. The size of the dowel bars depends on the slab thickness and anticipated loads. Typically, dowel bars have the diameter of 1 to ¾ in. and a length of 15 to 20 in. (Figure B15). One-half of the dowel bar is coated with a bond-breaking agent.

Backfilling the slots—It is important that backfill materials do not exhibit excessive shrinkage. For some installations, emphasis is placed on backfill materials that develop early strength to facilitate timely opening of the pavement to traffic. Polymer concretes and high early-strength PCC materials have been used in most installations to date.

Airport Experience

About one-quarter of surveyed airports report routine use or have tried dowel retrofit. Performance data from the survey are insufficient.

Fact Sheet 22—Crack and Joint Stitching

Illustration of Steps in Crack and Joint Stitching

Crack stitching is a rehabilitation method that repairs longitudinal and meandering cracks, and nonworking transverse cracks. Joint stitching strengthens longitudinal joints. There are two crack stitching methods: cross stitching and slot stitching. The illustration above shows an operational sequence of cross stitching of a longitudinal crack.

Sources of Information and Additional Resources

Gransberg, D.D., "Life-Cycle Cost Analysis of Surface Retexturing with Shotblasting as an Asphalt Pavement Preservation Tool," *Transportation Research Record: Journal of the Transportation Research Board, No. 2108,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 46–52.

Additional resources include:

The FHWA in conjunction with the ACPA has issued a useful publication entitled *Guide for Load Transfer Restoration.* ACPA has also issued *Stitching Concrete Pavement Cracks and Joints,* Special Report SR903P, which is available at: www.pavement.com.

Pierce, L.M., J. Weston, and J.S. Uhlmeyer, *Dowel Bar Retrofit—Do's and Don'ts,* Report No. WA-RD 576.2, Washington State Department of Transportation, Olympia, Mar. 2009.

Purpose and Selection Criteria

Crack and joint stitching is done by inserting tie bars across cracks or joints. This prevents widening of cracks and joints (slab migration). Narrow cracks maintain aggregate interlock, reduce the potential for faulting, and are easier to seal. Good candidates for crack stitching are pavements in good condition where longitudinal cracks and joints show signs of slab migration. If longitudinal cracks and joints perform well simply by sealing them, crack and joint stitching may not be necessary.

Typical Service Life and Costs

The estimated service life for crack stitching is 5 to 15 years. A pioneering crack stitching application on a highway pavement was still performing well after 15 years. A typical cost of crack stitching is in the order of \$60 to \$120 per dowel bar or tie bar.

Stitching of Cracks and Joints

Stitching of cracks using *slot stitching* is very similar to load transfer restoration with the following main exceptions:

- Stitching is done to repair longitudinal and meandering cracks, nonworking transverse cracks, and longitudinal joints.
- Deformed tie bars with a smaller diameter are used instead of smooth dowel bars and are placed further apart than dowel bars.
- Tie bars are not coated with a bond-breaking agent.

Cross stitching includes the following steps:

- Drilling holes at a 35° to 45° angle so that they intersect the longitudinal crack or joint at about the slab mid-depth (Figure B16).
- Cleaning of holes by air blasting.
- Injecting epoxy into the hole in a sufficient amount to fill all the available space after a tie bar is inserted.
- Inserting a tie bar into the hole, leaving approximately 1 in. between the pavement surface and the end of the tie bar.
- Removing excess epoxy and finishing it flush with the pavement.

Airport Experience

A small minority of surveyed airports reported routine or trial use of crack and joint stitching. Performance data from the survey are insufficient.

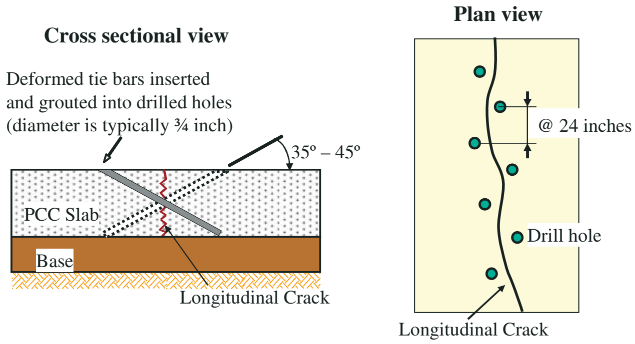
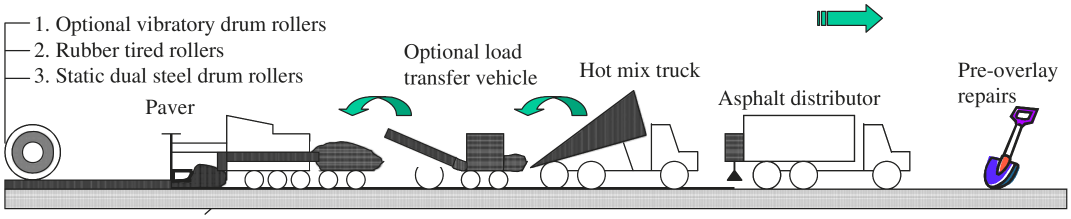


FIGURE B16 Stitched longitudinal crack.

Fact Sheet 23—AC Overlays of PCC Pavements



Schematic of Paving Operation for Asphalt Overlay of PCC Pavement

AC overlay of PCC pavements is a rehabilitation technique that includes repairs of structural deficiencies in the existing PCC slab, application of a bonding agent (tack coat) and/or a layer intended to mitigate the propagation of reflection cracking, and placement of a hot-mix asphalt overlay. The construction sequence is illustrated above.

Sources of Information and Additional Resources

California Department of Transportation, *Maintenance Technical Advisory Guide,* 2nd ed., Office of Pavement Preservation, Division of Maintenance, Sacramento, 2008.

Additional resources include:

The Asphalt Institute has issued a useful publication entitled *Asphalt Overlays for Highway and Street Rehabilitation,* Manual Series No. 17, Lexington, Ky., 1998.

Purpose and Selection Criteria

AC overlays of PCC pavements can be classified as functional overlays and structural overlays.

Functional overlays—The purpose of functional overlays is to improve functional deficiencies of the PCC pavement such as low pavement surface friction, inadequate cross-slope, and roughness. However, if roughness is caused primarily by slab stepping (faulting), a functional overlay may not be a cost-effective solution. The thickness of functional overlays ranges from 2 to about 3 in. Functional overlays are suitable for pavements in good structural condition without progressive faulting or for pavements that can be effectively brought to good structural condition by a limited amount of load transfer restoration, slab stabilization, and full-depth patching.

Structural overlays—The purpose of structural overlays is not only to improve the functional deficiencies, but also to improve the structural capacity of the entire pavement. The improvement in the structural strength of the pavement may be required because the structural capacity has been inadequate or is expected to be inadequate considering future aircraft operations.

Typical Service Life and Costs

The typical service life of AC overlays over PCC pavement is 8 to 15 years. Cost can range widely depending on the overlay thickness and on the treatment of the existing PCC pavement. Considering that a typical cost of hot mix is $60 to $90 per ton, a 4-in.-thick overlay will cost $12 to $18 per square yard. However, this cost does not include any rehabilitation of the underlying PCC pavement that may be required before placing the overlay.

Materials and Construction

Materials used for hot-mix overlay of PCC pavements are similar to those used for hot-mix overlay of AC pavements and are described in Fact Sheet 12, *Hot Mix Overlay of AC Pavement.*

The main challenge in constructing hot-mix overlay of jointed PCC pavements is the prevention or reduction of reflection cracking and the subsequent deterioration of reflection cracks. Over the years, many methods and materials have been developed and field tested. Some of these methods, arranged in the order of increasing costs, include:

Tack coat—Tack coat will not significantly affect reflection cracking, but will improve the bond of hot mix with the PCC surface and thus will reduce the potential for delaminating near the reflection cracks.

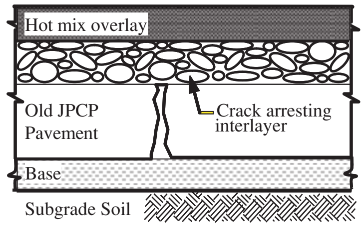


FIGURE B17 Crack arresting granular interlayer.

Sawing and sealing of joints in the overlay—Sawing is done directly above the joints in the underlying PCC pavement and the saw cuts are sealed with liquid asphalt or joint sealant material. This technique prevents uncontrolled reflective cracking and provides joints that can be maintained.

Stress relieving interlayers—A number of products designed to reduce stress in the overlays caused by joint movements have been tested. These products include geotextile fabrics and rubber or polymer-modified tack coats (with or without cover aggregate) and surface treatments used singly or in various combinations.

Crack arresting interlayers—Crack arresting interlayers are typically bound and unbound aggregate layers containing large aggregate particles. The thickness of the interlayer is typically more than 4 in., and the layer contains crushed open-graded aggregate with large numbers of voids (see Figure B17).

Increased overlay thickness—The increased overlay thickness delays the appearance of reflection cracks on the pavement surface. Typically, cracks propagate through the overlay at the rate of approximately ½ to ¾ in. per year.

Pre-overlay repairs—Repairs include slab repairs (slab stabilization, load transfer restoration, full-depth repairs) and improving drainage (retrofit subdrains).

Fracturing the PCC slabs—The methods include crack-and-seat and rubblization.

Airport Experience

Nearly one-half of the surveyed airports reported using AC overlays of PCC pavements routinely or have tried them. All surveyed airports that have used AC overlays rated their performance as very good or good.

Fact Sheet 24—Bonded PCC Overlay of PCC Pavements

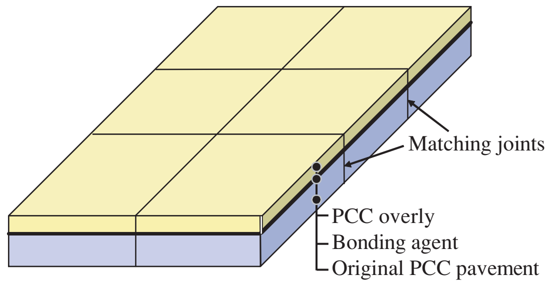


Illustration of Bonded PCC Overlay

Bonded PCC overlay of PCC pavements is a rehabilitation technique that features the placement of a thin PCC overlay directly on the surface of the existing PCC pavement with the overlay bonded to the existing pavement. Bonded overlays are typically 2 to 5 in. thick and are constructed as jointed plain concrete pavements with transverse and longitudinal joints matching those in the underlying pavement as shown in the illustration above.

Sources of Information and Additional Resources

Hicks, R.G., S.B. Seeds, and D.G. Peshkin, *Selecting a Preventive Maintenance Treatment for Flexible Pavements,* Publication FHWA-IF-00-027, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2000.

Additional resources include:

Up-to-date information on design, construction, and performance of PCCP overlays is summarized in *Portland Cement Concrete Overlays, State of the Art Technology Synthesis,* Publication FHWA-IF-02-045, U.S. Department of Transportation, Federal Highway Administration, Apr. 2002.

ACPA document TB-007 P, *Guidelines for Bonded Concrete Overlays,* provides useful practical guidelines.

Saeed, A., M.I. Hammons, and J.W. Hall, "Design, Construction, and Performance Monitoring of Ultra-Thin Whitetopping at a General Aviation Airport," *Proceedings of the 27th International Air Transportation Conference, Advancing Airfield Pavements,* American Society of Civil Engineers, Reston, Va., 2007.

Purpose and Selection Criteria

The purpose of the bonded PCC overlay is to improve pavement smoothness and pavement surface friction and to provide increased structural strength of the pavement. Most bonded PCC overlays are placed on jointed plain concrete pavements, and such placement is assumed herein.

A bonded overlay is an appropriate rehabilitation method if the structural strength of the pavement needs to be increased, and the existing PCC pavement is in a condition conducive to such a treatment. The need for the overlay is based on an anticipated increase in aircraft loads (more and/or heavier aircraft). If load-associated pavement defects are already visible, a bonded overlay is not an appropriate rehabilitation technique. Even though bonded overlays increase structural capacity of the pavement, they are unable to arrest progression of faulting. A bonded overlay is also inappropriate if durability-related defects are present, such as scaling and D-cracking. These defects limit the ability of the overlay to bond with its base.

Typical Service Life and Costs

The expected service life of bonded overlays is approximately 10 to 20 years, and their cost is approximately \$15 to \$25 per square yard for a 4-in.-thick overlay.

Materials and Construction

Bonded overlays usually use conventional PCCP paving mixes. Bonded overlays may also utilize high early-strength PCCP mixes and mixes containing polypropylene and other fibers. The construction of a bonded overlay consists of the following construction tasks:

Pre-overlay repairs—Bonded overlay is placed over pavements in good structural condition. However, some *localized* repairs may be required such as partial-depth repairs, full-depth patching, and load transfer restoration. All cracks (corner, longitudinal, or transverse) in the underlying pavement are repaired.

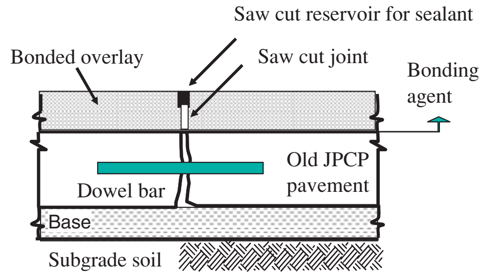


FIGURE B18 Cross section of bonded overlay of jointed plain concrete pavement

Surface preparation—It is essential to ensure that the bonded overlay slab and the slab underneath act as one monolithic slab. The existing concrete surface is cleaned and roughened through a mechanical process that removes a thin layer of concrete. The most commonly used procedures are shot blasting or micromilling followed by air blasting. A bonding agent is applied just prior to paving; a commonly used bonding agent is a mixture of cement and water; this slurry is placed immediately in front of the paver.

PCC placement, finishing, texturing, and curing—The placement of a bonded overlay and texturing uses conventional procedures. It is very important that the bonding agent not dry out prior to placement of new concrete. Proper curing is also important because of the large surface area of the overlay relative to its thickness. A higher than usual application rate of a curing compound is typically used.

Joint construction and sealing—It is important to locate the transverse and longitudinal joints of the bonded overlay directly above those in the underlying pavement, with the deviation not exceeding 1 in. Transverse joints are sawn through the entire slab thickness plus additional ½ in. to ensure a complete slab separation. Longitudinal joints are sawed to one-half of the slab thickness. Sawing is done as soon as possible and the joints are sealed. Sealing requires additional saw cutting to create a reservoir on the top of the pavement and filling the reservoir with sealant (Figure B18).

Airport Experience

A few surveyed airports reported the use of bonded overlays routinely or have tried them. Performance data from the survey are incomplete.

Abbreviations used without definitions in TRB publications:

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