United States General Accounting Office

GAO

Report to the Chairman, Subcommittee on Investigations and Oversight, Committee on Public Works and Transportation, House of Representatives

August 1988

HIGHWAYS

How State Agencies Adopt New Pavement Technologies

043005/136580

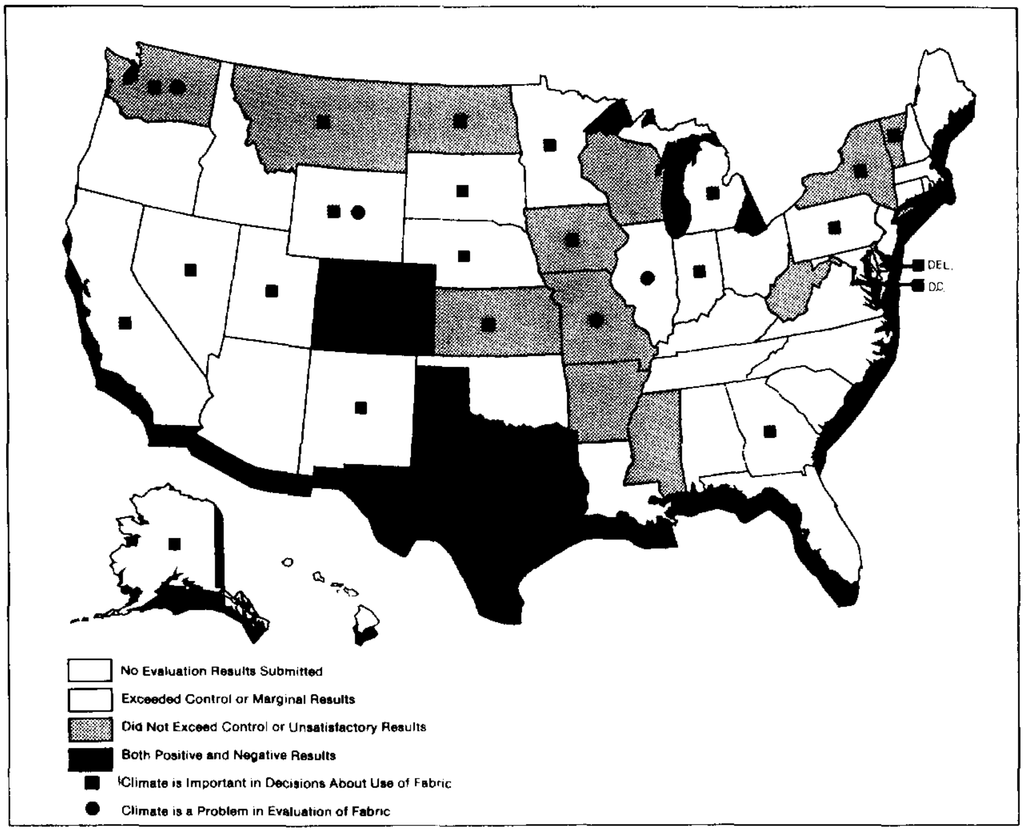
GAO

United States
General Accounting Office
Washington, D.C. 20548

Program Evaluation and
Methodology Division

August 29, 1988

Figure 4.1



This map replaces figure 4.1 now on page 55 of Highways: How State Agencies Adopt New Pavement Technology, GAO/PEMD-88-19 (August 12, 1988).

Michael J. Wargo
Associate Director

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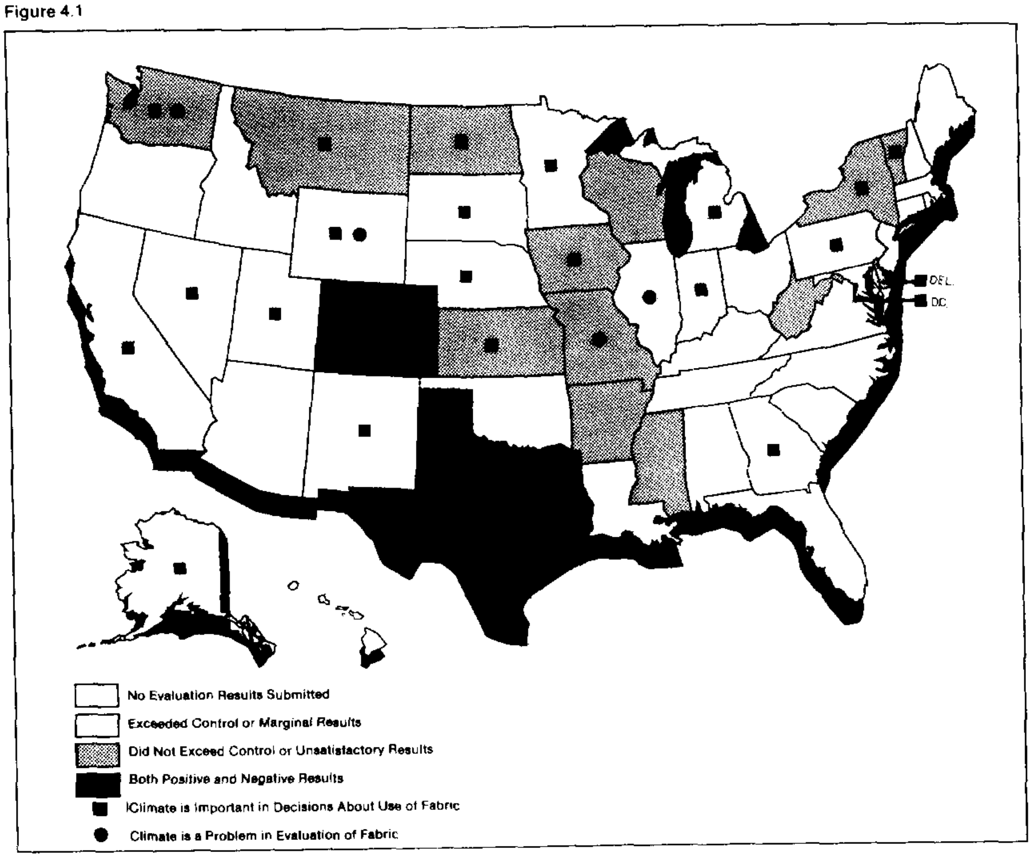

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Executive Summary

Purpose

Although the United States has invested about $1 trillion in its highway systems, many of the existing highways have deteriorated such that they now require improvement or rehabilitation. The use of cost-effective methods and products for highway rehabilitation is an important aspect of highway agencies' efforts to improve highways and reduce costs. Highway rehabilitation decisions are complicated by unanswered questions about how alternative methods and products (technologies) will perform in pavement systems over the long term. Interested in long-lasting and cost-effective highways, the House Committee on Public Works and Transportation and the Subcommittee for Investigation and Oversight asked GAO to determine (1) how highway pavement technologies are adopted for use, (2) the extent to which the states use selected technologies, (3) the criteria (cost or performance measures) the states use in adopting selected technologies and (4) barriers that prevent the states from adopting selected technologies.

Background

The Federal Highway Administration (FHWA) of the U.S. Department of Transportation (DOT) and state highway agencies share responsibility for constructing, maintaining, and rehabilitating the highways. Part of this responsibility is selecting feasible solutions to highway problems from among combinations of alternative methods and thousands of products introduced and evaluated by a diverse federal, state, and industry research and development community. FHWA and state highway officials' guidance to highway agencies encourages formal technology evaluation and adequate documentation of performance data. However, highway research efforts are often fragmented and, according to FHWA, a lack of uniformity in written evaluations affects the usefulness of the information.

To select appropriate rehabilitation technologies, highway engineers should, to the extent possible, identify causes of pavement deterioration, collect and analyze data on physical conditions, and project traffic loads. However, these tasks are made difficult because both separate and interacting effects of their components are not well understood. In addition, decisions are complicated by cost considerations and other factors unique to the environment within each highway agency.

Highway research is now being coordinated in six critical areas under the Strategic Highway Research Program, intended to produce solutions to long-standing highway research needs, including developing a better understanding of the properties of asphalt and concrete and developing a data base to help understand the interaction of traffic, climate, and

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B-227722

August 12, 1988

The Honorable James L. Oberstar
Chairman, Subcommittee on
Investigations and Oversight
Committee on Public Works and
Transportation
House of Representatives

Dear Mr. Chairman:

This report responds to a joint request from you and the late Chairman James J. Howard that we determine (1) how the states adopt highway pavement technologies for use, (2) the extent to which the states use selected technologies, (3) criteria the states use in adopting selected technologies (such as cost or performance measures), and (4) barriers that prevent the states from adopting selected technologies.

Copies of this report will be sent to the Department of Transportation. We will also make copies available to interested organizations, as appropriate, and to others upon request.

Sincerely yours,

Eleanor Chelimsky
Director

research review committees to select and prioritize potential technologies for test and evaluation.

For most of the six technologies, the literature review was the method used most to evaluate technologies, followed by the use of other states' information. As both providers and receivers of technology information, highway agencies differ in their levels of effort dedicated to technology transfer functions. Twenty-one states have a formal technology transfer office, 24 have widely varying levels of resources to perform the functions, and 6 have no such functions.

Extent of Use, Criteria, and Barriers

Highway agency officials' responses illustrated their use of the six technologies, their evaluation criteria and results, and the importance of various other factors in adoption decisions. There was generally widespread use of the six technologies; all highway agencies used hot mix recycling. At least 30 agencies reported they have adopted or are currently evaluating the five others. However, highway agencies' experiences with the selected technologies varied widely, from about 2 months to 30 years for the same technology. Officials reported that first performance and cost and then physical factors were important in their technology adoption decisions. Some key barriers that impeded technology adoption were opposition by key decisionmakers in the state, limited expertise in the technology application, and lack of the necessary equipment. Conversely, when these and other barriers were absent, adoption was facilitated.

Highway Agency Evaluations of Six Technologies

To observe the technology evaluation and adoption process from a different perspective, GAO asked agency officials to submit the evaluations that had most influenced their decisions to use these technologies. GAO's analysis revealed that their evaluations (1) relied on basic experimental measures and methods but often without control sections with which to compare the results of new technologies, (2) documented performance criteria far more than cost-effectiveness, (3) reported performance results that differed among states and within the same state for the same technology, and (4) often did not have full recommendations for or against use.

Recommendations

GAO makes no recommendations.

pavement performance. The transportation community recognizes, however, the important role played by local highway agencies in ensuring that the implementation of research results and technologies will improve highways and reduce costs.

In order to analyze the technology adoption decision process, GAO surveyed the 51 state highway agencies (including the District of Columbia) and requested examples of their technology evaluations for six selected technologies (see appendix I).

Results in Brief

Highway agencies have widely differing levels of experience with the six selected technologies. GAO found that many elements or steps in the adoption process differ and the combinations of those steps demonstrate differences in emphases and priorities regarding technology adoption.

Performance and cost are the most important factors in agency decisions about technologies. However, GAO found highway agencies that used the selected technologies regardless of evaluation performance results. The agencies that have produced evaluations that influenced their adoption decisions based them primarily on performance criteria. From agency responses, GAO also identified several other factors that might be barriers to the adoption of technology.

GAO observed three general conditions about the decision process that illustrate the difficulties inherent in the adoption of cost-effective technologies by highway agencies. Highway agencies tend to operate in an environment where (1) pavement research, development, and adoption processes appear fragmented, (2) the highway pavement technology adoption process tends to vary by state as well as by technology, and (3) technology evaluations are often less than comprehensive in measures, methods, and reporting details.

GAO's Analysis

The Technology Adoption Process

Highway agency officials both receive and provide information about technologies through technology transfer. While highway personnel receive information from various sources to learn about technologies, most rely on FHWA for their information. In addition, most rely on

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Agency Comments and GAO's Response

The Department of Transportation (DOT) commented that this report provides useful information that will be of further value and accurately describes product evaluation deficiencies in many states. (See appendix XI.) DOT also said it intends to approach the deficiencies through two new initiatives: (1) research methodology training, including a possible product evaluation guide, for state employees, and (2) the establishment of a national testing and evaluation data center or network to help the states exchange reliable evaluation information.

However, DOT expressed a concern that the questionnaire GAO used to poll the state highway agencies was too lengthy and broad-based to generate accurate and quantifiable answers. We believe that our 100-percent response rate from the states indicates that state officials did not consider the questionnaire too lengthy or too broad. Further, GAO used an expert advisory panel to develop the questionnaire and pilot-tested it in 5 states to ensure that the content and language were understood and considered acceptable by a wide range of potential recipients. A more complete discussion of DOT's comments and GAO's response are in chapter 5 and appendix XI.

Figures

Chapter 1

Introduction

Members of the Congress have expressed concern regarding the cost-effectiveness of various highway technologies used to remedy pavement deterioration. Consequently, the chairpersons of the House Committee on Public Works and Transportation and of the Subcommittee on Investigations and Oversight asked us to determine

- how highway pavement technologies are adopted for use,
- the extent to which the states use selected technologies,
- the criteria the states use in adopting selected technologies (for example, cost or performance measures), and
- barriers that prevent states from adopting selected technologies.

The committee and the subcommittee are interested in the adoption of highway technologies that would lead to the construction of cost-effective highways. While the United States has spent an estimated $1 trillion on the U.S. highway system, billions more will be needed to preserve the existing highways. In recent years, highway deterioration has received national attention because some highways need repair too early in their design period.[1]

Highway construction efforts now focus on rehabilitation to extend the service life of highways rather than on expansion of the highway system. Current traffic demands are placing a burden on the highway system, and the number of roads needing repair is increasing. The Federal Highway Administration (FHWA) projects that by the year 2000, approximately 41,000 miles of interstate highways and 970,000 miles of other U.S. highways will require improvements to maintain their continued use. However, it is uncertain whether sufficient highway revenues will be available to meet projected highway improvement needs.

The following sections of this chapter outline the environment in which highway officials must decide on alternative technologies.[2] This information provides a context for the data we obtained from the 51 state highway agencies (including the District of Columbia) about those decisions.

[1]The American Association of State Highway and Transportation Officials pavement design procedures for new construction or reconstruction define the performance period, or design period, as the period of time an initial or rehabilitated structure will last before it can no longer serve the traffic for which it was designed. Pavement structures are commonly designed for 10- or 20-year periods.

[2]We are defining technologies as any product, materials, or methods intended to improve the construction or rehabilitation of highways.

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
DOT	Department of Transportation
FHWA	Federal Highway Administration
GAO	U.S. General Accounting Office
NCHRP	National Cooperative Highway Research Program
NCP	Nationally Coordinated Program
NRC	National Research Council
SHRP	Strategic Highway Research Program
TRB	Transportation Research Board

Figure 1.2: Distress Caused by the Environment

requires extensive data collection and analysis to understand the conditions existing at an individual project site. Among the major factors that engineers include in highway design decisions and the selection of appropriate technologies are

- type and design of existing pavement,
- existing pavement condition,
- soil type,
- climate and the need for drainage features,
- traffic or loading, and
- available technologies.

Since each highway section is unique, a technology that works well in one section may not solve the problem of different circumstances. In addition, performance of a technology may be influenced by factors such as construction and maintenance practices. A further consideration for selecting alternative technologies is that many available rehabilitation methods are experimental, lacking full verification of performance; only short-term data are available on new technologies. Officials may

Technologies Address Pavement Deterioration

According to the pavement design procedures of the American Association of State Highway and Transportation Officials (AASHTO), rehabilitation project engineers should select rehabilitation techniques, or combinations of techniques, that will remedy deterioration or distress signs in the existing pavement and, if possible, prevent future premature deterioration. In order to select cost-effective techniques, the engineers should also consider future costs associated with the pavement section over its design period—that is, life-cycle costs.

Many observed distresses may have several causes, and they must be identified in order to select appropriate techniques. The factors that cause distress in pavements also influence the performance of technologies installed in pavement. Figures 1.1 and 1.2 are photographs of distress signs that various rehabilitation techniques are intended to remedy.

Figure 1.1: Distress Caused by Traffic

Because different combinations of methods and products are required to accommodate site-specific causes of distress, highway section design

Federal, state, and over 30,000 local agencies operate the nation's highway system. The state and local highway agencies and FHWA share responsibility for developing and selecting the best highway pavement technologies. At the same time, at the national level FHWA is responsible for reviewing and approving work done with federal funds, national leadership and guidance, and coordinating research and technology transfer efforts under the Nationally Coordinated Program (NCP).

In addition, we noted that the highway research community is multidimensional and includes other federal participants, universities, national associations, and private sector research organizations. This fragmentation among many organizations involved in research activities leads to diverse and voluminous information on technologies available to highway officials. Fragmentation of the transportation industry may also hinder long-term, large-scale highway research efforts, because resources and responsibility are spread among many organizations.

In their research effort, the states and FHWA support a large portion of highway research and development through the highway planning and research program.[5] In fiscal year 1985, funds totaling more than $174 million were made available for highway planning and research activities. In the same year, the states obligated $41.4 million exclusively for research activities. The states voluntarily pool 4.5 percent of their planning and research allocation to finance contractual research under the National Cooperative Highway Research Program (NCHRP), structured to respond to the needs of the highway agencies.

The States Conduct Research and Evaluate Technologies

State highway agencies may evaluate highway technologies to determine if products fill a need and are cost effective and to ensure that they will not produce undesirable side effects. Highway engineers learn about technologies and evaluate them through FHWA-coordinated research as well as their own independent efforts. For example, highway agencies reported spending an estimated $2.2 million in 1985 on independent research activities of this type. Other than NCHRP's contribution, each highway agency decides what research to conduct, whether to focus on local or national problems, and whether to coordinate with states and universities or to issue contracts for research services. However, FHWA asks highway agencies to submit progress reports twice

[5] Under this program, highway planning and research activities receive special funding of 1.5 percent of each state's federal-aid apportionment. State officials then decide the portion of this funding to allocate for planning versus research. States may carry over highway planning and research funds for obligation in subsequent years.

also be reluctant to try unproven technologies for fear that the failure of a highway section will cause added expense, liability, or public criticism.

The Major Causes of Deterioration Are Not Well Understood

According to AASHTO, the lack of knowledge about the interaction of physical factors that cause pavement deterioration limits engineers' abilities to accurately predict probable pavement performance. Despite this lack of information, highway engineers should, to the extent possible, factor future effects of the environment and traffic loads into pavement design in order to increase the likelihood that resulting pavement will perform well through its design periods.

The major factors influencing the loss of the serviceability of a pavement, about which data should be collected, are age, traffic, and environment (temperature and rainfall).[3] However, according to AASHTO, the separate or interacting effects of these components are not clearly defined at present. The properties of materials used for pavement construction change with time, and in most cases age itself negatively affects the pavement. However, very little information is available to quantify either the precise effect of aging or the effect of aging combined with traffic. In addition, the states experience difficulty in measuring and projecting traffic loads. Temperature, rainfall, and soil types also combine in ways that are difficult to predict or measure, causing distress to pavements such as cracking and heaving from freezing and thawing. In the same way, inadequate drainage of excess water from pavements combined with increased traffic loads, especially the weight and volume of commercial vehicles, often leads to early pavement deterioration.

The States and FHWA Share in Technology Research and Evaluation

Although the federal government, through the highway trust fund, provides funding for construction and research projects on the federal-aid system, the state and local governments administer and maintain the system and select pavement technologies.[4] Our earlier report entitled Highway Technology: The Structure for Conducting Highway Pavement Research describes the structure and funding for highway research and construction.

[3]Serviceability is the ability, at a given point in time, of a pavement to serve the traffic that uses it.

[4]The highway trust fund, established by the Highway Revenue Act of 1956 (Public Law 84-627), is a mechanism for financing the federal highway program. Revenues from taxes accrue to the fund and are now dedicated to use on federal-aid highways as well as mass transit projects.

FHWA also provides financial and technical assistance to states that evaluate technologies through technology transfer efforts under the experimental projects program and the demonstration projects program. The experimental program is designed to encourage construction and evaluation of promising new or innovative technologies, called experimental features, that have a limited performance record. A computerized data file of the results of these evaluations is published annually in The National Experimental Projects Tabulation. The demonstration program is intended to accelerate the adoption of technologies selected by FHWA through research and development projects using hands-on demonstrations and construction projects as well as workshop training and installation into pavements.

FHWA, AASHTO, and the highway agencies also cooperate to share information about new products. This effort, SPEL, the special product evaluation list, provides brief information about products the states have evaluated. The June 1985 list has over 6,500 products submitted by 35 states. However, FHWA and AASHTO caution that the information is not an endorsement or rejection of the products and that no conclusions should be drawn about the suitability of these products from the list alone.

Efforts to Fill Research Gaps

Recognizing that highway needs, particularly rehabilitation, far exceed available resources and that innovation with careful targeting of research is the key to bridging this gap, FHWA commissioned the Transportation Research Board (TRB) to study the problem, define research needs, and devise a plan for implementation.[6] The study committee included representatives from the transportation research community and federal, state, and local officials. This effort culminated in the publication in 1984 of TRB's special report 202, America's Highways: Accelerating the Search for Innovation. This study noted that because of the fragmentation of the highway research and development effort, "progress in developing improved materials and methods is too slow, uneven, and inadequate to cope with maintaining and replacing the rapidly deteriorating highway system."[7] In response to this structural problem, the study proposed the creation of a Strategic Highway Research Program

[6]The Transportation Research Board is a unit of the National Research Council, serving the National Academy of Sciences, the National Academy of Engineering, and the Institutes of Medicine to stimulate research and disseminate information derived from research. The National Research Council is the principal operating agency of the National Academy of Sciences. It was established to associate the broad community of sciences and technology with the academy's purposes of furthering knowledge and of advising the federal government.

[7](Washington, D.C.: 1984), p. 15.

yearly and final reports on all research studies using highway planning and research funds.

Published research reports are intended to document the studies in an adequate and timely manner and to encourage the distribution of research information. However, FHWA officials have said that, in practice, a lack of uniformity among research reports affects how useful the information is when shared among highway agencies. For example, meaningful comparison among research reports is impaired because (1) not all relevant conditions are explored, (2) available studies use different measurement techniques, or (3) the studies record different characteristics of the process. In addition, the usefulness of evaluation reports is limited because they are either site-specific or written in too highly technical language.

Technology Transfer

FHWA defines technology transfer as the process by which research, information, and new technologies are transferred into useful processes, products, and programs. Technology transfer activities are included in the Nationally Coordinated Program, FHWA serving as a bridge between research and the practical application of technology. The main goals of the technology transfer program are to

- serve as a communications link between the various sources of new technology and the state and local agencies that can apply the technology in daily operations and
- encourage organizational structures and personnel assignments throughout FHWA and state highway agencies to help transmit available technology from any source to field use.

State highway agencies participate in the program through the input and adoption of new technology.

In an effort to implement highway technologies, FHWA attempts to verify states' research and development efforts and evaluates technologies under varying conditions. When verification produces positive results, FHWA refines research findings and promotes the technology through a number of methods, including workshops, films, manuals, and training courses. States have also established processes for coordinating the technology transfer program with local highway agencies and FHWA.

Rehabilitation Guidance Emphasizes Need for Evaluation and Cost-Effectiveness

FHWA and AASHTO have provided guidance, encouraging state highway agencies to use cost-effective technologies for highway rehabilitation. The guidance also discusses the need to collect performance data on alternative techniques.

In June 1981, an FHWA notice on pavement management to headquarters and field locations noted that

> "Protecting the country's investment in the existing highway system is a major challenge facing highway administrators. . . . In view of declining highway revenues, escalating costs and inflationary pressures, energy and resource conservation needs, increasing axle weight accumulations, and the approaching end of the design life for many pavements, the application of innovative, systematic, and perhaps new PM (pavement management) techniques in the years ahead will be required to accomplish this goal."[8]

Although the notice has been cancelled, FHWA acknowledges that the concept quoted is still valid and is conveyed in FHWA's draft "pavement policy" printed in a notice of proposed rulemaking in the January 26, 1988, Federal Register. The notice would require all state highway agencies to have a comprehensive pavement management system within 4 years of its issuance. The notice also advised that new pavement design and rehabilitation techniques were being proposed and used with little knowledge of their cost effectiveness and the ultimate effect on pavement performance. In addition, instances of serious distress developing in new or newly rehabilitated pavements had occurred for reasons that had already been described in reports or technical advisories.

In January 1983, FHWA provided Review Guidelines for Pavement Management to the regional administrators for use in developing individual review programs at highway agencies. Guidance for field offices is also contained in the 1988 draft pavement policy referred to above and AASHTO's guidelines on pavement management. The guidelines note that while FHWA is not in a position to dictate how an individual highway agency should collect or use performance evaluation data, effective management of any product requires feedback on performance and cost of the product. With reference to new pavement materials and techniques, the guidelines state that because of the number of years required to develop a pavement performance finding, experimental features should be well thought out and evaluated against control sections on a systematic basis.

[8] FHWA notice N5080-92, June 19, 1981, p. 1.

(SHRP) in order to concentrate research efforts in critical highway pavement areas.

Following the study, the Surface Transportation and Uniform Relocation Assistance Act of 1987 (Public Law 100-17) established SHRP to carry out research, development, and technology transfer activities strategically important to the national highway system. The act sets aside up to one fourth of 1 percent of states' total highway trust fund authorizations for fiscal years 1987 through 1991. FHWA, which will oversee and approve SHRP study proposals, anticipates that this one fourth of 1 percent funding will amount to approximately $30 million per year up to 1991.

SHRP, now established as a unit of the National Research Council, will conduct research on six critical areas of pavement and bridges. The focus of these areas is the development of new technologies to solve critical problems, including

- identifying and defining the properties of asphalt in order to develop specifications and test procedures;
- improving the economy, versatility, and durability of concrete in highway pavements; and
- developing a data base on pavement performance over a wide range of conditions to enhance testing or comparisons of paving materials. This will provide information about pavement performance, climate, and traffic effects discussed earlier, how these interact, and the methods that can be used to determine associated costs.

SHRP will also focus on chemical control of snow and ice, protection of concrete bridge components, and maintenance and cost effectiveness.

The SHRP study committee recognized that the ultimate success of the program is dependent on the ability of managers, planners, and others to accept the introduction of innovative materials and processes. The committee also recognized, however, that efforts toward ensuring adequate local adoption cannot fully commence until the findings of the proposed research areas are known and found applicable to their needs.

- the importance of identifying causes of pavement problems,
- the need for engineering judgment in the face of incomplete knowledge about pavement performance,
- the need for highway agencies to provide continuous feedback on performance of rehabilitation alternatives, and
- the use of life-cycle cost analysis to optimize solutions.

Factors Affecting Technology Adoption

In summary, highway technology adoption is a state decision process that involves input from a variety of sources. Factors included in this process are collection of physical data, projections of future conditions, estimations of economic and other constraints, evaluation of performance, and other decisionmaking activities and criteria. Figure 1.3 illustrates the environment in which highway officials decide between alternative technologies. It presents the factors we discussed in this chapter and criteria and decision variables presented in chapters 2-4.

Objectives, Scope, and Methodology

The subcommittee asked us to assess the principal factors that determine (1) the adoption of and barriers leading to rejection of competing highway pavement technologies and (2) the extent to which decisions are based on cost or performance criteria. After subsequent discussions and agreement with the subcommittee, our specific objectives were to determine

1. how highway pavement technologies are adopted for use,

2. the extent to which states use selected technologies,

3. the criteria states use in adopting six selected technologies (for example, cost or performance measures), and

4. barriers that prevent states from adopting the six selected technologies.

To answer these four descriptive questions, we employed a variety of methodological approaches, including the development of an adoption decision model, a review of the literature, site visits and interviews, an expert advisory panel, the selection of sample technologies for examination, and two data collection instruments.

We developed an adoption decision model to capture the many elements involved in a state's decision to use a highway pavement technology.

Additional FHWA guidance to regional administrators, issued in November 1983 on developing cost-effective rehabilitation alternatives, states that there is no absolute method for selecting the most preferred alternative for a given project. However, the guidance includes the following recommendations to be used along with a considerable amount of engineering judgment:

- Alternatives should repair the existing distress and prevent future distress, if possible.
- A feasible alternative normally consists of a combination of different methods to return a deteriorated pavement to an acceptable condition.
- Alternatives should substantially extend service life.
- Traffic, climate, traffic control, and the like may dictate the selection of a given alternative.

The same guidance cites lack of good performance data on rehabilitation techniques as the weakest point in the rehabilitation process and emphasizes the need to provide feedback on performance of the various rehabilitation techniques. An accompanying memo from the federal highway administrator asked regional administrators to review their states' practices to ensure they were following this concept.

The guidance also recommended life-cycle cost analysis in selecting preferred rehabilitation alternatives and stated that the use of lowest initial cost of an alternative as reason for selecting it is a poor engineering practice that can lead to serious future pavement problems.

AASHTO Guidance

Guidance provided by AASHTO echoes that of FHWA. The association's 1985 Guidelines on Pavement Management advise that pavement management is important because of the change in emphasis from expanding the highway system to rehabilitating it and because there is marked absence of factual information on the consequences of previous pavement management decisions. In addition, a highway agency should work toward developing a program to measure and evaluate the effects of various strategies in design, construction, and maintenance of pavements.

In 1986, AASHTO published the Guide For Design of Pavement Structures, which is a rewrite of the interim guide, first issued in 1972 and used by state highway agencies to design pavements. The guide supports FHWA guidance in emphasizing

The components of the decision model consist of state efforts to learn about the technologies, to test and evaluate them, to use technology transfer as a means to both receive and provide information about technologies deemed successful, and to adopt or reject them.

We conducted a literature review using the Transportation Information Service and National Technical Information Service bibliographical retrieval systems to gather background knowledge and specific technology information for our study.

We visited the state highway agencies in Phoenix, Arizona; Sacramento, California; Denver, Colorado; and Harrisburg, Pennsylvania, to gain an understanding of the pavement technology area in state highway agencies. We chose these states for site visits because FHWA and our preliminary literature review indicated that these states are progressive in their research and implementation practices.

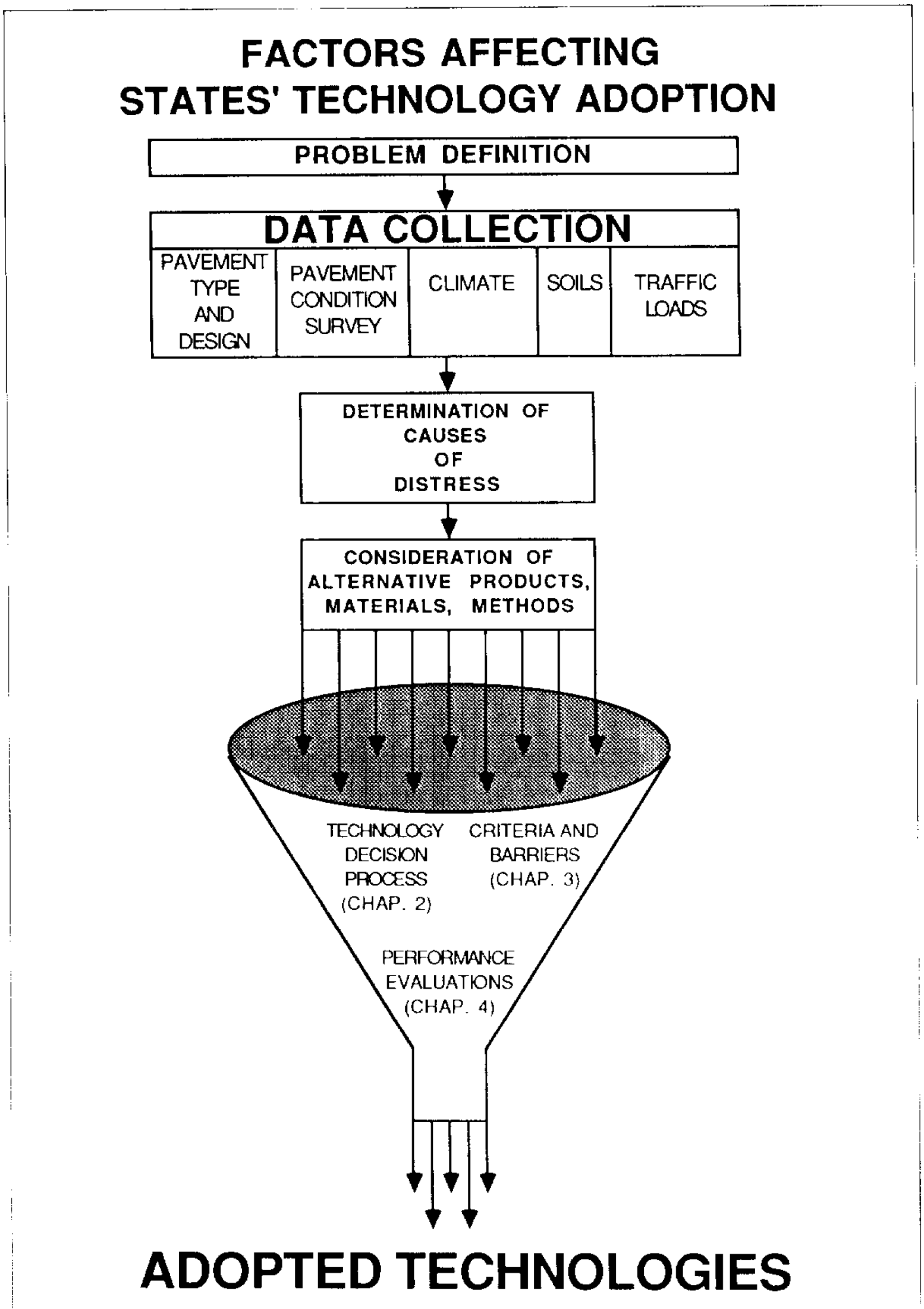
We interviewed highway and pavement industry experts to obtain opinions on which technologies are currently most important for states to be using or evaluating. These experts were individuals in universities, state highway agencies, trade associations, highway research, and FHWA.

We formed an advisory panel (listed in appendix II) to develop a list of sample technologies as a means to evaluate state highway agencies' technology adoption processes, assist in developing the data collection instruments, and identify barriers to the adoption of technologies. Collectively, the advisory panel had expertise in asphalt product research, concrete pavement product development, pavement design, new technology evaluation, state highway agency research administration, and SHRP activities. From our interviews and literature review, we developed a list of candidate technologies, which the panel helped narrow to six, based on the following criteria:

- more than just a few states have had experience with the technology,
- the technology appears to be successful and important for states to be trying, and
- the technologies, taken together, fall under functional categories of design, construction, and materials (asphalt, concrete, and rehabilitation).

We selected the following six technologies to examine as illustrative of the technology adoption process:

Figure 1.3: Factors Affecting States' Technology Adoption



the evaluations of the six selected technologies served as a method to reexamine and reinforce the survey results.

Offsetting these strengths were time and resource limitations, which did not allow us to determine the methodological soundness of the evaluations, examine the rationale for using particular methods or measures to evaluate technologies, or weigh the relative importance of evaluations in agency decisions relative to other criteria.

Organization of the Report

In chapter 2, we address the first evaluation question, how highway pavement technologies are adopted for use in a general sense.

In chapter 3, we address the remaining three questions—that is, for six selected technologies, what is the extent to which the highway agencies use them, what criteria were used in adopting them (criteria being either performance and cost or physical factors considered in the adoption process), and what evidence was there of barriers to adoption?

In chapter 4, we present our analysis of a set of highway-agency produced research reports (covering the six selected technologies) to provide additional insights on the criteria used in adopting selected technologies.

Finally, in chapter 5, we summarize our observations. The Department of Transportation provided written comments on a draft of this report. Its comments are presented and evaluated in chapter 5 and appendix XI.

- fabrics to retard reflective cracking,
- crack and seat,
- water-sensitive asphalt mix design,
- hot-mix recycling,
- edge drains (retrofit), and
- undersealing and subsealing.

Our technologies reflect an emphasis on rehabilitation. Appendix I defines and describes each of the technologies.

We developed a questionnaire to understand and analyze the factors that affect a highway agency's technology adoption process including potential barriers to adoption (evaluation questions 1, 3, and 4) and to determine the extent to which the agencies use the selected technologies (evaluation question 2). All 51 highway agencies completed our questionnaire. In this report, we use the term "highway agencies" to describe the 50 states and the District of Columbia's highway divisions or departments of transportation. To determine the extent to which the agencies have evaluated the selected technologies, the questionnaire asked whether they have produced written evaluations of the six technologies. In addition, the respondents were asked to submit the evaluations that most influenced the agency's decisions to use the technologies. We also developed a data collection instrument to capture data from the evaluations to illustrate evaluation methods, criteria, and results documented in their evaluation reports identified through our questionnaire (evaluation question 3). Our questionnaire and data collection instrument are in appendixes III and IV.

Field work was conducted between November 1986 and July 1987.

We solicited comments from the Department of Transportation and advisory panel members on our draft report. The full text of FHWA comments appears in appendix XI.

Strengths and Limitations of the Study

Our study identified criteria influential in highway agency technology decisionmaking and allowed us to contrast questionnaire responses about the importance of particular factors in decisionmaking with the prevalence of these factors in written evaluations. The questionnaire's 100-percent response rate was a strength that allows us to speak nationally, or generalize, about the characteristics of a process that has not been well examined or understood. Our use of case study observations in

How Do State Highway Officials Learn About and Select Technologies for Testing and Evaluation?

Highway officials learn about technologies from a wide array of sources and rely on these sources to differing degrees. For the purpose of this study, we decided that a technology introduced to a highway agency does not have to be a "new idea" but need be new only to a particular user. Our questionnaire results show that highway officials rely most on FHWA, research and development laboratories at state departments of transportation, and TRB and NCHRP. Forty-one respondents said they use FHWA to a great extent as a source to learn about highway technologies. Of the 42 respondents who said they had research and development laboratories, 29 use the labs to a great extent in learning about technologies. In addition, 34 respondents use TRB and NCHRP to a great extent in learning about technologies.

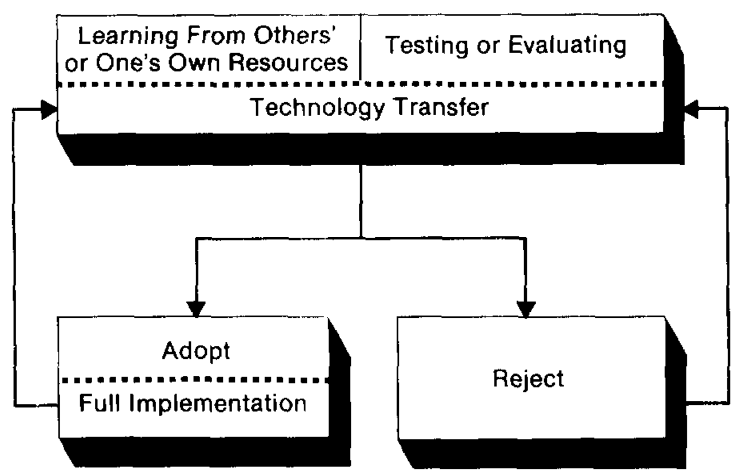
In contrast, state highway officials do not rely to a great extent on county or municipal personnel, trade magazines, their own state highway field staff, or trade associations as sources to learn about highway technologies. Table 2.1 illustrates highway agencies' reliance on particular sources to learn about technologies.

Highway Agencies' Technology Adoption Process

In this chapter, we address our first evaluation question: How are highway pavement technologies adopted for state use? We sent the questionnaire to 51 highway agencies to obtain information on the many activities, resources, and methods involved in a highway agency's decision to adopt or reject a technology. We compared and contrasted questionnaire results about technologies in general and about the six selected technologies. The selected technologies are used to illustrate the technology adoption process.

To facilitate understanding of technology adoption, we developed a technology adoption decision model consisting of four elements: state efforts to (1) learn about technologies (2) test and evaluate them, (3) use technology transfer as a means to both receive and provide information about technologies deemed successful, and (4) adopt or reject them. These elements attempt to organize our questionnaire data in a way to view the technology adoption decision process. Adoption of a technology may eventually lead to widespread use or implementation. However, as an agency gains additional information about the technology, an adoption decision can be reversed and the technology subsequently rejected. Figure 2.1 illustrates the decision model through which technology adoption can occur within a state highway agency.

Figure 2.1: Technology Adoption Decision Model



other agencies; most responses were in the "no to moderate extent" categories.

Also, respondents from 45 agencies said they used industry representatives as a source to learn about fabrics to retard reflective cracking. In contrast, not more than 26 state respondents said industry representatives were a source for learning about any of the five other technologies. For general responses, only 7 highway agencies said they used industry representatives to a great extent in learning about technologies.

Most respondents rely on state highway agency research review committees to select or prioritize potential technologies for testing or evaluation. Research review committees are responsible for recommending research policies, budgets, and project approvals and often are key components in determining technology use in highway agencies. Thirty-one respondents said they used research review committees to a great or very great extent in selecting or prioritizing potential technologies for testing and evaluation. Of the 50 respondents who said they used state highway headquarters staff to select or prioritize potential technologies, 24 respondents use headquarters staff to a great or very great extent. However, highway officials tended not to rely on university research in selecting or prioritizing the potential use of technologies. We list the resources states use to select technologies in appendix III, question 2.

How Do Highway Officials Test and Evaluate Technologies?

Data collected from testing technologies can provide an important tool for decisionmakers who use the data as input for evaluating and analyzing cost-effective alternatives. FHWA guidance encourages highway agencies to collect or use performance data and to provide feedback on performance evaluation. We obtained information on state organizations that test and evaluate technologies and also the extent to which highway officials used the particular methods to evaluate technologies. Additionally, chapter 4 presents criteria and methods state highway agency officials documented in written evaluations of the selected technologies.

Highway agency responses differ in the amount of technology evaluation and testing conducted and how agencies are organized to evaluate technologies. The agencies test and evaluate technologies primarily in state materials testing laboratories, new-product evaluation offices, state research and development offices, or combinations of them. The number of technologies these organizations tested or evaluated in 1986 ranged from none to over 75. Twenty respondents said their agency

Table 2.1: Sources Highway Officials Use to Learn About Technologies

Source	Number of agencies: No, little, or some extent	Moderate extent	Great or very great extent
National			
FHWA	2	8	41
AASHTO	13	20	18
TRB and NCHRP[a]	3	13	34
TRIS and HRIS[b]	16	17	18
State			
University research	17	18	16
State agency research and development laboratory[a]	6	7	29
Reports from other state agencies	9	24	18
New-product evaluation office[a]	8	10	19
Materials testing lab[a]	8	18	25
State highway field staff	31	10	10
County or municipal personnel[a]	46	1	1
Peer exchange	7	19	25
Industry			
Industry representatives	20	24	7
Trade associations	31	18	2
Trade magazines	35	13	3

[a]State responses do not total to 51 highway agencies. Some responses were categorized as not applicable or missing.

[b]The Transportation Research Information System and the Highway Research Information System are bibliographic information retrieval systems that provide information on transportation and highways.

In addition to asking which sources highway agencies use to learn about technologies in general, we asked how highway agencies learned about each of the six selected technologies.

State responses differed for the selected technologies compared with the response for technologies in general, reiterating priorities and variability of highway agency decisionmaking. Highway officials also responded that they relied on FHWA, TRB, and NCHRP to a great extent in learning about the selected technologies. Although both technology-specific and general responses are similar for these sources, highway officials differed in their responses about sharing knowledge among one another. Highway agencies that use the six technologies responded that they used reports from other highway agencies more frequently than most other sources to learn about the technologies. In contrast, responding for technologies in general, they placed less emphasis on using reports from respondents reported using the experience of other states to a lesser degree than for the selected technologies. Table 2.3 lists responses for methods used to test the six selected technologies.

Table 2.3: Methods Agencies Use to Test Selected Technologies[a]

Method	Fabric	Crack and seat	Asphalt mix design	Hot mix recycling	Retrofit edge drains	Undersealing and subsealing
Literature review	41	24	32	43	29	27
Pool fund study with other states	3	0	7	3	2	1
Review of other states' experience	43	27	28	45	29	30
Laboratory testing	16	0	33	40	6	6
Test sections and experimental projects	43	24	12	43	26	20
Developer's data on performance	30	4	9	11	14	4
Information provided by FHWA	34	17	20	40	23	21

[a]Questionnaire allowed state respondents to check all responses that apply; number of agencies responding varies for each response item

How Is Technology Transfer Used in the Highway Agencies?

Technology transfer can play an important part in the adoption of technologies in state highway agencies. (As noted in chapter 1, FHWA defines technology transfer as the process by which research, information, and new technologies are transferred to useful processes, products, and programs.) Technology transfer can serve two functions in a highway agency's technology adoption process: (1) it allows the highway agency to act as a receiver of new information from outside sources and (2) it allows the highway agency to act as a provider or promoter of information to various offices within the highway agency and also to other transportation agencies (for example, county, local, or municipal agencies within the state).

Our questionnaire results describe how technology transfer serves the functions above in the technology adoption process. Earlier in the chapter, we presented responses about the various sources of the information agencies receive on technologies and the extent to which they use the sources. In this section, our questionnaire results describe how the agencies are structured organizationally to perform technology transfer functions as both receivers and providers of technology information. The questionnaire results also describe the highway agency as a provider of technology information by presenting activities highway agency personnel use to promote technologies.

tested 51 or more technologies in the various organizations. Some respondents said they tested 51 plus technologies in each of two or more organizations, resulting in high cumulative totals for numbers of technologies tested during the year.

Highway officials use various methods to evaluate technologies, but literature reviews dominated other methods, regardless of organization. Respondents also said they rely on test sections and experimental projects as a method for technology evaluation. Highway officials do not rely to a great extent on pooled fund studies, which are studies funded by two or more highway agencies, nor developers' data as methods to evaluate technologies. Table 2.2 shows the average response for each method by type of organization. Average responses were based on a 5-point extent-of-use scale.

Table 2.2: Methods Highway Agencies Use to Evaluate Technologies: Extent of Use by Method and Mean Response[a]

Information	Literature review	Fund study	State experience	Section data	Developer data	Provided by FHWA
Organization						
State materials laboratory	3.51	1.72	3.40	3.13	2.48	3.27
New products evaluation office	3.42	1.50	3.21	3.33	2.50	2.71
State research and development office	3.65	2.44	3.17	3.42	2.42	3.28
University research	3.57	1.54	2.78	2.55	1.92	2.82
Private research under state contract	2.48	1.48	1.91	2.00	2.00	1.96
Other	2.40	2.20	2.80	3.40	2.00	3.40
Office combination responses						
Materials testing and new products evaluation office	2.50	1.33	3.00	4.00	2.75	2.25
Materials testing and research and development office	4.00	1.50	3.25	4.00	2.00	3.50
New products and research and development office	4.50	2.00	3.00	5.00	3.00	2.50
Materials testing, new products evaluation, and research and development office	5.00	2.67	3.67	3.00	3.33	3.33

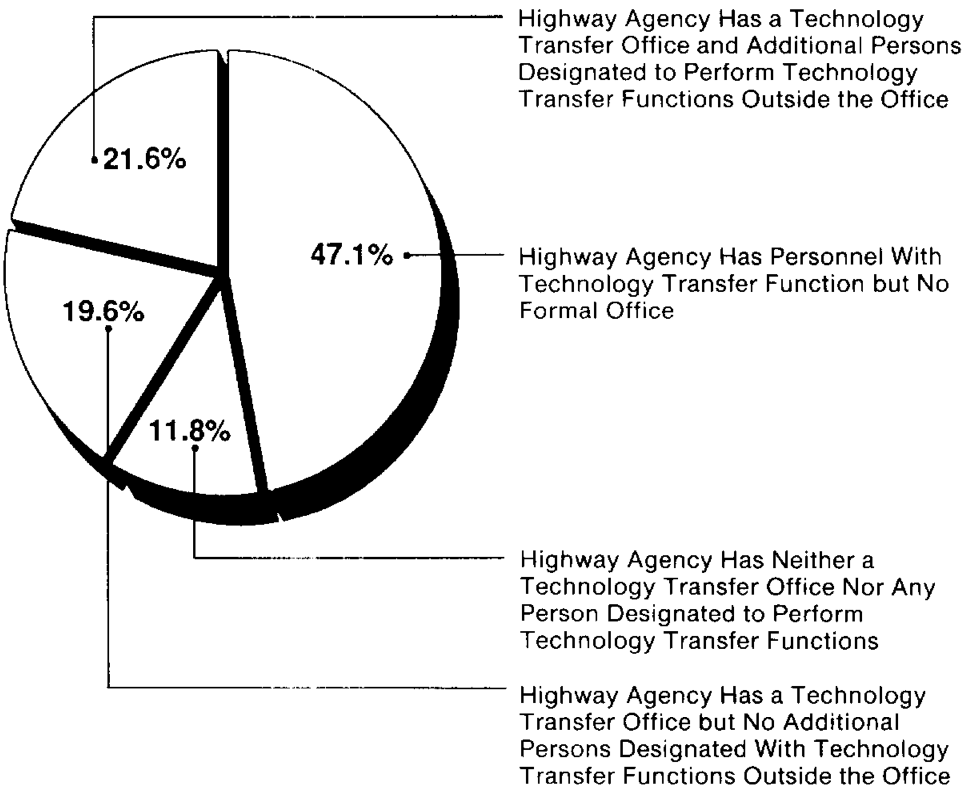
[a]Extent-of-use scale: 1.0 to little or no extent; 2.0 to some extent; 3.0 to a moderate extent; 4.0 to a great extent; 5.0 to a very great extent. Numbers of responses differ among response categories. Mean responses capture the relative extent of use for each method, based on the extent-of-use scale. Office combination responses varied from two to four respondents.

Responses for methods used to test the six selected technologies also indicated that literature reviews were a primary method. In addition, for four out of the six technologies, respondents said they used "reviewing other states' experience" as a method to evaluate technologies more frequently than other methods. However, for technologies in general,

Highway Agencies Organizational Structure for Carrying Out Technology Transfer Functions

Most states have a mechanism in their organization either to receive information or to promote the transfer of a successful technology. Forty-five respondents said they perform such activities either in a formal office or through persons assigned technology transfer functions or in a combination of both. Twenty-one highway agencies have their own technology transfer offices, and 11 of these agencies have additional personnel with technology transfer functions outside of the formal office. Twenty-four agencies do not have a technology transfer office but have persons designated to perform these functions. Only 6 highway agencies have neither a technology transfer office nor any person designated with technology transfer functions. Figure 2.2 illustrates the technology transfer effort in highway agencies. Appendix V lists the technology transfer staff effort by highway agency.

Figure 2.2: Technology Transfer Efforts for the 51 Highway Agencies[a]



[a]Percentages do not total 100 percent because of rounding.

Technology transfer functions are carried out in various divisions or units within a highway agency. Of the 21 highway agencies with technology transfer offices, 7 offices reside in research and development, and two offices reside in the administrative or state aid units. The remaining technology transfer offices are located in various units of the highway agencies. Table 2.4 summarizes their locations within highway agencies.

Table 2.4: Technology Transfer Office Location

Division or unit	Number of highway agencies
Research and development	7
Planning	5
University and state highway agency cooperative effort	4
Engineering or operations	2
Other	
Bureau of materials and research	1
State aid unit	1
Administrative	1
Total	**21**

Staff Effort Dedicated to Technology Transfer Activities

The staff effort dedicated to technology transfer activities ranges from an individual staff member's collateral duties to as many as 19 full-time technology transfer employees. Agencies with technology transfer offices reported a minimum of 1 and a maximum of 9 part-time staff and a minimum of 1 to a maximum of 10 full-time staff members.

Agencies that do not have a formal technology transfer office but have personnel doing technology transfer functions also varied in range of staff effort. Full-time staff ranged from 1 to 17 people, whereas part-time staff varied from 1 to as many as 63 people, as in the state of Virginia, where that many people perform technology transfer functions as part of their collateral duties on a research council. Nine highway agencies reported having staff dedicated to technology transfer functions in both a formal office and outside the office in various divisions or organizational units within the highway agency.

Extent of Use, Criteria for Technology Adoption, and Barriers to Adoption and Use

This chapter addresses evaluation questions 2-4, using the 51 highway agencies' responses to our questionnaire. To determine the extent to which highway agencies use each of the six selected technologies (question 2), we asked whether the agencies (1) have adopted the technology either for statewide use or project by project, (2) are currently evaluating the technology, (3) have used it previously but are not using it currently, (4) have little or no knowledge of the technology, or (5) believe the technology is not applicable for their state. We also asked the respondents how many years' experience their highway agency has had with the technologies.

Evaluation question 3—What criteria do state officials use in adopting selected technologies?—was addressed by asking respondents to rate the importance of various criteria in their use and nonuse decisions about the six technologies. In this chapter, we present these criteria in two categories: performance and cost and physical factors.

Respondents also rated the importance of additional factors that may be barriers to technology adoption (evaluation question 4).

We selected the criteria and potential barriers included on the questionnaire through our visits to 4 states, review of the literature, and discussions with highway experts, including our advisory panel members.

To What Extent Do States Use Selected Technologies?

Highway officials' experience with the six technologies varied among both highway agencies and technologies. While officials at one agency may have used a particular technology for several years, others may just be learning about it. Thus, years may be required to learn about a technology and decide whether it is appropriate for a particular state's highway conditions. In fact, the highway agencies' experiences either using or evaluating the selected technologies range from 0.2 years to 30 years, as shown in table 3.1.

Technology Transfer Activities in Highway Agencies

Questionnaire results show reports on specific technology topics (for example, NCHRP synthesis reports) and FHWA's rural assistance program technology transfer centers as activities that stand out for promoting technologies.[1] Respondents also reported that highway conferences and training courses are used to a great extent in disseminating information about technologies. For the most part, highway officials do not use electronic or private computer bulletin boards or trade publications as technology transfer activities. Table 2.5 shows the extent to which highway personnel use particular technology transfer activities to disseminate information.

Table 2.5: Technology Transfer Activities at Highway Agencies

	Number of agencies		
Technology transfer activity	No, little, or some extent	Moderate extent	Great or very great extent
Technology transfer specialists	23	12	12
Highway conferences	14	18	19
Audiovisual materials	24	14	13
Manuals or binders, periodically updated	22	16	13
Newsletter[a]	24	9	16
Electronic or private computer bulletin board[a]	39	1	2
Trade publications[a]	33	8	5
State-of-the-art reports on technology-specific topics (such as NCHRP synthesis reports)	10	18	23
Training courses	12	20	19
FHWA's rural technical assistance program and technology transfer centers[a]	17	11	21

[a]Responses may not total 51 highway agencies. Some responses were categorized as no basis to judge or missing.

[1]The rural technical assistance program provides technical assistance for rural agencies with transportation responsibilities. One of its projects is technology transfer to local programs, established to improve technology transfer to local transportation agencies; communication on technology transfer between FHWA, state highway agencies, local agencies, and universities; and encourage implementation of effective procedures and technology at the local level.

Figure 3.1: State Use of Fabrics

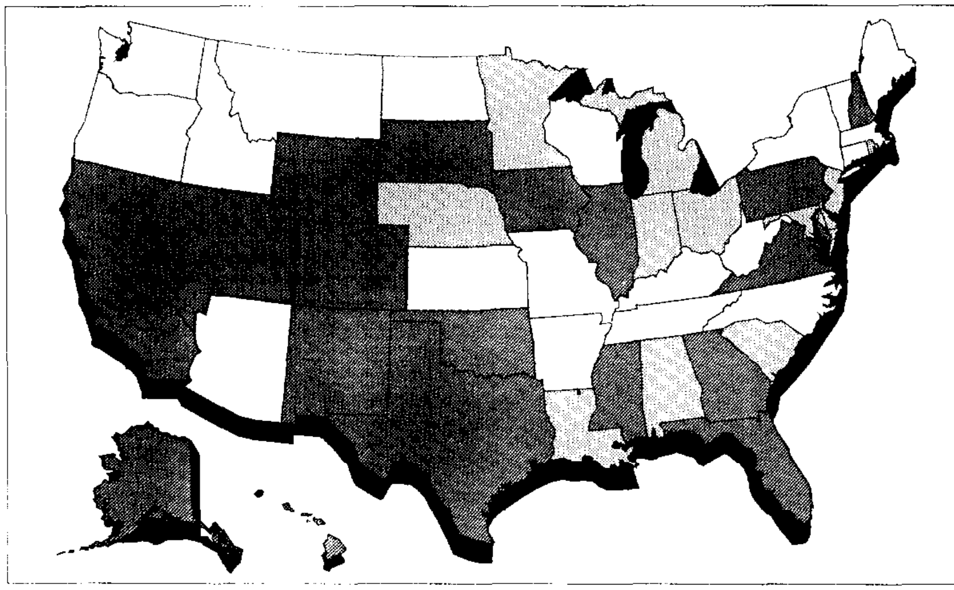
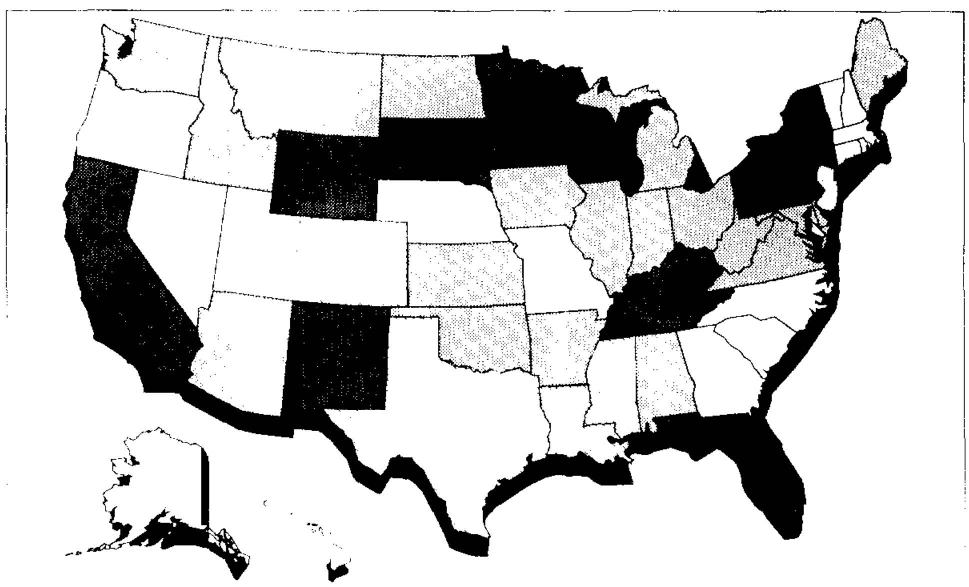


Figure 3.2: State Use of Crack and Seat



Adopted
Being Evaluated
Used Previously, Not Now
Little Knowledge of Technology
Technology Not Applicable

Table 3.1: Years of Highway Agency Experience With the Six Selected Technologies

Technology	Minimum	Maximum
Fabrics	1.0	20
Crack and seat	0.5	25
Asphalt mix design	0.2	30
Hot mix recycling	3.0	13
Retrofit edge drains	0.7	25
Undersealing and subsealing[a]	1.0	50

[a]Ohio has used undersealing substantially for 10 years but reported that the technology existed experimentally as early as the 1930's

The variation is illustrated by the experience of several states. New York's highway agency has used and evaluated crack and seat for over 20 years, and officials believe the technology to be effective for that state's highways. However, Indiana and Michigan agencies are currently evaluating crack and seat, and while it has been found initially successful in Indiana, Michigan officials have recommended a moratorium against its use until cost-effectiveness can be demonstrated.

Officials from at least 30 highway agencies reported that they have adopted or are currently evaluating each of the technologies, with all agencies reporting they are now using or have in the past used hot mix recycling. The maps in figures 3.1 to 3.6 show these levels of experience with each technology, and appendix VI lists the agencies that have adopted or are currently evaluating each of them. Despite the wide range of experience illustrated, a few agency officials reported they have little or no knowledge of one or more technologies.

Figure 3.5: State Use of Retrofit Edge Drains

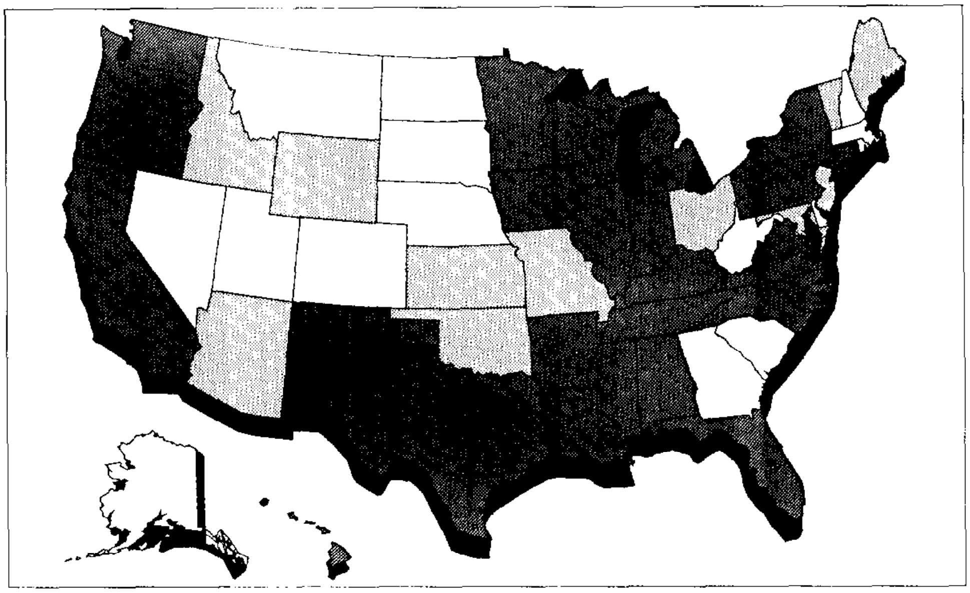
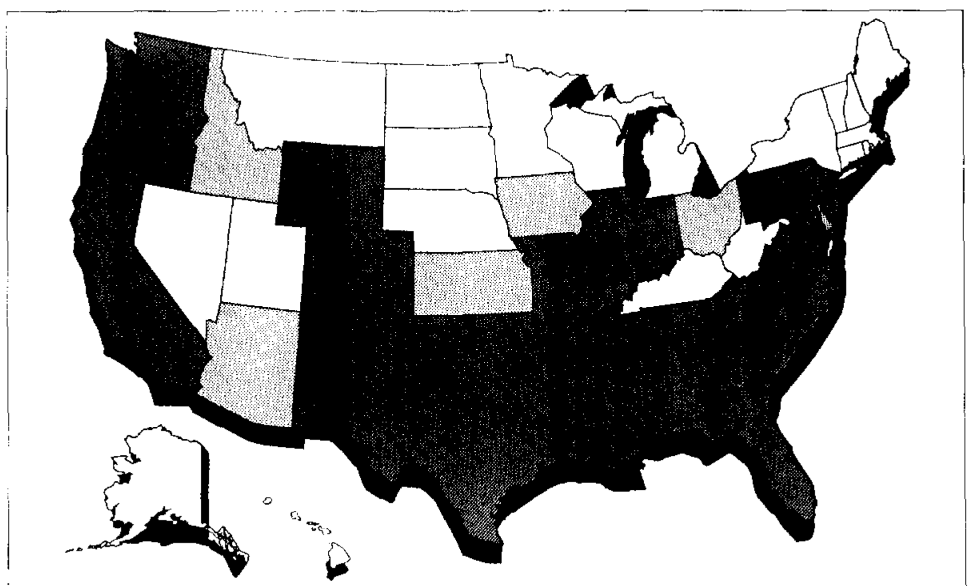


Figure 3.6: State Use of Undersealing and Subsealing



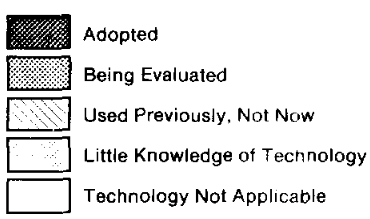


Figure 3.3: State Use of Asphalt Mix Design

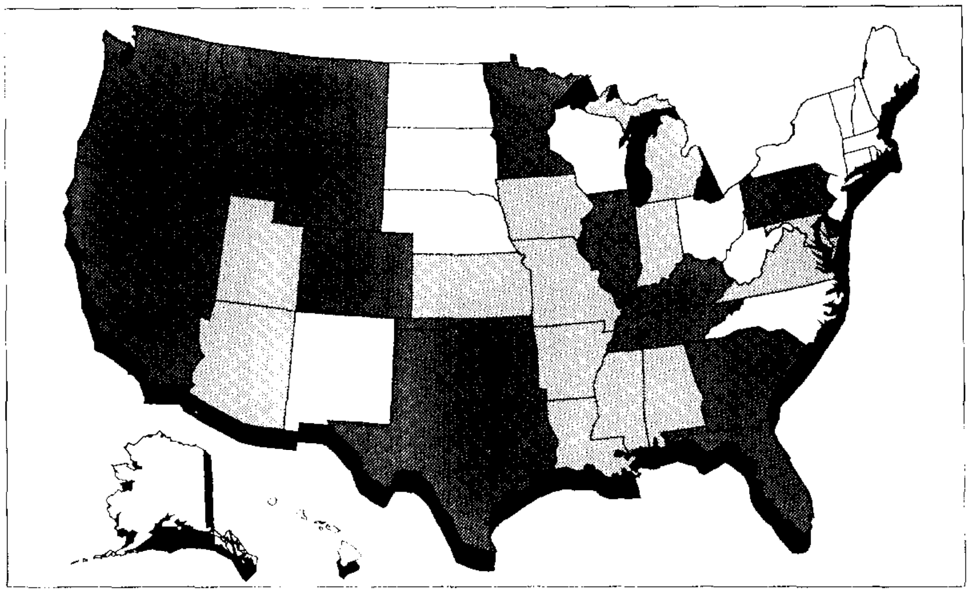
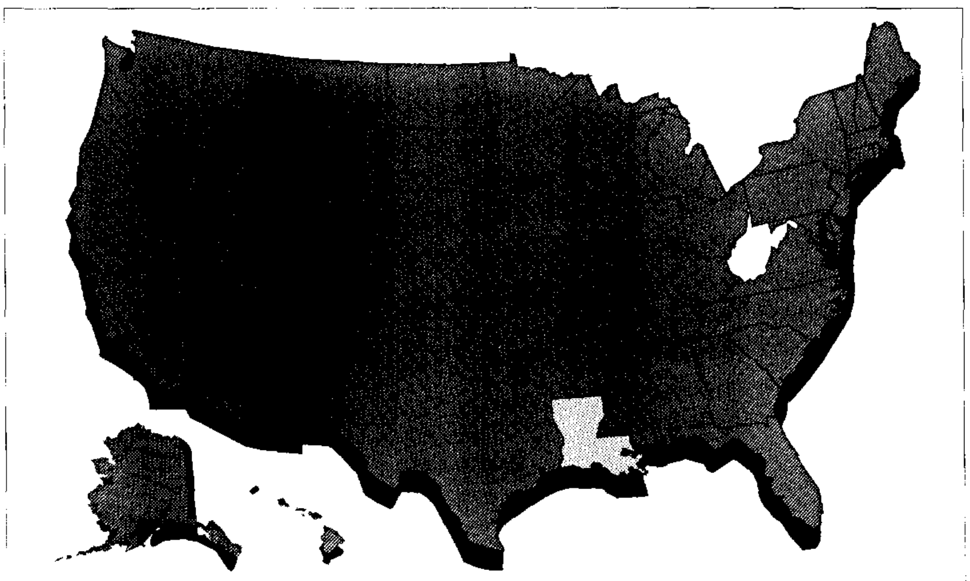


Figure 3.4: State Use of Hot Mix Recycling



Adopted

Being Evaluated

Used Previously, Not Now

Little Knowledge of Technology

Technology Not Applicable

Table 3.3: Importance of Performance, Life-Cycle Cost, and First Cost in Adoption Decisions Where Technologies Are Used[a]

Technology	Performance	Life cycle cost	First cost
Fabric	79.3%	90.3%	67.7%
Crack and seat	81.5	75.8	86.2
Asphalt mix design	87.0	81.8	67.4
Hot mix recycling	95.9	93.8	91.8
Retrofit edge drains	85.7	80.5	77.7
Undersealing and subsealing	79.3	100.0	90.0

[a]Number of responses ranged from 27 to 49 among the 18 calculations. Percentage responses indicate moderate to very great importance.

Response levels indicating importance were high for all three reasons, although first cost appears a little less important overall, particularly for fabrics and asphalt mix design. The corresponding responses from states where technologies are not used are presented in table 3.4.

Table 3.4: Importance of Performance, Life-Cycle Cost, and First Cost in Adoption Decisions Where Technologies Are Not Used[a]

Technology	Performance	Life cycle cost	First cost
Fabric	100.0%	61.9%	61.9%
Crack and seat	62.5	35.3	41.2
Asphalt mix design	20.0	13.3	20.0
Hot mix recycling[b]	0	50.0[b]	50.0
Retrofit edge drains	18.2	25.0	25.0
Undersealing and subsealing	52.9	23.5	35.3

[a]Number of responses ranged from 2 to 21 for the 18 calculations. Percentage responses are from moderate to very great importance categories.

[b]Hot mix recycling received only 2 responses.

The responses from nonusers show more variation and technology specific differences, but other than for fabrics, these factors do not appear to be very important, since most responses were in the no to some importance categories. In contrast to table 3.3 results, performance rather than life-cycle cost is the most important reason for deciding not to use fabrics. Life-cycle cost and first cost are rated relatively important for fabric decisions but of low importance for crack and seat, asphalt mix design retrofit edge drains, and undersealing. Respondents rated the three factors as particularly low in importance for asphalt mix design.

What Criteria Do States Use in Adopting Selected Technologies?

Questionnaire responses from agencies that use the selected technologies described in appendix I indicated that the primary influences on decisions to use technologies were performance (the agencies' response on whether the technology achieved its expected results) and cost factors. Using a 5-point scale (no to little, some, moderate, great, and very great importance), the respondents rated the importance of performance, life-cycle cost, and first costs in their decisions. Officials from agencies where the technologies are not used responded separately to the importance of these reasons in their decisions against use.

Table 3.2 compares the percent of responses in the great and very great importance categories for agencies that use the six technologies and those that do not use them.

Table 3.2: Importance of Performance and Cost in Technology Decisions[a]

Factor in decision	Use technologies[b]	Do not use technologies[c]
Performance	72.0%	43.9%
Life-cycle cost	67.8	28.6
First cost	51.4	23.8

[a]Percentage responses are from great and very great importance categories.

[b]Number of responses ranged from 27 to 49 among technologies.

[c]Number of responses ranged from 2 to 21 among technologies.

For the six technologies combined, more agency officials responded that performance and cost were important in their decisions to use technologies than they did in decisions against use, and for both decisions performance was cited most often, followed by life-cycle cost, then first cost.

While the great and very great response categories illustrate the high level of importance placed on performance and cost, there were many responses in the moderate importance category. In order to collect as much data as possible on the importance of these factors in adoption decisions, we include the percentage of moderate responses together with great and very great in table 3.3 for highway agencies that used the selected technologies. All responses and numbers of respondents are depicted in appendix X.

compared with climate. Compatibility with past practices is generally rated as less important relative to the other factors.

Table 3.7 and appendix X present the corresponding responses for the importance of physical factors in decisions by agencies that do not use the technologies.

Table 3.7: Importance of Physical Factors in Adoption Decisions Where Technologies Are Not Used[a]

Technology	Soil type and aggregate	Climate	Past practices
Fabric	9.5%	33.3%	14.3%
Crack and seat	23.5	11.8	29.4
Asphalt mix design	46.7	0	14.3
Hot mix recycling[b]	50.0	50.0	0
Retrofit edge drains	33.0	33.3	16.7
Undersealing and subsealing	17.6	11.8	5.9

[a]Number of responses ranged from 2 to 21 among the 18 calculations. Percentage responses are from moderate to very great importance categories.

[b]There were only 2 responses for hot mix recycling.

The responses from agencies that do not use the technologies indicate that physical factors were relatively unimportant in their decisions. However, about a third of the respondents said that climate was a factor in the use of fabrics and edge drains and soil type and aggregate were important for asphalt mix design and edge drains.

What Barriers Hinder Technology Adoption?

We included questions about potential barriers to technology adoption on our questionnaire as additional factors that may have been important in highway agency decisions about the technologies. The list of barriers was developed with the assistance of our advisory panel and are those believed by highway experts to most hinder the use of technologies by highway agencies. They include such factors as unacceptable motorist cost or delays, lack of equipment to implement the technology, unavailable expertise, risk of failures, and others (see tables 3.8 and 3.9). The questionnaire responses indicated that the absence of some of these barriers was much more important in decisions to use technologies than the presence of the barriers was reported to be in the decision not to use them.

Physical Factors Also Influence Technology Decisions

While according to the questionnaire responses, observed performance and cost are the most important factors in decisions about technology adoption, the response indicated that physical factors are important as well. The physical factors included on the questionnaire were (1) soil type or aggregate, (2) compatibility with the state's climate, and (3) compatibility with past construction practices such as type of existing pavement.[1] Table 3.5 compares percentage of total state responses in the great and very great importance categories among these physical factors.

Table 3.5: Importance of Physical Factors in Technology Decisions[a]

Factors in using decisions	Use technologies[b]	Do not use technologies[c]
Soil type and aggregate	32.8%	15.5%
Climate	35.1	11.9
Past practices	18.3	6.0

[a]Percentage responses are from great and very great importance categories.

[b]Number of responses ranged from 28 to 49 among technologies.

[c]Number of responses ranged from 2 to 21 among technologies.

Overall, in comparison with performance and cost (see table 3.2) the physical factors are rated lower in importance. Table 3.6 and appendix X present the importance of the physical factors in decisions to use the specific technologies

Table 3.6: Importance of Physical Factors in Adoption Decisions Where Technologies Are Used[a]

Technology	Soil type and aggregate	Climate	Past practices
Fabric	23.3%	51.6%	25.8%
Crack and seat	42.8	43.3	31.0
Asphalt mix design	60.6	75.8	51.5
Hot mix recycling	53.1	53.1	57.1
Retrofit edge drains	77.1	72.2	36.1
Undersealing and subsealing	37.9	33.3	36.7

[a]Number of responses ranged from 28 to 49 among the 18 calculations. Percentage responses are from moderate to very great importance categories.

Soil, aggregate, and climate are important for edge drain decisions, and climate is somewhat more important for asphalt mix design. However, soil and aggregate and past practices are of little importance for fabrics

[1] Aggregate is the sand, gravel and pebbles added to cement in making concrete.

be dispersed across organizational functions such as materials, construction, and maintenance. According to America's Highways, determining what is achievable in changing political or organizational realities is most difficult.[2] The training requirements, organizational change, investment in equipment, cash flow requirements, personnel implications, and legal liabilities of new approaches are crucial aspects of a research result.

Perspectives of decisionmakers within an agency might also influence acceptance of innovative technologies that require a change from past practices. Also, the likely reaction of employee or labor groups may affect whether organization officials try a new method or product. Any change that would result in loss of job rights or security may be avoided. In addition, local decisionmakers might avoid trying new technologies in pavement sections because they perceive an element of risk that the technology could fail and that this failure could result in public criticism or legal liability. Another source of public criticism may stem from the inconvenience and delays motorists experience during highway construction.

Agency officials may obtain information about technologies from the existing voluminous and dispersed sources, as well as from each other, but may have difficulty comparing results or conditions obtained elsewhere. Thus, because data on past performance of existing pavements are often deficient or absent, one aspect of decisions to try technologies is the quality of the information and knowledge highway officials gain about the technology. As discussed in chapter 2, highway agencies differ with respect to levels of research, evaluation, and technology transfer resources.

Diversity of local materials and services may also influence choices among technologies. Some highway agencies require the use of local suppliers because of political pressure and the high cost of transporting bulky, low-value construction materials such as sand. However, local materials may be inferior and not perform well. Also, highway work requires a large number of diverse local suppliers, equipment, and expertise. For example, mixing and placing asphalt pavements involves construction contractors, sand-and-crushed-stone suppliers, asphalt suppliers and mixing-plant operators, and equipment manufacturers. This structure impedes innovation because no one organization has the

[2]National Research Council, Transportation Research Board, America's Highways: Accelerating the Search for Innovation (Washington, D.C.: 1984).

Table 3.8: Importance of Barriers for Agencies Not Adopting Technologies[a]

Technology[b]	Unacceptable motorist cost or delays	Likely loss of employee job rights	Lack of equipment to implement	Expertise unavailable in state	Low bid procurement inhibited use	Risk of failure too high	Not supported by key decision-makers	Experience of other states	Percent responses for all factors
Fabrics (n = 19 to 21)	5%[c]	0	5%[c]	5%[c]	0	42%	19%	43%	16%
Crack and seat (n = 17)	35	6[c]	29	29	6%[c]	65	53	47	34
Asphalt mix design (n = 15)	0	7	20	27	7[c]	7[c]	20	13	12
Retrofit edge drains (n = 11 to 12)	17	8[c]	17	33	8	27	42	18	21
Undersealing (n = 16 to 17)	6[c]	0	18	24	0	29	29	29	17

[a]Percentage responses are from moderate to very great importance categories

[b]Hot mix recycling is omitted because there were zero responses in moderate to very great importance categories

[c]Only one response in moderate to very great importance categories.

Table 3.9: Importance of Absence of Barriers for Agencies Adopting Technologies[a]

Technology	Motorist costs but not in delays	Equipment was available	Implementation was easy	Key decisionmakers supported	Expertise available	Responses for all factors
Fabric (n = 31)	32.3%	64.5%	61.3%	83.9%	71.0%	62.6%
Crack and seat (n = 29)	58.6	62.1	58.6	82.8	62.1	64.8
Asphalt mix design (n = 32 to 33)	18.7	51.5	54.5	81.8	60.6	53.7
Hot mix recycling (n = 49)	46.9	83.7	83.7	93.9	83.7	78.4
Retrofit edge drains (n = 36)	19.4	50.0	55.5	88.9	77.8	58.3
Undersealing (n = 30)	43.3	66.7	53.3	86.7	70.0	63.6

[a]Percentage responses are from moderate to very great importance categories.

Description of Barriers

As described in our interim report, each highway agency has its own organizational structure, political climate, public priorities, and historical perspectives. This diversity may contribute new ideas and approaches to highway research, but interest in new technologies may

Highway Agency Evaluations of Six Technologies

We analyzed a set of research reports submitted by highway agencies to provide supplemental information on the third evaluation question—What criteria do states use in adopting selected technologies? The analysis examined the research measures, methods, and results documented in the submitted evaluations in order to illustrate the approach highway agencies take when investigating highway pavement technologies. Additionally, the analysis explored differences that might exist in the way the states evaluate the selected technologies.

To obtain a set of evaluations, we asked whether the agencies had produced written evaluations of the six selected technologies and whether the evaluations were based on performance or cost. Forty-one agencies responded that they had produced a written evaluation of at least one selected technology. The most-evaluated technologies were hot mix recycling (35 agencies) and fabrics (34 agencies). Fewer agencies responded that they had produced written evaluations of edge drains and undersealing (11 agencies) and crack and seat and asphalt mix design (10 agencies).

Responses indicated that cost was a criterion for 27 of the 35 agencies that had evaluated hot mix recycling, while performance was a criterion for 32. In contrast, 8 of 34 agencies that evaluated fabrics used cost, and for asphalt mix design and undersealing one agency noted cost.

Types of Evaluations Submitted

We asked the highway agencies to submit up to two evaluations (for each technology) that had influenced most their decisions about the use of the technology. In total, we received 162 reports from 33 agencies. We excluded 64 reports from analysis because they did not cover any of the six technologies, contained duplicate information, or did not summarize research. The remaining 98 studies were submitted by 31 states and formed the base for the analysis.

Fabrics and hot mix recycling accounted for 67 of the 98 evaluation reports we analyzed, while none of the 4 other technologies had over 9 evaluations analyzed. Most agencies that submitted evaluations have adopted or are currently evaluating the technologies reported upon. However, 10 agencies that submitted fabric evaluations reported they do not currently use fabrics. Appendix VIII lists the agencies that submitted at least one research report evaluating each of the technologies and whether or not the agency uses that technology.

resources or incentive to undertake major research aimed at improving pavement performance and reducing costs.

Another barrier to technology adoption may be low-bid procurement, where the least expensive method or product could be selected without regard to improved performance or lower long-term (life-cycle) costs.

Table 3.8 presents responses from highway agencies that do not use the technologies about the importance of the selected barriers in their decisions. Percentages shown include moderate, great, and very great importance response categories and refer to the number of resources for each technology. The "n" refers to the number of responses for each technology.

As shown, none of the factors received high levels of responses indicating importance. Risk of failure of the technology and other states' experience are more important than other barriers in decisions not to use fabrics and crack and seat. Also, the fact that the technology was not supported by key decisionmakers was important for crack and seat and edge drains but less for fabrics.

Responses from agencies that use the technologies indicated that barriers were much more important in decisions to use them. This is shown in table 3.9.

Considerations of equipment availability, support of key decisionmakers, ease of implementation, and availability of expertise appear to influence decisions about technologies. The support of key decisionmakers received the most responses indicating importance for all technologies. The availability of equipment to implement the technology was important for hot mix recycling, fabrics, and crack and seat, and the availability of expertise was important for hot mix recycling, edge drains, and undersealing and fabrics.

Our questionnaire asked whether the highway agencies had generally produced written evaluations using cost or performance measures. Our analysis of the states' evaluation reports suggests that cost measures were used less often than had been reported overall. Specifically, cost measures appear in 15 of the 30 hot mix recycling evaluations, but 27 agencies said they had used cost factors. Similarly, 8 agencies said they used cost measures in their fabric evaluations, but only 3 of these submitted, according to our analysis, documented cost measures.

Methods Reported in Evaluations

The methods documented in the evaluations further demonstrated the importance of performance criteria in the evaluation of the six technologies. Of the 98 studies reviewed, 88 relied on some form of test section methodology. In addition to the test section methodology, 19 of these 88 studies used laboratory testing. The remaining 10 studies relied solely on laboratory testing, with the exception of one study that utilized a literature review as well.

There were several different versions of the test section methodology employed in the studies. Common to each version was the use of a field section of pavement to test the performance of the technology (that is, a "test section"). However, some studies had only one such field section, while others used multiple sections in order to test different versions of the technology. In addition to the test section, some studies used a pavement section as a control condition, while other studies did not. A control section is a road section similar to the test section except it does not contain the technology being investigated. Table 4.2 presents a summary of the methods used by each of the studies.

Several of the evaluations indicated that fabrics and hot mix recycling, the two most represented evaluations, were supported and promoted directly to the highway agencies by financial or technical support from industry representatives or FHWA. Fabric evaluations indicated that manufacturers' representatives provided guidance to contractors during fabric installation, which was beneficial since the contractor had limited prior experience with fabrics. Hot mix recycling technology was important in FHWA demonstration projects for several years, and at least 8 of the 30 evaluations we obtained were conducted as part of these projects. FHWA and industry representatives had also been mentioned in the questionnaire as important sources of information on technologies.

Measures Reported in Evaluations

The measures used in the majority of evaluations pertained to the assessment of performance, through either physical and chemical tests or visual observation. As presented in table 4.1, 84 evaluations relied upon physical tests (for example, of pavement distress) and 71 evaluations upon visual observation (for example, viewing the extent of distress signs in the pavement). However, 63 evaluations reported that more than one type of measure was used to evaluate the technology, and 20 evaluations used 3 measures in combination.

Table 4.1: Measures Highway Agencies Most Frequently Use to Evaluate Technologies

Technology	Physical tests[a]	Visual observation	Cost effectiveness
Fabric	28	30	4
Crack and seat	7	6	1
Asphalt mix design	9	0	0
Hot mix recycling	28	22	15
Retrofit edge drains	7	8	4
Undersealing	5	5	2
Total	**84**	**71**	**26**

[a]Instances of specific tests to determine roadway performance are crack surveys, dynaflect deflection readings, and May's meter ride quality measures. Instances of tests used to assess the quality of asphalt are viscosity, immersion and compression, and the Lottman tests.

Twenty-six of the reports we reviewed documented cost as a measure, 15 of these evaluating hot mix recycling. The greater emphasis on documenting cost in evaluating this technology may result because, unlike the remaining technologies, the purpose of recycling is to save money or conserve resources while equaling the performance of pavements constructed with new material. The 5 others are intended to improve performance by remedying causes of distress (see appendix I).

Of the studies that used test and control sections, test section performance was documented as exceeding control condition performance in 19 studies, while test section performance equaled control condition performance in 23 studies. The studies without control conditions noted successful performance more often than studies with control conditions. Among studies without control conditions, satisfactory performance was noted in 21 studies, while unsatisfactory performance was noted in 11 studies. Since studies that do not use controls are generally less reliable and credible than studies that do, these results could be considered more tentative than the corresponding results from studies that used control sections. Table 4.3 presents results of performance tests that used each of the different methods involving field test sections.

Table 4.3: Results of Technology Performance Using Test Section Methods

	Control[a]			No control		
Technology	**Exceeded control**	**Equaled control**	**Inconclusive**	**Satisfactory**	**Marginal or unsatisfactory**	**Inconclusive**
Fabric	12	14	4	0	5	1
Crack and seat	2	1	1	2	0	1
Asphalt mix design	0	0	1	0	2	0
Hot mix recycling	3	5	1	15	0	3
Retrofit edge drains	2	2	1	0	2	0
Undersealing	0	1	0	4	2	0
Total	**19**	**23**	**8**	**21**	**11**	**5**

[a]One additional study using a control section resulted in the control performance exceeding that of the test section.

The technology results suggest that determining whether performance should be considered successful can also depend on the particular technology being investigated. For fabrics, having the test section performance equal control section performance can be considered poor performance. This is because fabrics are intended to retard reflective cracking to a greater extent than if they were not installed in the pavement. However, for hot mix recycling, having the test section performance equal the control section performance can be considered successful performance.

Laboratory Testing Results

Highway agencies used various laboratory tests in 29 evaluations. These tests included procedures for examining asphalt viscosity, penetration, and water sensitivity (via immersion-compression tests, etc.). Fifteen of

Table 4.2: Summary of Methods Highway Agencies Use to Evaluate Technologies[a]

	Field test				
	Control		No control		
Technology	Single test	Multiple tests	Single test	Multiple tests	Laboratory test
Fabric	7	23	4	2	3
Crack and seat	2	2	2	1	0
Asphalt mix design	1	0	2	0	9[b]
Hot mix recycling	7	3	14	4	15
Retrofit edge drains	4	1	0	2	1
Undersealing	1	0	3	3	1
Total	**22**	**29**	**25**	**12**	**29**

[a]The total number of methods used by evaluations exceeds the number of evaluations because of the use of multiple methods by several studies

[b]One additional asphalt mix design study used a literature review.

Although the use of field test section methods was widespread, there were differences among the six technologies. For example, most fabric evaluations compared control sections with test sections, and some evaluated more than one test condition or more than one fabric product. In fact, 27 different fabric products were investigated in 37 evaluations. In contrast, 64 percent of the hot mix recycling reports did not use control sections, and 21 of the 28 field test sections relied on a single test condition.

Performance Results of Technologies

The results documented in the evaluations demonstrate how there can be successful as well as unsuccessful performance of the technology being tested. These results cannot be considered, however, to be assessments on the overall adequacy of the selected technologies, as no formal criteria for judging performance were utilized. Rather, we documented the results based on what the evaluations reported technology performance to be relative to the test methods employed. Thus, for studies with test and control sections, we documented the performance of the test section vis-a-vis the control section. Similarly, for studies with only test sections, we classified performance of this test section as satisfactory, marginal, unsatisfactory, or inconclusive, based only on the performance results reported in the evaluations. This level of performance review permits illustration and examination of performance differences but not any overall conclusions on the merits of each selected technology.

Table 4.4: Recommendations From Highway Agency Technology Evaluations

Technology evaluations	For use	Against use	No recommendation	Total
Fabric	6	8	23	**37**
Crack and seat	2	1	4	**7**
Asphalt mix design	5	0	4	**9**
Hot mix recycling	8	0	22	**30**
Retrofit edge drains	3	0	5	**8**
Undersealing	0	1	6	**7**
Total	**24**[a]	**10**	**64**	**98**

[a]Nineteen recommendations were conditional—that is, use with reservations or under certain conditions.

When provided, recommendations were usually based on performance criteria. Table 4.5 presents the criteria used by the 34 evaluations that did make recommendations. The criteria stated most often were per-

Table 4.5: Criteria for Recommendations in Highway Agency Technology Evaluations

	Performance		Cost		
Technology criteria	Compared to standard technology	Compared to similar products	First	Life-cycle	Other
Fabric	14	1	0	1	0
Crack and seat	2	0	0	0	1
Asphalt mix design	3	1	0	0	1
Hot mix recycling	6	0	2	0	4
Retrofit edge drains	1	0	0	0	2
Undersealing	0	0	0	0	1

these evaluated hot mix recycling and nine (all studies analyzed) evaluated 15 different asphalt mix design tests. For 10 of the 29 (including asphalt mix design) laboratory testing was the only method used, and results for these were either nonevaluative or demonstrated positive performance.

Three of the 9 asphalt mix design evaluations used pavement test sections in addition to laboratory tests to investigate the ability of the laboratory procedures to predict field performance. These tests resulted in inconclusive, marginal, and unsatisfactory results, illustrating the difficulty in predicting field performance of asphalt (in reducing stripping distress) based on previous laboratory testing. In these cases, the evaluations indicated that the expected distress did not appear and cited several possible reasons, including (1) the monitoring period was too short to observe distress and (2) additional conditions (traffic and freezing) would be required to cause distress.

Examples of Performance Differences

Although conclusions about the overall feasibility of individual technologies cannot be drawn from the evaluation reports submitted, the reports do illustrate the varying methods used and results obtained as states examine the performance of highway technologies. This difference can be illustrated by three studies submitted on the retrofit edge drain technology. One study submitted by California assessed performance of edge drains under laboratory conditions, and while the drains were found to function properly in that setting, the study did not include field installation of the drains. A second study submitted by Iowa documented that the drains were successfully draining water but that the performance of the field test section in which the drain was installed equaled control conditions. A third study submitted by Georgia investigated different types of drain installed in multiple field test sections. The study observed that if edge drains were used without filter fabric (another pavement technology), drains caused more severe faulting in concrete pavement slabs, and if used with fabrics, the drains became ineffective in rapidly removing water.

Recommendations for Technology Use

The written evaluations submitted usually did not contain recommendations regarding future use of the technology being investigated. Of the 98 studies, 34 made recommendations, 19 of these being conditional recommendations for use, such as use under certain conditions or use with reservation. As table 4.4 shows, 10 studies did recommend against use of a technology.

fabric evaluations. As discussed earlier, respondents also noted application and equipment considerations as important factors in their technology adoption decisions. Similarly, all nine instances of environmental hazards problems were in hot mix recycling evaluations. Among the "other" problems, there were 5 studies that had technical problems with laboratory tests related to water-sensitive asphalt mix design.

Other problems affecting the results included instances in which the technology just did not function as intended. For example, in one crack and seat study, particular pavement sections did not exceed the control condition performance because the cracking procedure had not been successful in cracking the concrete slabs completely through. The study concluded that the method may be effective only if the slab is completely broken. Similarly for edge drains, in the one study with unsatisfactory performance of multiple test sections and no control section, the failure of the technology was the result of its own functional inappropriateness. The report stated that edge drains definitely could accelerate (not retard) the deterioration process by increasing the amount of water flushed through the system and, ultimately, the amount of material loosened from under the pavement.

Climate incompatibility was noted in 5 studies, all of which were investigating the fabrics technology. These evaluations illustrated not only how climate may affect fabric performance but also how performance varies, even in similar geographical areas. For example, Washington conducted an evaluation that observed a 3-year trend of successful fabric performance in two test conditions. However, an unusually cold fourth year caused 100 percent reflective cracking in both conditions.

Although five of the fabrics evaluations mentioned climate problems, most of the studies did not provide details on the climate setting of the study. In 85 of the 98 studies, the wet-dry conditions of the settings were not stated or were unclear, while in 84 studies, the temperature conditions were not stated or unclear. Also, only 2 evaluations mentioned aggregate or soil incompatibility as a problem in the study.

Figure 4.1 integrates the "climate incompatibility" results with evaluation information pertaining to fabric performance and with questionnaire responses indicating that climate was important in decisions about technologies. The figure demonstrates the variability in fabric performance results as related to instances in which climate had been noted to formance comparisons with a standard technology, such as a control section with only the asphalt overlay. Only three recommendations were based on cost, and two of these indicated the difficulty in projecting costs when performance level is unknown. The one fabric evaluation that used life-cycle cost calculated the additional cost of the technology over the life of the pavement but concluded that the percentage improvement did not justify the increased cost because the necessary level of service "remains to be seen." Two hot mix recycling evaluations that used first-cost recommended future use. However, one of these studies, which compared initial costs of several alternative methods, noted that annual costs cannot be compared until the actual service lives of the test pavements are known.

Comparison of Evaluation Results and Technology Adoption

With some exceptions, highway agencies had adopted technologies that performed well for them in the submitted evaluations, whether or not the evaluations included recommendations for future use. The emphasis on performance-based decisions is exemplified by the 12 fabric studies where test conditions exceeded the control; the 10 states that produced these evaluations have adopted the technology, even though only 4 of these studies contained recommendations for future use. (Conversely, for 10 of the 14 evaluations in which fabric performance only equaled the control, the states had not adopted it.)

In the case of edge drains, 3 evaluations contained recommendations for future use, and 5 contained no recommendations. However, 7 of the 8 states have adopted the technology. The only agency that reported not adopting edge drains obtained unsatisfactory evaluation results; the study did not contain a recommendation.

Problems Encountered During Evaluation

The evaluations often cited problems that affected technology performance. Fifty-seven reports mentioned one problem, and 5 reports mentioned more than one. Appendix IX presents the problems cited for each technology. These problems included "equipment malfunctioning," "methods of application too complex," "climate incompatible," "aggregate soil incompatible," and "other" technical problems.

Problems with equipment malfunctioning were cited by 19 evaluations, 9 of which were hot mix recycling. The second problem mentioned most was "methods of application too complex," and all but 1 of the 13 were

Summary Observations

Through the course of our work, we have developed several general observations that illustrate the difficulties inherent in the adoption of cost-effective technologies by state highway agencies. Given the information produced in this study and our earlier report, we have observed that (1) the highway pavement research, development, and adoption process appears fragmented; (2) the highway pavement technology adoption process tends to vary by state as well as by technology; and (3) highway pavement technology evaluations are often less than comprehensive.

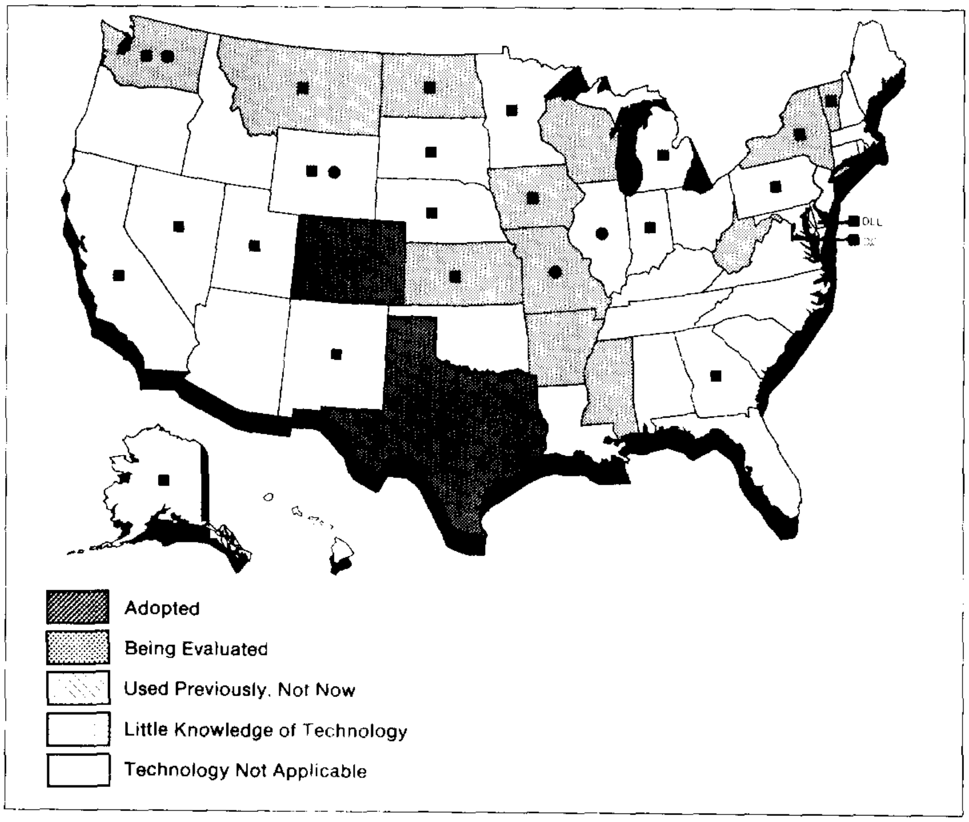
Fragmented Research, Development, and Adoption

As we documented earlier, the highway pavement research and development effort involves many federal organizations, national associations, and private research organizations, as well as state and local highway agencies. TRB's proposal to establish SHRP noted that because of this fragmentation, current research and development efforts were inadequate to address the needs of a rapidly deteriorating highway system. In response to this structural problem, SHRP was initiated in a manner that would attempt to centralize efforts for research and development in critical highway (and bridge) pavement areas.

Our study, with its focus on the adoption of highway pavement technologies at the highway agency level, has shown that fragmentation also currently exists across states, as they become aware of, test, and adopt new technologies. Although states do rely on federal assistance, they have their own methods for prioritizing, testing, and adopting highway pavement technologies. For example, most states rely on their own state research offices to test and evaluate technologies. As a consequence, varying levels of effort are devoted by the states to investigate technologies. Thus, while 1 state has 30 years of experience with hot mix recycling, another has 2 months.

The fragmentation of the state adoption process raises an important issue regarding the effective implementation of new technological innovations, specifically those that might be produced by SHRP's effort. Although SHRP does concentrate research and development activities in critical areas, it is not designed to concentrate efforts on implementing technological innovations. Hence, implementation represents a crucial phase, which because of its fragmented nature represents an important challenge when attempting to transfer new technologies to the states.

Figure 4.1: Evaluation Results and the Importance of Climate in Adoption Decisions About Fabrics



have influenced the fabric performance. For example, evaluations conducted in Wyoming and Illinois both cited climate incompatibility problems, even though their respective evaluations had test section performance exceeding that of the control condition. Conversely, Missouri and Washington both cited climate incompatibility and reported that test condition performance equaled that of the control condition. In addition to evaluation results, 23 questionnaire respondents said that climate was important in decisions about use of fabrics, and as shown they represent states in all geographical areas of the United States.

In contrast to the evaluations we reviewed, the questionnaire results indicated that both performance and cost were often considered by state officials to be very important factors in decisions to use the selected technologies. Life-cycle cost was also considered an important factor in decisions to use each technology, and it was the most important factor for fabrics and undersealing (100 percent), for which performance was rated least important. However, states that do not use fabrics responded (100 percent) that performance was the most important factor in their decisions. In this example, life-cycle cost may have become important once performance was established, but states that rejected the technology based their decisions primarily on poor performance.

FHWA guidance emphasizes the importance of comparing technology performance in test sections to that in control sections. We found that states do rely on installation of a technology into pavement test sections with subsequent observation of deterioration. However, 37 tests of 88 that used this method did not compare performance to pavement control sections. Results of performance tests varied from state to state and within states, and positive results were, not surprisingly, reported more frequently in tests that lacked control sections.

As demonstrated by the fabric technology results, local conditions such as climate can have an instrumental effect on the success of rehabilitation strategies. Thus, an important component of effective technology adoption is the appropriate selection of the rehabilitative technology in light of the local conditions. The written evaluations often did not document climate data, thus omitting an important aspect in understanding the performance of the technology within the study setting.

The importance of producing high-quality factual information can be illustrated by the questionnaire result that literature reviews were rated most often by state officials as an important method of evaluation. This suggests that state highway officials look to other experiences when obtaining information on new technologies. Use of rigorous methods, and description of the study's setting can help ensure that information does not mislead potential adopters.

Agency Comments and Our Response

The Department of Transportation's response to a draft of this report states that we have provided useful information that will be of further value and that we have accurately described product evaluation deficiencies in many states. DOT also said it intends to approach this evaluation problem through two new initiatives. The first is research

State and Technology Differences

The state technology adoption responses discussed in chapters 2 and 3 illustrate that the process can vary by state highway agency and technology. Each state agency conducts a process for adopting highway technologies, and within this process they can vary in a number of areas, such as their staff commitment to technology transfer and their methods and measures for testing technologies. The responses on "barriers" to adoption further illustrate how specific factors, such as support of key decisionmakers, can be influential.

Regarding the six selected technologies, differences in highway agency experiences with them highlight the different adoption paths the same technology can take across the various states. The selected technologies were believed by highway experts to be important rehabilitation techniques, but state agency experience with the selected technologies ranges widely, many states having less than 3 years experience with a technology. For example, according to questionnaire responses, 1 state has had about 2 months of experience with water sensitive asphalt mix design, while another has had 30 years of experience with the same technology. Additionally, states had conflicting results in their testing of the same technology. Thus, while California found performance successful with edge drains, Georgia experienced unsuccessful performance.

The questionnaire and evaluation data also illustrate how highway pavement technologies can have differential adoption, based on support within the highway industry. FHWA appears to be an important source of financial and technical support generally, as illustrated by its involvement in hot mix recycling. The results on fabrics to reduce reflective cracking suggest that states may be encouraged to use a technology if industry representatives provide information and technical assistance. It is interesting to note how the four other technologies did not have this explicit support and were much less often examined by the highway agencies (as measured by the submission of written reports).

Evaluations Often Not Comprehensive

Data on the written evaluations conducted by states on the selected technologies suggests that such evaluations often are not comprehensive in terms of the measures, methods, and reporting details. FHWA and AASHTO guidance emphasize the need to determine the cost-effectiveness of alternative pavement strategies and to develop life-cycle cost analyses. Except for hot mix recycled asphalt, the written evaluations of field tests usually did not address the cost of the technology.

Technology Descriptions

Fabrics to Reduce Reflective Cracking

Fabrics to reduce reflective cracking in the rehabilitation of pavements are polypropylene or polyester. A fabric is placed between the old pavement and the new asphalt overlay. Its intended purpose is to absorb vertical and horizontal movement in the underlying old pavement, thereby reducing the occurrence of reflective cracks in the new layer of pavement. (Reflective cracks are caused by movements in the old pavement that "reflect" through to the new overlay.)

Many types of fabric are available. One design guide lists 30 different fabric products that can be used. "Petromat" is one of the more widely used products. This fabric, manufactured by the Phillips Petroleum Company, is a thin, black, nonwoven plastic. Petromat, like the other fabrics, comes in large rolls that are unfurled over the old pavement prior to the installation of the new asphalt overlay.

Crack and Seating

Crack and seating is a rehabilitative operation performed on cement concrete pavements prior to the installation of a new layer of asphalt pavement. Like the fabrics technology, the intended result of crack and seating is the reduction of reflective cracking in the overlayed asphalt pavement. The purpose of the crack and seating process is to reduce the movements in the old pavement that cause the reflective cracks. In the crack and seating process, the concrete slabs are first "cracked" into smaller sized slabs with a hammer, and then these smaller slabs are rolled over, "seated," with a heavy (50-ton) roller. When the concrete slabs are cracked into smaller slabs, each slab should shrink less horizontally in cold temperature, thereby reducing horizontal movement. The seating component stabilizes the cracked slabs, further reducing vertical movement by the concrete slabs.

The crack and seating operation can vary according to length and width. For instance, 3-, 6-, or 10-foot lengths can be produced, while one or more longitudinal cracks can be used, depending on the desired slab width. The thickness of the asphalt placed over the cracks and seated pavement can vary as well.

Water Sensitive Asphalt Mix Design

This technology involves a testing procedure for determining the moisture susceptibility of the asphalt mixtures to be used in pavement projects. The purpose of the procedure is to assess whether the asphalt is sufficiently impervious to deterioration from moisture. With such a test, asphalt identified as water-susceptible can then either be treated to increase its moisture resilience or not used.

methodology training, possibly issuing a product evaluation guide, for state employees. The second approach, now under consideration, would be the establishment of a national testing and evaluation data center or network that would facilitate the exchange of reliable information.

DOT expressed a concern that the questionnaire we used to poll the states was too lengthy and broad-based to generate accurate and quantifiable answers, and a single respondent may or may not be the most knowledgeable about a state's practices. We believe that our 100-percent response rate from the states indicates that state officials did not consider the questionnaire too lengthy or too broad. We agree that knowledge varies widely among and within the states. It was for this reason that we used an expert advisory panel and relied on extensive advice from FHWA's research and development offices to help us develop the questionnaire as well as the wording of individual questions. We then pretested the instrument in 5 states, including one of the largest with 24 semiautonomous districts, to ensure that the contents and language were understood and considered acceptable by a wide range of potential recipients. We were also aware of the respondents' potential need for additional expertise from various offices within the state highway agencies. Therefore, we encouraged respondents to identify and take advantage of other experts within their states when completing the questionnaire. (See the first two pages of appendix III.) Almost all states (90 percent) reported relying on more than one respondent.

Also, to help ensure the return of accurate and quantifiable answers, we shared draft copies of our questionnaire with representatives of both FHWA and AASHTO. Both were helpful in notifying the eventual recipients to help clarify our purpose.

DOT also is concerned that 4 of the 6 technologies we used to illustrate the technology transfer process were not fully developed and proven and that they are still being evaluated by a number of the states. It is important to understand that we did not select technologies primarily for the purpose of evaluating how well they performed or the extent to which they were used or were not used. Rather, we selected the technologies as a vehicle for understanding the state highway agency technology adoption process. Accordingly, we purposely selected technologies that were in varying stages of being tested and accepted or rejected. (See appendix XI for a discussion of specific selection criteria we used.)

("grout") through these holes. The purpose of this procedure is to stabilize the concrete slabs by providing uniform support to the subbase underneath them. When stabilized, the slabs are more resistant to a vertical movement process called "faulting," which causes pavement deterioration.

Undersealing can vary by the hole pattern from drilling holes in the pavement. Which hole pattern to use depends upon the expected location of holes underneath the concrete slabs. For example, one pattern would be to drill holes throughout the length of the slabs; another pattern would be to concentrate the holes toward the edges of the slabs.

Numerous tests are available for assessing the moisture sensitivity of asphalt. One is the "wet-dry indirect tensile test." This test involves testing the strength of the asphalt mixture both before and after it has been immersed in moisture. If the asphalt tested has less than 70 percent of its dry condition strength when wet, then it can be considered moisture susceptible and can either be treated or not used.

Hot Mix Recycling

Hot mix recycling is a process by which existing asphalt pavement is recycled for use. The procedure involves removing asphalt from an existing roadway, recycling the asphalt through a "hot-mix" drum mixing machine, and then applying this asphalt in the rehabilitation or reconstruction of pavements. There are several purposes for using hot mix recycling. It can be a cost-effective approach to producing material for rehabilitation projects. Also, recycling can conserve energy and natural resources.

Recycled asphalt can be produced without being mixed with new asphalt or can be blended with new asphalt. Numerous blend ratios can be used, recycled asphalt accounting for 50 to 70 percent of the total blend.

Retrofit Edge Drains

Retrofit edge drains are drainage systems installed along the shoulder or "edge" of the pavement as a rehabilitation measure. The intent is to drain water from underneath the pavement, thereby reducing the deteriorating effect this water could have on the pavement.

Two types of edge drains used are slotted longitudinal pipes and the Monsanto drainage mat system. Slotted longitudinal pipes consist of perforated plastic pipes placed in an aggregate-covered ditch adjacent to the pavement. Lateral outlets are provided periodically along the pipe to release the water. With the Monsanto drainage mat system, a fabric is placed vertically along the edge of the pavement, extending down approximately 12 inches into the ground. The fabric absorbs water from the pavement section and then releases it away from the shoulder through flow outlets.

Undersealing

Undersealing—also called subsealing—is a rehabilitation process whereby spaces underneath existing concrete pavements are filled by drilling holes in the pavement and then injecting a filler material

Highway Technologies Survey

U.S. GENERAL ACCOUNTING OFFICE

SURVEY CONCERNING THE USE OF HIGHWAY TECHNOLOGIES

INTRODUCTION

The U.S. General Accounting Office is conducting an examination of the use of highway technologies by state highway agencies. The study will examine the decisionmaking process used by the state in deciding whether or not to adopt highway technologies. Part of our study involves gathering data from all 50 states and the District of Columbia by means of a questionnaire. For the purposes of this questionnaire, we are defining **technologies** as any product, materials, or methods intended to improve construction or rehabilitation (i.e., extend pavement life and/or lower costs) of your state's highways.

The attached questionnaire is to be filled out by you concerning your state's highway activities. The questions primarily focus on the areas of Technology Transfer, Research and Development, Materials Testing and New Product Evaluation. Many of the questions may require the expertise of people from these functional areas within your state highway agency. Please feel free to seek their help in answering our questions.

Questions 1 thru 15 ask you to give us generic (unrelated to any specific technology) information about the decision making process used by your state in choosing whether or not to adopt highway technologies. Questions 16 thru 25 focus on 6 specific technologies and ask you to tell us how your state highway agency went about deciding whether or not to adopt each of the technologies.

Please return the completed questionnaire and the requested evaluations in the enclosed pre-addressed envelope within 2 weeks of receipt. If the requested evaluations are too bulky for our envelope, please mail them separately to the same address. In the event the envelope is misplaced our return address is:

U.S. General Accounting Office
Program Evaluation and Methodology
Division
441 G Street, N.W
Room 5844
Washington, DC 20548
Attn: Susan Ragland

If you have any questions about the questionnaire, please call Arleen Alleman or Karen Ichiba at (303) 964-0006. Thank you for your cooperation.

Due to the type of data received, the following questions are not captured in summarized form. Questions 3,5,8,14,17,18,21,22, and 24-30.

1

Advisory Panel Members and Areas of Expertise

Member	Area of expertise
Mr. Gary Byrd Washington, D.C.	Strategic Highway Research Program (SHRP) activities
Dr. Jon Epps Reno, Nevada	New highway technology evaluations
Mr. Fred Finn Scotts Valley, California	Pavement design, construction maintenance, and research
Mr. Francis Francois Washington, D.C.	State highway department research administration
Dr. Shiraz Tayabji Skokie, Illinois	Concrete pavement product development
Mr. Gerald Triplett College Park, Maryland	Asphalt product research

1. To what extent, if at all, does your state highway headquarters use each of the following sources to learn about highway technologies? *(CHECK ONE BOX FOR EACH SOURCE.)*

Sources	Little or no Extent (1)	Some Extent (2)	Moderate Extent (3)	Great Extent (4)	Very Great Extent (5)	Not Applic-able (6)
1. Federal Highway Administration		2	8	30	11	
2. University research		14	18	15	1	
3. Your State Department of Transportation R&D Laboratory		6	7	18	11	
4. Reports from other State Departments of Transportation		8	24	18		
5. AASHTO	1	12	20	11	7	
6. Industry representatives		19	24	7		
7. Your State DOT New Product Evaluation Office		7	10	12	7	
8. Your State DOT Materials Testing Lab		8	18	17	8	
9. Trade associations	1	27	18	2		
10. Your State highway field staff		29	10	7	3	
11. TRB/NCHRP		3	13	24	10	
12. Trade magazines		31	13	3		
13. County or municipal personnel		8	1	1		
14. TRIS/HRIS		14	17	13	5	
15. Peer exchange		6	19	21	4	
16. Other		1	4	3	2	

- 3 -

Please provide the names, titles and phone numbers of all persons contributing to the completion of this questionnaire. Use additional sheets if necessary.

Lead Person

1. Name: ______
   Title: ______
   Phone #: ______

Other

1. Name: ______
   Title: ______
   Phone #: ______
2. Name: ______
   Title: ______
   Phone #: ______
3. Name: ______
   Title: ______
   Phone #: ______

– 2 –

6. In which of the following divisions or organizational units does your state highway technology transfer office reside? *(CHECK ONE.)*

1. ☐ Planning 5
2. ☐ Research and Development 7
3. ☐ Engineering/Operations 2
4. ☐ Separate Technology Transfer Office 0
5. ☐ Other (Please Specify) ______ 7

7. In other than a formal office, does your state highway agency have full-time or part-time person(s) who have technology transfer functions?

1. ☐ Yes 35
2. ☐ No **(Skip to question 10)** 16

8. In which of the following divisions or organizational units do the above person(s) (question 7) reside? *(PLEASE PLACE THE NUMBER OF STAFF IN THE APPROPRIATE BOX.)*

Division/Unit	Full-time staff	Part-time staff
1. Planning		
2. Research and Development		
3. Engineering/Operations		
4. Other (Please Specify) ______		

9. To what extent, if at all, does your state highway agency use each of the following offices to transfer information about technologies? *(CHECK ONE BOX FOR EACH SOURCE.)*

Offices	Little or no Extent (1)	Some Extent (2)	Moderate Extent (3)	Great Extent (4)	Very Great Extent (5)	No Basis to Judge (6)
1. *Your own State Technology* Transfer Office	3	3	3	5	6	10
2. Rural Technical Assistance Program (RTAP)	8	5	6	5	6	4
3. Other ______	1	1	5	1	7	1

– 5 –

2. To what extent, if at all, are the following resources used to select and/or prioritize potential technologies for testing or evaluation? *(CHECK ONE BOX FOR EACH RESOURCE.)*

Resources	Little or no Extent (1)	Some Extent (2)	Moderate Extent (3)	Great Extent (4)	Very Great Extent (5)	No Basis to Judge (6)
1. State highway agency research review committee	5	2	6	15	16	7
2. State highway agency administrative policy or directive	12	10	8	12	5	4
3. State highway agency district/regional staff	7	17	12	9	4	2
4. State highway agency headquarters staff	1	9	16	15	9	1
5. University research	13	19	11	6	1	1
6. State highway agency New Product Evaluation Office	1	9	9	10	8	13
16. Other ______ ______			1	1	3	1

NOTE: The next group of questions focus on information regarding those people working solely in highway related activities. Do not include staff involved in mass transit, airport functions or other non-highway related activities.

3. How many full-time and part-time staff does your state highway agency have? *(Do not include staff involved in mass transit, airport functions and such.)*

______ *(Number of full-time employees)*

______ *(Number of part-time employees)*

4. Does your state highway agency have its own technology transfer office?

1. ☐ Yes 21

2. ☐ No **(Skip to question 7)** 30

5. How many full-time and part-time staff does your state highway technology transfer office have?

______ *(Number of full-time employees)*

______ *(Number of part-time employees)*

– 4 –

11. To what extent, if at all, does your state highway agency use the following technology transfer activities to disseminate information within your state about technologies? *(CHECK ONE COLUMN FOR EACH TECHNOLOGY TRANSFER ACTIVITY.)*

Technology Transfer Activities	Little or no Extent (1)	Some Extent (2)	Moderate Extent (3)	Great Extent (4)	Very Great Extent (5)	No Basis to Judge (6)
1 Technology transfer specialists	20	3	12	5	7	4
2 Highway conferences	3	11	18	17	2	
3 Audio/visual materials	[illegible]	17	14	9	4	
4 Manuals or binders which are periodically updated	10	12	16	9	4	
5 Newsletter	14	10	9	12	4	2
6 Electronic/PC bulletin board	34	5	1	2		9
7 Trade publications	16	17	8	5		4
8 State of the art reports containing consolidated information on specific topics (for example, NCHRP synthesis reports)	5	5	18	14	9	
9 Training courses	2	10	20	13	6	
10 FHWA RTAP/T[2] Centers	10	7	11	15	6	2
11 Other		1	1	3	2	

10. From which of the following sources, if any, have the person(s) in the State Technology Transfer Office, RTAP, and/or other offices received formal training in how to transfer technical information to users? *(CHECK ALL THAT APPLY.)*

Sources	Your own State Technology Transfer Office	Rural Technical Assistance Program (RTAP)	Other
1. Your state	7	9	2
2. Other state(s)	4	14	0
3. AASHTO	2	5	1
4. FHWA	14	23	7
5. Another Federal government agency	0	5	1
6. Private industry	2	5	1
7. Other (Please Specify) ______	7	4	2
8. No formal training	16	8	7
9. Not applicable	12	6	2

– 6 –

13. Approximately, how many products, materials, and/or methods did each of the following organizations test/evaluate for your state highway agency in calendar year 1986 (underway or completed)? *(CHECK ONE COLUMN FOR EACH ORGANIZATION.)*

Organizations	State does not have organization	None	1-25	26-50	51-75	Over 75
1. State Materials Testing Laboratory (not to include test samples of everyday products/i.e., standard testing)	1	1	23	12	2	2
2. New Product Evaluation Office	26	3	7	4	6	4
3. State Research & Development Office	14	7	21	2	6	1
4. University research	4	12	34			1
5. Private research under state contract	4	12	34			1
6. Other (Please Specify)	44	1	4			1

Due to space restrictions, data capturing number of states citing office/organization combinations are not presented. Number of states in these categories range from 1 to 3.

9

12. For the activities checked in question 11, please tell us if each was developed by the state, FHWA, or jointly between the state and FHWA. *(CHECK ALL THAT APPLY.)*

Technology Transfer Activities	State (1)	FHWA (2)	Joint (3)	Not Applicable (4)
1. Technology transfer specialists	13	3	14	16
2. Highway conferences	16	3	24	2
3. Audio/visual materials	4	11	20	1
4. Manuals or binders which are periodically updated	16	5	18	5
5. Newsletter	22	5	9	9
6. Electronic/PC bulletin board	5		3	39
7. Trade publications	7	1	9	29
8. State of the art reports containing consolidated information on specific topics (for example, NCHRP synthesis reports)	10	10	23	3
9. Training courses	5	1	27	
10. FHWA RTAP/T² Centers	2	5	29	9
11. Other ______ ______	4		1	1

Due to space restrictions, data capturing number of states checking categories of both state and FHWA or state and Joint are not presented. Number of states in these categories primarily range from 1 to 4.

- 8 -

15. To what extent, if at all, does your state highway agency use technology evaluations in the following ways? *(CHECK ONE COLUMN FOR EACH USE OF EVALUATION.)*

Use of Evaluations	Little or no Extent (1)	Some Extent (2)	Moderate Extent (3)	Great Extent (4)	Very Great Extent (5)	No Basis to Judge (6)
1. To write or revise state standard specifications		9	12	21	9	
2. To promote a technology's use statewide		7	21	17	6	
3. To convince FHWA of the merits of a technology		21	20	4	3	
4. As input to FHWA Technology Transfer program (RTAP, Demonstration projects)	[illegible]	17	15	8	2	1
5. As input to AASHTO's Special Product Evaluation List Network	[illegible]	12	13	8	3	2
6. As input to FHWA's National Experimental Projects Tabulation (Form 1461)	[illegible]	10	15	10	5	3
7. Other						

16. For the following list of selected technologies, please check the one category that **best** describes your state's experience to date with the selected technologies. *(CHECK ONE.)*

	(1) Adopted		(2)	(3)	(4)	(5)
	Project by Project	Statewide use	Currently being evaluated	Used previously but not currently	Little or no knowledge of technology	Technology not applicable
1. Fabrics to retard reflective cracking	15	5	12	18		1
2. Crack and seat (PCCP)	8	3	19	5	5	11
3. Improved test procedures for water sensitive asphalt mix design (such as the Lottman Method)	4	15	14	2	8	8
4. Hot mix (AC) recycling	16	33	1	1		
5. Retrofit edge drains	15	10	11	2	5	8
6. Undersealing/subsealing	16	9	6	2	8	10

11 –

14. For the type of organization, please indicate the extent to which each method was used to evaluate technologies. **Show your answer by writing the appropriate code for extent of use in each category.**

For example, if your State Materials Testing Laboratory uses a literature review to a very great extent as a method of evaluating technologies, place a number 5 in the box.

Extent of use code

1 – To little or no extent
2 – To some extent
3 – To a moderate extent
4 – To a great extent
5 – To a very great extent

	Organization					
Method	State Materials Testing Laboratory	New Product Evaluation Office	State Research & Development Office	University Research	Private Research Under State Contract	Other
1. Literature review						
2. Pool fund study with other states						
3. Review of other states experience						
4. Test sections/ experimental projects						
5. Developer's data on performance						
6. Information provided by FHWA						
7. Other ______ ______						

18. **For technologies you do not currently utilize** (columns 3, 4, or 5 in question 16), please indicate the importance of each reason for not utilizing a particular technology. Use the following numerical code to indicate importance.

For example, if your state highway agency does not use fabrics to retard reflective cracking and the life cycle cost reason was of very great importance in deciding **not** *to use the selected technology, place a number 5 in the box.*

Extent of use code

1 - Of little or no importance
2 - Of some importance
3 - Of moderate importance
4 - Of great importance
5 - Of very great importance

Reasons	Fabrics to retard reflective cracking	Crack and Seat	Water sensitive asphalt mix design	Hot Mix (AC) Recycling	Retrofit edge drains	Under-sealing/ sub-sealing
1. Life cycle cost						
2. First costs						
3. Technology would cause unacceptable costs/delays for motorists						
4. Technology did not achieve expected results						
5. Technology not compatible with past practices						
6. Change would likely cause a loss of employee rights or job security						
7. Contractor, state or other personnel lack equipment to satisfactorily implement technology						
8. Expertise in technology application unavailable in state						
9. Technology not compatible with state's climate						
10. Technology not compatible with state's soil type and/or aggregates						
11. Mandatory criteria for award of contract on the basis of low bid inhibited highway agency from pursuing technology						
12. Risk of failure considered too high						
13. Technology not supported by key decisionmakers						
14. Experience of other states						
15. Other (Please Specify)						

13

17. **For technologies your state has adopted or is currently evaluating** (columns 1 or 2 in question 16), please indicate the importance of each reason for utilizing a particular technology. Use the following numerical code to indicate importance.

For example, if your state highway agency has adopted or is currently evaluating any fabrics to retard reflective cracking and the life cycle cost reason was of very great importance in your state's selection of this technology, place a number 5 in the box.

Extent of use code

1 – Of little or no importance
2 – Of some importance
3 – Of moderate importance
4 – Of great importance
5 – Of very great importance

Reasons	Fabrics to retard reflective cracking	Crack and Seat (PCCP)	Water sensitive asphalt mix design (for example Lottman)	Hot Mix (AC) Recycling	Retrofit edge drains	Under sealing/ Sub-sealing
1. Life cycle cost						
2. First costs						
3. Motorist's cost/delay considerations						
4. *Technology achieved expected* results						
5. Technology compatible with past practices						
6. Contractor, state or other personnel has equipment to satisfactorily implement technology						
7. Technology compatible with state's climate						
8. Technology compatible with state's soil type and/or aggregates						
9. Implementation of technology was easy						
10. Key decisionmakers supported technology						
11. Benefits of technology were observable						
12. Expertise in technology application was available						
13. Other (Please Specify) ________ ________						

12

20 In making the decision to use or test these selected technologies, which of the following methods, if any, were used by your state highway agency? *(CHECK ALL THAT APPLY.)*

Methods	Fabrics to retard reflective cracking	Crack and Seat	Water sensitive asphalt mix design	Hot Mix (AC) Recycling	Retrofit edge drains	Under-sealing/ sub-sealing
1. Literature review	41	24	32	43	29	27
2. Pool fund study with other states	3		7	3	2	1
3. Review of other states' experience	43	27	28	45	29	30
4. Laboratory testing	16		33	40	6	6
5. Test sections/experimental projects	43	24	12	43	26	20
6. Developer's data on performance	30	4	9	11	14	4
7. Information provided by FHWA	34	17	20	40	23	21
8. Other (Please Specify) ______	4	2	1	3	1	3
9. Don't use technology	6	15	10		12	14

21 Estimate the number of years of experience your state has had with the selected technologies.

If less than a year, please tell us how many months you have used the technology. Please note if the units are in months. If unknown, please write "unk." If your state has had no experience with the technology, please write "0."

	Number of years used
Fabrics to retard reflective cracking	______
Crack and seat (PCCP)	______
Water sensitive asphalt mix design (such as Lottman)	______
Hot mix (AC) recycling	______
Retrofit edge drains	______
Undersealing/subsealing	______

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19. From which of the following sources, if any, did your state highway headquarters learn about the selected technology? *(CHECK ALL THAT APPLY.)*

Sources	Fabrics to retard reflective cracking	Crack and Seat	Water sensitive asphalt mix design	Hot Mix (AC) Recycling	Retrofit edge drains	Under-sealing/ sub-sealing
1. Federal Highway Administration	43	33	33	47	33	33
2. University research	16	4	23	15	11	6
3. Your State Department of Transportation R&D Laboratory	20	12	20	21	10	10
4. Reports from other State Departments of Transportation	42	40	25	44	36	34
5. AASHTO	15	15	15	24	12	16
6. Industry representatives	45	10	11	26	26	18
7. Your State DOT New Product Evaluation Office	18	5	2	7	10	3
8. Your State DOT Materials Testing Lab	24	13	26	29	12	13
9. Trade associations	15	19	7	22	3	12
10. Your State highway field staff	12	11	8	15	10	12
11. TRB/NCHRP	40	27	29	39	29	30
12. Trade magazines	35	23	7	33	23	23
13. County or municipal personnel	1	4	1	3	1	1
14. TRIS/HRIS	24	17	16	25	14	17
15. Peer exchange	31	31	25	37	30	29
16. Other (Please Specify)						

– 14 –

24. If your state has developed information on cost savings, please provide us the amount of cost savings for each technology and tell us what unit of measurement was used (savings per mile, savings per year, etc.). *Skip if your state has not completed a study of cost savings.*

	Cost savings	per	Unit
Fabrics to retard reflective cracking	______		______
Crack and seat (PCCP)	______		______
Water sensitive asphalt mix design (for example, Lottman)	______		______
Hot mix (AC) recycling	______		______
Retrofit edge drains	______		______
Undersealing/subsealing	______		______

25. What activity, method or product, if any, is being replaced by the selected technologies? *If nothing was done previously, please write "NONE."*

Fabrics to retard reflective cracking	replaced	______________________
Crack and seat (PCCP)	replaced	______________________
Water sensitive asphalt mix design (for example, Lottman)	replaced	______________________
Hot mix (AC) recycling	replaced	______________________
Retrofit edge drains	replaced	______________________
Undersealing/subsealing	replaced	______________________

– 17 –

22. For each selected technology, please estimate the miles of road and number of projects in your state which have used the selected technology.

If unknown, please write "unk." If your state has had no experience with the technology, please write "0."

	Number of miles	Number of projects
Fabrics to retard reflective cracking		
Crack and seat (PCCP)		
Water sensitive asphalt mix design (such as Lottman)		
Hot mix (AC) recycling		
Retrofit edge drains		
Undersealing/subsealing		

23. Has your state highway department produced written evaluations of the selected technologies on the following factors? *(CHECK ALL THAT APPLY.)*

	Technologies					
Factors	Fabrics to retard reflective cracking	Crack and Seat	Water sensitive asphalt mix design	Hot Mix (AC) Recycling	Retrofit edge drains	Under-sealing/ sub-sealing
1 Cost savings	8	2	1	27	3	1
2 Performance	34	9	10	32	10	11
3 Other (Please Specify)	3	3	2	4	4	2
4 No evaluations	15	41	40	16	38	39

PLEASE NOTE: *Of the evaluations identified in question 23 please send us two evaluations, if available, for each technology. Mail us the two that were most influential in your state's decision to use or not use each technology.*

If you used evaluations performed by others as a basis for making your decision, please give us the reference citation(s). Please use a separate piece of paper to list these items and attach it to any evaluations you are sending us.

16

28. What problems has your state encountered in preparing these estimates? *Use additional sheets if necessary.*

29. Please make any other comments you would like concerning your state's decisionmaking activities with regard to highway technologies. *Use additional sheets if necessary.*

30. Would you be interested in receiving a copy of our final report?

☐ Yes ☐ No

Please specify the name and address where we should send the final report. Thank you for your help.

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NOTE: The following questions will help us in our analysis of the previous responses.

26. Please provide the following information pertaining to funding for highway research and evaluations performed during your fiscal years 1984 and 1985.

Amount Spent

	FY 1984	FY 1985
a. State matching amount for HP & R funds	______	______
b. Amount spent from HP & R *funds on research*	______	______
c. 100% state funded independent research activities	______	______
d. Estimated total federal dollars state spent on research and evaluations (for example, construction or experimental projects, FHWA contracts, etc.)	______	______
e. Total spending on 3R/4R activities (state and federal funds)	______	______
f. State only spending on highway maintenance activities	______	______

27. What methods does your state use to estimate the truck volume and axle loading occurring on your highwa; *Use additional sheets if necessary.*

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DATA COLLECTION INSTRUMENT
****

METHODOLOGY

PAGE REF.

9. TECHNOLOGY EVALUATED: p. ____

37 FABRICS TO REDUCE REFLECTIVE CRACKING
7 CRACK & SEAT ASPHALT OVERLAYS
9 WATER SENSITIVE ASPHALT MIX DESIGN
30 HOT MIX ASPHALT CONCRETE RECYCLING
8 RETROFITTED EDGE DRAINS
7 UNDERSEALING/SUBSEALING
\- OTHER ____________________

10. PAVEMENT TYPE(S): p. ____

49 ASPHALT
8 PORTLAND CEMENT CONCRETE
35 BOTH
6 OTHER ____________________

11. CLIMATE CONDITIONS (CHECK ONE FROM EACH COLUMN) p. ____

0	WET	1	NO FREEZE
2	DRY	0	FREEZE-THAW CYCLE
85	NOT STATED OR UNCLEAR	2	HARD FREEZE, SPRING THAW
		84	NO TEMP STATED OR UNCLEAR
4	VARIABLE	4	VARIABLE
7	NOT APPLICABLE	7	NOT APPLICABLE

12. METHODS USED TO EVALUATE TECHNOLOGY: (CHECK ALL THAT APPLY) p. ____

1 LITERATURE REVIEW
0 COOPERATIVE EFFORT WITH OTHER STATES
29 LABORATORY TESTING
47 TEST SECTIONS WITH SINGLE TECHNOLOGY IMPLEMENTATION
41 TEST SECTIONS WITH MULTIPLE TECHNOLOGY IMPLEMENTATIONS
51 USED CONTROL SECTIONS
0 DEVELOPER'S PERFORMANCE DATA
0 OTHER ____________________

13. MEASURES USED IN EVALUATION: (CHECK ALL THAT APPLY) p. ____

26 COST EFFECTIVENESS OF TECHNOLOGY
1 CALCULATIONS SHOWING POTENTIAL PERFORMANCE
71 VISUAL OBSERVATION OF PERFORMANCE/DISTRESS
84 PHYSICAL TESTS DOCUMENTING PERFORMANCE

NAME(S) OF TEST(S): ____________________

0 OTHER ____________________

2. ID (___ ___ ___ - ___ ___)

Data Collection Instrument

DATA COLLECTION INSTRUMENT

****

BACKGROUND INFORMATION — PAGE REF.

1. ___ ___ ___ - ___ ___ REPORT NUMBER p.___

2. ________________________________ p.___
   ________________________________ TITLE

3. REPORT TYPE: p.___

   11 CONSTRUCTION — 62 FINAL
   17 INTERIM — 1 ANNUAL
   7 OTHER ____________

4. ___/___ DATE OF REPORT p.___

5. _______ YEARS (NUMBER OF YEARS STUDY CONDUCTED) p.___

6. ORGANIZATION REPORTING: p.___

   90 STATE HIGHWAY DEPARTMENT
   OFFICE:
   - 34 MATERIALS TESTING LABORATORY
   - 0 NEW PRODUCT EVALUATION OFFICE
   - 11 RESEARCH & DEVELOPMENT OFFICE
   - 15 NOT SPECIFIED
   - 30 OTHER ____________

   4 UNIVERSITY RESEARCH OFFICE
   0 PRIVATE RESEARCH FIRM
   4 OTHER ____________

7. EVALUATION FUNDING SOURCES: p.___

TYPE OF FUNDING	FUNDING AMOUNT
35 FEDERAL HIGHWAY ADMINISTRATION	$______
6 HIGHWAY PLANNING & RESEARCH	______
9 EXPERIMENTAL PROJECT	______
9 DEMONSTRATION PROJECT	______
0 POOLED FUND	______
0 CONSTRUCTION FUNDS	______
11 NOT SPECIFIED	______
0 OTHER FEDERAL FUNDS	$______
3 STATE	$______
0 LOCAL	$______
0 OTHER	$______
62 NOT SPECIFIED	$______

8. TOTAL PROJECT FUNDING : $______ p.___

e to the type of data received, the following questions are not ptured in summarized form: questions 1,2,4,5,8, and 18.

1.

DATA COLLECTION INSTRUMENT

RECOMMENDATIONS

PAGE REF.

16. DID THE STUDY RECOMMEND USE OF THE TECHNOLOGY? p.____

64 NO RECOMMENDATION MADE
10 RECOMMENDATION MADE AGAINST USE OF TECHNOLOGY
24 RECOMMENDATION MADE FOR USE OF TECHNOLOGY:
  3 FOR FULLSCALE STATEWIDE IMPLEMENTATION
  19 FOR IMPLEMENTATION UNDER CERTAIN CONDITIONS OR WITH RESERVATIONS: ____

17. CRITERIA USED TO DETERMINE RECOMMENDATION (CHECK ALL THAT APPLY): p.____

2 FIRST COSTS
1 LIFE CYCLE COSTS
(USER COSTS
- PERFORMANCE RELATED TO:

  26 STANDARD TECHNOLOGY NOW USING: ____

  2 COMPARING SIMILAR PROPRIETARY FEATURES : ____

  0 SAME PRODUCT ON DIFFERENT ROAD SECTIONS: ____

  9 OTHER: ____

18. COMMENTS ON QUALITY OF EVALUATION: ____

4. ID (-)

DATA COLLECTION INSTRUMENT
****

RESULTS

PAGE REF.

14. RESULTS OF EVALUATION: (CHECK ALL THAT APPLY) p.____

IF TEST/ CONTROL METHOD

19 TECHNOLOGY PERFORMANCE EXCEEDED CONTROL CONDITION
23 TECHNOLOGY PERFORMANCE EQUALED CONTROL CONDITION
1 CONTROL CONDITION EXCEEDED TECHNOLOGY PERFORMANCE
8 RESULTS INCONCLUSIVE
0 OTHER____

IF TEST ONLY METHOD

21 SATISFACTORY PERFORMANCE OF TECHNOLOGY
7 MARGINAL PERFORMANCE OF TECHNOLOGY
4 UNSATISFACTORY PERFORMANCE OF TECHNOLOGY
5 RESULTS INCONCLUSIVE
0 OTHER____

IF MULTIPLE TEST METHOD

27 SOME TEST CONDITION PERFORMANCES EXCEEDED OTHERS
11 TEST CONDITIONS PERFORMED EQUALLY
1 RESULTS INCONCLUSIVE

OTHER RESULTS____

15. PROBLEMS ENCOUNTERED WITH TECHNOLOGY: (CHECK ALL THAT APPLY) p.____

0 UNACCEPTABLE DELAYS/COSTS FOR MOTORISTS
9 ENVIRONMENTAL HAZARDS
0 EQUIPMENT UNAVAILABLE/TOO COSTLY
19 EQUIPMENT MALFUNCTION/BREAKDOWN
5 CLIMATE INCOMPATIBLE WITH TECHNOLOGY
2 AGGREGATE/SOIL INCOMPATIBLE WITH TECHNOLOGY
13 METHODS FOR APPLICATION TOO COMPLEX
0 TECHNOLOGY HAZARDOUS TO WORKERS
14 OTHER____

41 NONE SPECIFIED

3. ID (___ - __)

State	No technology transfer office: No staff with technology transfer functions	No technology transfer office: Staff with technology transfer functions	Technology transfer office: No other staff with technology transfer functions	Technology transfer office: Other staff with technology transfer functions
Oklahoma		X		
Oregon	X			
Pennsylvania		X		
Rhode Island		X		
South Carolina		X		
South Dakota				X
Tennessee			X	
Texas				X
Utah			X	
Vermont	X			
Virginia				X
Washington				X
West Virginia	X			
Wisconsin				X
Wyoming		X		
Total	**6**	**24**	**10**	**11**

Technology Transfer Staff Efforts

State	No technology transfer office: No staff with technology transfer functions	No technology transfer office: Staff with technology transfer functions	Technology transfer office: No other staff with technology transfer functions	Technology transfer office: Other staff with technology transfer functions
Alabama		X		
Alaska			X	
Arizona		X		
Arkansas		X		
California				X
Colorado				X
Connecticut				X
Delaware			X	
District of Columbia		X		
Florida		X		
Georgia		X		
Hawaii				X
Idaho	X			
Illinois		X		
Indiana				X
Iowa	X			
Kansas				X
Kentucky		X		
Louisiana			X	
Maine		X		
Maryland		X		
Massachusetts			X	
Michigan			X	
Minnesota		X		
Mississippi		X		
Missouri		X		
Montana		X		
Nebraska		X		
Nevada			X	
New Hampshire	X			
New Jersey		X		
New Mexico			X	
New York		X		
North Carolina		X		
North Dakota			X	
Ohio		X		

(continued)

State[a]	Fabric	Crack and seat	Asphalt mix design	Hot mix recycling	Edge drains	Undersealing
Rhode Island	Y			X		
South Carolina	Y		X	X		X
South Dakota	X	X		X		
Tennessee		X	X	X	X	X
Texas	X		X	X	X	X
Utah	X		Y	X		
Vermont				X	Y	
Virginia	X	Y	Y	X	X	X
Washington		Y	X	X	X	X
West Virginia		Y				
Wisconsin		X		X	X	
Wyoming	X	X	X	X	Y	X
Total X	**20**	**11**	**19**	**49**	**25**	**25**
Total Y	**12**	**19**	**14**	**1**	**13**	**6**

[a] X = state has adopted the technology either project by project or for statewide use.
Y = state is currently evaluating the technology

Appendix VI

Highway Agencies' Adoption and Evaluation of Selected Technologies

State[a]	Fabric	Crack and seat	Asphalt mix design	Hot mix recycling	Edge drains	Undersealing
Alabama	Y	Y	Y	X	X	X
Alaska	X			X		
Arizona		Y	Y	X	Y	Y
Arkansas		Y	Y	X	X	X
California	X	X	X	X	X	X
Colorado	X		X	X	Y	X
Connecticut				X	X	
Delaware	Y	Y	X	X		Y
District of Columbia	X		Y	X	X	X
Florida	X	X	X	X	X	X
Georgia	X		X	X	Y	X
Hawaii	X			X	X	
Idaho		Y	X	X	Y	Y
Illinois	X	Y	X	X	X	X
Indiana	Y	Y	Y	X	X	X
Iowa	X	Y	Y	X	X	Y
Kansas		Y	Y	X	Y	Y
Kentucky		X	X	X	X	
Louisiana	Y		Y	Y	X	X
Maine		Y		X	Y	
Maryland	Y	Y	Y	X	Y	X
Massachusetts				X		
Michigan	Y	Y	Y	X	X	
Minnesota	Y	X	X	X	X	
Mississippi	X		Y	X	X	X
Missouri			Y	X	Y	X
Montana		Y	X	X		
Nebraska	Y			X		
Nevada	X		X	X		
New Hampshire	X			X		
New Jersey	Y			X	Y	X
New Mexico	X	X		X	X	X
New York		X		X	X	
North Carolina				X	X	X
North Dakota		Y		X		
Ohio	Y	Y		X	Y	Y
Oklahoma	X	Y	X	X	Y	X
Oregon			X	X	X	X
Pennsylvania	X	X	X	X	X	X

(continued)

States That Analyzed Evaluations and Their Levels of Use of Selected Technologies

State[a]	Fabric	Crack and seat	Asphalt mix design	Hot mix recycling	Retrofit edge drains	Undersealing and subsealing	Total
Arizona			X	X			2
Arkansas	O			X			2
California	X	X	X	X	X	X	6
Colorado	X			X		X	3
Connecticut				X			1
Delaware	X						1
Florida				X			1
Georgia					O	X	2
Illinois	X				X		2
Indiana	X	X			X	X	4
Iowa	X			X	X	X	4
Kansas	O	X		X			3
Michigan	X	X		X			3
Minnesota	X						1
Mississippi	X						1
Missouri	O		X	X			3
Montana	O						1
New Jersey				X			1
New York	O	X		X		O	4
North Dakota	O			X			2
Pennsylvania	X				X		2
South Carolina			X	X			2
Tennessee				X			1
Texas	X		X	X		X	4
Utah				X			1
Vermont	O			X			2
Virginia	X		X	X			3
Washington	O			X			2
West Virginia	O	X					2
Wisconsin	O						1
Wyoming	X			X			2
Total X	**13**	**6**	**6**	**21**	**5**	**6**	
Total O	**10**	**0**	**0**	**0**	**1**	**1**	
Total states	**23**	**6**	**6**	**21**	**6**	**7**	

[a]O = Highway agencies not using the technology; X = highway agencies using the technology. Agencies may have submitted more than one evaluation report.

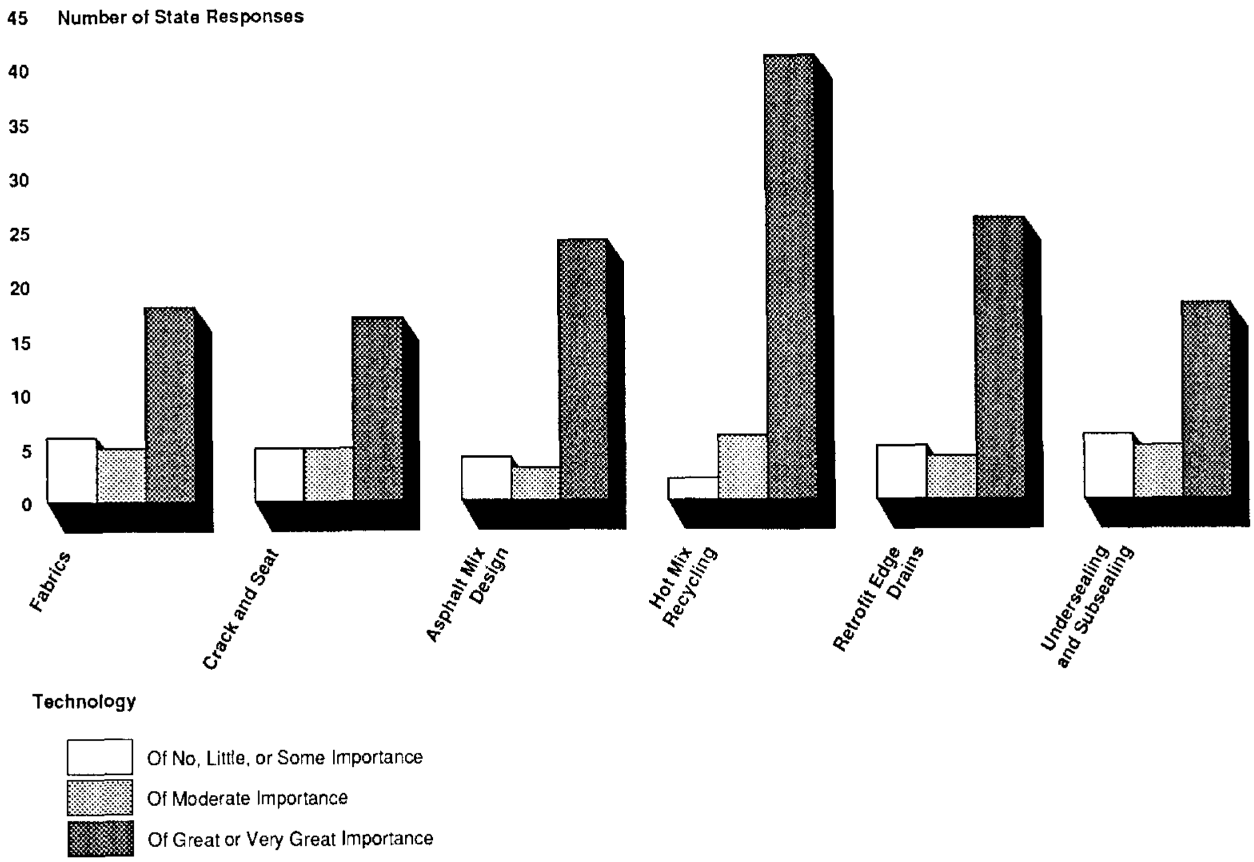
Highway Agencies That Are Evaluating Technologies but Did Not Submit Written Evaluations

Technology	Agencies that said they had evaluated the technology	Agencies currently evaluating the technology	Total
Fabric	2	6	**8**
Crack and seat	1	14	**15**
Asphalt mix design	1	10	**11**
Hot mix recycling	1	0	**1**
Retrofit edge drains	3	8	**11**
Undersealing and subsealing	2	3	**5**

The States' Reasons for Using or Not Using the Six Technologies

Figures X.1 through X.6 show performance and cost criteria the states indicated were reasons for their use or nonuse of the six technologies discussed in this report. Figures X.7 through X.12 show physical factors the states used as criteria for using or not using the technologies.

Figure X.1: Technology Achieved Expected Results as a Reason for Using



Highway Agencies Reporting Problems

Technology evaluation	Equipment malfunction	Application too complex	Environmental hazards	Climate incompatible	Aggregate and soil incompatible	Other technical problems
Fabric	4	12	0	5	1	1
Crack and seat	1	0	0	0	0	2
Asphalt mix design						5
Hot mix recycling	9	0	9	0	0	3
Retrofit edge drains	5	0	0	0	1	2
Undersealing and subsealing	0	1	0	0	0	1
Total evaluations	**19**	**13**	**9**	**5**	**2**	**14**

Figure X.3: Life-Cycle Costs as a Reason for Using

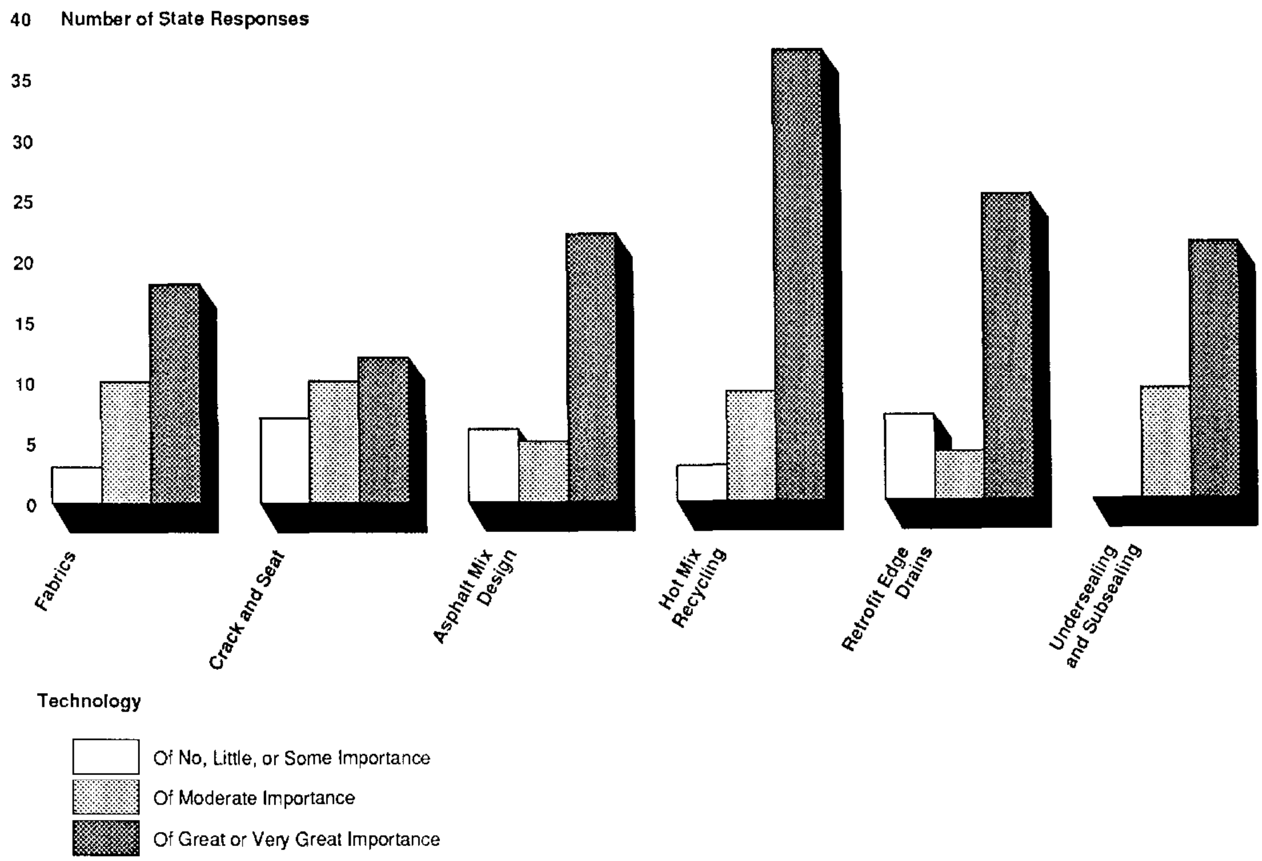


Figure X.2: Technology Did Not Achieve Expected Results as a Reason for Not Using

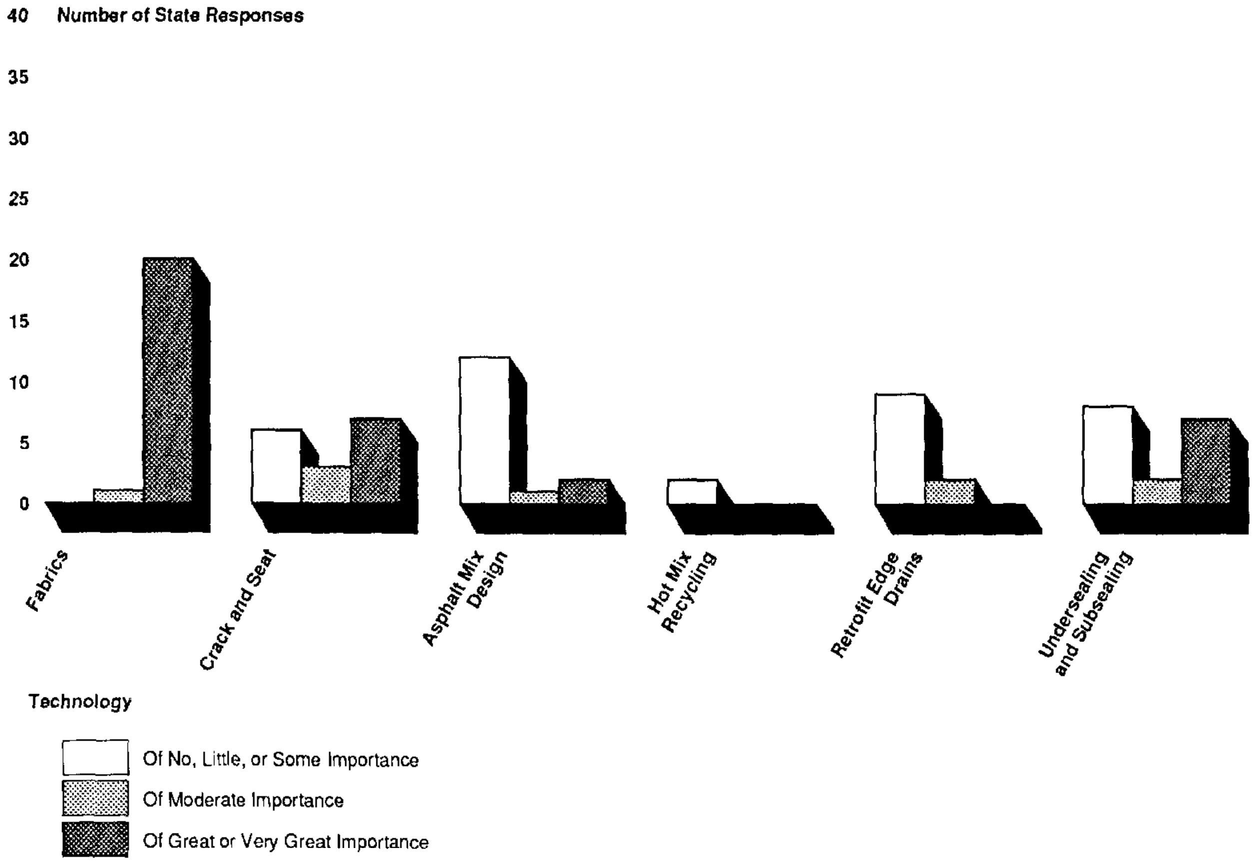


Figure X.5: First Costs as a Reason for Using

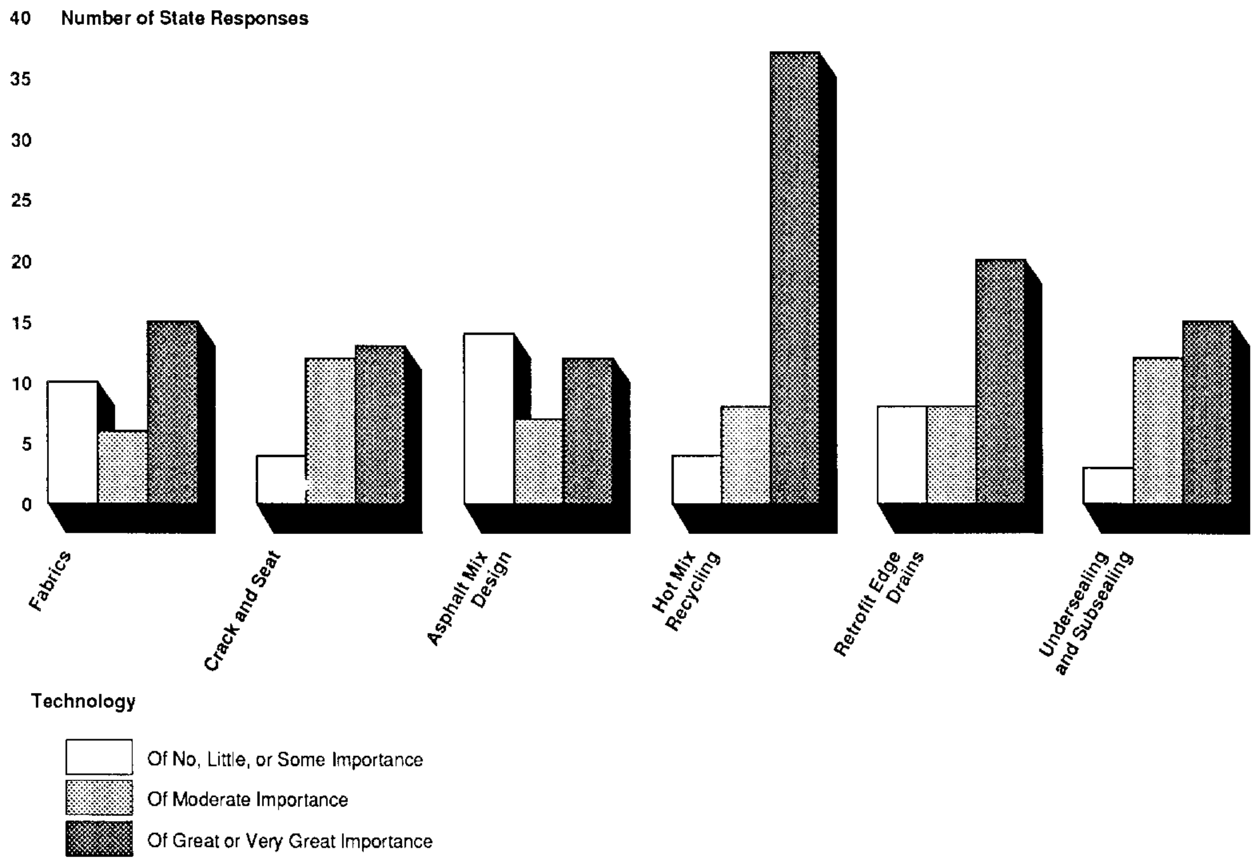


Figure X.4: Life-Cycle Costs as a Reason for Not Using

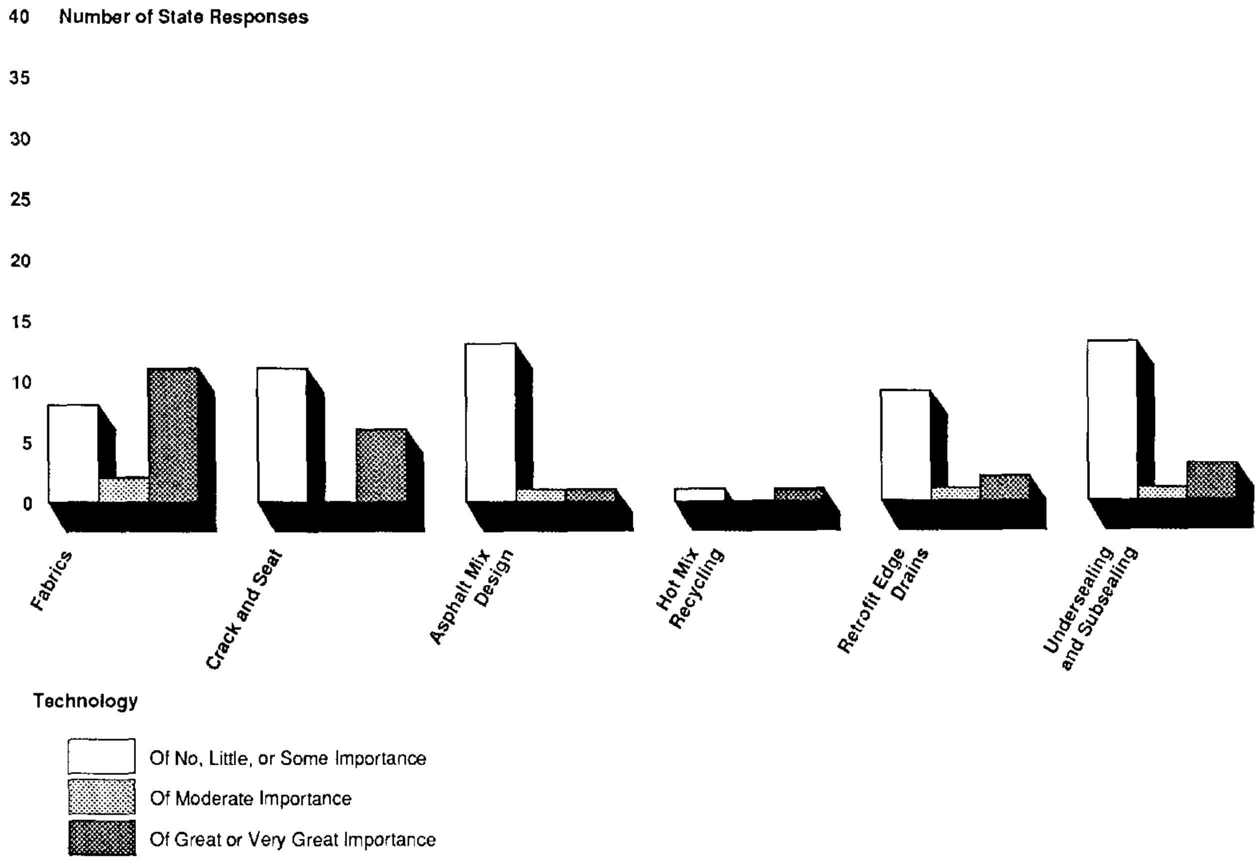


Figure X.7: Technology Compatible With State's Soil Type or Aggregates as a Reason for Using

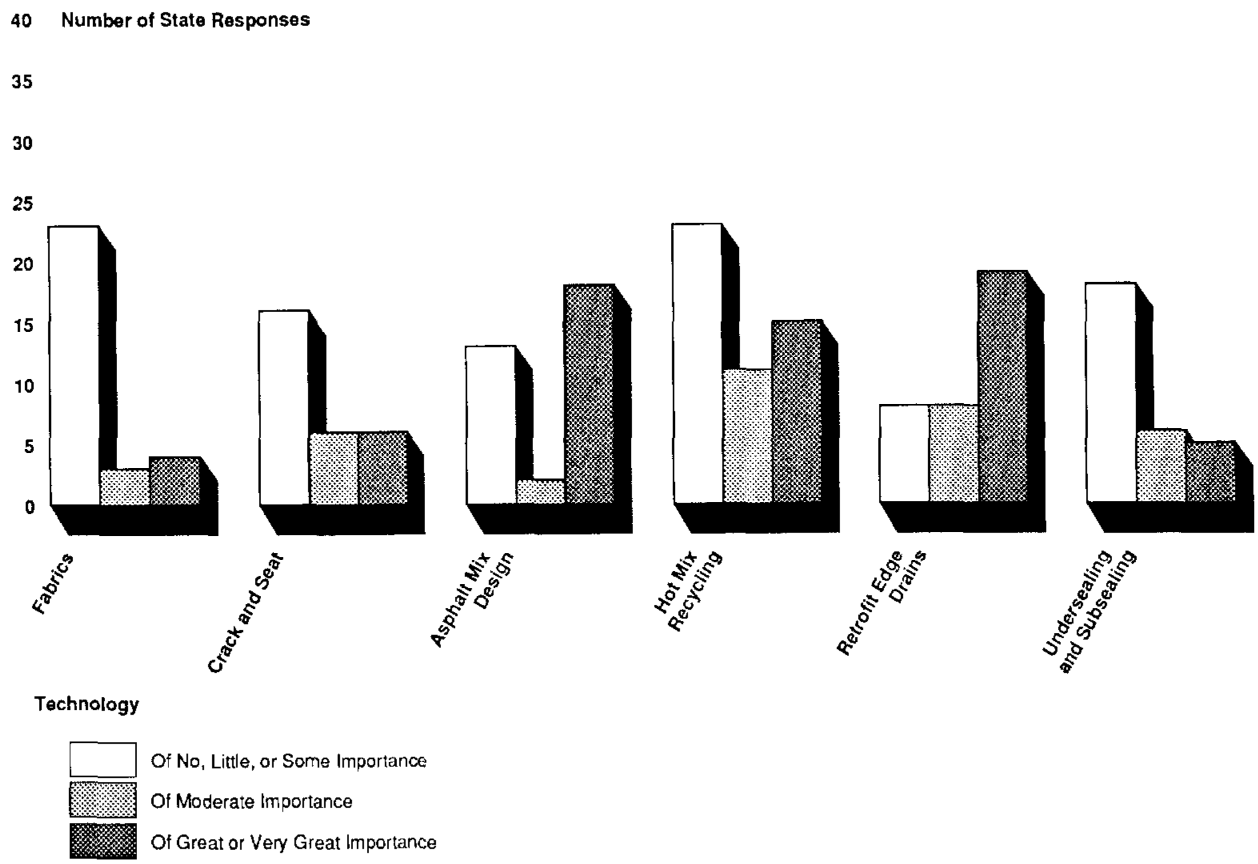


Figure X.6: First Costs as a Reason for Not Using

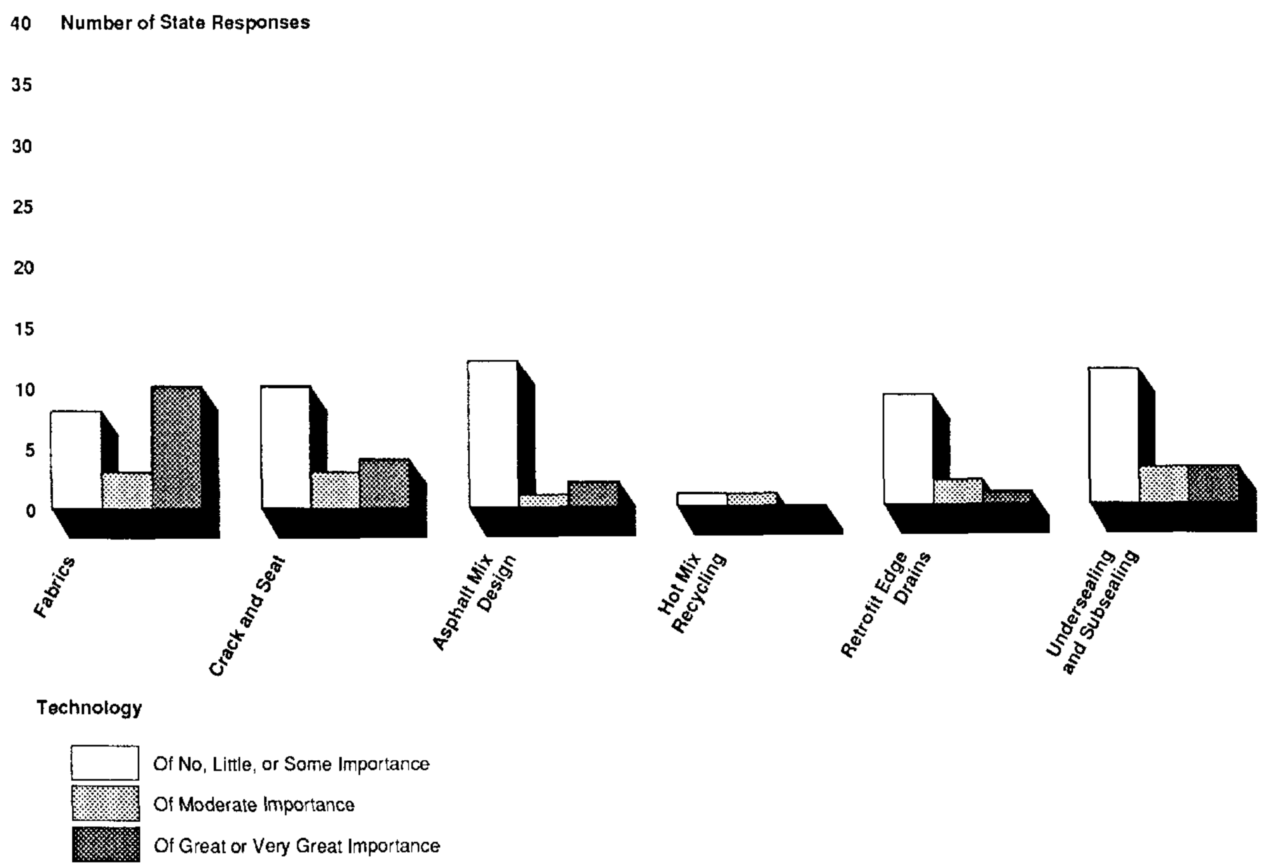


Figure X.9: Technology Compatible With State's Climate as a Reason for Using

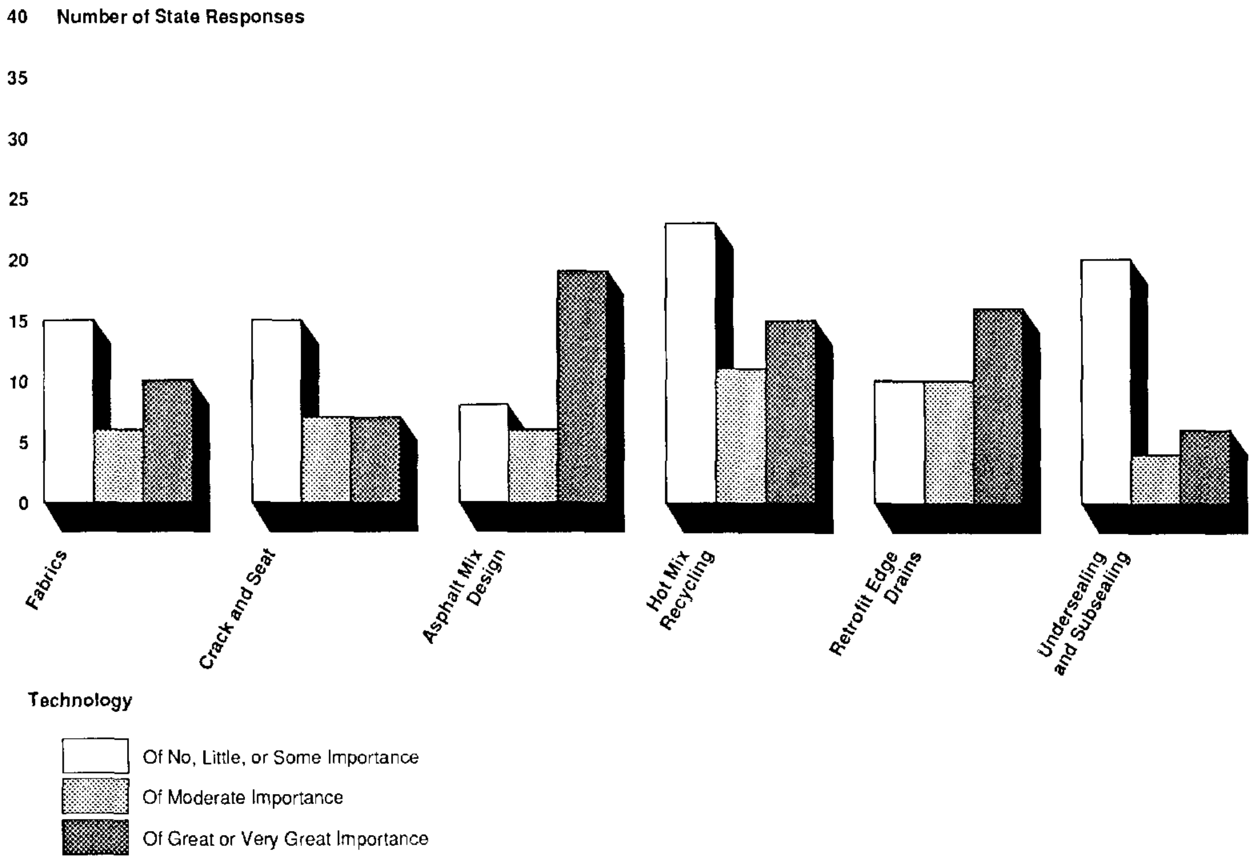
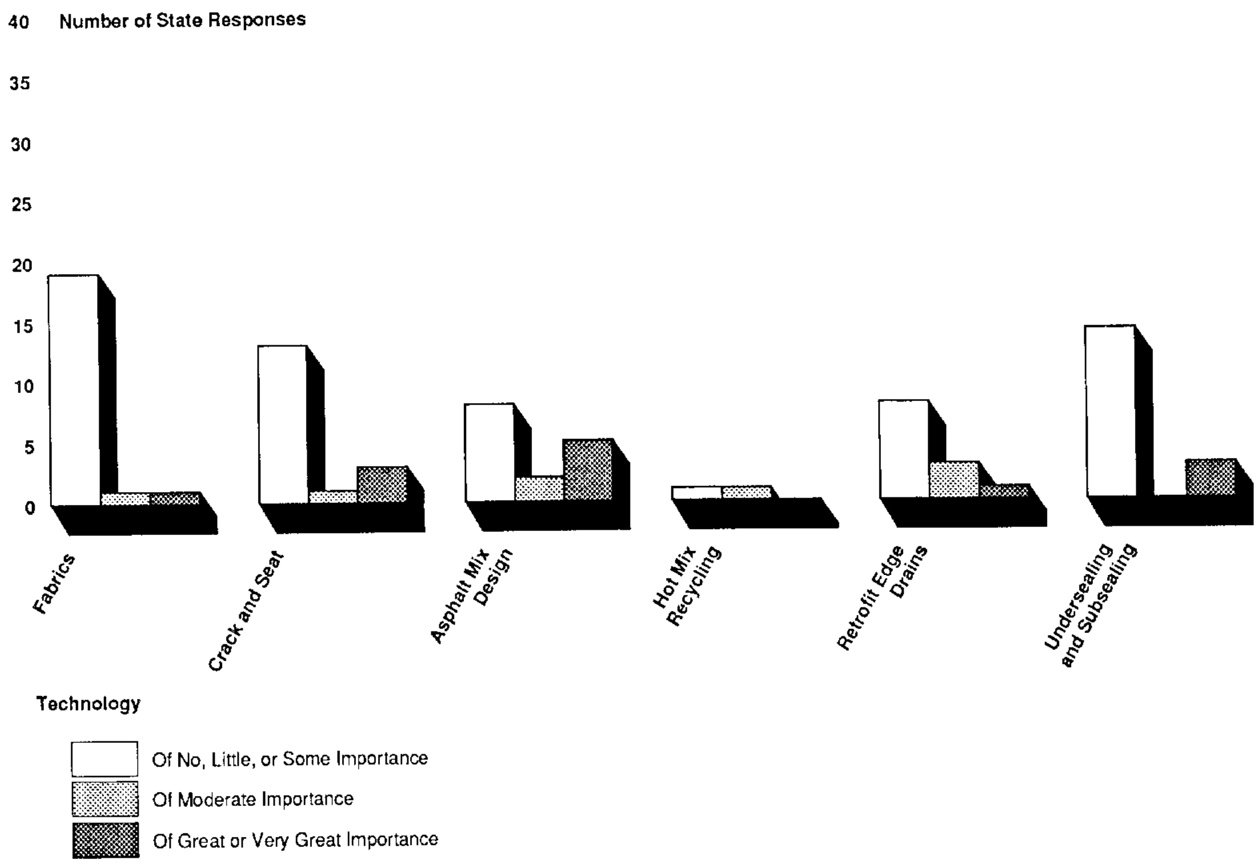


Figure X.8: Technology Not Compatible With State's Soil Type or Aggregates as a Reason for Not Using



Comments From the U.S. Department of Transportation

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

U.S. Department of Transportation

Assistant Secretary for Administration

400 Seventh St. S.W. Washington, D.C. 20590

MAY 4 1988

Mr. Kenneth M. Mead
Associate Director
Resources, Community, and Economic
Development Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Mead:

Enclosed are two copies of the Department of Transportation's comments concerning the U.S. General Accounting Office draft report entitled, "Highway Pavement Technologies: The Adoption Process from the State Highway Agencies' Perspective."

Thank you for the opportunity to review this report. If you have any questions concerning our reply, please call Bill Wood on 366-5145.

Sincerely,

Melissa J. Allen for
Jon H. Seymour

Enclosures

Figure X.10: Technology Not Compatible With State's Climate as a Reason for Not Using

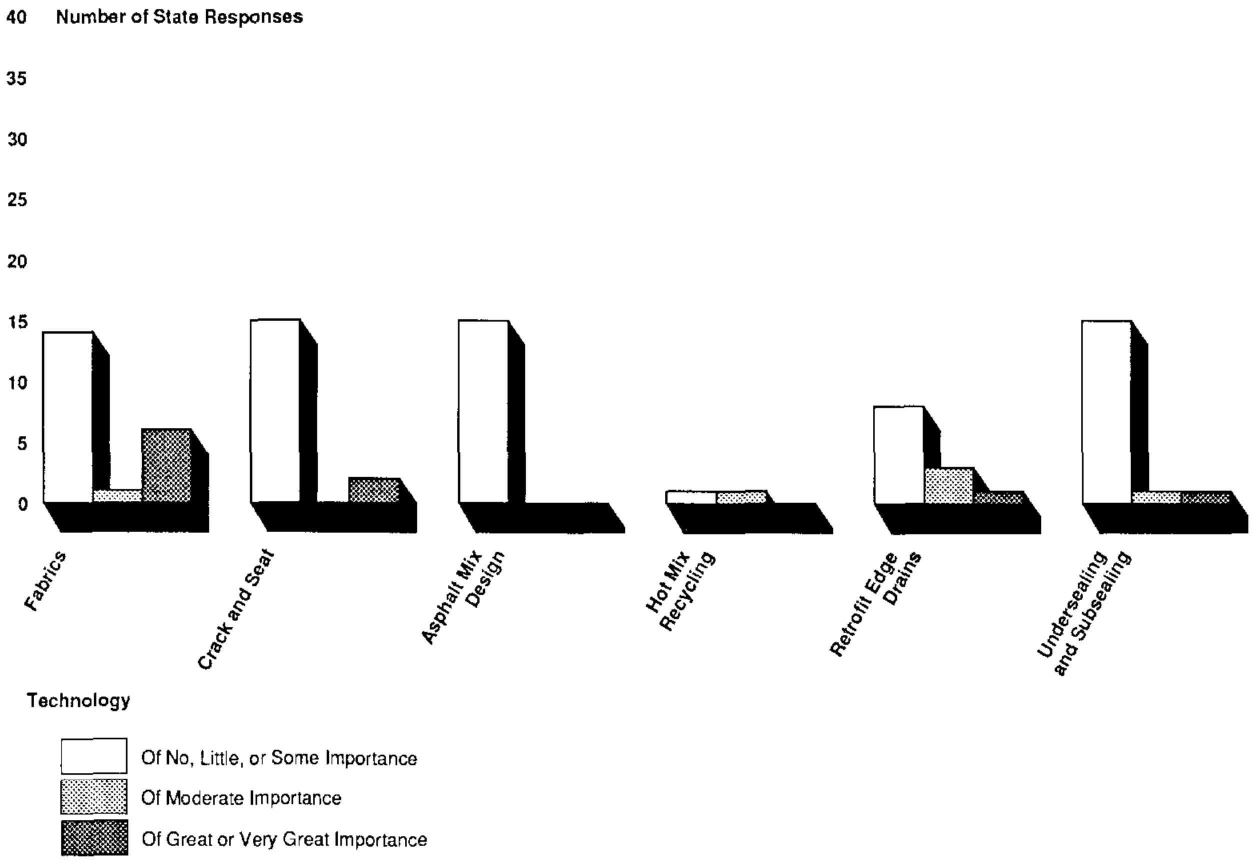


Figure X.11: Technology Compatible With Past Practices as a Reason for Using

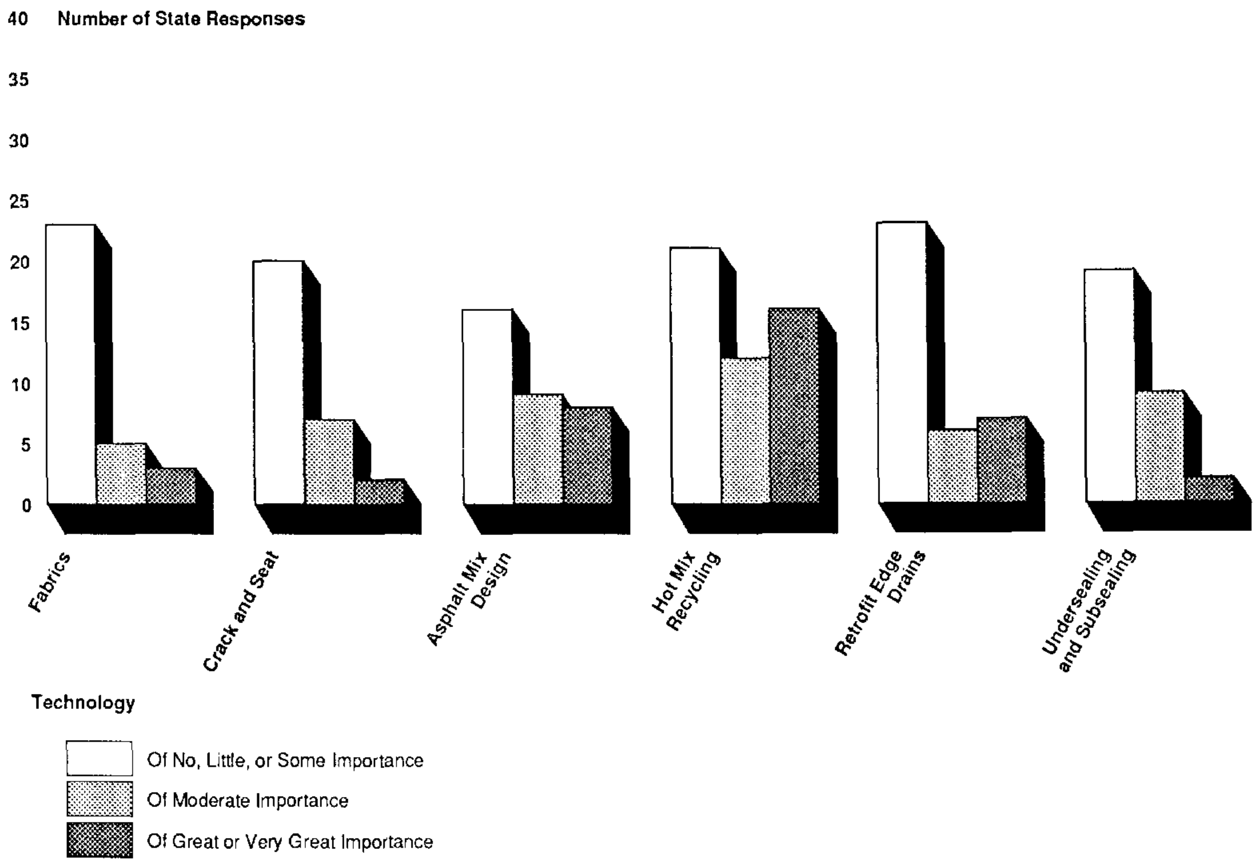
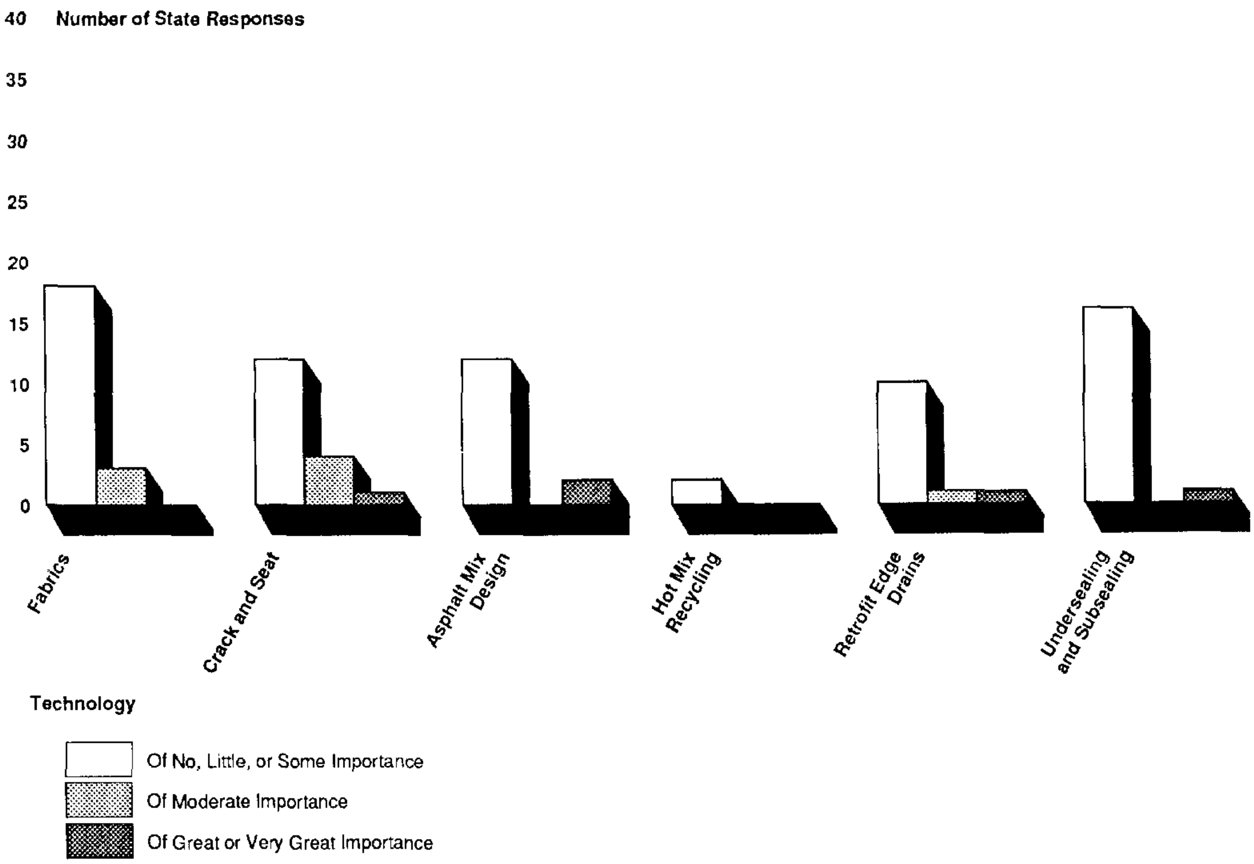


Figure X.12: Technology Not Compatible With Past Practices as a Reason for Not Using



2

The Department, however, has two concerns with the report. First, in regard to the questionnaire which the GAO used to obtain information from the States, we believe that it was too lengthy and broad-based to generate accurate and quantifiable answers. Also, although the report adequately reflects the analysis of the survey information provided, the state of knowledge varies widely among and within the States. The individual that completed the questionnaire in a State may or may not be the most knowledgeable person in that State. In larger States, there may be several semiautonomous districts (up to 24, as in Texas) with their own priorities and practices, and the responses to the questionnaire may not be representative of the state of the practice on a particular technology.

The second concern is that four of the six technologies selected for review, namely, crack and seat, water sensitive asphalt mix design, undersealing/subsealing, and retrofit edge drains, are not fully-developed or fully-proven or cost-effective products and are still being evaluated by a number of States.

More detailed comments on the content of the report are attached.

Department of Transportation Reply to GAO Report of April 1988 on Highway Pavement Technologies: The Adoption Process From the State Highway Agencies' Perspective

Summary of GAO Findings

The GAO found for six selected technologies (i.e., (1) fabric to retard reflective cracking, (2) crack and seat, (3) asphalt mix design, (4) hot mix recycling, (5) retrofit edge drains, and (6) undersealing/subsealing) that many elements or steps in the technology adoption decision process differ among highway agencies and the combinations of those steps demonstrate differences in emphases and priorities regarding technology adoption. Although performance and cost are the most important factors in agency decisions about technologies, the GAO found that there were highway agencies that used selected technologies regardless of evaluation performance results. Those agencies that have produced evaluations that influenced their adoption decisions, did primarily base them on performance criteria.

The GAO also found three general conditions about the decision process that illustrate the difficulties inherent in the adoption of cost-effective technologies by highway agencies. Highway agencies tend to operate in an environment where (1) pavement research, development, and adoption processes appear fragmented, (2) the highway pavement technology adoption process tends to vary by State as well as by technology, and (3) technology evaluations are often less than comprehensive in measures, methods, and reporting details.

Additionally, the GAO found that some key barriers that impeded technology adoption were opposition by key decisionmakers in the State, limited expertise in the technology application, and lack of the necessary equipment.

The GAO made no recommendations.

Summary of Department of Transportation Position

The Department of Transportation believes that the GAO has provided useful information which will be of further value to the Department, and has accurately described product evaluation deficiencies which exist in many States. The Department does intend to approach this evaluation problem through two new initiatives. The first would be research methodology training, including a possible product evaluation guide, for State employees. The second approach, now under consideration, would be the establishment of a national testing and evaluation data center or network which would facilitate the exchange of reliable information among the States.

2

Also, the relative costs must be considered. A typical pavement cost is about $15 per square yard in place for a 10" thickness, which is less than the cost of most living room rugs. Consideration of alternatives is a must; if there is an option of using a paving fabric at $3/sq. yd., a question that must be asked is whether 2 more inches (at $1.50/in./sq.yd.) would be more effective. These are often difficult questions to answer.

3. One of the ways to ensure that the new technologies will be implemented by the State highway agencies is through the dissemination of reliable evaluation information. Ongoing efforts in Special Product Evaluation Lists (SPEL) and Experimental Projects are a start, but have limitations. There have been several recommendations recently (as a result of the studies that are listed below) that the FHWA establish a national testing and evaluation facility. Several options are presently being considered by the FHWA. One option is the establishment of a technical information exchange service on products, materials and processes (excluding software). References on the test and evaluation concept include the following studies:

   a. Innovations in Transportation, L. G. Byrd, July 1987.

   b. RD&T Contract and Staff Research Program, Office of Program Review, October 26, 1987.

   c. Ad Hoc Task Force on Asphalt Pavement Rutting and Stripping Report, W. S. Mendenhall, Chairman, August 14, 1987.

   d. National Workshop on Highway Research, ASCE, April 1, 1988.

<u>Specific Comments</u>

Now page 12.

See comment 3.

1. <u>Page 1-6</u>. While this portion of the report is substantially correct, it is an oversimplification of the technologies addressing pavement deterioration. The FHWA has developed an 8-step rehabilitation design process that includes: (1) obtaining available project information such as construction and materials data, as-built design information, and historical traffic loadings, (2) determining existing pavement conditions and identifying distress types, amounts, and severities, (3) determining the cause of the distress, (4) developing feasible alternatives, (5) performing engineering and economic analyses on the alternatives, (6) selecting the best rehabilitation alternative considering life cycle cost, economic constraints, etc., (7) ensuring proper design and construction of the rehabilitation strategy, and (8) providing feedback on the performance of the rehabilitation technique.

DOT's General and Specific Comments on the GAO Draft Report -- Highway Pavement Technologies: The Adoption Process from the State Highway Agencies' Perspective

General Comments

See comment 1.

1. One concern the Federal Highway Administration (FHWA) had at the outset of the study was over the six technologies selected for study. As early as January 14, 1987, in a meeting with FHWA personnel to discuss the proposed questionnaire to be used in the review, the GAO was advised that a number of the technologies were still not fully proven and were still being evaluated by several States. For example, there are still many questions relative to the performance and cost-effectiveness of "crack and seat." What type of pavements are best suited--plain jointed, reinforced jointed, continuously reinforced? How thick an overlay should be placed? What is the appropriate structural coefficient to use in the design of the overlay? The FHWA, along with the States, is currently addressing these many important concerns.

   Another example is "Water Sensitive Asphalt Mix Design." It was only recently that two new tests became available to test for water sensitivity of asphalt mixes. Others existed but were not fully accepted by the industry for good reasons--they did not always give the correct results. Even with these new tests, there still remains doubt in some minds that they will always give accurate results.

   The status of the development and performance of "undersealing/subsealing" and "retrofit edgedrain" technologies is similar to the two just cited. For this reason, the FHWA questions the selection of these four technologies for inclusion on a questionnaire that was designed to provide information on their adoption and use.

See comment 2.
Now appendix I.

   The definitions of the six technologies contained in Appendix II of the draft report are not technically accurate. If these definitions were used in connection with the questionnaire or interviews, they could have perhaps misled people into furnishing inaccurate answers. For example, hot mix recycling is defined as that produced in a drum mixing machine. It is estimated that at least 50 percent of all recycled mixes today are not manufactured in a "drum mix plant," but in what industry calls a "batch type plant."

2. One must also consider cost-effectiveness, which is properly treated in the GAO report. However, even if the life of a technology (treatment) could be defined, the advantages of a process could be missed until the State (contractor) uses the technique often enough to reach economies of scale. Often initial experimental treatments are exceedingly high-priced because of the uncertainty involved. For instance, initial jobs using epoxy covered rebars went for $.40/lb. but today go for about $.15/lb.

4

Now page 18.
See comment 8.

6. Page 1-17. The FHWA's guidance to field offices concerning pavement management is reflected in the references cited above. The FHWA is currently preparing a technical advisory on pavement management to assist field offices in implementing the pavement policy once it is approved.

Now page 19.
See comment 9.

7. Page 1-18. Guidance concerning design of rehabilitation projects is contained in the draft pavement policy. It is essentially unchanged from that contained in former Administrator Barnhart's memorandum dated November 15, 1983.

Now page 35.

8. Page 3-4. In using new technology, private industry sometimes takes a strong position. This is particularly evident in fabrics and preformed edge drains, which are being promoted by international petrochemical industries. This push is almost absent in the use of the other technologies. Some industries in the past have done massive promotions, both technically and politically, to sell their products, only to find that inherent problems existed which later caused miles of prematurely failed pavement. This problem is very much akin to those that result in recalls in products sold to the public. However, since the States have no recourse in obtaining satisfaction, the users have become quite calloused and conservative in their "show me" attitude. There has been some industry push for crack and seat, and it may explain the moratorium described on this page.

In addition, the GAO report points to the need for more education, more coordination, and more technology transfer in the highway industry, particularly among the users. The DOT continues in its efforts to convince people of the values of some of these technologies and to help them put them into practice. Despite the difficulties which seem to exist in getting new technologies into practice, there has been progress as illustrated in the Transportation Research Board's (TRB) booklet entitled "Research Pays Off."

Now page 37.
See comment 10.

9. Page 3-8. The use of hot mix recycling as shown on a national map indicates that West Virginia has used this technology previously but not now, and that Louisiana is still evaluating its use. A check with the FHWA's field offices indicates that both States allow the use of hot mix recycling on all their projects. Louisiana indicated it concluded years ago that this was a viable and attractive highway rehabilitation strategy.

Now page 43.
Now table 3.8 on page 43.
See comment 11.

10. Page 3-27. Table 3.8 on this page is very confusing and difficult to understand. Subjective answers are quantified, but the information is still subjective. The use of tenths is meaningless. The essence of the data is what is important. Use of Low, Medium, and High could improve the presentation.

3

Now pages 13-14.
See comment 4.

2. Pages 1-8 through 1-12. The description of the Research and Technology Transfer (T^2) programs on these pages are much too general. As an example, the FHWA does far more than just look at progress reports and the final reports for Highway Planning Research (HPR) studies. Annual work programs and individual study plans are submitted to the FHWA for review and approval. Extensive technical guidance and coordination with researchers of similar studies is done by FHWA technical reviewers. The Nationally Coordinated Program (NCP) is the overall framework by which the research is coordinated. The umbrella of the NCP covers all highway research, including that done by the States (HPR and 100 percent State), National Cooperative Highway Research Program (NCHRP), Strategic Highway Research Program (SHRP) and other agencies. The T^2 activities include a wide variety of publications including the NCP report, Public Roads magazine, one- or two-page technical summaries, training materials and brochures, in addition to technical reports.

Now page 16.
See comment 5.

3. Pages 1-12 and -13. The title of the cited publication, The Experimental Projects Tabulation, is incorrect. The correct title is The National Experimental Projects Tabulation.

Now pages 16, 17, 56, and 2.
See comment 6.

4. Pages 1-14, 1-15, 5-2, and ES-2. Discussions relating to SHRP on these pages need some clarification. First of all, SHRP is a short term, highly focused contract research program. All elements of the critical areas cannot be funded by SHRP and several are being done by the FHWA as a part of its research program, i.e., development of Calcium Magnesium Acetate (CMA) as an alternate deicer and corrosion protection of prestressed concrete bridge elements. While SHRP has major efforts in the pavement area, work goes beyond pavements and includes protection of concrete bridge components, cement and concrete in highway pavements and structures, chemical control of snow and ice, maintenance cost effectiveness as well as asphalt characteristics and long-term pavement performance. The SHRP is a research program; it does not include technology transfer activities as such. Research results are to be in a form that can be directly used by a State highway agency. The FHWA has a role in the administration and fiscal management of SHRP, but it does not approve SHRP study proposals.

Now page 18.
See comment 7.

5. Page 1-16. It is inappropriate to quote from the June 1981 FHWA Notice on Pavement Management since it was cancelled on March 23, 1987. However, the concept quoted is still valid and is conveyed by the issuance of FHWA's draft Pavement Policy (Notice of Proposed Rulemaking January 26, 1988, Federal Register Page 2041) which would require all State highway agencies to have a comprehensive pavement management system within 4 years after its issuance. Reference should also be made to the American Association of State Highway and Transportation Officials (AASHTO) Guidelines on Pavement Management which has been accepted by the FHWA.

The following are GAO's comments on the Department of Transportation's May 4, 1988, letter.

GAO Comments

1. As we explain in chapter 5, to better understand the technology adoption process, we purposely selected a range of technologies that were in varying states of being tested and accepted or rejected for general use. In asking our advisory panel for help in selecting technologies to demonstrate that process, we suggested the criteria of "more than a handful of states have had experience with it" and "technology appears to be successful and important for states to be trying."

2. We did not furnish a set of definitions to the states to use in responding to the questionnaire. Rather, the definitions in appendix I were culled from the evaluations that the states sent back to us.

3. We agree that the eight-step rehabilitation design process is a comprehensive framework for looking at the entire rehabilitation process. However, our discussion focuses on only part of that process—specifically, the major factors used by engineers to select appropriate technologies (see page 12).

4. Because of the complex relationship between federal, state, and local highway agencies, and the often misunderstood basis for financing highway projects, we published a separate briefing report entitled Highway Technology: The Structure for Conducting Highway Pavement Research, GAO/PEMD-88-2BR (November 1987). Rather than repeat that discussion in this report, we have provided readers with a reference to it on page 13.

5. The citation, now on page 16, has been changed.

6. A detailed discussion of SHRP's role and objectives is contained in the briefing report referred to above. We have added SHRP's three nonpavement specific areas of concentration. That SHRP was designed as a research program, rather than a technology transfer activity, is also explicitedly noted. See pages 17 and 56.

7. The reference, now on page 18, has been changed.

8. The text, now on page 18, has been changed.

9. The change has been noted in comment eight.

Now page 50.
See comment 1.
Now tab'- 4.3 on page 50.

Appendix G is now the glossary.
See comment 12.

5

11. Page 4-10. The technologies selected are not all fully-developed, cost-effective products. The variability of success of the technologies is pointed out in Table 4.3. While 39 installations exceeded control or were satisfactory, another 47 were only equal, marginal or inconclusive. This wide discrepancy in results reflects the variability among the States from environment, local materials, installation procedures, etc. Hence, it is hard to generalize conclusions. Some of these technologies can be considered as "tools" by the designer to use, as appropriate, or as a particular project (job) in a systems approach, such that all parts work together synergistically to prevent failure. For instance, it is foolish to use retrofit edgedrains if all joints are not sealed to keep as much water out of the pavement as possible. Hence both must be done to be successful.

12. Appendix G and footnotes throughout the text should use standard highway definitions from AASHTO, TRB, etc. The use of nontechnically accepted definitions reduces the credibility of the report with highway people.

Glossary

Asphalt	A variety of bitumen found in nature or obtained by evaporating petroleum into a brown or black tarlike substance that is mixed with sand or gravel and used for paving.
Concrete	Sand and gravel bonded together with cement into a hard, compact substance and used in making bridge and road surfaces.
Design (Performance) Period	The time in which an initially constructed or rehabilitated pavement structure will last (or perform) before ceasing to be of service; also referred to as the "design period."
Life-Cycle Costs	All costs (and, in the complete sense, all benefits) involved in the provision of pavement during its complete life cycle; includes construction, maintenance, and rehabilitation.
Pavement Distress	Pavement problems such as raveling, faulting, cracking, and rutting caused by moisture, freeze-thaw, traffic loading, and so on.
Pavement Management	All the activities in planning, designing, constructing, maintaining, evaluating, and rehabilitating a pavement.
Pavement Performance	"Functional performance" is how well pavement serves the user in terms of riding comfort or ride quality. "Structural performance" is the physical condition of a pavement in terms of cracking, faulting, or other conditions that affect load-carrying capability.
Rehabilitation	Work to extend the service life of an existing highway; may include the placement of additional surfacing material or the complete removal and replacement of the pavement structure or other work necessary to return an existing roadway, including shoulders, to structural or functional adequacy
Serviceability	The ability, at a given point in time, of a pavement to serve the traffic (automobiles and trucks) being driven along it.

10. Responses from both states have since been verified, and their replies were found to be correctly reported.

11. The table title has been clarified, and tenths of a percent are no longer reported.

12. Because our report was written for a broad audience, we have purposely used nontechnical definitions and limited our use of technical highway terms.

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Technology Adoption	The decision by a highway agency to use a technology.
Technology Implementation	The process by which a technology becomes part of the permanent standard practice of a highway agency, including variables influencing the process.
Technology Transfer	The process by which research, information, and new technology are turned into useful processes, products, and programs.
Traffic Load	The weight and volume of mixed streams of traffic calculated by estimating the number of equivalent single axle loads that, for the performance period, represent the cumulative number from the time the roadway is opened to traffic to the time serviceability is reduced to minimum value.

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